Learn Chemistry

Chemistry's Interfaces: Geochemical Time Travel

Tutor Guide

Developed by Dr. Carys Bennett, University of Leicester

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Introduction

This resource is designed as an introduction to geochemistry in the context of the geological and archaeological record. This problem is based around the following question: What would the geochemical record of human activities and civilisation be in the geochemical record of the future?

The resource is focussed at level 1 and 2 students so it places a particular emphasis on simple organic and inorganic chemical formulae and equations related to geochemistry and climate change science. Analytical techniques such as mass spectroscopy are also examined. No prior archaeological or geological knowledge is required or expected to complete this problem.

Many of the underlying concepts that students should understand in order to do this problem are covered in year one chemistry courses on organic chemistry and atmospheric chemistry. If students are yet to study some (or all) of these concepts, this problem could also be used to introduce the concepts alongside lecture – the problem will give students an opportunity to see how the geochemical study of the past can be used to predict the record of the future.

The range of applications covered in this problem brings together a number of different areas of overlap between chemistry, earth sciences, the physical and life sciences. This problem is unique in that it allows the students to utilise current research publications to produce a synthesis of information about this new and interdisciplinary area of scientific research.

The recommended reading is diverse in subject matter and there are extension papers for the more advanced questions. Although the problem has been primarily designed with year 1 and 2 students in mind, it could be used with year 3 or 4 students by utilising more of the extension papers and expanding some of the facilitation questions.

We recommend that this problem is used with small groups of students (typically group sizes of 4-6 work best). We also recommend that each facilitator guides no more than 2 or 3 groups at the same time – if a facilitator has to work with any more groups than this, it is likely to mean that very little time is spent with each group.

We have found that postgraduate students can make good PBL/CBL facilitators if they are given guidance in this style of teaching and the nature of the problem before the start of the module. It is advisable to have at least one staff facilitator on duty during all sessions.

Criterion	Value
Intended level	Year 1-2
Subject area	Geochemistry
Contact Hours	3-4 hours
Group size	4-6

Outline tutor answers have been provided for the facilitation questions in red script. Please note that these are neither model answers nor guidelines to the amount of content that students should produce. These answers only provide a minimal outline of the concepts being asked and students should go into more detail and provide examples of each of these concepts.

Additional information can be found in a glossary of geological terms at the end of this document. A PowerPoint Presentation duplicates the questions in this document, but also includes some useful images and additional background information. This presentation can be used as a reference or the illustration of tasks or key questions during the facilitation sessions.

Tutor text has been included in this version of the problem. The tutor text is shown in red; this text should not be shown to students.

Background

This resource was inspired by the recent global news debate and scientific coverage of The Anthropocene. This debate brought to light the fact that the significance of human impact on the planet may be to such an extent as to leave a measureable imprint in the geological record. In fact, The Anthropocene may be named as a new Epoch of geological time. This emerging new research area is highly cross-disciplinary, (incorporating geology, geography, environmental science, climate science, materials science, biology and chemistry) but is in fact underpinned by chemical evidence.

The development team wanted to create a resource which could provide chemistry undergraduates with an insight into this interdisciplinary area by problem based learning and experience the importance of cutting edge global research. We hope to challenge the perception of how chemistry undergraduates think, and allow them to apply their subject knowledge in real-world scenarios.

One of the novel aspects of this resource is that it encounters the geochemical record through time, as recorded in rocks, soils and ice cores. Most of this record if a record of changes in the chemistry of the Earth's atmosphere or oceans. A different aspect that is addressed in the problem is the more tangible chemical composition and durability of a range of man-made and natural materials. The students will predict how these materials would be preserved in the 'Human Strata' i.e. the geological record of the future.

The resource was trialled at the University of the West of England (UWE) and Edge Hill University. Students engaged well with the resource well (student feedback included "*I wish I had more time to do this, it was great*" and "*I love detective work and was thinking of changing to forensic science, but now I realise that all science is about detective work*") and found the recommended reading accessible and informative. The resource also highlights the range of applications of the chemical sciences, one student commented ""*I thought that being a scientist was about working in a laboratory but now I realise just how much you have to know*". The resource was trialled with year 2 students, but the extended reading of scientific papers and extension activities also make this resource suitable for year 3 students. Students doing an environmental science module were especially engaged with the context of the problem and the aspects of pollution and the archaeological record. After the trial we reflect that this resource can be used with many different modules, such as atmospheric chemistry, organic chemistry and environmental sciences.

Transferable Skills Development

This resource makes use of a number of types of assessment which share a common theme of communication. The authors have found that the use of C/PBL resources can be an ideal way of teaching communication skills in a scientific context and it is hoped that this resource will raise awareness of the relevant issues when communicating science to a range of audience types. The following transferable skills are encountered in this problem:

- Discussing relevant aspects of science with peers **- Relevant throughout the problem**
- Working within a group to prepare a scientific poster – **Leading up to session 4.**
- Preparing a short (2-3 pages long) educational resource which will be used as a museum guide **– Leading up to session 4.**
- Presenting a scientific poster and answering relevant questions from peers – **Session 4.**

The Scenario

The scenario places the students in the role of staff working for the National Museum. They are tasked with organising a new exhibit which demonstrates how geochemical analysis can be used as a powerful tool to look back into the past and predict what evidence of our existence will exist in the geochemical record of the future.

Session 1 – Geochemical Time Travel

In Session 1 the students will be introduced to the problem: **"If humans were to become extinct would we leave a geochemical record behind?"** This is the theme that will be used for the new exhibit. It is central to the current debate on the naming of a new geological epoch, called the Anthropocene. The Anthropocene is the period of time in which humans have significantly altered our environment so much as to substantially change the geochemical record. The exhibit will examine the geochemical record of the past, present and predict that of the future. This requires some understanding of geological time periods. At the start of this session the first task is to construct a time chart that encompasses the intervals that will be included in Parts 1-4 of this problem, encompassing 1 million years ago to 1 million years into the future. To introduce the key concepts of the Anthropocene the students will examine data presented in a recent key review paper by Steffen et al. (2011). The session also covers the ‘Pre-Anthropocene’ which will provide a discussion of the ‘background’ geochemical record of a time before humans altered the environment. At the end of the session students then have to decide which groups will do Session 2(b) and which Session 2(c) in the next session.

Session 2 – Geochemistry of the Anthropocene

In this session the students have the option of working on Session 2(b): The Early Anthropocene, or Session 2(c): The Great Acceleration. These optional units are **assessed** in the form of an A0 size poster for the museum exhibit, based on one of the key research questions for each part (a choice of four for each). These sessions can be run concurrently and some of the recommended reading is in common for both parts. Two optional extension task for both units are available; an oral poster presentation and producing an Open University Guide to the museum exhibition.

In Session 2(b): The Early Anthropocene, students will examine the geochemical record of human activities from 1000 years ago to 1945. In Session 2(c): The Great Acceleration, the geochemical record from 1945 to the present day will be examined. Both parts examine the durability of materials through time and which environmental changes will become a part of the geochemical record of the future. Important anthropogenic industrial chemicals are discussed and the analytical techniques used to examine them in the recent sediment record.

Session 3 – The Future

This session consists of ‘The Future’, a compulsory segment. The purpose of this section is to examine what the geochemical record of human activity and civilisation would look like in the record in 100, 1000 and 1 million years time. It also involves discussion on the durability and degradation of synthetic polymers, important long-lasting geochemical components of our future geochemical record. The geochemistry of the ‘Human Strata’ is then summarised, by considering the geology, climate history and geochemical markers. Students may wish to incorporate information from this session into their posters and present the posters in the extension Session 4.

This table below gives a summary of the organisation of the problem units:

Tutor text

The red text in this version of the guide is meant to be seen by the tutor only. This text includes guidance on how the problem can be run, marking criteria, feedback from the trials and some (where appropriate) example answers.

Acknowledgements

The authors would like to thank Dr. Andy Tubb and Dr. James Costello at the University of the West of England, and Dr. Rajeev Shrivastava at Edge Hill University for trialling this resource and providing useful feedback. We would also like to thank Professor Simon Belt (University of Plymouth) for reviewing a draft version of the resource. Finally we would like to thank the project managers at the Royal Society of Chemistry.

Problem Unit	Research Questions	Summatively assessed?
Session 1: Compulsory Units: Introduction and 'Pre-Anthropocene'		
Introduction	What is the Anthropocene?	No
Session 1(a) Pre-Anthropocene	What is the background signal of climate change and how is this recorded by geochemistry?	No
Session 2: Optional Units: A choice of Session 2(b) or 2(c)		
Session 2(b). The Early Anthropocene	What evidence is there of human agriculture, industry and technologies in the geochemical record?	Yes
Session 2(c). The Great Acceleration	How will modern day materials, chemicals and structures be preserved in the geochemical record of the future?	Yes
Session 3: Compulsory Unit: 'The Future'		
Session 3(d) The Future	How will the geochemical record of our human civilisation be preserved in the geochemical record of the future?	Yes
Extension Session 4: Poster Presentations		Yes

The role of the facilitator

The tutor (or facilitator to use the normal C/PBL terminology) guides students through the problem solving process without being as directing as a lecturer or tutor would be in other forms of teaching (e.g. lecturing). This teaching approach is student centred which means students will have to research the topics discussed in each session and plan how to apply their understanding in order to solve a problem (in this case the development of learning resources for a museum exhibit). You can give students advice on their proposed problem solving strategy and you should always give students feedback at the end of the session on how they are progressing. For further information please see the following guide:

- *PossiBiLities: a Practice Guide to Problem-based Learning in Physics and Astronomy*, Derek Raine and Sarah Symons, Higher Education Academy, **2005**

The tutor is not expected to be a subject expert in this area but if you have limited experience of this area it is worth familiarising yourself with the resource before using it.

