Data Mining Test for 2023 IESO

In the data mining test (DMT) of this year, we will focus on different mathematical techniques and algorithms that are widely used in Earth science studies. In this case study, we focus on a critical interval of Earth's history, i.e., the Paleocene-Eocene transition at ~ 55 Ma (million years ago), during which the Earth System had experienced an extreme hothouse climatic condition. Firstly, we will apply the cyclostratigraphy to develop the time scale of the event by using the data form drill cores. Then, we will use different geochemical proxies to constrain the temperature, CO_2 concentration and other environmental factors so as to understand the causes of this critical interval in the Earth's history.

The platform for the DMT is powered by the Deep-time Digital Earth (DDE) program. DDE is the first IUGS-recognized big science programme. DDE is committed to developing itself as a provider of public goods and services for science and technology development globally, in particular to assist countries to realize SDGs adopted by the UN in 2015. The overall mission of DDE is to harmonize global earth evolution data and share global geoscience knowledge. The long-term vision of DDE is to transform the earth sciences by encouraging a data-driven research paradigm.

Data: All data you need in the DMT are provided online by DDE. It should be noted that, the data you can access is more than the data you need for examination. Some are very useful, if you choose the correct data. However, the selection of wrong data would be misleading. Please be cautious to find the appropriate data and start your analyses based on the data you select.

Algorithm, code and software: Please note that CODING IS NOT REQUIRED for the examination. All algorithms are integrated as a could application in the website below with graphical user interface. However, you need to understand some basic principles of the algorithms and its input and output parameters. The questions below will teach you how to use and understand your tools step by step. The outputs of the software/algorithm are either figures or data that can be plotted as figures. The figures are displayed with interactive tools and thus based on which you make interpretations.

Resources online available for this test:

https://ieso2023.deep-time.org

Instruction:

Open the website above with your browser (**Google Chrome is highly recommended for better experience**). Login with the username and password that you were informed, and click the start button **after your DMT start**, then you will be able access your answer sheet and the cloud application for data mining.

The answer sheet is integrated in the website. Any change on your answer will be automatically saved. NO SUBMITTING OPREATION REQUIRED. **When the test time is up, the website will close IMMEDIATELY and your answer sheet will be submitted automatically.**

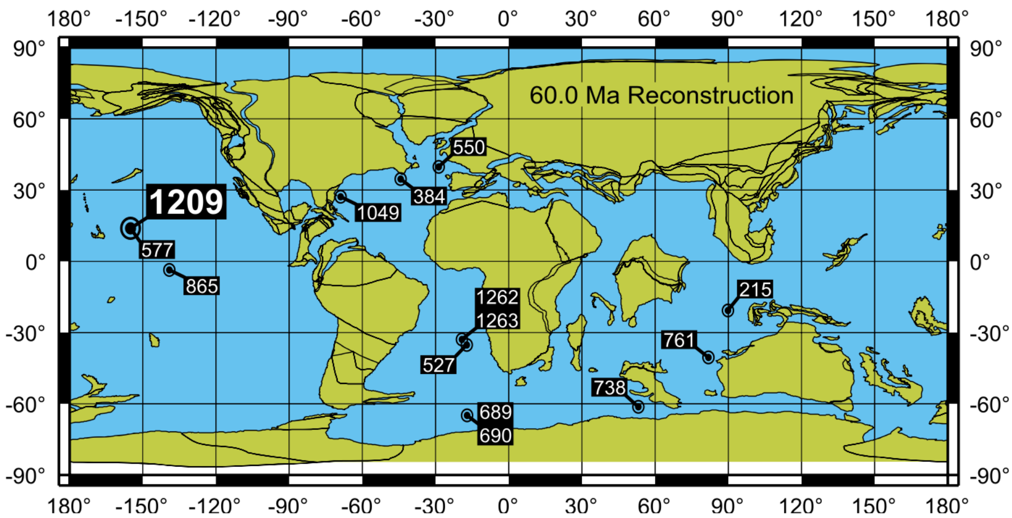
The cloud application is actually a Linux remote desktop with a Firefox the Acycle software powered by MATLAB. The homepage of Firefox is the DDE database, where you can access and download all data you need in the DMT. Acycle is a comprehensive, but "user-friendly" software package for analysis of time-series designed for (but not limited to) climate research and education.

When you see the **Instruction** part next time, follow the instructions and interact with the website to mine the information you need to answer the relative question.

Scores: The answer sheet automatically saved at the end of the DMT will be the only basis for scoring. All questions could have one or more than one correct answer. When choosing one correct answer, you will receive 1 point, while choosing a wrong answer, you will lose 1 point.

Part 1: Discovering PETM

The history of Earth system in the past 200 million years is recorded in marine sediments. To unravel the paleoenvironment, particularly paleoclimate, the scientific drilling programs were applied for more than 50 years. Starting with the Deep Sea Drilling Project (DSDP) (1966 - 1983), followed by the Ocean Drilling Program (ODP) (1983 - 2003) and the Integrated Ocean Drilling Program (IODP) (2003 - 2013), the most recent drilling program, collectively called International Ocean Discovery Program (IODP) (since 2013), is the most advanced scientific platform for multidisciplinary researches on the deep time Earth system, so as to provide the long-term historical perspectives on the present global change, the largest challenge for all human beings. These drill programs collect complete sediment drill cores from the seafloor, and scientists conduct multidisciplinary researches of deep-sea sediment samples. In the past 50 years, it is witnessed the rapid development of the drilling techniques and core analysis methodologies, which fostered international collaborations in research, education, and public engagement. The following picture shows the palaeogeographic reconstruction of the position of some important ODP and IODP sites for the study of PETM at 60.0 Ma.



The first step of core analyses is to precisely determine the depth of sediment samples. The measurement of sediment depth is a central concept for IODP activities. The conventional utilizations of the units, **meters below sea floor (mbsf)** and **meters below rig floor (mbrf)** in ODP/IODP seems inadequate at current time. Nevertheless, these traditional units are still widely used in IODP publications.

More measurements have been developed. For example, the **drilling depth below rig floor (DRF)** represents the sum of lengths of all drill string components deployed beneath the rig floor, including length of all components and the portions thereof below rig floor. **Drilling depth below sea floor (DSF)** is the length of all drill string components between the sea floor and the target (i.e., core sample), and is calculated by subtraction of sea floor depth from DRF. Both DRF and DSF were previously reported using the unit mbsf (meters below sea floor) in DSDP and ODP.

Core depth below sea floor (CSF) is the distance from the sea floor to the target within the Recovered Core. CSF combines DSF to top of Cored Interval with Curated Section length to target within cored material. Rebound of the sediment under reduced pressure would cause the cored sediment sequence to be expanded relative to the drilled interval. **Core composite depth below sea floor (CCSF)** is the distance from sea floor to target within recovered core using a scale of adjusted depths constructed to resolve gaps in the core recovery and depth inconsistencies. CCSF typically uses CSF as a baseline depth scale, based on the curated lengths of Core recovered Sections and drilling depth. CSF was previously reported using the unit mbsf (meters below sea floor), and CCSF was previously reported using the unit mcd (meters composite depth).

Q1: Based on above information, choose ALL CORRECT answers.

A. The depth of data is not processed after measure, if it is reported using the unit mbsf.

B. The depth of data is the exact depth below sea floor, if it is reported using the unit mcd.

C. The CCSF usually increases downhole relative to the CSF.

D. The CCSF usually decreases downhole relative to the CSF.

E. DSF is affected by random variations in ship motion and heave.

F. CCSF is affected by random variations in ship motion and heave.

Ocean Drilling Program (ODP) Leg 198 on Shatsky Rise was designed to address the causes and consequences of Cretaceous and Paleogene global warming. The objectives were to address the origin of the long-term climatic transition into and out of "greenhouse" climate as well as abrupt and transient climatic events, including the Paleocene-Eocene Thermal Maximum (PETM), the mid-Maastrichtian deep-water event (MME), and the early Aptian Oceanic Anoxic Event (OAE1a). Shatsky Rise is a medium-sized large igneous province containing sediments of Cretaceous and Paleogene age at relatively shallow burial depths on three prominent highs. As a result, sediments of both ages can be reached readily through drilling, and fossil materials are sufficiently well preserved for stable isotope and trace element analyses and for faunal and floral assemblage studies.

