

Tutor-Marked Assignment 03

Cut-off-date: Monday 3rd February 2020

You must submit this TMA by the cut-off date via the [online eTMA system on StudentHome](#).

If any points of clarification require adding following questions on the Discussion forum they will be added in [blue](#) to the online version only. Please bear this in mind if you are working from this downloaded version.

There are notes on advisory and mandatory word limits at the end of this document.

Plagiarism: It is important that you read, understand and comply with the University's plagiarism policy in all of your assignments. What constitutes plagiarism is outlined in the Open University document: [Plagiarism Policy](#). You should write in your own words and avoid in all instances directly copying phrases. Except in a few instances where short quotes may be appropriate, they should also be avoided, as they will not constitute your own work. All work submitted for S309 assessment will be carefully checked for plagiarism and if you are found to have plagiarised you could lose marks and the case will go on your record. The OU Library [Referencing and plagiarism](#) page provides guidance on how to correctly cite references in your assignments and how to avoid the plagiarism pitfalls. For further help with your academic writing and avoiding plagiarism, please consult the [Developing Good Academic Practice](#) website and/or discuss this matter with your tutor, who will be very happy to help.

Overview

There are three questions in this TMA and the breakdown is: Question 1 (40 marks), Question 2 (56 marks) and Question 3 (4 marks). Question 3 will help you to prepare for the S309 project work and hence the project report which forms the majority of the EMA.

Learning outcomes for TMA 03

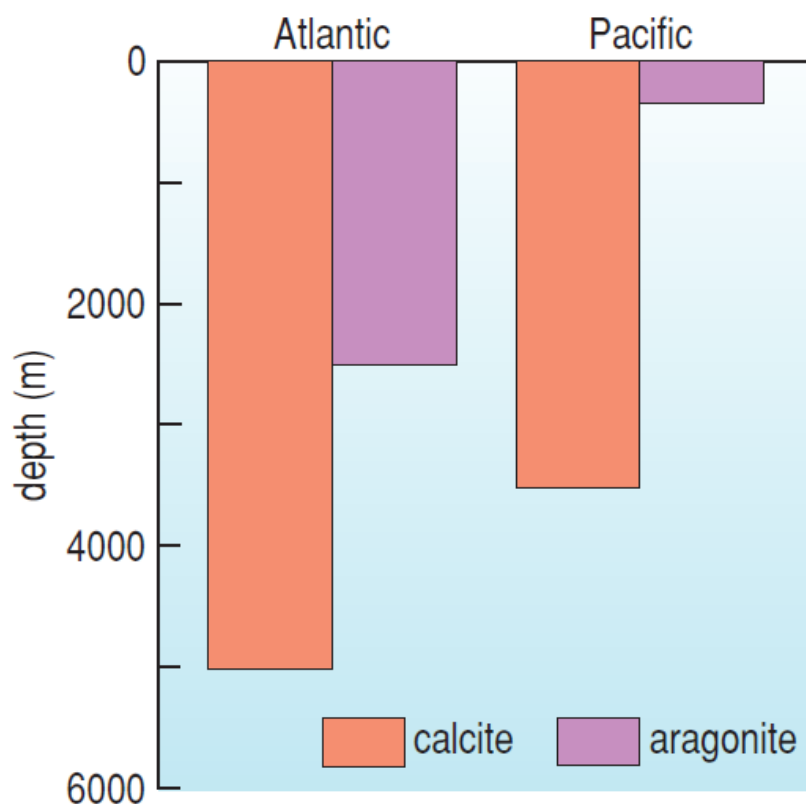
Learning outcome (LO)	Total marks for the LO	Section of the TMA
Knowledge (Kn1)	8	Q1 (a) (knowledge of nutrients in the oceans)
	4	Q2(e) (understanding of the carbon cycle)
Solutions (C3)	24	Q1 (b), (c)
	12	Q2 (e) (synthesise data and information from figures and module materials to make informed interpretations)
Graphics (Ky3)	28	Q2(a), (b), (c), (d) (use of numerical techniques)
Scales (C4)	8	Q1(d) (integrating and evaluating a wide range of information about the carbonate cycle to explain why the CCD exists)
Applications (C1)	12	Q2(f) (apply understanding of the ocean carbonate system and the PETM event to describe likely future changes in the CCD)
Time management (Ky4)	4	Q3 (planning for the S309 project)

Question 1 (40 marks)

This question is about the oceanic recycling of organic matter, nutrients, and the impact on ocean chemistry and carbonate dissolution.