Geochemical Time Travel - Suggested Reading

Students are advised to focus on the abstract and figures only of the suggested reading papers to start with. Questions that ask specific questions about individual papers direct the students to a particular section or figure. The extended reading will be useful for advanced study or for specific research for the poster assessment.

Note: Many papers are from the Anthropocene Special Volume of the Philosophical Transactions of the Royal Society A, which can be accessed free online at: http://rsta.royalsocietypublishing.org/site/2011/anthropocene.xhtml

Recommended Reading

This is a list of all of the recommended reading for the problem – individual reading lists for each session have also been provided

Tutor note – it is up to you to decide whether you want to show this full reading list to students or not.

www.bbc.co.uk/news/science-environment-13335683

www.ipcc.ch/index.htm

http://news.nationalgeographic.com/news/2009/08/090820-plastic-decomposes-oceans-seas.html

Lisiecki, L.E. & Raymo, ME. (2005) *A Pliocene-Pleistocene stack of 57 globally distributed benthic d^{18}O records.* Paleoceanography 20, 1-17.

Petit, J.R. et al. (1999) *Climate and atmospheric history of the past 420,000 years from the Vostok ice core, Antarctica.* Nature 399, 429-436.

Ruddiman, W. S. (2003) *The anthropocene greenhouse era began thousands of years ago.* Climatic change 61, 261-293.

Steffen, W., Grinevald, J., Crutzen, P. & McNeill, J. (2011) *The Anthropocene: cultural and historical perspectives.* Philosophical Transactions of the Royal Society A 369, 842-867.

Tyrrell, T. (2011) *Anthropogenic modification of the oceans.* Philosophical Transactions of the Royal Society A 369, 887-908.

Vane, C. H., Chenery, S. R., Harrison, I., Kim, A. W., Moss-Hayes, V. & Jones, D. G. (2011) *Chemical signatures of the Anthropocene in the Clyde estuary, UK: sediment-hosted Pb, $^{207/206}$Pb, total petroleum hydrocarbon, polyaromatic hydrocarbon and polychlorinated biphenyl pollution records*. Philosophical Transactions of the Royal Society A 369, 1085–1111.

Walker, G (2004) *Frozen Time*. Nature 429, 596-597.

Walton, D., J. & Lorimer, J., P. (2001) *Polymers.* Oxford Chemistry Primer 85, Oxford University Press.

Zalasiewicz, J. et al. (2011) *Stratigraphy of the Anthropocene.* Philosophical Transactions of the Royal Society A 369, 1036-1055.

Extension Reading

Artuchelvi, J., Sudhakar, M., Arkatkar, A., Doble, M., Bhaduri, S. & Uppara, P.V. (2008) *Biodegradation of polyethylene and polypropylene*. Indian Journal of Biotechnology 7, 9-22.

Crutzen, P.J. (2002) *Geology of mankind.* Nature 415, 23.

Ellis, E. (2011) *Anthropogenic transformation of the terrestrial biosphere.* Philosophical Transactions of the Royal Society A 369, 1010-1035.

Marshall, W. A., Gehrels, W. R., Garnett, M. H., Freeman, S. P. H. T., Maden, C. & Xu, S. (2007) *The use of 'bomb spike' calibration and high-precision AMS 14C analyses to date salt marsh sediments deposited during the last three centuries*. Quaternary Research 68, 325-337.

Minh, N.H., Minh, T.B., Kajiwara, N., Kunisue, T., Iwata, H., Viet, P.H., Tu, N.P.C., Tuyen, B.C. & Tanabe, S. (2007) *Pollution sources and occurrences of selected persistent organic pollutants (POPs) in sediments of the Mekong River delta, South Vietnam.* Chemosphere 67, 1794-1801.

Price, S.J., Ford, J.R., Cooper, A.H. & Neal, C. (2011) *Humans as major geological and geomorphological agents in the Anthropocene: the significance of artificial ground in Great Britain*. Philosophical Transactions of the Royal Society A 369, 1056-1084.

Zachos, J.C., Pagani, M., Sloan, L., Thomas, E. & Billups, K. (2001) *Trends, Rhythms, and Aberrations in Global Climate 65Ma to Present*. Science 29*2,* 686-693.

Zalasiewicz, J., Williams, M., Haywood, A. & Ellis, M. (2011) *The Anthropocene: a new epoch of geological time?* Philosophical Transactions of the Royal Society A 369, 835-841.

Module Pacing: n.b. These are suggested timeframes and can be altered to suit teaching timetables/staff commitments.

Wk	Session	Topics	Transferable Skills	Assessment	Feedback
1	1 (60-90 mins)	• The Pleistocene • The Holocene • The Anthropocene • Rocks, soil and ice cores • Analytical geochemical methods	• Team working • Group discussion • Independent learning • Critical thinking • Decision making • Time management • Planning • Oral communication	Students will discuss the reading and questions given for this session. Students should make notes based on these discussions.	In session: • Students will discuss their understanding of the reading in this session. Provide verbal feedback during the session and highlight any areas that students may need to revisit. • Towards the end of the session ask students to present their plan of action for what needs to be done before the next session and provide verbal feedback.
2	2(b) (60-90 mins)	• The Early Anthropoceene • Climate Science • Extraction of polycyclic aromatic hydrocarbons	• Team working • Group discussion • Independent learning • Critical thinking • Decision making • Time management • Planning • Oral communication	Students will produce an outline plan of their poster which gives details on what will be included, what needs to be researched and an outline of the structure.	In session: • Provide verbal feedback on student discussions. • Towards the end of the session ask students to present their plan of action for what needs to be done before the next session and provide verbal feedback.
2	2(c) (20-30 mins)	• The Anthropocene from 1945 • Industrial and agricultural pollutants • Extraction of PCBs	• Team working • Group discussion • Independent learning • Critical thinking • Decision making • Time management • Planning • Oral communication	Students will produce an outline plan of their poster which gives details on what will be included, what needs to be researched and an outline of the structure.	In session: • Provide verbal feedback on student discussions. • Towards the end of the session ask students to present their plan of action for what needs to be done before the next session and provide verbal feedback.
3	3	• The future of the anthropocene • Polymer chemistry	• Team working • Group discussion • Independent learning • Critical thinking • Decision making • Time management • Planning • Oral communication • Using a poster to communicate science to a non-expert audience	Students should update their poster plan based on the group discussion that has taken place in this session.	In session: • Students will present their poster plan to you. Provide detailed verbal feedback on this. • Towards the end of the session ask students to present their plan of action for what needs to be done before the next session and provide verbal feedback. • Ask students how they need to update their poster plans based on this session's discussion.
4		• Poster presentations of various stages of the anthropocene.	• Team working • Critical thinking • Time management • Oral communication of science to the public • Using a poster to communicate science to a non-expert audience	Students present their posters on the anthropocene in this session. Students will be questioned on the content of their posters.	After the session: • Provide detailed written feedback on the quality of the poster and the group's performance when presenting the poster.

Introductory Information for Students

Problem Format

This problem has been designed to be student-centred which means that you (in your groups) must plan your own progress through the problem. This involves deciding how best to research the problem and then how to put the researched information together to create a solution.

Learning Outcomes and Pre-session Preparation

The resource includes a list of relevant intended learning outcomes from each session. This acts as a check list for what you should be able to do after tackling the part of the problem covered in that session. The assessments for each part of the problem is aligned to these lists so please make sure you demonstrate the competencies listed in your assessed work.

The pre-session preparation should guide your research before each session. It is worth remembering that the information presented in the problem is meant to be a starting point, you will need to do further research to fully prepare for each session.

Assessment

This resource makes use of a range of different types of assessment based on the general theme of science communication. Communicating your understanding to a range of different audience types in a number of different ways is a very important skill to have. This resource aims to give you the opportunity to develop a range of communication skills and to learn how to independently research an active area of research.

Facilitation

You will be guided through the problem solving process by a facilitator (or tutor). Although your facilitator can provide advice on problem solving strategies, the facilitator will not freely give information about the problem away (for example, they won't tell you which proposal they would back in the first part of the problem). Your facilitator will help you by encouraging discussion amongst the group and (if needed) focussing this discussion. Your facilitator will also provide you with feedback on the problem solving strategy adopted by your group and on any work submitted by your group.

The Scenario

You are working for the National Museum. You have been tasked with organising a new exhibit (**"If humans were to become extinct would we leave a geochemical record behind?")** which demonstrates how geochemical analysis can be used as a powerful tool to look back into the past and predict what evidence of our existence will exist in the rock record of the future. You will be asked to start working on a poster in session 2 which will bring together some of the key points from your discussions in the first three sessions. You will present this poster in session 4.