Ocean Drilling Program (ODP) Leg 208 was designed to recover lower Cenozoic sediments on the northeastern flank of Walvis Ridge. Previous drilling in this region (Deep Sea Drilling Project [DSDP] Leg 74) recovered pelagic oozes and chalk spanning the Cretaceous/Paleogene (K/P), Paleocene/Eocene, and Eocene/Oligocene boundaries. The objective of Leg 208 was to recover intact composite sequences of these "critical" transitions from a wide range of depths and construct "composite sections." The composite sections provide a detailed history of paleoceanographic variation associated with several prominent episodes of early Cenozoic climate change, including the K/P boundary, the Paleocene/Eocene Thermal Maximum (PETM), the early Eocene Climatic Optimum, and the early Oligocene Glacial Maximum.

Task: Use DDE database to find the basic information and relative data of from ODP Leg 198 and Leg 108. Find and download “Series for DMT” in DDE database. You can find “**Series.txt**” in “Series for DMT”.

Instruction:

You can use Acycle to analyses the data you find in the DMT. Double-click the Acycle icon and wait for a while to open Acycle. DO NOT CLOSE the terminal window, or the GUI of Acycle will be also closed. All the data you need is provided in meter by default. **Set the default unit of Acycle to meter by selecting "m" in the "unit" dropdown list at the right of the Acylce toolbar.**

The data provided in the database is not always sorted by depth, while almost all algorithms and plotting programs required sorted data. Following steps can help you in sorting data by depth.

1) Find and select the data like ["**Series.txt**"] in Acycle;
2) Click "Math" -> "Sort/Unique/Delete-empty" in the menu;
3) Set "Sort data in ascending order?" to "1", "Unique values in data?" to "1", "Remove empty row?" to "1" and "apply to ALL" to "0";
4) Click "OK" and the sorted data will be saved as ["**Series-sue.txt**"] in the same folder.

Following steps can help you in sorted data plotting data as an interactive figure.

1) Find and select the sorted data like ["**Series-sue.txt**"] in Acycle;
2) Click "Plot" -> "Plot" in the menu;
3) The selected data will be plotted as an interactive figure;

Q2. Choose ALL CORRECT answers.

A. Walvis Ridge is in the west-central Pacific at present.

B. Shatsky Rise is in the west-central Pacific at present.

C. Walvis Ridge was more closed to the equatorial divergence during the PETM.

D. Shatsky Rise was more closed to the equatorial divergence during the PETM.

E. Site 1207 – 1204 were reported in ODP Leg 198.

F. Site 1260 – 1267 were reported in ODP Leg 208.

Global Boundary Stratotype Sections and Points (GSSPs) are reference points on stratigraphic sections of rock which define the lower boundaries of stages on the International Chronostratigraphic Chart. The base of the Eocene Series and Ypresian

Stage is defined in the DBH Subsection of the Dababiya Section, on the east bank of the Nile River, 25km south of Luxor, Egypt. The GSSP is located at the base of a lithostratigraphic unit where the base of the so-called Carbon Isotope Excursion (CIE) is recorded. The base of CIE marked by a prominent negative excursion in carbon stable isotope is correlated with the initiation of basal Eocene Thermal maximum ("PETM") event.

What are isotopes? Isotopes are distinct nuclear species of the same element. Isotopes of the same element have the same number of protons (thus in same position in the periodic table), suggesting that they have almost the same chemical properties. However, isotopes have different neutron numbers, and thus have different atomic mass and physical properties. For example, carbon (C) has two stable isotopes, ^{12}C and ^{13}C. ^{12}C has 6 protons and 6 neutrons, while ^{13}C has the same number of protons but 7 neutrons. When chemical reactions occur, because of the mass difference of isotopes (e.g., ^{12}C vs. ^{13}C), reactions have their preferences for either heavier (^{13}C) or lighter (^{12}C) isotopes, causing what we call the isotopic fractionation. The fractionated isotopic signal can be recorded in sediments or sedimentary rocks. Thus, we can analyze the isotopic compositions of sediments or sedimentary rocks to recover the geochemical reactions in the past.

We use the delta notation to report the isotopic compositions, which can be expressed by the following equations in permil (‰),

$$\Delta X = \left(\frac{R_{sample}}{R_{standard}} - 1\right) \times 1000$$

where X represents the isotope of interest (e.g., ^{13}C) and R represents the ratio of the isotope of interest and its natural form (e.g., $^{13}C/^{12}C$). Higher (or less negative) delta values indicate increases in a sample's isotope of interest, relative to the standard, and lower (or more negative) values indicate decreases.

The isotopic value of a sample is linear relative to its deviation from standard. For a single element, different sources in nature have different isotopic values. The lighter the isotopes are, the smaller isotopic value is; and *vice versa*.

Task: Find and download the $\delta^{13}C$ Data of ODP Site 1209.

Q3. Choose the CCSF of the Paleocene/Eocene boundary in ODP Site 1209.

A. 218.02 m

B. 217.89 m

C. 217.47 m

D. 198.05 m

E. 196.32 m

F. 195.94 m

$\delta^{18}O$ is a measure of the ratio of stable isotopes oxygen-18 (^{18}O) and oxygen-16 (^{16}O). In geochemistry, paleoclimatology and paleoceanography, $\delta^{18}O$ data from corals, foraminifera and ice cores are used as a proxy for temperature. Based on the simplifying assumption, it is estimated that a $\delta^{18}O/T = -0.213‰/°C$. For $\delta^{18}O$ of the calcium carbonate from *N. truempyi*, T = 11.4 °C when $\delta^{18}O = -0.45$ ‰ during early Paleocene.

Task: Find and download the $\delta^{18}O$ data of ODP Site 1209.

Q4. Choose the max $\delta^{18}O$ temperature during PETM in ODP Site 1209.

A. 12 °C

B. 13 °C

C. 14 °C

D. 15 °C

E. 16 °C

F. 17 °C

Part 2: Development of the timeframe of PETM

In the 1920s, Serbian geophysicist and astronomer Milutin Milanković proposed a hypothesis, arguing that variations in eccentricity, axial tilt, and precession combined to result in cyclical variations in the intra-annual and latitudinal distribution of solar radiation in Earth's surface, and that this orbital forcing strongly influenced the Earth's climate. Such astronomically forced climatic fluctuations originated from variations in the Earth’s orientation with respect to the Sun imposed by gravitational attraction from the Moon, Sun and other planets. The motions of the attracting bodies are described by astrodynamical theory, and their interactions with the Earth invoke geodynamical theory. The coupling of these variations with the incoming solar radiation, known as insolation, is embodied in the Milankovitch theory of climate. The cyclic climatic fluctuations could be recorded in sediments or sedimentary rocks.

Being questioned and challenged for almost half century, cyclostratigraphy, the stratigraphic record of astronomically forced paleoclimatic change, has come to be widely accepted by geoscientists. Cyclostratigraphy depicts a paleoclimate system that is intimately connected with and pervasively tuned to the variations of co-occurring astronomical and geophysical parameters that have affected the Earth through geologic time. For the most recent ten million years, cyclostratigraphy has been precisely correlated to quantitative astronomical models. This has led to the rise of astrochronology, which assigns cyclostratigraphy to a specific time scale based on its correlation to astronomical solutions.

Modern astronomical solutions are highly consistent, indicating that the theory of Solar System dynamics has been described as completely as possible for 0 to at least 50 million years ago (Ma). This indicates that cyclostratigraphy can be correlated to the full Earth orbital eccentricity and/or inclination solution in the Cenozoic Era, to contribute a high-precision astrochronology for the geologic time scale.