(a) (8 marks) Are deep waters richer in dissolved nutrients in the Pacific Ocean or Atlantic Ocean? Provide reasons for your answer.
(Advisory limit 70 words)

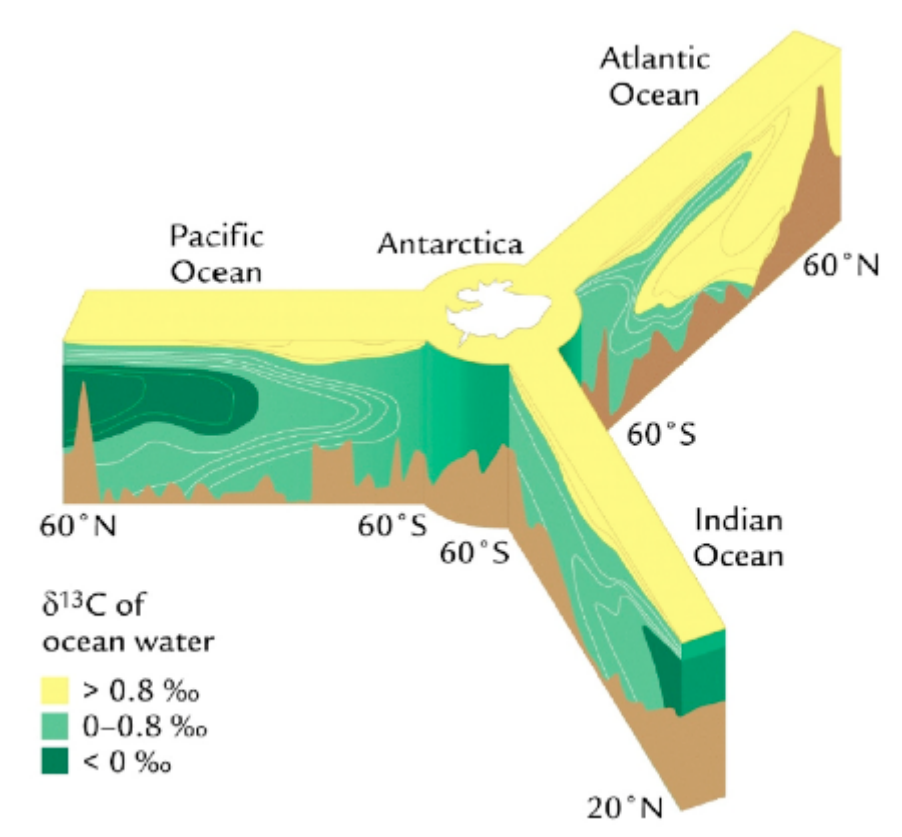
(b) (4 marks) Succinctly describe and explain what Figure 1 shows, and summarise the main quantitative observations provided by the data.
(Advisory limit 100 words)



Source: James (2005)