Tutor note

Due to the lack of familiarity of most students with problems of this type, you may want to reinforce the above text at the start of the first session in order to remind students what is expected from them. This approach is student-centred so it is inappropriate for them to expect the tutor to answer all of the research questions for them. The role of the tutor (or facilitator) is to guide the students through the problem solving process without being directing. You should remind students that they have access to the intended learning outcomes which will help focus their learning.

Session 1 (60-90 minutes) – Geochemical Time Travel

(a) Introduction and Pre-Anthropocene

Pre-Session Preparation

You should advise students to read the recommended resources below so that they are prepared to discuss the following topics in the facilitation session:

- The geological epochs of the Pleistocene, Holocene and the currently debated Anthropocene.
- The geochemical record of human activities and environmental changes of the Anthropocene.
- Rocks, soils and ice cores as repositories of ancient climatic and environmental geochemistry.
- Analytical geochemical methods.
- Natural climate variations through the last 1 million years and Milankovitch cyclicity.
- Oxygen isotopes in sediment cores recorded from ocean dwelling fossils.

Intended Learning Outcomes

By the end of this problem students should be able to:

- Illustrate the relative dates of the following geological epochs: Pleistocene, Holocene and the currently debated Anthropocene.
- Appraise current research papers in the fields of geochemistry, Anthropocene, Holocene and Pleistocene environmental and climate science.
- Discuss the future geochemical record signal of present day anthropogenic activities and environmental changes.
- Explain the analytical equipment used to determine isotope and trace element compositions from rocks, soils and ice cores.
- Use the equation $N = N_0\, e^{-\lambda T}$ to calculate the amount of radiometric decay and thus the age of a given specimen.
- Record the natural variation of greenhouse gases during the last 420 thousand years, from ice core data.
- Compare global palaeoclimate geochemical compilations to local/regional data.
- Interpret a global oxygen isotope record from marine fossils from the last 1 million years in terms of glacial and interglacial cycles.
- Discuss the astronomical causes for the cyclicity of glacial and interglacials at periods of 100Ka, 40Ka and 20Ka.

Resources

Make the following resources available to students **before** this facilitation session:

- www.bbc.co.uk/news/science-environment-13335683
- www.ipcc.ch/index.htm
- Lisiecki, L.E. & Raymo, ME. (2005) *A Pliocene-Pleistocene stack of 57 globally distributed benthic d^{18}O records.* Paleoceanography 20, 1-17.
- Petit, J.R. et al. (1999) *Climate and atmospheric history of the past 420,000 years from the Vostok ice core, Antarctica.* Nature 399, 429-436.
- Steffen, W., Grinevald, J., Crutzen, P. & McNeill, J. (2011) *The Anthropocene: cultural and historical perspectives.* Philosophical Transactions of the Royal Society A 369, 842-867.
- Walker, G (2004) *Frozen Time*. Nature 429, 596-597.

Extension reading:

- Crutzen, P.J. (2002) *Geology of mankind.* Nature 415, 23.
- Zachos, J.C., Pagani, M., Sloan, L., Thomas, E. & Billups, K. (2001) *Trends, Rhythms, and Aberrations in Global Climate 65Ma to Present*. Science 292*,* 686-693.
- Zalasiewicz, J., Williams, M., Haywood, A. & Ellis, M. (2011) *The Anthropocene: a new epoch of geological time?* Philosophical Transactions of the Royal Society A 369, 835-841.

Research Questions

The exhibit aims to address these questions, which you will discuss during this session:

- What changes to the geochemical record are likely to be seen as a result of human civilisation?
- What geochemical signals are found in the geochemical and ice core record before humans?
- What is the natural state of climate variation during the past 1Ma?
- What drove the non-anthropogenic changes in climate?

Background Information

In 2002, Paul Crutzen, the Nobel Prize–winning chemist, suggested that we had left the Holocene and had entered a new Epoch the 'Anthropocene' because of the global environmental effects of increased human population and economic development.

Geologists across the globe are currently debating whether to include the Anthropocene as an official unit in the Geological Timescale. Its importance is such that humans have significantly altered the environment enough to change the geochemical record, through activities such as burning fossil fuels to cause global warming, deforestation and pollution. During this problem you will investigate the geochemical signal of human civilisation.

In this session you will examine the natural geochemical state of the environment before the Anthropocene. The time before the Anthropocene encompasses 1 million years ago to 1 thousand years ago and includes part of the Ice Age. The end of the Ice Age occurred at the start of the Holocene Epoch, 11,700 years ago.

Before 1 thousand years ago human populations were small and the use of fossil fuels was limited. The climate is not thought to have been influenced by humans during this period.

Facilitation Questions

You may want to ask some of the following questions to stimulate discussion amongst groups during this session:

Introduction to the Anthropocene

- The following dates are important points in time to be featured in the exhibit: 1Ma, 1Ka, 50years ago, the present day, 100 years in the future, 1Ka in the future, 1Ma in the future. Note that Ma = millions of years, Ka = thousands of years. How would you put all the different time periods of the exhibit into a geological context? Construct a chart to scale to encompass the time range featured in the exhibit and mark on the time intervals.
  Slide 9 of the PowerPoint presentation provides a Geological Timeframe context for constructing the time chart.
- Look at Steffen et al. (2011), an introductory paper on the Anthropocene. Figure 1 illustrates changes in human activity since 1750 and subsequent changes to the environment as a result. Using this figure discuss what would be the geochemical record of these activities and environmental changes (if any), 1 million years in the future.

Steffen et al. 2011. Fig 1. A (human activities):

Population – more human fossils in geochemical record, greater environmental change due to living humans, so greater changes to the rocks and their geochemistry

Total GDP – no direct effect to geochemical record

Foreign direct investment – no direct effect to geochemical record

Damning of rivers – change to sediments in geochemical record

Water use – change to soils and vegetation therefore rock types

Fertiliser consumption – change to river, ocean and therefore rock geochemistry

Urban population – the urban population increase has resulted in massive cities. These megacities will be preserved in the rocks as thick layers of concrete, rock and metal

Paper consumption – deforestation, change in soil therefore rock type, change in the carbon cycle on Earth, rock geochemistry

McDonalds – no direct geochemical record link, linked to animal farming

Transport: Motor vehicles – the increased number of cars has led to more metals being used, resulting in metal rich parts of the 'human strata' of rock

Communication: telephones – rare metals used in mobile telephones will be more enriched in the 'human strata' (the human rock layer)

International tourism – no direct effect to geochemical record

Steffen et al. 2011. Fig 1. B (environmental changes):

Atmosphere: CO_2 conc. – change to rock geochemistry

Atmosphere: N_2O conc. – change to rock geochemistry

Atmosphere: CH_4 conc. – increased methane in the atmosphere leads to the chemical change of the oceans, which is recorded in the sediments deposited on the sea floor as a change to rock geochemistry

Atmosphere: ozone depletion – change to rock geochemistry

Climate: N hem. Surface T – change to rock geochemistry

Climate: Great floods – indirect, there may be some change to rock types due to soil changes caused by flooding

Ocean ecosystems – modern extinctions of much marine life will be recorded as a future fossil record and ocean chemical changes

Coastal zone: structure – different fossils in rocks

Coastal zone: biogeochemistry – change to rock geochemistry

Terrestrial ecosystems: woodland loss – change to climate so therefore rock geochemistry

Terrestrial ecosystems: domesticated land – change to soil and rocks

Global biodiversity – change to fossil record, extinctions

(a) Pre-Anthropocene

Rocks, soils and ice cores contain information about the past climate and natural geochemical variations before the Anthropocene. **Rocks** are formed by the compression of sediments over thousands or millions of years. Sediments that formed on the ocean floor are the most common type and often contain fossils that are climate indicators. **Soils** can contain archaeological artefacts from thousands of years ago, and record the ancient environment from that time. Over time, some of these soils turn into rocks. **Ice cores** have been recovered from thick ice sheets such as Greenland and Antarctica. They contain a record of snow fall that dates back thousands to hundreds of thousands of years, which contains climatic information.

- What piece of analytical equipment is used to determine isotope and trace element compositions from rocks, soils and ice cores?

A mass spectrometer. Extension: Ask the students to explain how it works. Extension 2: List the different types of mass spectrometer are used, e.g. LA-ICPMS (Laser Ablation - Inductively Coupled Plasma Mass Spectrometer) – for trace element compositions from ice cores. AMS (Accelerator Mass Spectrometer) – for analysing radioisotopes such as ^{14}C. It may be work re-visiting this question later on once the students have discussed more of the data.

- Which different isotopic decay systems are used to give absolute dates for soils and rocks on timescales of thousands to millions of years?