Planetary orbital motions are modeled as variations in orbital eccentricity and inclination. Longer-term variations are caused by interactions involving the perihelia and nodes of the planets Mercury, Venus, Earth, Mars, and Jupiter. When the orbit is more elongated, there is more variation in the distance between the Earth and the Sun, and in the amount of solar radiation, at different times in the year. The Earth also experiences precession and obliquity variations due to its axial tilt and gravitational attraction from the Moon and Sun, and to a minor extent other planets. Earth’s precession and obliquity variations control the amount of solar energy incident on the Earth, and influence paleoclimate change.

The Earth's orbit approximates an ellipse. Eccentricity measures the departure of this ellipse from circularity. Eccentricity varies primarily due to the gravitational pull of Jupiter and Saturn. The major component of these variations occurs with a period of 405,000 years (long eccentricity period). Other components have 95,000-year and 124,000-year cycles, and loosely combine into a 100,000-year cycle (short eccentricity period) with a beat period of 400,000 years.

The obliquity of the ecliptic, or the angle of the Earth's axial tilt with respect to the orbital plane, varies between 22.1° and 24.5°, over a cycle of about 41,000 years (obliquity period). Axial precession with a period of about 25,700 years is the trend in the direction of the Earth's axis of rotation relative to the fixed stars, caused by the tidal forces exerted by the Sun and the Moon on the rotating Earth. Apsidal precession, with a period of about 112,000 years, occurs in the plane of the ecliptic and alters the orientation of the Earth's orbit relative to the ecliptic, primarily as a result of interactions with Jupiter and Saturn. Axial and apsidal precession combine into a shorter period of about 21,000 years (precession period).

Q5. Based on the information given above, choose ALL CORRECT answers.

A. The eccentricity period contributes to the periodic variation of the lengths of the astronomical seasons.

B. The obliquity contributes to the periodic variation of the lengths of the astronomical seasons.

C. The precession contributes to the periodic variation of the lengths of the astronomical seasons.

D. Tidal dissipation in the Earth-Moon system increases the frequencies in the Earth’s precession and obliquity.

E. The annual cycle of the solar irradiance has very strong direct contributions from the Earth’s obliquity and eccentricity variations.

F. There is no precession variation inherent to the global insolation of the solar irradiance.

The study of stratigraphic records of environmental cycles has been called cyclostratigraphy. Here, cycles can be thought of as essentially periodic, or regular, oscillations in some variable. In cyclostratigraphic data, the environmental signal recorded during sedimentation is often corrupted to some extent by interruptions and distortions. Hence, cyclostratigraphic data contain information about normal environmental variability, abnormal environmental variations and the processes that produce the records themselves. The quantitative techniques used for the study of such data collected relative to a depth or thickness scale are known as methods of time-series analysis. Here, time series include any sequence of measurements or observations collected in a particular order.

Oscillations of constant wavelength are described by mathematicians as periodic, and those of nearly constant wavelength as quasi-periodic. Periodic or quasi-periodic cyclostratigraphic sections have repetitions of a particular observation at essentially constant stratigraphic intervals. According to Fourier's theorem, any time series, no matter what shape it is provided it has some oscillations and no infinite values, can be recreated by adding together regular sine or cosine waves in different frequencies which have the correct wavelengths and amplitudes.

Clearly it would be convenient to be able to take a time series and quickly assess how many regular component oscillations are present. This is most readily achieved by using power-spectral analysis. Put simply the power spectrum shows the relative power (the squared amplitude) and the wavelength or the period of all the regular components in the time series. When power spectra are generated all the phase information is discarded. The larger the spectral peak, the greater the amplitude of the corresponding wavelength of oscillation and the greater its weight in controlling the overall shape of the time series.

Task: Check "Series_Syn.txt" in the folder "Problem_A" form "Series for DMT". This time series is synthesized by simply adding several sine waves with different frequencies together. All possible sine waves that maybe used in synthesis is given as "Series_[X].txt" in the same folder. Try spectral analysis on these series and solve the following problem.

Instruction:

Following steps can help you in the spectral analysis.

1) Find and select the data "**Series_Syn.txt**";
2) Click "Timeseries" -> "Spectral Analysis" in the menu;
3) Select "Periodogram" in the "Select method" dropdown list of the new window;
4) Tick "Linear Y" in the "Plot: max frequency & Y" part of the same window;
5) Click Run and the spectra will be displayed as an interactive figure.

Q6. Choose all series that was added together to synthesize "Series_Syn.txt":

A. Series_A.txt

B. Series_B.txt

C. Series_C.txt

D. Series_D.txt

E. Series_E.txt

F. Series_F.txt

G. Series_G.txt

H. Series_H.txt

In signal processing, the term noise is also used to mean signals that are unpredictable and carry no useful information. Noise usually gets added as unwanted modifications to the intended signal. During the identification of environmental oscillations, other non-periodic information recorded in the cyclostratigraphic data is regarded as noise background. Different kinds of noise signal have different power spectra, and thus significantly different properties, known as the colors of noise. Distinguish the periodic signal with the noise signal is an important theme in cyclostratigraphic spectral analysis.

White noise is a random signal having theoretically equal intensity at different frequencies, giving it a roughly constant and flat power spectrum. In discrete signal processing, white noise samples are regarded as a sequence of serially uncorrelated random variables with zero mean and finite variance. Put simply white noise is a series of independent and identically distributed random variables. Therefore, white noise can be produced by randomly choosing each sample independently. Mathematically, a series of white noise is denoted as $\{\varepsilon_t\}$ here.

Red noise, also known as Brownian, is the type of signal noise produced by Brownian motion, hence its alternative name of random walk noise. Red noise can be produced by adding a random offset to each sample to obtain the next one. Therefore, red noise can be produced by integrating white noise. Mathematically, a series of red noise is denoted as $\{\sigma_t\}$ here, where $\sigma_{t+1} = \sigma_t + \varepsilon_{t+1}$.

AR(1) noise can be generated by a first-order autoregressive model, or known as AR(1) model. Each value in an AR(1) series depends linearly on its previous value and a stochastic term (an unpredictable term). AR(1) model roughly represents the process of natural evolution, and thus AR(1) noise is used as a simple approximation for noise in a complex system like the earth system. Mathematically, a series of AR(1) noise is denoted as $\{\varphi_t\}$ here, where $\varphi_{t+1} = \rho\varphi_t + \varepsilon_{t+1}$ and $|\rho| \leq 1$ is a parameter. During spectral analysis, the total noise signal of all non-periodic information in cyclostratigraphic data is usually seen as an AR(1) noise.

Task: Check the folder "Problem_B" form "Series for DMT". Three series are provided as samples for white noise ("Series_WN.txt"), red noise ("Series_RN.text") and AR(1) noise with $\rho = 0.5$ (Series_AR1_rho_0.5.txt). Try spectral analysis on these series and solve the following problem.

Q7. Based on your observation, choose ALL CORRECT answers.

A. White noise can be seen as a kind of AR(1) noise.

B. Red noise can be seen as an AR(1) noise with $|\rho| = 1$.

C. A new AR(1) noise with $|\rho| = 0.2$ can be synthesized by two independent AR(1) noise with both $\rho = -0.2$.

D. A new AR(1) noise with $\rho = 0.6$ can be synthesized by an AR(1) noise with $\rho = 0.4$ and an AR(1) noise with $\rho = 0.8$.

E. It is possible to identify a strong periodic signal when a weak white noise existing.

F. It is easier to identify a periodic signal in lower frequency when a red noise existing.

G. It is easier to identify a periodic signal when an AR(1) noise with smaller $|\rho|$.

The parameter rho of AR(1) can be estimated though a robust algorithm, and through the reconstructed AR(1) noise, the significance testing of the an oscillation signal becomes possible. There may be a strong oscillation signal at a certain frequency, if the power is higher at that frequency is lower than the threshold lines of the estimated noise.