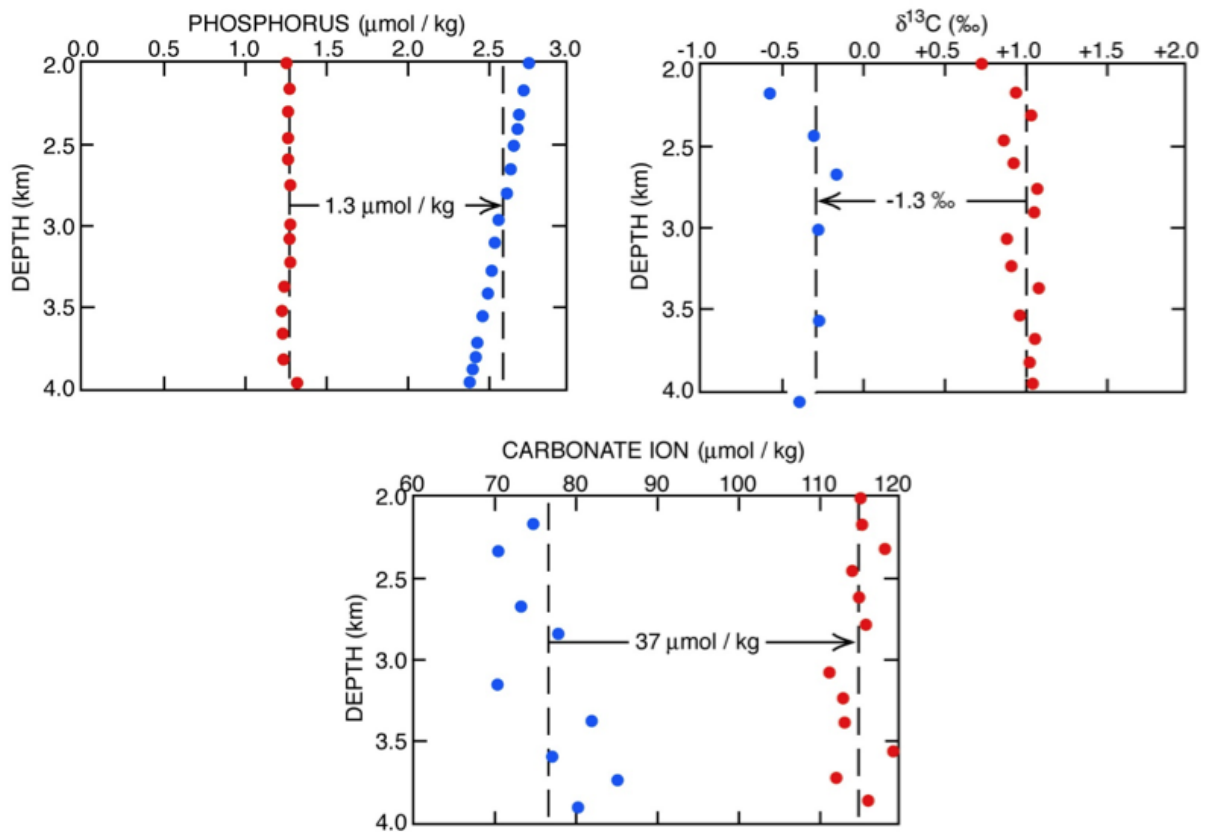
Figure 1. Average water depth to which calcium carbonate (both calcite and aragonite shown) is preserved in seafloor sediments in the Pacific and Atlantic Oceans.

(c) (20 marks) Use the information presented in Figures 2 and 3 to qualitatively explain the observations from Figure 1 that you just described in (b). (Advisory limit 120 words)



Source: Ruddman (2002)

Figure 2. Distribution of $\delta^{13}\text{C}$ in the modern oceans.



Source: <https://www.ldeo.columbia.edu/~broecker/>

Figure 3. Distribution of phosphorous, $\delta^{13}\text{C}$ and carbonate ion versus water depth in the western equatorial Atlantic (red) and Pacific (blue) Oceans.