Thousands of year old soils and rocks:
$^{14}C/^{14}N$ half life 5.570 Ka – suitable for sediments <30,000yrs old
Millions of year old rocks:
$^{87}Rb/^{87}Sr$ half life 47 Ga (47 billion of years = 47 x10^9 years)
$^{238}U/^{206}Pb$ half life 4.47 Ga
$^{40}K/^{40}Ar$ half life 1.25 Ga

- Radioactive materials become less active with time according to the equation:
$N = N_0 e^{-\lambda T}$
Where N is the radioactivity measured at the present day, N_0 is the initial radioactivity, λ is the decay constant and T is the time elapsed.
A mineral found in a sedimentary core has an initial radioactivity of 1400 counts per second (cps) and its present day radioactivity is 280 cps. The decay constant is 10^{-6} years^{-1}.
Calculate the age of the mineral.
First re-arrange for T:
N0 = N/e-λT
e-λT = N0/N
-λT = ln(N0/N)
T = ln(N0/N)/ λ
= ln(1400/280)/10-6
= 1609438 years
= 1.6 Ma
- Ice cores contain information about past atmospheric geochemistry and climate. Skim through Walker (2004) to find out where in the ice core geochemical data is extracted from and list the important atmospheric chemicals present.
The sub-section titled 'Climate Clues' has this information. Gas bubbles within the ice are records of the past atmosphere. They contain data on atmospheric levels of CO_2, CH_4, N_2O, N and O isotopes.
- One of the most famous ice cores is the Vostock Ice Core from Antarctica which produced a 420Ka long climate record. Study the geochemical results from this core, shown in Figure 3 of Petit et al. (1999):

Students need access to the Petit et al. (1999): paper

Discuss the following points about the graph:
  - Over the past 420Ka, which atmospheric chemicals have changed in sync with temperature changes?
    CO_2, CH_4 and $\delta^{18}O$.
  - What do the times of colder temperatures correspond to?
    Ice Ages or glacial periods, when greenhouse gas composition were lower.
  - Where in the ice core is the CH_4 data recovered from?
    See the section 'The Ice Record' on the first page of Petit et al. (1999). CH_4 is recorded from air bubbles in the ice. Note: the ice itself can give information on the $\delta^{18}O$ composition of rain, the dust content and sodium content.

- How is the atmospheric temperature calculated? Read the section called 'Climate and atmospheric trends' on p.431 of Petit et al. (1999).
  Atmospheric temperature is calculated from the $\delta^{18}O$ composition of snow, which varies linearly according to the temperature at which the precipitation forms.

- Go to the following website for the Intergovernmental Panel on Climate Change: www.ipcc.ch/index.htm Locate the following: **IPCC Climate Change Report 2007: The Physical Science Basis, Chapter 6, Fig. 4.** This figure consists of 4 graphs of data from ice cores.
  - From the figure record the minimum and maximum values of CO_2, CH_4 and N_2O prior to the Anthropocene.
    This is the figure that the students should find (shown below). The range of CO_2, CH_4 and N_2O for the last is shown by the grey boxes (and covers the average for the last 650Ka).
    CO_2: Minimum 180ppm, maximum 300ppm
    CH_4: Minimum 350ppb, maximum 800ppb
    N_2O: Minimum ~200ppb, maximum 290ppb
  - How do the CO_2 and CH_4 range in values compare with that of the Vostock ice core?
    CO_2: Has the same range
    CH_4: Has a greater range: Minimum 300ppb, maximum 800ppb
  - What may cause this difference?
    The difference may be because the IPCC data is an average compilation from many sites, so some will have CH4 at less than 350ppb, but some greater than 350ppb, so it is averaged as that. The Antarctic is known for having the greatest warming on the planet in modern times, so it can be expected that it also had large greenhouse gas variability during icehouse to greenhouse transitions.

    Refer to IPCC Climate Change Report 2007: The Physical Science Basis

- Ocean sediments contain geochemical climate information that extends to millions of years further back in time than the ice core record. Study Figure 4 of Lisieki & Raymo, 2005 (shown below), which is a compilation of global fossil $\delta^{18}O$ data for the last 1Ma:

  Students need access to the Lisieki & Raymo, 2005 paper

  Discuss the following points about the graph:
  - What do the odd and even numbered peaks correspond to?
    Odd numbers: interglacials (times of less ice), even numbers: glacials (when there were large ice caps). Note that both glacial and interglacials occur within the most recent Ice Age that lasted since 2.5Ma. The end of the Holocene marks the end of the last glacial period at 11.7Ka.
  - Why does the $\delta^{18}O$ of benthic foraminifera record ancient climatic changes that happened during the past 1 million years?
    From section 2 of Lisieki & Raymo (2005): 'Foraminiferal $\delta^{18}O$ is a function of the temperature and $\delta^{18}O$ of the water in which it forms, and the $\delta^{18}O$ of seawater is a function of global ice volume and water salinity.'
  - Why is $\delta^{18}O$ heavier at times of glacials?
    It is heavier because more of the lighter ^{16}O isotope is incorporated into ice sheets, while ^{18}O is preferentially concentrated in the oceans, which is then incorporated into fossil calcite shells. Students should refer to slides 27 and 28 of the PowerPoint Presentation for further guidance.
  - What is the wavelength of the $\delta^{18}O$ cycles? i.e. How much time passes between the peaks of maximum or minimum $\delta^{18}O$?

Wavelength of approximately 100Ka, and there are also smaller cycles within that time.

- What could be done to enhance the 'global signal' of the data if further sampling were possible?

  Refer to Figure 1 of Lisieki & Raymo (2005), shown on slide 26. More data is needed from the Pacific, Indian and Southern oceans to give a more robust 'global signal', as most of the sediment cores used from the study are from the Atlantic.

- The climate cycles seen in the ice core and sedimentary record correspond to periodic glacial and interglacial cycles on a timescale of 100Ka, with smaller frequency cycles on a timescale of 40Ka and 20Ka. What astronomical cycles are driving these climate changes?

  Milankovitch cycles, the orbital interaction between the orbits of the Earth and Sun:
  <u>100 Ka - Eccentricity:</u> the shape of the Earth's orbit varies from being nearly circular (low eccentricity of 0.005) to being mildly elliptical (high eccentricity of 0.058).
  <u>41 Ka - Obliquity:</u> causing a slow 2.4° change in the tilt of the axis (obliquity) with respect to the plane of the Earth's orbit.
  <u>19-23 Ka - Precession:</u> precession of the equinoxes is the change in the direction of the Earth's axis of rotation relative to the Sun at the time of perihelion and aphelion.
  Illustrations of this are shown in Zachos et al., 2001, Figure 1.

Assessment

There is no assessment for Session 1, but students should try to incorporate some of the key points from the discussion of the 'Pre-Anthropocene' into their posters (this is particularly relevant in the introduction). At the end of the session the students should split themselves into two groups and decide which group will do Session 2(b) The Early Anthropocene, and which Session 2(c) The Great Acceleration.

Group reflection

At the end of this session give students around 10 minutes to reflect upon their discussions in this session. Students should ask themselves whether they are confident that they understand the material covered or do they need to carry out further research on some topics.

Construct a brief plan of action – the plan should include a list of the tasks that each group member is expected to do and a timescale for each of these tasks to be done. Remember to include enough time to proof read each other's work before submission. You should briefly present this plan to your tutor before the end of the session.

Session 2 (60-90 minutes) – Geochemistry of the Anthropocene

Choose to do Session 2(b): The Early Anthropocene or Session 2(c): The Great Acceleration.

Sessions 2(b) and 2(c) can be run concurrently.

Session 2(b): The Early Anthropocene

Pre-Session Preparation

You should advise students to read the recommended resources below so that they are prepared to discuss the following topics in the facilitation session:

- Environmental and human activity changes of early Anthropocene.
- Anthropogenic materials, their durability, soil/rock record and geochemical signature.
- Geochemical signals of the Industrial Revolution.
- Radionucleides in the geological record.

Intended Learning Outcomes

By the end of this problem students should be able to:

- Appraise current research papers in the fields of geochemistry and early Anthropocene environmental and climate science.
- Discuss the future geochemical record signal of anthropogenic activities and environmental changes that took place from 1800 to 1945.
- Describe how the geochemistry of the Anthropocene is different to that of the Pleistocene and Holocene.
- Examine the durability of different materials used by man in the early Anthropocene and their long-term signature in the geochemical record.
- Discuss the different suggested dates for the start of the Anthropocene based on geological and archaeological geochemical data records.
- Describe how changes to land use will leave geochemical imprints in the future geochemical record.
- List early Anthropogenic industrial chemicals and atomic bomb signatures that are found in recent sediments and explain their origin.
- Explain the chemical method used to extract polycyclic aromatic hydrocarbons from sediments.

Resources

Make the following resources available to students **before** this facilitation session:

- Ruddiman, W. S. (2003) *The anthropocene greenhouse era began thousands of years ago.* Climatic change 61, 261-293.
- Steffen, W., Grinevald, J., Crutzen, P. & McNeill, J. (2011) *The Anthropocene: cultural and historical perspectives.* Philosophical Transactions of the Royal Society A 369, 842-867.
- Vane, C. H., Chenery, S. R., Harrison, I., Kim, A. W., Moss-Hayes, V. & Jones, D. G. (2011) *Chemical signatures of the Anthropocene in the Clyde estuary, UK: sediment-hosted Pb, $^{207/206}$Pb, total petroleum hydrocarbon, polyaromatic hydrocarbon and polychlorinated biphenyl pollution records*. Philosophical Transactions of the Royal Society A 369, 1085–1111.

Extension reading:

- Ellis, E. (2011) *Anthropogenic transformation of the terrestrial biosphere.* Philosophical Transactions of the Royal Society A 369, 1010-1035.
- Marshall, W. A., Gehrels, W. R., Garnett, M. H., Freeman, S. P. H. T., Maden, C. & Xu, S. (2007) *The use of 'bomb spike' calibration and high-precision AMS ^{14}C analyses to date salt marsh sediments deposited during the last three centuries*. Quaternary Research 68, 325-337.
- Price, S.J., Ford, J.R., Cooper, A.H. & Neal, C. (2011) *Humans as major geological and geomorphological agents in the Anthropocene: the significance of artificial ground in Great Britain*. Philosophical Transactions of the Royal Society A 369, 1056-1084.