The Longyearbyen outcrop section and core BH9/05 are located in the Paleogene Central Basin of Spitsbergen, the largest island in the Svalbard Archipelago, situated on the NW corner of the Barents Shelf. During the Paleogene Spitsbergen was situated at ~75°N, adjacent to the NE corner of Greenland, but with the progressive opening of the northern North Atlantic, the Central Basin developed as a subsiding foreland basin, the sediment shed from the rising West Spitsbergen Orogenic Belt resulting in a thick sedimentary succession. In the Longyearbyen outcrop section, the coeval presence of the PETM diagnostic dinoflagellate cyst *Apectodinium augustum* is present in the Gilsonryggen Member of the Frysjaodden Formation, a unit of around 250 m of homogeneous mudstones, above the top of the underburned Hollendardalen Formation.

The Frysjaodden Formation is identified from 551 to 110 m depth in core BH9/05, drilled NW of the town of Sveagruva near Urdkollbreen. The cored succession cannot be divided into members due to the fine-grained nature of the lithologies. The mudstone-dominated succession is continuous across the upper Paleocene–lower Eocene interval, with only minor amounts of carbonate detected in XRD analyses. Fe and Mn time series were generated for core BH9/05 using an X-Ray Fluorescence (XRF) scanner.

Task: Find and download the XRF Data of core BH9/05. Try spectral analysis with the significance testing of AR(1) noise on the XEF Mn data and solve the following problem.

Instruction:

Preprocessing, including interpolation and detrending, is necessary in analysis of the real cyclostratigraphic data. Following steps can help you in preprocessing.

1) Find and select the XRF Mn data “**XRF_Mn.txt**” in Acycle;
2) Click “Math” -> “Interpolation” in the menu;
3) Just keep the default parameter (**0.39**) and click “OK” in the new dialog box.
4) Select the new file “**XRF _Mn-rsp0.39.txt**” in the same folder;
5) Click “Timeseries” -> “Detrend | Curve Fitting” in the menu;
6) Set “Window” to **50%** and tick “**LOESS**” in the new window; (IMPORTANT!)
7) Select “LOESS” in the dropdown list of the same window;
8) The prepared data is “**XRF_Mn-rsp0.39-207.675-LOESS.txt**” in the same folder.

Following steps can help you in the spectral analysis with AR(1) estimation and the significance testing of the spectra.

1) Select the prepared data “**XRF_Mn-rsp0.39-207.675-LOESS.txt**” in Acycle;
2) Click “Timeseries” -> “Spectral Analysis” in the menu;
3) Set “Input” to “0.6” with the radio button selected and tick “Linear Y” in the “Plot: max frequency & Y” part of the new window;
4) Click “Run” and keep the default parameter, and then click “OK” in the new dialog box.
5) Wait for a while and the spectra with the significance testing of AR(1) noise will be displayed as an interactive figure.

Q8. Based on the spectra you get, choose ALL periods with 99% significance in XRF Mn Data.

A. 188 m

B. 83 m

C. 40 m

D. 19 m

E. 12 m

F. 8.5 m

G. 7.2 m

H. 5.1 m

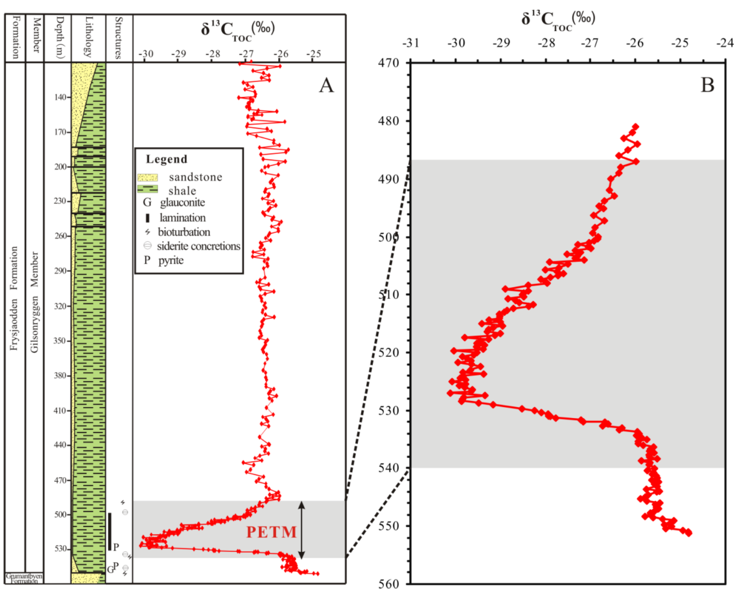
I. 4.5 m

J. 4.0 m

K. 3.8 m

L. 2.7 m

According to the cyclostratigraphy of the ODP Site 690 and the ODP Site 1262, the duration of the PETM, form the rapid onset to the full recovery of the CIE, is shorter than one long eccentricity period. In the Longyearbyen outcrop section, two conspicuous bentonite horizons occur at 10.90 and 14.60 m above the top of the Hollendardalen Formation, coincident with two bentonite horizons lying at 517.20 and 511.10 m depth in core BH9/05, respectively. The 13C curve of core BH9/05 is shown below:



Q9. What is the most possible 100 kyr short eccentricity peiod?

A. 188 m

B. 83 m

C. 40 m

D. 19 m

E. 12 m

F. 8.5 m

G. 7.2 m

H. 5.1 m

I. 4.5 m

J. 4.0 m

K. 3.8 m

L. 2.7 m

Without additional chronostratigraphic information, traditionally there is a huge challenge to evaluate whether a periodic signal detected in the cyclostratigraphic data is the record of a certain astronomical cycle. COCO is a modern cyclostratigraphic method designed for such problems, which employs the correlation coefficient between the power spectra of a proxy series and that of an associated astronomical forcing series, converting the proxy series to time for a range of "test" sedimentation rates, with the number of astronomical parameters contributing to the estimated sedimentation rates is taken into account.

COCO addresses two fundamental issues in cyclostratigraphy and paleoclimatology: identification of astronomical forcing in sequences of stratigraphic cycles, and accurate evaluation of sedimentation rates. This technique considers these issues part of an inverse problem and estimates the product-moment correlation coefficient between the power spectra of astronomical solutions and paleoclimate proxy series across a range of test sedimentation rates. The number of contributing astronomical parameters in the estimate is also considered. This procedure tests the hypothesis that astronomical forcing had a significant impact on proxy records. The null hypothesis of no astronomical forcing is evaluated using a Monte Carlo simulation approach. The most possible average sedimentation rate is found by combining the tested sedimentation rates with greater correlation coefficient and significance level.

Task: Try COCO analysis on the XEF Mn data and solve the following problem.

Instruction:

Following steps can help you in the COCO analysis.

1) Select the prepared data "**XRF_Mn-rsp0.39-207.675-LOESS.txt**" in Acycle;
2) Click "Timeseries" -> "Correlation Coefficient (COCO/eCOCO)" in the menu;
3) Set "Minimum" to "**0.1**", "maximum" to "**30**" and "step" to "**0.1**" in the "Test sedimentation rate" part of the new window; (IMPORTANT!)
4) Set "Middle age of data" to the age of the Paleocene-Eocene transition and select the "Lasker04 Solution" radio button in the "Target: Astronomical cycles";
5) Keep the other parameters as default and click "OK";
6) Wait until the progress bar reaches 100% and the COCO result will be displayed as an interactive figure.

Q10. Based on the most possible average sedimentation rate you got, what is the speed of global warming after the onset of PETM?

A. 0.005 °C/kyr

B. 0.015 °C/kyr

C. 0.025 °C/kyr

D. 0.05 °C/kyr

E. 0.15 °C/kyr

F. 0.25 °C/kyr

G. 0.5 °C/kyr

H. 1.5 °C/kyr

I. 2.5 °C/kyr

When time series are long in comparison to the scale of the regular cyclicity of interest, then it is feasible to generate many spectra from many subsections and still have a sufficient information for each cycle detection. This is known as evolutionary spectral analysis and in geophysics evolutionary spectra are called spectrograms.