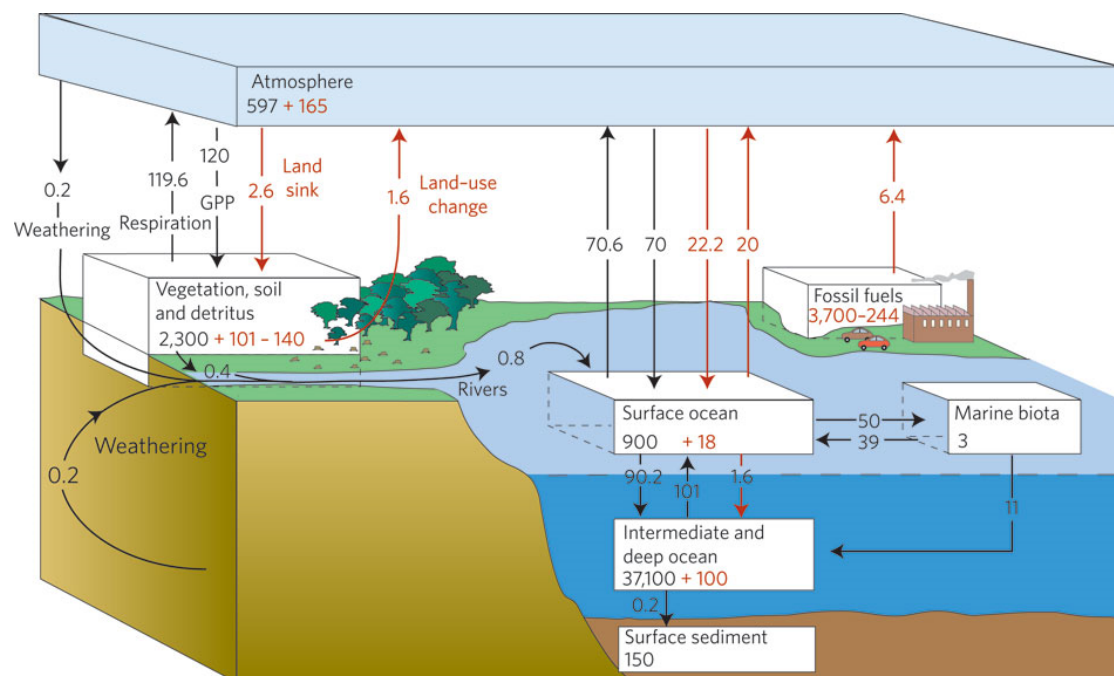
(d) (8 marks) Calcium carbonate dissolution in the oceans intensifies below the Carbonate Compensation Depth (CCD). Explain why a CCD exists at all. (Note: your answer should include reference to the 'ingredients' for calcium carbonate). (Advisory limit 120 words)

Learning outcomes: In your answer to Question 1 you will need to apply your knowledge of organic matter recycling and ocean nutrient distributions (Kn1) to evaluate their impact on ocean chemistry and calcium carbonate dissolution (C3). To do this will require you to use and synthesise information from the module (C3) and this TMA. You will then be able to combine this information with your understanding of the 'ingredients' for calcium carbonate formation to examine why a CCD in our oceans exists at all (C4).

Question 2 (56 marks)

This question is about the insights that the concept of residence time can provide into the operation of the short-term and long-term carbon cycles. **Important: you should keep your calculations consistent (and correct) by using inputs of carbon into the atmosphere, not outputs of carbon from it.** In (a) to (d) you should show your working, and your answers to (a), (b) and (d) should be quoted to three decimal places.

(a) (8 marks) Calculate the residence time of carbon in Earth's atmosphere for the pre-industrial era, using the inputs of carbon into the atmosphere from respiration from the terrestrial realm and the surface ocean shown in Figure 4. (A calculation)



Source: Gent (2012)

Figure 4. The global carbon cycle, showing the main fluxes (arrows) and reservoirs (boxes). Black numbers in boxes and arrows are the respective reservoir sizes and fluxes for the pre-industrial Earth, while those in red are for the industrial era in the 1990s. Annual fluxes are in gigatonnes of carbon (10^{15} g) per year and reservoir sizes are in gigatonnes of carbon (10^{15} g).