Research Questions

The exhibit aims to address these questions, which you will discuss during this session:

- How is the geochemistry of the Anthropocene different to that of the Pleistocene and Holocene?
- Why do some people think the Anthropocene began thousands of years ago?
- What geochemical signals of past human activity such as changes in land use are present in the archaeological and geological records?
- What signatures are there of the Industrial Revolution and atomic bombs in the geochemical record?

Background Information

The Early Anthropocene encompasses 1 thousand years ago to approximately 50 years ago, up until the end of World War 2. During this time human populations were still fairly low but were large enough that human activities started to alter the environment.

The time from 1800 to 1945 is also referred to as The Industrial Era. This is because of the Industrial Revolution (around 1800AD) when there was intensive fossil fuel use. Another important date is 1945AD, which was the first use of atomic bombs.

Facilitation Questions

You may want to ask some of the following questions to stimulate discussion amongst groups during this session:

- What technological advances that have taken place from 200 to 50 years ago would leave a geochemical record in the rocks?
  This is an introductory question to get the discussion going. Students should refer back to the graphs studied in the Introduction (Session 1) from Steffen et al. (2011). The extension paper about changes to the landscape of Great Britain by Price et al. (2011) is also very useful for generating discussion, especially Figure 1.
- How is the geochemistry of the Anthropocene different to that of the Pleistocene and Holocene eras?
  The Anthropocene is characterised by high greenhouse gas levels and anthropogenic chemicals in the 'Human Strata' such as PCBs, petroleum-based compounds and plastics. CO_2 levels in the Anthropocene are markedly higher, from ~280ppm in 1800AD to ~390ppm in 2010.
- List the materials that humans used from 1000 up to 50 years ago, both natural and man-made. Discuss how long these materials would take to decay. Note that some materials will not decay and will become a rock strata of their own e.g. Bricks. What type of signature do they leave in the soil and do they have a geochemical signature? The following table can be used as a guideline:

Material	Material durability	Soil signature	Geochemical signature
Concrete	Millions of years	Concrete layer in the rock	C isotopes
Building stones			
Wood			
Metals			
Plant foods			
Fabrics			
Plastics			

Example answers:

Material	**Material durability**	**Soil signature**	**Geochemical signature**
Concrete	Millions of years	Concrete layer in the rock	C isotopes
Building stones	Millions of years	Stones in soil	No
Wood	Hundreds of years	Some wood preserved, but most decays	C isotopes
Metals	Hundreds of years	Traces of metallic oxides	Pb, Fe, Zn etc. spikes
Plant foods	Years	Some preserved, most decays or is eaten by bacteria	No
Fabrics	Years	They would degrade, leaving no 'layer'	C isotopes from polymer fabrics and natural ones
Plastics	Hundreds to thousands of years	Plastic layer in rocks	Organic biomarkers (C isotopes), toxic compounds

- 1800AD is commonly agreed as the start date, but some scientists think the Anthropocene began thousands of years ago. Discuss the reasons why.
  Humans have been affecting the environment for longer than the last 200 years, including deforestation, building cities, using fossil fuels, all of which would leave an imprint in the geochemical record.
- Read the abstract of Ruddiman 2003 and find the answer to these questions:
  1. Which greenhouse gases show anomalously high concentrations in ice cores from thousands of years ago?
     CO_2 and CH_4
  2. What changes to farming methods at 8Ka and again at 5Ka may have been responsible for an increase in atmospheric CO_2 levels?
     Forest clearance and rice irrigation
  3. How did the bubonic plague affect the climate?

Farm abandonment caused forest re-growth and a slight drop in atmospheric CO_2 levels as a result

- What other anthropogenic changes to the land during the Early Anthropocene would leave a geochemical record?

  Ellis (2011) is a good review paper on this topic – Figures 2 and 3 show that much of the land surface's natural biomes were turned into 'anthromes' (anthropogenic biomes) by 1950. Table 1 lists how this would affect the archaeological and geological record e.g. changes in phosphorous and nitrogen concentrations (from soil changes) and carbon isotope change (for example from vegetation type change and increasing atmospheric CO_2 levels due to deforestation).
- What anthropogenic chemicals derived from the Industrial Revolution can be found in the geochemical record? Examine the case study by Vane et al (2011) of Clyde Estuary sediments. Record the pre-1945 anthropogenic chemicals present and their origin.
  Polyaromatic hydrocarbons (PAHs) – from grass/wood/coal and petroleum combustion Pb and $^{206/207}Pb$ isotope ratios – from lead industries and petrol
- What is the isotopic signature of lead from the Industrial Revolution? Refer to Figure 5 of Vane et al. (2011).
  Figure 5 shows that the $^{207/206}Pb$ isotope ratio was approximately 0.853 during the Industrial Revolution period.
- What chemical methods did Vane et al. (2011) use to extract and determine polycyclic aromatic hydrocarbons from the estuary sediments?
  From Vane et al. (2011), section 2. Material and methods, part (d): 'Sediments (5 g) were extracted with 25 ml of a 1:1 v/v mix of acetonitrile and tetrahydrofuran in an ultrasonic bath (Camlab, 300W) for 45 min at 50◦C. Samples were stored in the dark (2 h), to permit some clarification of the supernatant, before taking a 2 ml aliquot and filtering with a 0.2 mm in-line syringe filter (25mm diameter, nylon 66). Filtered sample extracts were injected into the high-performance liquid chromatography (HPLC) system (Waters 600E) via a 5ml sample loop (Rheodyne). Separation of 17 PAHs was achieved within 40 min by gradient programming the eluent. PAH detection was accomplished employing a scanning fluorescence detector (Waters 474).'
- What geochemical signatures are found in sediments of atomic bombs that were first used in 1945?
  Elevated levels of the isotope ^{14}C and the radionucleides ^{137}Cs, ^{210}Pb, ^{241}Pu and ^{241}Am. Data is from Marshall et al. (2007).

Assessment

Produce a poster for the exhibit that addresses ONE of the research questions that are central to the geochemistry of The Early Anthropocene. You should also incorporate the relevant points from your discussions in sessions 1 and 3**.**

Your poster should reinforce the fact that predictions as to what the future geochemical record of humans might look like will be built upon past climate records and an investigation into which chemical changes or man-made compounds would become set in stone.

Before the next session you need to create a poster plan. The poster plan can take the form of an A4 version of your poster which shows the general layout together with a separate sheet which outlines what content will be discussed in the poster.

The poster should be understandable to members of the public with GCSE level science and maths. It should be produced at A0 size using Microsoft PowerPoint (or equivalent software) and contain relevant graphs, images, text and scientific references to communicate the science. Work in groups of 2 or 3 to produce the poster.

Tutor note: although students are asked to focus on one aspect of their research, they should include relevant points from the discussions in sessions 1 and 3 in the poster.

Extension Assessment Task

Produce an **accompanying resource** that will be used by the Open University in their teaching and that links to the exhibit. This will take the form of a 2-3 page guide and should include scientific references, key images and graphs that explain the geochemistry of The Early Anthropocene. This should be suitable for students studying year one degree level chemistry. In the Open University Guide you need to address **ALL** of the **research questions** for this section. Work in groups of 2 or 3 to produce the guide.

Group reflection

At the end of this session give students around 10 minutes to reflect upon their discussions in this session. Students should ask themselves whether they are confident that they understand the material covered or do they need to carry out further research on some topics?

Construct a brief plan of action – the plan should include a list of the tasks that each group member is expected to do and a timescale for each of these tasks to be done. Remember to include enough time to proof read each other's work before submission. You should briefly present this plan to your tutor before the end of the session.

Session 2(c): The Great Acceleration

Pre-Session Preparation

You should advise students to read the recommended resources below so that they are prepared to discuss the following topics in the facilitation session:

- Environmental and human activity changes of the Great Acceleration 1945 to present.
- Anthropogenic materials, their durability, geochemical record and geochemical signature.
- Industrial pollutants used since 1950: PCBs, DDT, lead and petroleum-derived compounds.
- The chemistry of ocean acidification.

Intended Learning Outcomes

By the end of this problem students should be able to:

- Appraise current research papers in the fields of geochemistry and Anthropocene environmental and climate science.
- Discuss the future geochemical record signal of anthropogenic activities and environmental changes that took place from 1945 to present.
- Examine the durability of different Anthropogenic materials and their long-term signature in the geochemical record.
- List common industrial pollutants and Persistent Organic Pollutants that are found in recent sediments and explain their origin.
- Explain the chemical method used to extract PCBs from sediments.
- Draw the chemical structure of DDT and PCBs and explain why these compounds persist in sediments to become part of the geological record.
- Describe the process of ocean acidification in relation to changes to the Dissolved Inorganic Carbon composition of seawater.
- Discuss the geochemical record in soils and rocks of changes to the land that have occurred over the last 50 years.