Evolutionary spectral analysis can be characterized by the use of either consecutive or overlapping data subsections. When the subsections do not overlap, there can be an independent evaluation of the changing nature, or otherwise, of the complete time series. Most commonly, the spectra are based on overlapping data segments on the assumption that there are gradual changes in the frequency distribution of the power through the time series. Abrupt changes in power distribution cannot be resolved with overlapping subsections; for step-like changes in cycle frequency, the overlapping segments produce a low stratigraphic or temporal resolution.

Task: Clip the XRF Fe Data and keep the part of data from 470 m in depth to the bottom. Try evolutionary spectral analysis on the clipped XEF Fe data and solve the following problem.

Instruction:

Following steps can help you in clipping and preprocessing the XRF Fe data.

1) Find and select the XRF Mn data “**XRF_Fe.txt**” in Acycle;
2) Click “Math” -> “Select Parts” in the menu;
3) Set the “START of interval” (default = 135.81, the depth of the top) and “END of interval” (default = 551.2, the depth of the bottom) in the dialog box;
4) Keep the “Apply to ALL? (1 = yes)” as default (**0**); (IMPORTANT);
5) Click “OK” and the clipped data is “**XRF_Fe_470_551.2.txt**” in the same folder.
6) Select the clipped data “**XRF_Fe_470_551.2.txt**” and click “Math” -> “Interpolation” in the menu;
7) Just keep the default parameter (**0.2**) and click “OK” in the new dialog box.
8) Select the new file “**XRF_Fe_470_551.2-rsp0.2.txt**” in the same folder;

9) Click “Timeseries” -> “Detrend | Curve Fitting” in the menu;
10) Tick “**1 order (Linear)**” in the “Polynomial fit” part of the new window; (IMPORTANT!)
11) Select “Linear” in the dropdown list of the same window;
12) The prepared data is “**XRF_Fe-rsp0.2-207.675-Linear.txt**” in the same folder.

Following steps can help you in evolutionary spectral analysis.

1) Select the prepared data “**XRF_Fe-rsp0.2-207.675-Linear.txt**” in Acycle;
2) Click “Timeseries” -> “Evolutionary Spectral Analysis” in the menu;
3) Set “Use Input” to “0.6” (blue text box) and click “Run”.
4) Wait for a while and the evolutionary spectra will be displayed as an interactive figure.

Q11. Based on your result, choose ALL CORRECT answers.

A. The signal of 405 kyr long eccentricity period is strong in the clipped XRF Fe Data.

B. The signal of 100 kyr short eccentricity period is strong in the clipped XRF Fe Data.

C. The signal of 41 kyr obliquity period is stronger than 21 kyr precession period.

D. There is an abrupt interference in power distribution at the depth of the two bentonite horizons.

E. There is an abrupt interference in power distribution at the depth before PETM.

F. There is no abrupt interference in power distribution at the depth of the onset of PETM.

G. There is no abrupt interference in power distribution at the depth of the full recovery of PETM.

H. The sedimentation rate keeps constant after the PETM event.

Since random variations in accumulation rate can severely distort the spectra, it is desirable to remove their effect when possible. This is the case for Neogene to Recent deep-sea sediments when orbital cycle (‘astronomical’) time scales are of interest. The procedure of orbital tuning matches records of varying sediment composition or isotopic signals to either the calculated orbital-cycle history or models of global icevolume history, as driven by the orbital cycles. The orbital tuning allows the history of accumulation rate variations to be established between the control points.

Filtering involves manipulating a time series so that there is a change in the spectral characteristics of the data. The most commonly used methods in cyclostratigraphy are band-pass filtering. These techniques result in the retention, in the spectra of the filter output, of a narrow band of power. Frequency-selective filters treat the 'pass-band' information as signal and the 'rejected' information in the 'stop-band' as noise to be removed or 'filtered out'. Band-pass filters are useful for isolating individual regular cyclic components, or a single delimited range of frequencies.

Gaussian filtering is a widely used method for band-pass filtering in cyclostraigraphy to extract the astronomical signal from the cyclostraigraphic data. The identification of astronomical cycle signal is necessary for determining the parameters. Usually, the frequencies of the left and right intersections of the astronomical cycle signal peak and the 90% significance threshold in spectra are adapted as the lower and upper bounds of the frequencies of the oscillation signal extracted in Gaussian filtering. The peaks and troughs of astronomical cycle signal are great control points for orbital tuning, and the chronostratigraphy form radioisotope dating provides the key anchor point for astrochronology.

Task: Try to extract the signal of the precession period in the clipped XRF Fe data.

Instruction:

Following steps can help you in filtering the clipped XRF Fe data.

1) Select the prepared data "**XRF_Fe-rsp0.2-207.675-Linear.txt**" in Acycle;
2) Click "Timeseries" -> "Filtering" in the menu;
3) Find the "Bandpass filter: frquency" part in the new window and Set "f lower" and "f upper" to **[f_MIN]** and **[f_MAX]**, the lower and upper bounds of the frequencies of the oscillation signal that needs to be extracted in Gaussian filtering.
4) Keep "Gaussian" selected (by default) in the dropdown list of the same part,

and click “OK”.

5) The extracted signal will be plotted together with the original data used for filtering, and the extracted data will be saved as “**XRF_Fe_470_551.2-rsp0.2-Linear-Gau-flow-[f_MIN]-fhigh-[f_MAX].txt**” in the same folder;

Q12. <u>Based on your results</u>, choose the duration of the PETM Event.

A. 60 kyr

B. 100 kyr

C. 140 kyr

D. 180 kyr

E. 220 kyr

F. 260 kyr

G. 320 kye

H. 380 kyr

Analysis of zircons from the lower bentonite layer in the Longyearbyen section (sample SB01-1) by using U-Pb ID-TIMS provides a range of zircon $^{206}Pb/^{238}U$ ages from 57.08 ± 0.06 to 55.71 ± 0.14 Ma, with the five youngest analyses yielding a weighted mean $^{206}Pb/^{238}U$ age of 55.785 ± 0.034(0.066)[0.086] Ma (MSWD = 0.88).

Task: Try to tune the extracted signal of the precession period.

Instruction:

Following steps can help you in tuning the extracted astronomical cycle signal to astronomical cycle period.

1) Select the extracted data is “**XRF_Fe_470_551.2-rsp0.2-Linear-Gau-flow-[f_MIN]-fhigh-[f_MAX].txt**” in Acycle;
2) Click “Timeseries” -> “Bulid Age Model” in the menu;
3) Set “period (kry)” to **[T]**, the period of astronomical cycle you extracted; (IMPORTANT!)

4) Leep “Use 1 = peak 0 = trough” as default (**1**), and click “OK”;
5) The tuned results will be plotted as interactive figures with the original data used for filtering, and the age model will be saved as “**XRF_Fe_470_551.2-rsp0.2-Linear-Gau-flow-[f_MIN]-fhigh-[f_MAX]-agemodel-[T]_max.txt**” in the same folder.

Q13. <u>Based on the tuning result</u>, choose the age of Paleocene/Eocene Boundary.

A. 55.75 Ma

B. 55.80 Ma

C. 55.85 Ma

D. 55.90 Ma

E. 55.95 Ma

F. 56.00 Ma

Part 3: Unravelling PETM

From the previous two parts, we have already known that PETM represents the temperature maximum in Cenozoic, i.e., the extreme hot-house climatic condition. In this part, we will explore what causes PETM and how the Earth system was functioned under such an extreme hot-house climatic condition.

When studying the evolution of Earth system, we normally approach with various geological and geochemical proxies based on sedimentary rocks. The most commonly used approaches are isotopes. For example, geochemists often use oxygen isotope to recover the paleo-temperature. Now, we are going to learn some basic principles of isotopes, and then use some typical isotopes to retrieve the paleoenvironments in PETM.