(b) (8 marks) Calculate how fossil fuel-derived CO₂ emissions have changed the pre-industrial residence time of carbon in Earth's atmosphere. To make this calculation, you will need the following information. Today, the concentration of CO₂ in our atmosphere is ~410 ppm (<https://scripps.ucsd.edu/programs/keelingcurve/>). First, you will need to calculate the mass of C in Earth's atmosphere today (in Gt of C, quoting your answer to the nearest Gt) by using the appropriate conversion factor from Table 3 on this website (<https://cdiac.ess-dive.lbl.gov/pns/convert.html>). The rate of fossil fuel CO₂ release into the atmosphere is currently averaging 9.4 Gt of C/yr. Second, calculate the residence time of atmospheric carbon today by assuming that the other input fluxes of carbon into the atmosphere (from terrestrial respiration and surface ocean respiration) remain the same today as their pre-industrial fluxes that are shown in Figure 4. (Two calculations)

(c) (4 marks) The Palaeocene-Eocene Thermal Maximum (PETM), was marked by a massive injection of carbon into the exchangeable carbon reservoirs at Earth's surface from the long-term carbon cycle. Much of this carbon release is estimated to have occurred during the first ~8000 years of the event (Gutjahr et al., 2017), averaging about 0.4 Gt of carbon per year during this 8000 years (Gutjahr et al., 2017). Calculate the total amount of carbon released to the atmosphere during these 8000 years (remembering to quote your units of measurement). (A calculation)

(d) (8 marks) 8000 years after the PETM onset the concentration of CO₂ in Earth's atmosphere is estimated to have been ~2200 ppm (Gutjahr et al., 2017). First, as you did for part (b), calculate the mass of C in Earth's atmosphere 8000 years after the PETM onset (in Gt of C, quoting your answer to the nearest Gt) by using the appropriate conversion factor from Table 3 on this website (<https://cdiac.ess-dive.lbl.gov/pns/convert.html>). Second, calculate the residence time of carbon in the atmosphere 8000 years after the PETM onset. As well as the PETM-specific release of CO₂ into the atmosphere of 0.4 Gt of C per year (Gutjahr et al., 2017), you can assume for the purposes of this calculation that the other inputs of CO₂ into the atmosphere from respiration from the terrestrial realm and the surface ocean had values identical to the pre-industrial era of 119.6 and 70.6 Gt/C/yr, respectively (see Figure 4). (A calculation)

(e) (16 marks) Explain the reasons why the predicted total atmospheric lifetimes of our ongoing fossil fuel CO₂ release (Archer et al., 2009) and the CO₂ release at the PETM (Gutjahr et al., 2017) are both so much longer than the simple atmospheric residence time calculation for CO₂ that you just made in your answer to (d). In accounting for the long duration of the PETM and modern carbon cycle perturbations, your answer should include reference to key, common features of their CO₂ releases, and the nature of the carbon cycle processes involved. (Advisory limit 240 words)

(f) (12 marks) Given what you already know about what happened at the PETM carbon cycle perturbation, and building on your answers to Q1, explain, and account for, how the Carbonate Compensation Depth (CCD) will respond to changes in rock weathering throughout the next 100,000 years as a consequence of humanity's accelerating release of fossil fuel-derived carbon? (Advisory limit 150 words)

Learning outcomes: In your answer to Question 2 you will need to use data from a variety of sources and numerical techniques to make calculations about carbon's residence time in Earth's atmosphere under different climatic states (Ky3). You will then be able to apply your knowledge of the controls on the short-term and long-term carbon cycles (Kn1), and the differing timescales of carbon cycle processes (C3). You can then apply your understanding of the ocean carbonate system and the PETM event to describe likely future changes in the CCD arising from fossil fuel carbon dioxide release (C1).

Question 3 (4 marks)

This question is about the S309 project and builds on work you did in Week 5, for TMA 01 and TMA 02. Whilst it is only worth 4 marks, it is well worth completing so that you are better prepared for your EMA and can gain valuable feedback from your tutor on your ideas.