Resources

Make the following resources available to students **before** this facilitation session:

- Steffen, W., Grinevald, J., Crutzen, P. & McNeill, J. (2011) *The Anthropocene: cultural and historical perspectives.* Philosophical Transactions of the Royal Society A 369, 842-867.
- Tyrrell, T. (2011) *Anthropogenic modification of the oceans.* Philosophical Transactions of the Royal Society A 369, 887-908.
- Vane, C. H., Chenery, S. R., Harrison, I., Kim, A. W., Moss-Hayes, V. & Jones, D. G. (2011) *Chemical signatures of the Anthropocene in the Clyde estuary, UK: sediment-hosted Pb, $^{207/206}$Pb, total petroleum hydrocarbon, polyaromatic hydrocarbon and polychlorinated biphenyl pollution records*. Philosophical Transactions of the Royal Society A 369, 1085–1111.

Extension reading:

- Ellis, E. (2011) *Anthropogenic transformation of the terrestrial biosphere.* Philosophical Transactions of the Royal Society A 369, 1010-1035.

- Minh, N.H., Minh, T.B., Kajiwara, N., Kunisue, T., Iwata, H., Viet, P.H., Tu, N.P.C., Tuyen, B.C. & Tanabe, S. (2007) *Pollution sources and occurrences of selected persistent organic pollutants (POPs) in sediments of the Mekong River delta, South Vietnam.* Chemosphere 67, 1794-1801.

Research Questions

The exhibit aims to address these questions, which you will discuss during this session:

- How is the geochemistry of the Great Acceleration period of the Anthropocene different to that of the Pleistocene, Holocene and Early Anthropocene?
- What Anthropogenic materials and man-made chemicals would be recorded in the 'Human Strata' rock layer of the future?
- What is the effect of the current high atmospheric levels of CO_2 on the oceans?
- What is the geochemical record of changes to the land that have occurred in the last 50 years?

Background Information

The Great Acceleration period of the Anthropocene encompasses 1945 up to the present and is the time when the impact of human activities accelerated so much as to cause global environmental stress and climate change.

These human activities will leave a significant geochemical imprint in the geological record in terms of environmental changes and pollutants. There will also be a change to the rocks themselves due to the massive use of resources worldwide such as metals and rocks for building materials.

Facilitation Questions

You may want to ask some of the following questions to stimulate discussion amongst groups during this session:

- What advances that have taken place from 1945 to present that would characterise the Great Acceleration and leave a geochemical record in the rocks?
  This is an introductory question to get the discussion going. Students should refer back to the graphs studied in the Introduction (Session 1) from Steffen et al. (2011).
- List the materials that humans have used in the past 50 years, both natural and man-made. Discuss how long these materials would take to decay. Note that some materials will not decay and will become a rock strata of their own e.g. Bricks. What type of signature they would leave in the soil and rock record of the future? Would they have a geochemical signature? The following table can be used as a guideline:

Material	Material durability	Soil / rock record signature	Geochemical signature
Concrete	Millions of years	Concrete layer in the rock	C isotopes
Building stones			
Wood			
Metals			
Plastics			
Fabrics			

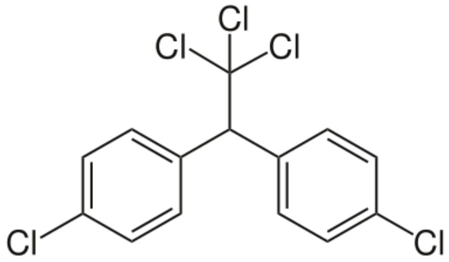
Example answers:

Material	Material durability	Soil / rock record signature	Geochemical signature
Concrete	Millions of years	Concrete layer in the rock	C isotopes

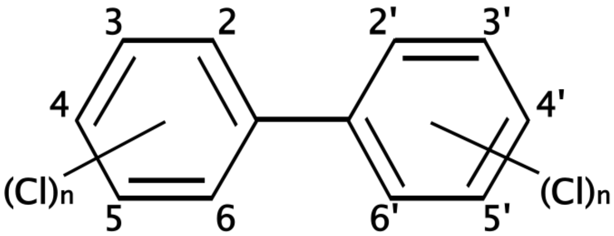
Building stones	Millions of years	Stones in soil	No
Wood	Hundreds of years	Some wood preserved in rock, but most would decay	C isotopes
Metals	Hundreds of years	Rock layers of metallic oxides	Pb, Fe, Zn etc. spikes
Plastics	Hundreds to thousands of years	Plastic layer in rocks	Organic biomarkers (C isotopes), toxic compounds
Fabrics	Years	They would degrade, leaving no 'layer'	C isotopes from polymer fabrics and natural ones

- What anthropogenic chemicals derived from post-1945 industries can be found in the geochemical record? Examine the case study by Vane et al (2011) of Clyde Estuary sediments. Record which chemically commonly occur after 1950 and their origin.
  Polyaromatic hydrocarbons (PAHs) – from grass/wood/coal and petroleum combustion, most common before 1950.
  Total petroleum hydrocarbons (TPHs) – from petroleum burning (rather than coal).
  Polychlorinated biphenyls (PCBs) – from chlorinated industrial chemical manufacturing.
  Pb and $^{206/207}$Pb isotope ratios – from lead industrial use and lead petrol.
- How did the isotopic signature of lead change from 1950? Refer to Figure 5 of Vane et al. (2011).
  Figure 5 shows that the $^{207/206}$Pb isotope ratio became heavier after 1950 and rose to as much as 0.890. This is due to the use of lead in petrol. Note that data from different locations and sources give different isotope ratio results.
- What chemical methods did Vane et al. (2011) use to extract and determine PCBs from the estuary sediments?
  From Vane et al. (2011), section 2. Material and methods, part (c): 'sediments were extracted with hexane/acetone (1:1 v/v) in an ASE 200 (Dionex) and washed with concentrated H_2SO_4. PCB congeners were separated from other compound classes using a
  florsil/sodium sulphate column and the *n*-hexane eluent subject to liquid–liquid extraction using dimethylsulphoxide (2 × 12 ml) and de-ionized water (25 ml) prior to extraction with *n*-hexane. The *n*-hexane extracts volume was reduced to 5 ml, passed through anhydrous sodium sulphate (1 g) and reduced to 100 ml. Combined gas chromatography–mass spectrometry (GC-MS) was performed on a Carlo Erba Mega 500 series GC directly coupled to a Varian 1200L triple quadrupole mass spectrometer.
- What common Persistent Organic Pollutants from modern industry that can be found in river and ocean sediments?
  See for example Minh et al. (2007) study of Mekong River delta sediments:
  Most common chemicals:
  DDT – dichlorodiphenyltrichloroethane – a banned organochlorine pesticide
  PCBs – Polychlorinated biphenyls – used in chlorinated industrial chemical manufacturing and it was also used in heavy weapons.
  Other industrial chemicals found:
  CHLs - chlordane compounds
  HCHs - hexachlorocyclohexane isomers
  HCB - hexachlorobenzene

- Draw the chemical structure of DDT and PCBs.
  Wikipedia common's images:
  DDT:



  PCBs (Numbers indicate the possible positions of chlorine atoms on the benzene rings):



- Why do these two compounds persist in the environment to become part of the geochemical record?
  They are lipophilic and hydrophobic and thus do not readily form hydrogen bonds and are insoluble in water. Thus they persist a long time in the environment and will remain as 'organic biomarkers' in the sediment.

- Name the three most important Dissolved Inorganic Carbon species found in the ocean and the approximate percentage of each species found in surface ocean waters?

CO_2	**HCO_3^-**	**CO_3^{2-}**
Carbon dioxide	**Bicarbonate ions**	**Carbonate ions**
1%	**91%**	**8%**

- The current high atmospheric CO_2 levels are leading to ocean acidification, through the following process:
  $H_2O + CO_{2\,(aq)} \leftrightarrow H_2CO_3 \leftrightarrow HCO_3^- + H^+ \leftrightarrow CO_3^{2-} + 2H^+$
  What causes ocean acidity?
  A greater input of CO_2 results in an increase in H^+ ions that lower ocean pH.
- What would happen to carbonate rocks and calcitic fossils on the ocean floor due to ocean acidification? Refer to Tyrell (2011).
  They would dissolve due to the ocean becoming unsaturated with respect to carbonate ions at depth. This will continue occurring until the CO_3^{2-} added into the water from the dissolving rocks and fossils balances out the high $CO_{2(aq)}$ levels that originate from high levels of atmospheric CO_2. See Tyrell (2011) for further information.
- What anthropogenic changes to the land during the Great Acceleration will leave a geochemical record?
  Ellis (2011) provides a good review of this topic – Figures 2 and 3 show that much of the land surface's natural biomes have been transformed into 'anthromes' (anthropogenic biomes). Table 1 lists how this would affect the archaeological and geological record e.g. changes in phosphorous and nitrogen concentrations (from

soil changes and fertilisers) and carbon isotope change (for example from vegetation type change and increasing atmospheric CO_2 levels due to deforestation).
The Haber process and the use of nitrogen-based fertilisers have resulted in a twofold increase in the amounts of reactive nitrogen at the Earth's surface and in the oceans.

Extension discussion question: explain how the Haber process works to produce ammonia and nitrogen-fertilisers.