(1) <u>The mass and isotopic balances</u>

The mass balance and isotopic balance are two basic principles in quantitative geochemical analyses. Normally, we assume a steady state, by taking the global ocean as an example, which refers both the concentrations and isotopic compositions of seawater remaining invariant. That is, for element X, the input flux of X (F_{in}) **into the ocean** equals to the output flux (F_{out}) of X **from the ocean**,

$$F_{in} = F_{out}$$

For isotopic balance of X, we have,

$$F_{in} \times \delta X_{in} = F_{out} \times \delta X_{out}$$

in which δX_{in} and δX_{out} represent the isotopes of input flux and output flux, respectively. When several sources and sinks exist, different components should be added together,

$$F_{in1} + F_{in2} + \ldots = F_{out1} + F_{out2} + \ldots$$

$$F_{in1} \times \delta X_{in1} + F_{in2} \times \delta X_{in2} + \ldots = F_{out1} \times \delta X_{out1} + F_{out2} \times \delta X_{out2} + \cdots$$

Q14: Now, we consider a system with one single source ($F_{in}, \delta X_{in}$) and two sinks ($F_{out1}, \delta X_{out1}$; $F_{out2}, \delta X_{out2}$). Which of the following equations is true?

A. $\frac{F_{out1}}{\mathrm{F_{in}}} = (\delta X_{out1} + \delta X_{in})/(\delta X_{out1} + \delta X_{out2})$

B. $\frac{F_{out1}}{\mathrm{F_{in}}} = (\delta X_{out1} + \delta X_{in})/(\delta X_{out1} - \delta X_{out2})$

C. $\frac{F_{out1}}{\mathrm{F_{in}}} = (\delta X_{out1} - \delta X_{in})/(\delta X_{out1} + \delta X_{out2})$

D. $\frac{F_{out1}}{\mathrm{F_{in}}} = (\delta X_{out1} - \delta X_{in})/(\delta X_{out1} - \delta X_{out2})$

(2) <u>The carbon cycle in PETM</u>

Now we consider a simplified model of marine carbon cycle. In this simplified C cycle model, terrestrial weathering input through river water input is the only major C source, while carbonate precipitation (with flux denoted as F_{carb}) and organic carbon burial (with flux denoted as F_{org}) are the two major processes (or sinks) removing C from the marine inventory. The riverine C input is in the form of dissolved inorganic C (DIC). Organic matter in the ocean is mainly produced by phytoplanktons (unicellular algae floating in the ocean surface), i.e., primary productivity. There are following geochemical principles.

(1) In organic matter production, phytoplanktons preferentially utilize ^{12}C relative to ^{13}C, and thus organic matter (CH_2O) is more enriched in ^{12}C than CO_2 (or seawater DIC), i.e., $\delta^{13}C_{org} > \delta^{13}C_{DIC}$. We assume that the isotopic fractionation in organic matter production, i.e., $\Delta_{org}=\delta^{13}C_{org} - \delta^{13}C_{DIC}= -25‰$.

(2) There is no C isotopic fractionation in carbonate precipitation, i.e., $\Delta_{Carb}=\delta^{13}C_{DIC} - \delta^{13}C_{carb}=0$.

(3) Assuming a steady state, we define f to describe the fraction of organic C burial with respect to total C sinks, i.e., $f=F_{org}/(F_{org}+F_{carb})$.

Task: Recall the $\delta^{13}C$ Data of ODP Site 1209.

Q15: If we assume the isotopic composition of weathering input ($\delta^{13}C_W$) is 0‰, the fraction of organic C burial (*f*) before PETM is,

A. 4%

B. 10%

C. 20%

D. 40%

Q16: During PETM, the carbon isotope of carbonates shifted from positive values to negative values. If only one assumption changed, which of the following changes could be the reason of this negative carbon isotope excursion?

A. Fraction of organic C burial (f) increased.
B. Fraction of organic C burial (f) decreased.
C. C isotope value of weathering input ($\delta^{13}C_W$) decreased.
D. C isotope value of weathering input ($\delta^{13}C_W$) increased.
E. Other heavier sources of C appeared.
F. Other lighter sinks of C appeared.

G. There is a positive fractionation in carbonate precipitation, i.e., $\Delta_{Carb}=\delta^{13}C_{carb}$ - $\delta^{13}C_{DIC} > 0$.

H. There is a negative fractionation in carbonate precipitation, i.e., $\Delta_{Carb}=\delta^{13}C_{carb}$ - $\delta^{13}C_{DIC} < 0$.

Now we dive deeper into the global C cycle. In continental weathering, both silicate and carbonate are weathered, which can be described by the following equations,

Silicate weathering: $CaSiO_3 + 2CO_2 + H_2O= 2HCO_3^{2-} + SiO_2 + Ca^{2+}$

Carbonate weathering: $CaCO_3 + CO_2 + H_2O = 2HCO_3^{2-} + Ca^{2+}$

Generally speaking, carbonate weathering is easier and thus faster than silicate weathering. Yet different silicate minerals have different resistance to chemical weathering depending on their stability in Earth surface. Normally, minerals that are most stable in the Earth's surface are less likely to be weathered. According to the above information and your own knowledge, please answer the questions about continental weathering below:

Q17: Which of the following statements about continental weathering is (are) correct? (one or more correct answers),

A. Continental weathering consumes atmospheric CO_2 and release O_2.

B. Dissolution of primary minerals, e.g., feldspar, is thermodynamically favored, because igneous minerals are not thermodynamically stable at room temperature.

C. Continental weathering generates a soil layer in the surface of continent, which habitats the terrestrial ecosystem. Therefore, there was no soil layer in continent before the evolution of land plants.

D. Clay minerals formed in continents are the major mud source of marine sediments.

E. Since continental weathering consumes atmospheric CO_2, atmospheric CO_2 level is only controlled by the intensity of continental weathering.

Q18: Dissolution of primary minerals is the initial process of continental weathering. Which of the following statements about continental weathering are correct?

A. Olivine is most easily dissolved, because it is black.

B. Mica or biotite are most weatherable, because they are fragile and easy to break.

C. The easiness of mineral dissolution follows the Bowen reaction sequence, i.e. olivine > pyroxene > hornblende > biotite.

D. Quartz is difficult to weather because it is hard and rigid.

Q19: Continental weathering also generates clay minerals. Which of the following statements about continental weathering are correct?

A. Clay mineral is more stable in Earth surface.

B. Clay mineral is less stable than feldspar that is more dense and less fragile.

C. Large surface area of clay minerals would absorb some trace metals, favoring the accumulation of some elements.

D. Smectite [$(Na, Ca)_{0.33}(Al, Mg)_2(Si_4O_{10})(OH)_2 \cdot nH_2O$] could be further converted to kaolinite [$Al_2Si_2O_5(OH)_4$] and gibbsite [$Al(OH)_3$].

Continental weathering (riverine) input is not only the major C source, but also a major source of nutrient, such as P. The availability of these nutrients largely influences the biomass and productivity of the ocean, therefore influencing the C cycle in the ocean. The chemical weathering processes of these nutrients, however, are in turn largely affected by atmospheric CO_2 concentration. A negative feedback of C cycle coupling with the cycle of nutrients is hence established. According to the given information and your knowledge, please answer the questions about nutrient elements below:

Q20: The major source of oceanic P is through riverine input. River water P derives from dissolution of apatite [$Ca_3(PO_4)_2$]. P is efficiently uptake by bioactivity in soil porewater, therefore the microenvironment of soil porewater has

large influence on dissolution of apatite. Experimental study indicates that dissolution of apatite is favored at low pH. Which of the following statements about P and apatite are correct?

