Learn Chemistry

Chemistry's Interfaces: Geochemical Time Travel

Student Guide

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This resource was produced as part of the National HE STEM Programme

National HE STEM Programme

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Registered Charity Number 207890

Table of Contents

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

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.

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.

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

(a) Introduction and Pre-Anthropocene

Pre-Session Preparation

You should read the resources listed below so that you 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 you 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.

Reading

Essential:

- 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:

- 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 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.

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

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.
- 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.

(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?
- Which different isotopic decay systems are used to give absolute dates for soils and rocks on timescales of thousands to millions of years?
- 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} $years^{-1}$.
- 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.
- 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):
  Discuss the following points about the graph:
  - Over the past 420Ka, which atmospheric chemicals have changed in sync with temperature changes?
  - What do the times of colder temperatures correspond to?
  - Where in the ice core is the CH_4 data recovered from?
  - How is the atmospheric temperature calculated? Read the section called 'Climate and atmospheric trends' on p.431 of Petit et al. (1999).
- 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.
  - How do the CO_2 and CH_4 range in values compare with that of the Vostock ice core?
  - What may cause this difference?
- 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:
  Discuss the following points about the graph:
  - What do the odd and even numbered peaks correspond to?
  - Why does the $\delta^{18}O$ of benthic foraminifera record ancient climatic changes that happened during the past 1 million years?
  - Why is $\delta^{18}O$ heavier at times of glacials?
  - What is the wavelength of the $\delta^{18}O$ cycles? i.e. How much time passes between the peaks of maximum or minimum $\delta^{18}O$?

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

Group reflection

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.

Session 2(b): The Early Anthropocene

Pre-Session Preparation

You should read the resources below so that you 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 you 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

Essential:

- 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:

- 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

- What technological advances that have taken place from 200 to 50 years ago would leave a geochemical record in the rocks?
- How is the geochemistry of the Anthropocene different to that of the Pleistocene and Holocene eras?
- 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 Building stones	Millions of years	Concrete layer in the rock	C isotopes
Wood			
Metals Plant foods			
Fabrics Plastics			

- 1800AD is commonly agreed as the start date, but some scientists think the Anthropocene began thousands of years ago. Discuss the reasons why.
- 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?
    2. What changes to farming methods at 8Ka and again at 5Ka may have been responsible for an increase in atmospheric CO_2 levels?
    3. How did the bubonic plague affect the climate?
- What other anthropogenic changes to the land during the Early Anthropocene would leave a geochemical record?
- 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.
- What is the isotopic signature of lead from the Industrial Revolution? Refer to Figure 5 of Vane et al. (2011).
- What chemical methods did Vane et al. (2011) use to extract and determine polycyclic aromatic hydrocarbons from the estuary sediments?
- What geochemical signatures are found in sediments of atomic bombs that were first used in 1945?

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.

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

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 read the resources below so that you 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 you 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.

Reading

Essential

- 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:

- 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

- What advances that have taken place from 1945 to present that would characterise the Great Acceleration and leave a geochemical record in the rocks?
- 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			

- 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.
- How did the isotopic signature of lead change from 1950? Refer to Figure 5 of Vane et al. (2011).
- What chemical methods did Vane et al. (2011) use to extract and determine PCBs from the estuary sediments?

- What common Persistent Organic Pollutants from modern industry that can be found in river and ocean sediments?
- Draw the chemical structure of DDT and PCBs.
- Why do these two compounds persist in the environment to become part of the geochemical record?

- 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?
- The current high atmospheric CO_2 levels are leading to ocean acidification, through the following process:
  $H_2O + CO_{2\,(aq)} \leftrightarrows H_2CO_3 \leftrightarrows HCO_3^- + H^+ \leftrightarrows CO_3^{2-} + 2H^+$
  What causes ocean acidity?
- What would happen to carbonate rocks and calcitic fossils on the ocean floor due to ocean acidification? Refer to Tyrell (2011).
- What anthropogenic changes to the land during the Great Acceleration will leave a geochemical record?

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.

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 read the resources below so that you 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 you 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

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)?

- What are the products of polymer degradation?
- 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).
- 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?
- Draw the structure of bisphenol-A and explain why it is toxic to marine life.
- What categories of plastics degrade to produce bisphenol-A?
- Which polymers are most resistant to natural degradation by bacteria?
- 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^{o}C. Hint: what is the geothermal gradient?
- 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?

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.
- The IPCC estimates that by 2100, global warming could be as much as 3.5^{o}C. How would this warmer climate affect the environment, and be recorded in the 'Human Strata'?
- 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?
- What geochemical signatures would be present in the 'Human Strata' from anthropogenic chemicals?

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.

Group reflection

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

Intended Learning Outcomes

By the end of this problem you 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.

Group reflection

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