Note: Three study weeks (26 to 28) or a total of 60 study hours have been scheduled for you to undertake your project. We suggest that you use part of this study time to complete the first full draft of a technical report as outlined in Question 1 of the EMA. You can then complete the final draft between the end of Week 30 and the EMA cut-off date (see the calendar for details). There are further guidelines for the project work in Weeks 26 to 28.

You may not have decided what your final project will be yet, and may be waiting until you have studied more material before you make a final decision. This is not a problem at all. However, to ensure you are prepared to start project work when you do make your decision, we suggest you start recording all your thoughts, as you progress through the module, in a project notebook. This can be using either a paper notebook or an electronic format on a tablet or computer. Use your notebook to complete the following task.

Using either specific ideas you have for possible projects you would like to undertake or any of the ideas you submitted for TMA 02, outline a draft time plan in the form of one of the following:

- a schematic diagram
- a flow chart
- a series of bulleted notes.

Include notes on any skills or knowledge that you still need to address and that you identified in TMA 01. The aim of this question is to prompt you to produce notes or a diagram that help you to visualise and remember the tasks you will need to complete in order to finish your project on time. Scan the notebook page or copy and paste your electronic notes into your answer for TMA 03. (One diagram or chart or set of notes.)

Learning outcome: In your answer to this question we would like you to demonstrate that you can plan time effectively for project work and reflect on your own learning (Ky4).

References

The papers below are cited in the text above. You do not need to read these papers unless you want to, but they are provided here for further information and to deepen your understanding (and hopefully inspire you too).

Archer, D., M. Eby, V. Brovkin, et al. (2009), Atmospheric lifetime of fossil-fuel carbon dioxide. *Ann. Rev. Earth Planet. Sci.*, **37**, 117–134.

Gent, P. R. (2012). Carbon cycle: Wind bias and ocean carbon uptake. *Nature Climate Change*, **2**, 25-26.

Gutjahr, M., Ridgwell, A., Sexton, P.F., Anagnostou, E., Pearson, P.N., Pälike, H., Norris, R.D., Thomas, E. and Foster, G.L. (2017), Very large release of mostly volcanic carbon during the Palaeocene-Eocene Thermal Maximum, *Nature*, **548**, 573-577.

James, R. H. (2005) *Marine Biogeochemical Cycles*, co-published by Elsevier (Butterworth-Heinemann) and The Open University, Milton Keynes.

Ruddiman, W. F. (2002). *Earth's Climate: Past and Future*. W.H. Freeman.

Notes advisory and mandatory word limits

One of the key skills in science is communicating clearly and succinctly. As a scientist almost everything one writes has a word limit whether it is an academic paper, an abstract for a talk, a course text or a piece for the general press. If a paper or abstract is submitted to a journal that is over the word limit it will incur a penalty because it will not be accepted.

In order to help you develop this key graduate skill and to give you practice in writing succinctly ready for the EMA, all of the S309 TMAs have **advisory word limits** (i.e. suggested maximum number of words you can use for your answer). We strongly suggest you edit your answers so that they are within these advisory limits. There are many guides and websites with tips on how to write succinctly and how to edit your work, try searching for 'write succinctly' or similar.

Some TMA questions and the EMA have a **mandatory word limit** (i.e. an absolute maximum number of words you can use for your answer without incurring a penalty). If your answer in a TMA exceeds the mandatory maximum a penalty will be incurred and 10% or less of the marks will be deducted. If your EMA exceeds the mandatory word limit any work over the limit will not be marked.

- Please remember that you do not have to reach the limit to get full marks. We have set the limits so that they are reasonable.
- Your answers should take the form of full sentences except when it asks for another form of answer (e.g. bulleted list, figure, table).
- Please make sure that you do not write unnecessary sentences and that you edit your answers to make them succinct.
- Your point will be more clearly made if you are succinct and you are more likely to gain higher marks.
- Usually you should be able to present more than one point in each sentence.

You are also required to provide an accurate word count for all questions that state a mandatory word limit. Please ensure that your word counts are clearly marked on the same page as the answer.