Assessment

Produce a poster for the exhibit that addresses ONE of the research questions that are central to the geochemistry of The Great Acceleration. You should also incorporate the relevant points from your discussions in sessions 1 and 3

Your poster should reinforce the fact that predictions as to what the future geochemical record of humans might look like will be built upon past climate records and an investigation into which chemical changes or man-made compounds would become set in stone.

Before the next session you need to create a poster plan. The poster plan can take the form of an A4 version of your poster which shows the general layout together with a separate sheet which outlines what content will be discussed in the poster.

The poster should be understandable to members of the public with GCSE level science and maths. It should be produced at A0 size using Microsoft PowerPoint (or equivalent software) and contain relevant graphs, images, text and scientific references to communicate the science. Work in groups of 2 or 3 to produce the poster.

Tutor note: although students are asked to focus on one aspect of their research, they should include relevant points from the discussions in sessions 1 and 3 in the poster.

Extension Assessment Task

Produce an **accompanying resource** that will be used by the Open University in their teaching and that links to the exhibit. This will take the form of a 2-3 page guide and should include scientific references, key images and graphs that explain the geochemistry of The Great Acceleration. This should be suitable for students studying year one degree level chemistry. In the Open University Guide you need to address **ALL** of the **research questions** for this section. Work in groups of 2 or 3 to produce the guide.

Group reflection

At the end of this session give students around 10 minutes to reflect upon their discussions in this session. Students should ask themselves whether they are confident that they understand the material covered or do they need to carry out further research on some topics?

Construct a brief plan of action – the plan should include a list of the tasks that each group member is expected to do and a timescale for each of these tasks to be done. Remember to include enough time to proof read each other's work before submission. You should briefly present this plan to your tutor before the end of the session.

Session 3 (60-90 minutes)

(d) The Future

Pre-Session Preparation

You should advise students to read the recommended resources below so that they are prepared to discuss the following topics in the facilitation session:

- The classes of synthetic polymers.
- The mechanisms of polymer degradation.
- Polymer pollutant compounds in ocean sediments.
- Geology and geochemistry of the 'Human Strata'.

Intended Learning Outcomes

By the end of this problem students should be able to:

- Appraise current research papers in the fields of geochemistry, synthetic polymers and Anthropocene environmental and climate science.
- List the main types of synthetic polymers, their composition, uses and estimated degradation time.
- Explain how synthetic polymers degrade due to the effect of bacteria, UV radiation and heat.
- Describe which polymers produce bisphenol-A and why it is toxic.
- By use of the geothermal gradient, calculate how long it would take the most durable synthetic polymers to degrade.
- Define the geochemical characteristics of the 'Human Strata'.

Resources

Make the following resources available to students **before** this facilitation session:

- http://news.nationalgeographic.com/news/2009/08/090820-plastic-decomposes-oceans-seas.html
- Walton, D., J. & Lorimer, J., P. (2001) *Polymers.* Oxford Chemistry Primer 85, Oxford University Press.
- Zalasiewicz, J. et al. (2011) *Stratigraphy of* the *Anthropocene.* Philosophical Transactions of the Royal Society A 369, 1036-1055.

Extension reading:

- Artuchelvi, J., Sudhakar, M., Arkatkar, A., Doble, M., Bhaduri, S. & Uppara, P.V. (2008), *Biodegradation of polyethylene and polypropylene*. Indian Journal of Biotechnology 7, 9-22.

Research Questions

The exhibit aims to address these questions, which you will discuss during this session:

- What will happen to synthetic polymers in the future?
- What man-made materials would be preserved in the 'Human Strata' in the geochemical record in 1 thousand and 1 million years time?
- How will global warming effect the geochemistry of the oceans, land and therefore the geochemical record?
- What geochemical signatures would be present in the 'Human Strata' from anthropogenic chemicals?

Background Information

The future of the global environment is uncertain, with most climate scientists predicting that global warming will continue. The population has now reached 7 billion and continues to rise, with extreme population and climate changes likely to occur by 2100. Even if humans went extinct in the near future, we would still leave a geological record. In this part you will examine which man-made materials would be preserved in the rocks 1 thousand and 1 million years from now.

Facilitation Questions

You may want to ask some of the following questions to stimulate discussion amongst groups during this session:

Synthetic Polymers

Synthetic polymers form an essential part of everyday life – from packaging to construction materials. It is important to investigate the types of polymers and their breakdown products to find out if they would persist in the geochemical record of the future.

- What are the 7 main classes of synthetic polymers? State the composition and uses of each class. How long does each class of polymer take to degrade (if at all)?
  Synthetic polymers are classed based on their recycling code. Example table of data:

Class	Composition	Uses	Time to degrade
1	PET Polyethylene terephthalate	Water bottles, clear plastic bottles	5-10 years
2	HDPE High-density polyethylene	Shampoo and detergent bottles, milk bottles	~100 years
3	PVC Polyvinyl chloride	Drain pipes, shower curtains, some water bottles, cling film	Unknown time to degrade, perhaps millions of years?
4	LDPE Low-density polyethylene	Carrier bags, garment bags, coffee can lids	500-1000 years
5	PP Polypropylene	Margarine containers, yoghurt pots, sweet wrappers, aerosol can tops, translucent plastic containers	1000s years
6	PS Polystyrene	Styrofoam, hard clear plastic cups, packaging 'popcorn', eating utensils, DVD cases	Under 50 years
7	Other	A range of uses and plastic types e.g. nylon, Teflon (Poly tetra polyethylene), TPU (thermoplastic polyurethanes), polycarbonate	Most do not readily breakdown

- What are the products of polymer degradation?
  Small organic molecules, some toxic products such as bisphenol-A and PCBs, depending on the presence of additives and impurities in the initial polymer chain structure.
- Give examples of the different mechanisms of polymer degradation for different polymer types, e.g. the thermal degradation of polystyrene by initial scission and chain breakup (unzipping).
  <u>Thermal degradation</u>: The breakup of polymer chains will occur to all polymers that are heated to high enough temperatures. It starts with an initial scission in the middle of the chain, followed by breakup of the oligomers, or by sequential loss of monomers from the end, in the exact reverse of propagation (i.e. unzipping). Short-

chains subjected to further heating produces mixtures of monomers, dimmers, trimers, and beyond.

Hydrolysis: main chain scission of step-growth polyester and polyamides.

UV radiation/neutrons/x-rays: Causes breakage of the polymer chain (brittle failure), for example PVC, which has C-C bond dissociation energy smaller than the energy emitted by UV light. UV radiation can be absorbed by the polymer leading to photo-oxidation by a free radical mechanism. The end products are small organic molecules and in some cases toxic products e.g. PCBs.

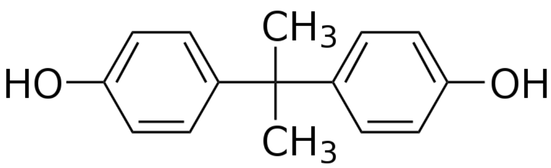
Biological degradation: polyurethanes, particularly polyester-polyurethanes, can be degraded over time by bacteria. Microorganisms such as moulds, fungi and bacteria break down the polymers into carbon dioxide, water and other simple organic molecules. Once a microorganism attaches itself to the surface it can grow by using the polymer as a carbon source. Enzymes secreted by the organisms can cleave the main chain of the polymer leading to the formation of low molecular weight fragments (oligomers), dimmers or monomers.

- There are concerns that there is already a layer of plastic debris across the floor of the world's oceans, some of which may break-down into pollutant chemicals: http://news.nationalgeographic.com/news/2009/08/090820-plastic-decomposes-oceans-seas.html

  Under what conditions in the ocean do plastics breakdown to produce bisphenol-A?

  At temperatures of 30°C, plastics can breakdown in the ocean to produce bisphenol-A
- Draw the structure of bisphenol-A and explain why it is toxic to marine life.

  Structure (Wikipedia common's image):



  It is toxic as it interferes with endocrine hormone production and the reproductive systems of marine animals.
- What categories of plastics degrade to produce bisphenol-A?

  Polystyrene and its derivatives e.g. Styrofoam cups
- Which polymers are most resistant to natural degradation by bacteria?

  Polyalkenes (polyethene, polypropene), polyhalocarbons (PVC, PTFE) and aromatic-containing step-growth systems (PET, polycarbonates, some polyamides) are very resistant to microbial degradation.

  Extension info: Microorganisms can only attach to hydrophilic polymer surfaces. Polythene contains only CH_2 groups so is hydrophobic. However, the surface of the polymer can become more hydrophilic if it is subject to chemical or physical degradation before biodegradation takes place. Additives, antioxidants and other stabilisers are sometimes added to commercial polymers which are toxic to microorganisms and therefore slow down the rate of biodegradation, so the ultimate degradation of polymers may take thousands of years.
- How deep would polymers need to be buried by sediment for them to degrade naturally i.e. break-down due to heat in the rocks at depth? Assume that most plastics will have melted by a temperature of 200°C. Hint: what is the geothermal gradient?

  Oil may form at temperatures as low at 150°C from organic material in rocks, some plastics melt at 40°C, while some thermoset polymers are stable up to 300°C, so a 200°C temperature is used as an average here. The average geothermal gradient in

the Earth's crust is 22°C/km depth (in non-plate boundary or volcanically active regions), so a burial depth of ~10km would be needed to reach 200°C.