A. Porewater pH in soil layer is determined by atmospheric CO_2 level.

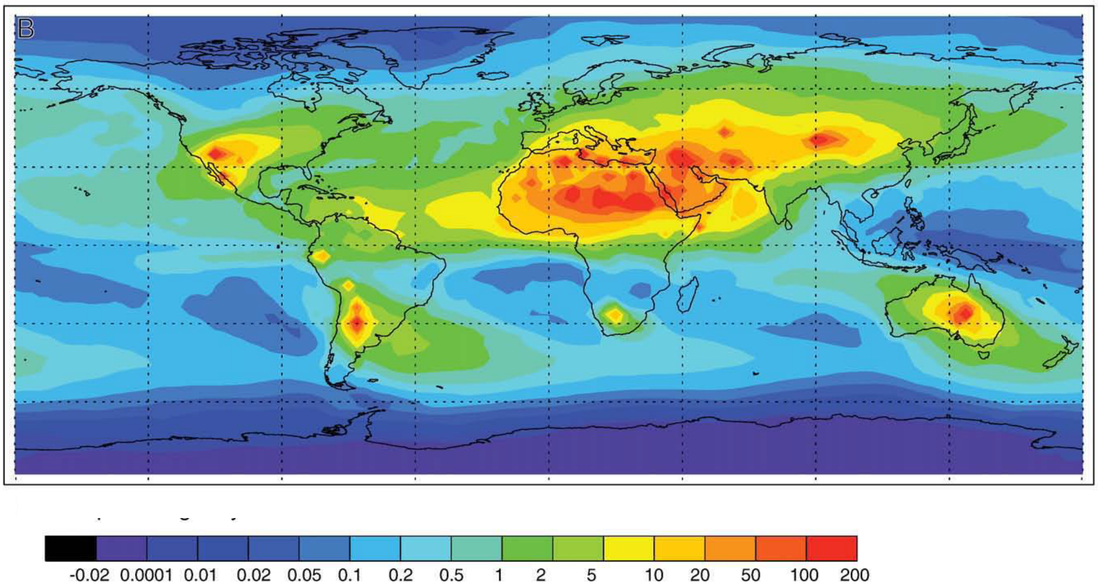
B. Apatite dissolution was more efficient in Proterozoic when atmospheric CO_2 level (1000s ppm) was higher than the present CO_2 level (~400 ppm).

C. P is a vital element of life mainly because it is a structural element in protein.

D. Southern Ocean has the highest surface P concentration because it has the most sufficient P input of all oceans.

Fe is a major element of the continental crust. Fe cycle in continental weathering is a critical link between the terrestrial and marine systems, because Fe is an essential element in N_2 fixation and many other physiological activities for eukaryotes. Fe cycle is notably different from the cycle of most nutrient elements, however, because Fe is insoluble in normal pH and redox condition of both river water and seawater. Some particulate inorganic Fe can be transported into seawater in fragments of rock or Fe-rich minerals, but these particles deposit quickly in the near shore shallow marine environment and cannot be transported further into the open ocean. A famous experiment called “Fe fertilization” was conducted in the Southern Ocean. In the experiment, scientists took a boat and poured Fe-rich particles along their way in the Southern Ocean. They observe a significantly increase in the surface ocean productivity along their path.

The availability of Fe input to the ocean is demonstrated in the map below. The red color denotes high Fe content, while the blue color indicates low Fe content.



Q21: Which of the following statements about the Fe cycle in continental weathering is correct?

A. Dissolution of Fe-rich igneous minerals, such as olivine, generates Fe^{2+}, thus soil porewater enriches in Fe^{2+}.

B. River water delivers abundant Fe^{2+} into the ocean.

C. Fe is most abundantly delivered to the ocean with siliciclastic sediments.

D. Fe is a bio-limiting nutrient in modern ocean.

E. Terrestrial Fe input is mainly in the form of Fe_2O_3.

F. The main source of Fe into the open ocean (Pacific, Atlantic and Indian Oceans) is aeoline dust.

It is widely accepted that photosynthesis by phytoplankton, i.e., unicellular algae, is responsible for the majority of marine primary productivity.

Q22: Which of the following statements about nutrients and primary productivity are correct?

A. Marine primary productivity is sustained by nutrient inputs from continents.

B. Surface ocean primary productivity reflects the interactions between lithosphere (via continental weathering) and hydrosphere, but has little to do with atmosphere.

C. High riverine P flux would certainly result in high marine productivity.

D. Aeolian dust contains very low P contents, and thus would not affect marine primary productivity.

Q23: Although both organic carbon burial and carbonate precipitation transfer C from the ocean-atmosphere system into the lithosphere, they have different impact on the Earth system. Which of the following statements are correct?

A. High organic matter burial lowers atmospheric CO_2 level, which tends to prevent continental weathering and thus reduces weathering consumption of atmospheric CO_2.

B. High carbonate precipitation lowers atmospheric CO_2 level, which tends to prevent continental weathering and thus reduces weathering consumption of atmospheric CO_2.

C. High organic matter burial lowers atmospheric CO_2 level, which would prevent continental weathering and thus reduce terrestrial P input, lowering the marine primary productivity.

D. The continuous decline of atmospheric CO_2 level by organic matter burial can be prevented by negative feedbacks.

(e) Under ice-house climatic conditions, atmospheric CO_2 tends to be depleted.

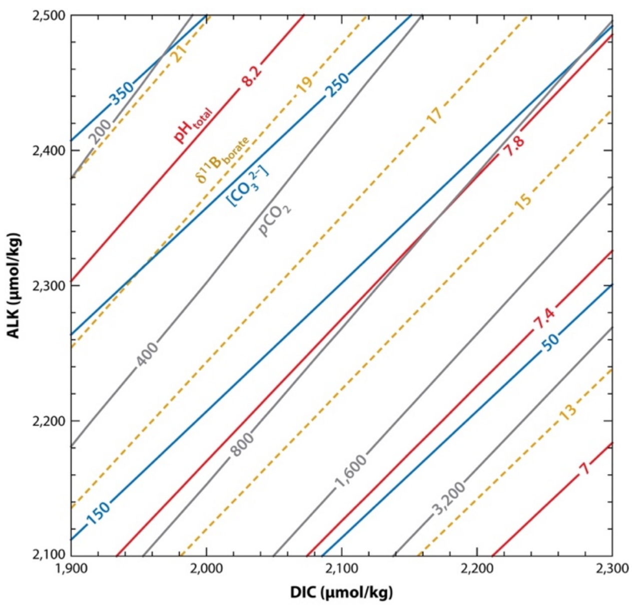
(3) <u>Boron isotope and seawater pH</u>

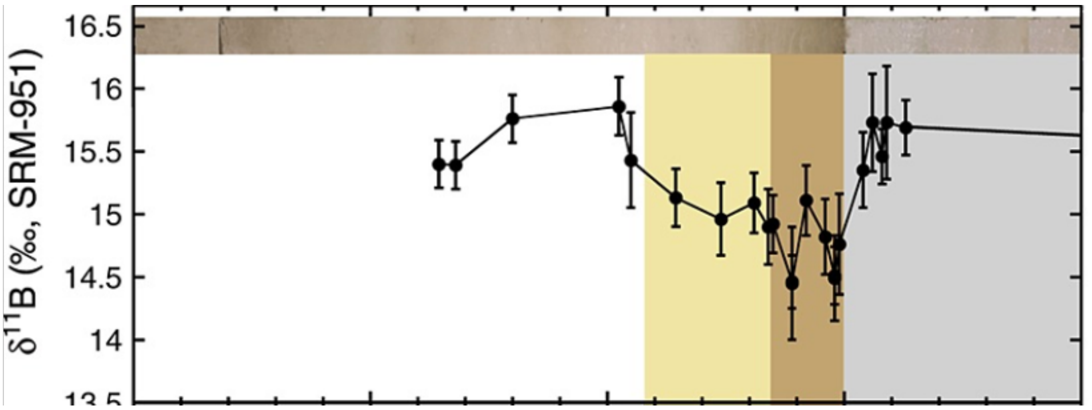
In our simplified model, we made the assumption that the only C source is from continental weathering. This is a fair assumption in most cases. However, in PETM, some studies indicate that additional C source might have been added into the ocean. Now we are going to use a more direct proxy – boron (B) isotope system to learn what really happened in PETM ocean. B isotope is rather sensitive to seawater pH, and thus has been used for reconstruct seawater pH. B in seawater is mainly composed of two species: $B(OH)_3$ and $B(OH)_4^-$. When the total B concentration in seawater keeps constant, the concentration of the two species changes with seawater pH. In addition,

$B(OH)_3$ and $B(OH)_4^-$ have distinct B isotopic compositions. Since carbonate only take up $B(OH)_4^-$, and thus measuring the B isotope of carbonate can be used to recalculate the seawater pH. We normally use the B isotope of carbonate shell of foraminifera to retrieve the seawater pH.

Q24: In the open ocean, carbonate concentration of seawater ($[CO_3^{2-}]$) and atmospheric CO_2 concentration (pCO_2) are also function of seawater pH, assuming the ocean-atmosphere equilibrium. The relationship among foraminifera B isotope, seawater pH, seawater DIC concentration and atmospheric CO_2 concentration is demonstrated in the figure below. Seawater pH is demonstrated in red, atmospheric CO_2 concentration (pCO_2) in grey, seawater carbonate concentration ($[CO_3^{2-}]$) in blue and B isotope ($\delta^{11}B_{borate}$)in dashed orange. According to the figure and data you have, the change of pCO_2 in PETM can reach:

A. 200ppm
B. 400ppm
C. 600ppm
D. 800ppm





(4) Possible causes of PETM

Q25: Combining all information above, which of the statements below do you think are possible reasons of PETM?

A. Large igneous province emitted massive CO_2 into the atmosphere-ocean system.

B. Woody plants appeared and formed large area of forest coverage.

C. Melting permafrost released large amount of CH_4.

D. Destabilization of CH_4 clathrate in the seafloor and resulting in CH_4 release.

E. Reduced organic carbon burial resulting in a higher atmospheric CO_2 level.

F. Change of Earth's orbit parameters

(5) Biodiversity in PETM

We have observed a lot of phenomena in PETM that are very similar to what we are facing now, for example, temperature and CO_2 level increases and acidification of ocean. In fact, PETM is well studied by many Earth scientists because it is considered as an analog of the global warming that we are facing now. Therefore, the reaction of biosphere in PETM is also a focus of paleontologists. Here, we focus on the diversity of benthic foraminifera in Pacific.

Task: Find the information and data of the relative abundances of benthic foraminifera and stable carbon isotope ratios data in ODP 198-1211B. Process these data to answer the following question.

Q26: We choose We want to divide the 38 taxa in this data into three groups: "Extinction", "Opportunistic" and "Survivor". Species in "Extinction" group had the most abundance before PETM, and diminished through and after PETM. Species in "Opportunistic" group had the most abundance during PETM, but had low abundance both before and after PETM. Species in "Survivor" group survived through PETM. Some species in "Survivor" have the same abundance both before and after PETM; some only get larger abundance after PETM. The ratio of the three groups "Extinction", "Opportunistic" and "Survivor" to the whole benthic assemblage are approximately:

A. 25%, 15%, 60%

B. 60%, 15%, 25%

C. 15%, 60%, 25%

D. 60%, 25%, 15%

(6) <u>Comparing PETM with the modern global warming</u>

Q27: We have explored the duration, temperature increase and pCO_2 concentration rise in PETM. The figure below demonstrates some future climate models based on different CO_2 emission standard over the 21^{st} century. The horizontal axis shows the temperature increase relative to the average temperature from 1850 to 1900. Which of the model fits the speed of temperature increase of PETM the most?

A. SSP1-1.9

B. SSP1-2.6

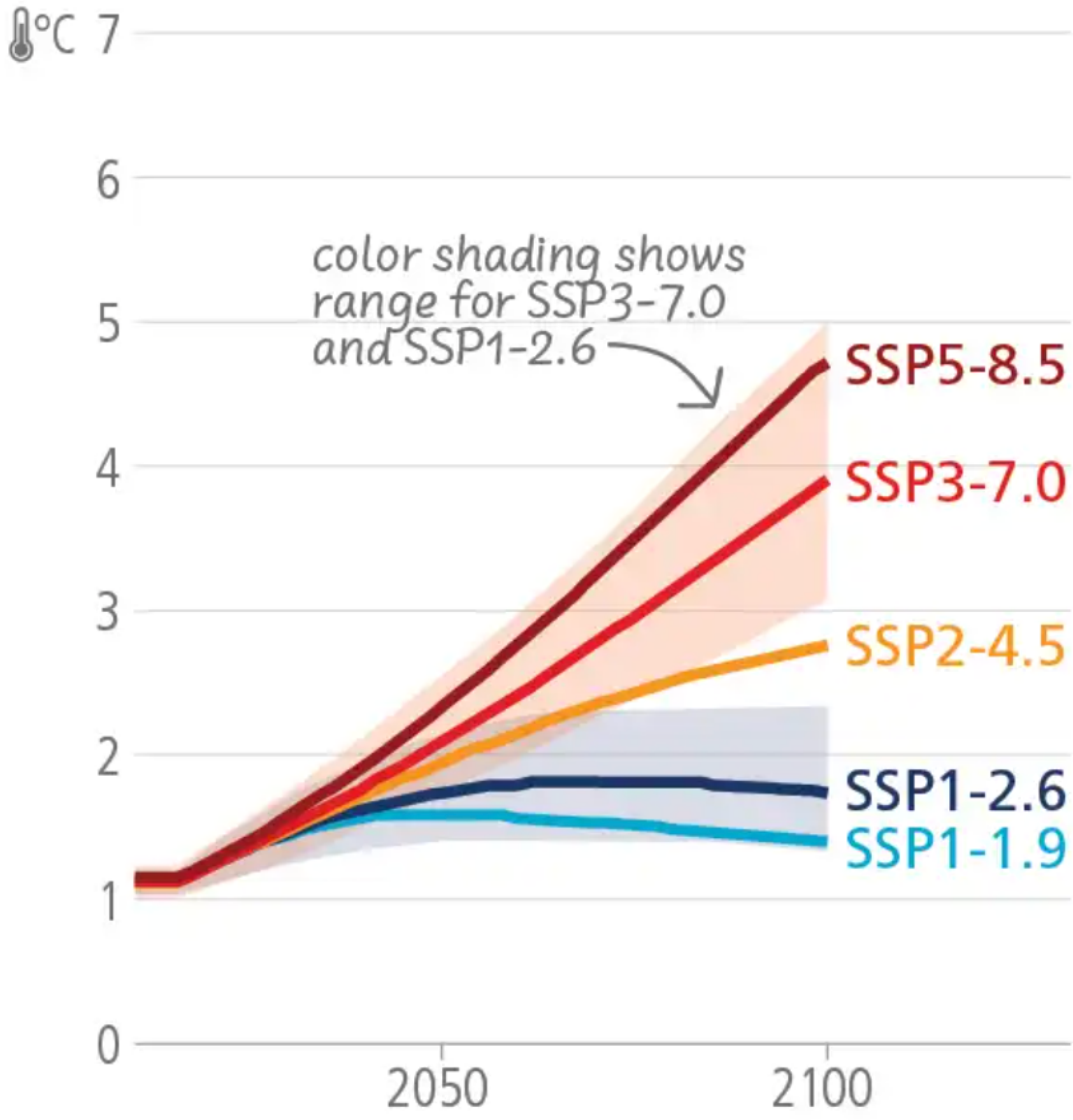
C. SSP2-4.5

D. SSP3-7.0

E. SSP5-8.5

F. The speed of all of the models above are faster than PETM

G. The speed of all of the models above are slower than PETM



°C
7
6
5
4
3
2
1
0
color shading shows range for SSP3-7.0 and SSP1-2.6
SSP5-8.5
SSP3-7.0
SSP2-4.5
SSP1-2.6
SSP1-1.9
2050
2100