- Given an average sedimentation rate of 1mm/year on the deep ocean floor, how long would it take for polymers to be buried to the required depth for thermal degradation?

  1 km of sediment = 1 million mm's of sediment (1 m contains 1000 mm's; 1000 mm x1000 m = 1 million mm's)

  1 x 10^6 mm = 1 x 10^6 years to form

  10 km depth = 1 x 10^7 mm sediment = 1 x 10^7 years, equivalent to 10 million years

The 'Human Strata'

Imagine that humans went extinct in 2100. If we travelled forward in time, there would be a substantial rock layer or 'Human Strata' of our cities and civilisation.

- Discuss what would the rocks of the 'Human Strata' will be made of in 1 thousand years and 1 million years time.

  In 1 thousand years - The 'Human Strata' would contain building materials, metals, concrete, bricks and stones. Some man-made plastics and wood may also be preserved, but all fabrics and natural organic material would have degraded.

  In 1 million years - The 'Human Strata' would contain building materials, metals, concrete, bricks and stones. Tiny particles or plastic may be present, but most would have degraded like other organic compounds. If the rocks are buried deep enough the plastic may have started to turn into oil.

  Students can refer to Zalaseiwicz et al. (2011), Part c – Lithostratigraphy

- The IPCC estimates that by 2100, global warming could be as much as 3.5°C. How would this warmer climate affect the environment, and be recorded in the 'Human Strata'?

  Students should refer to Zalasiewicz et al. (2011), Part d - Chemostratigraphy.

  In summary, the geochemical record signals of CO_2 increase would show:

  A global temperature rise, recorded in oxygen and carbon isotopes in rocks and in future ice cores.

  Ocean acidification, recorded in sediment types and ocean geochemical isotopes.

  Mass extinctions, recorded in the fossil record.

  Sea level rise, recorded by rock types - the oceans expand when warmer and melting ice caps will increase their volume.

- The ratio of ^{13}C:^{12}C is reported as $\delta^{13}C$. Would the $\delta^{13}C$ ratio preserved in rocks and ice cores become more positive or negative if carbon dioxide levels in the atmosphere continue to rise?

  $\delta^{13}C$ would become more negative due to input of lighter ^{12}C which is the isotope that is found in CH_4 and CO_2 in the atmosphere. Note: lighter = more negative and heavier = more positive.

- What geochemical signatures would be present in the 'Human Strata' from anthropogenic chemicals?

  PCBs, DDT, TPHs, PAHs, Lead, radionucleides, plastics, bisphenol-A, increased nitrogen concentration etc.

Assessment

Towards the end of this session update you poster plan to include any of the key points from today's discussion that you feel should be on your poster.

Tutors – you should give students feedback on their amended poster plans.

Group reflection

At the end of this session give students around 10 minutes to reflect upon their discussions in this session. Students should ask themselves whether they are confident that they understand the material covered or do they need to carry out further research on some topics?

Modify your poster plan to take today's discussion into account – you should leave this session with a clear idea of what each group member's responsibilities are and when they need to send their work back to the rest of the group. Remember to include enough time to proof read each other's work before submission. You should briefly present this plan to your tutor before the end of the session.

Extension Task: Session 4 (60-90 minutes) – Poster Presentations

This session will be used for the presentation of the posters for the Geochemistry through Time museum exhibit. Each group should spend 5-10 minutes talking through their poster and then at least 5 minutes answering questions from the rest of the group. You may want to consider asking students at the same level who do not study this module to form an audience and possibly peer assess the groups and contribute to the questioning.

Alternatively if it is not practical to run one presentation at a time, you may prepare a large number of questions for Session 2(b) and Session 2(c) posters, which could be asked at the end and will avoid making the process easier for groups who go later in the session.

Intended Learning Outcomes

By the end of this problem students should be able to:

- Verbally communicate scientific ideas to an audience of peers.
- Respond to a range of questions on the ideas presented.
- Act as ambassadors of science in the community by helping the public gain a deeper understanding of novel scientific concepts.

Assessment

The poster presentations can be assessed by the facilitator or by peer review (by other students in the group), using the marking criteria for oral presentations below.

Group reflection

At the end of this session give students around 10 minutes to reflect upon their discussions in this session.

Marking Criteria

Poster

- **Does the poster include a suitable introduction which explains what the Anthropocene is and provides an idea of the timescale of the Anthropocene relative to the Pleistocene and Holocene?**
- **Does the poster communicate the key findings from the research in an accessible way for a non-expert audience?**
- **Does the poster provide any discussion of the geochemical signal of anthopogenic activities for their chosen period of time (i.e. either 1800-1945 or 1945-now)?**
- **Has the geochemistry of the Anthropocene been compared to that of the Pleistocene and Holocene**
- **Has the durability of anthropogenic materials been discussed? Does the poster include a review of the long term signature of these materials in the geochemical record?**
- **Have common industrial and agricultural pollutants been discussed? Does the poster describe how some of the key chemical indicators can be isolated?**
- **Does the poster make the observable effects of anthropogenic activity clear (e.g. ocean acidification).**
- **Has any attempt been made to discuss current research on geochemistry, synthetic polymers and Anthropocene environmental and climate science?**

OU Guide

Students doing 2(b)

- **Has the geochemistry of the Anthropocene been compared to that of the Pleistocene and Holocene?**
- **Has the question of the starting point of the Anthropocene been discussed?**
- **Has the significance of human activity (such as changes in land use) to the archaeological and geological records been discussed? Have the geochemical signals of past human activity been identified?**
- **Were the signatures of key anthropogenic events such as the Industrial Revolution and atomic bombs identified?**

Students doing 2(c)

- **Has the geochemistry of the Anthropocene been compared to that of the Pleistocene, Holocene and Early Anthropocene?**
- **Does the guide identify which anthropogenic materials and man-made chemicals will be recorded in the 'Human Strata' rock layer of the future?**
- **Has the effect of high atmospheric levels of CO_2 on the oceans been described?**
- **Does the guide describe the geochemical record of changes to the land that have occurred in the last 50 years?**

Written content:

- **A (1st) - Excellent** The answer contains all the things listed in the criteria and one or two extra related things.

- **B (2.1) - Very Good** The answer has almost all the things listed in the criteria (only minor things missing) – any calculated values are close to the recommended values.
- **C (2.2) - Good** Most of the things listed in the criteria appear in the answer, some missing content and/or some error in written content and/or calculations.
- **D (3rd) - Modest** The answer has significant content missing. There are a number of errors throughout the answer.
- **E (Fail) - Poor** The answer contains only a few of the important points from the list. There are significant sections missing.

Presentation of written solutions

A (1st) - Excellent The solution is very well structured and produced. It is easy to find the different sections and there is similar presentation on different pages. Each section is virtually free from errors in grammar, spelling and punctuation and makes good use of **referenced & labelled** diagrams.

- **B (2.1) - Very good** The solution is well structured and produced. It is clearly written apart from relatively minor aspects which would not seriously affect the understanding of the reader. The solution makes good use of referenced and labelled diagrams to clarify key points in the answer.
- **C (2.2) - Good** Though reasonably well structured and produced, the solution contains significant errors in grammar and spelling. Diagrams were provide, these were not always referenced and/or there was little attempt made to relate these to the answer.
- **D (3rd) - Modest** The solution was disorganised and disjointed and so badly produced that it would inevitably misguide the reader. There were lots of errors – spelling, grammar, lots of different fonts and little or no evidence of teamwork. There was little or no effort to provide diagrams or examples to illustrate points in the answer.

Oral presentation of poster

<u>Mark awarded out of 10</u>**:**

- **8 -**The oral presentation was well structured, clear, made good use of audio visual material and successfully conveyed results, objectives, results and conclusions to the listener in an enthusiastic manner. **All questions were well answered and covered all of the points listed at the top of these criteria.**
- **7 -** The oral presentation was sufficiently clear and structured to allow the listener to grasp the majority of the objectives, results and conclusions. **The answers to the questions were generally good and covered most of the points in the criteria.**
- **5 -** The oral presentation though reasonably structured was poorly presented **The answers to the questions were somewhat vague and may not have covered many of the points in the criteria.**
- **3 -** The oral presentation was so incoherent that the listener would be unlikely to derive any useful information. **The answers to the questions were poor. Very few or none of the points listed in the criteria were adequately covered.**

Glossary of Geological Terms

Benthic – Refers to the mode of life of animals or fossils that lived on the sea floor, as opposed to those that swam at the sea surface (planktonic).

Bioturbation – The burrowing of sediment by animals such as worms and snails. In the Anthropocene some human buildings and tunnels are similar in structure to fossil burrows.

Geothermal gradient – The temperature increase in degrees centigrade per kilometre depth downwards into the Earth's crust, the average is 22^{o}C/km (in non-plate boundary or volcanically active regions).

Ice Age – The North Pole has been glaciated since 2.5 million years ago, causing the most recent Ice Age. Since this time there have been periodic intervals of glacials and interglacials, where the extent of the ice sheets has waxed and waned.

Palaeoclimate – The ancient climate that existed thousands or millions of years ago

Pliocene – The geological Epoch before the Pleistocene, ranging from 5.33 to 2.59 million years ago.

Strata – Layers of rock that are approximately the same age and consist of the same type of material e.g. the 'Human Strata' being made up of building materials, concrete, plastics etc.