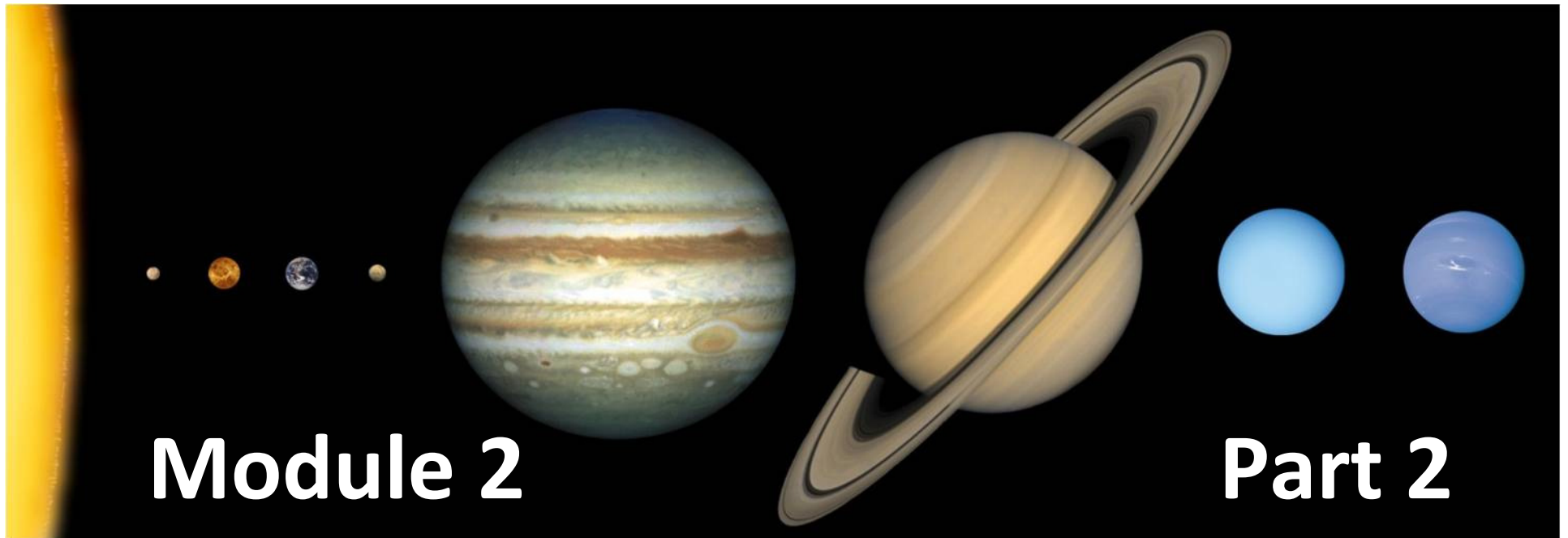


Earth Sciences 2150 – Fall 2022

Solar System and Planetary Science



**Earth Science Background Concepts:
Revisiting what you need to know**

EASC 2150: The Solar System

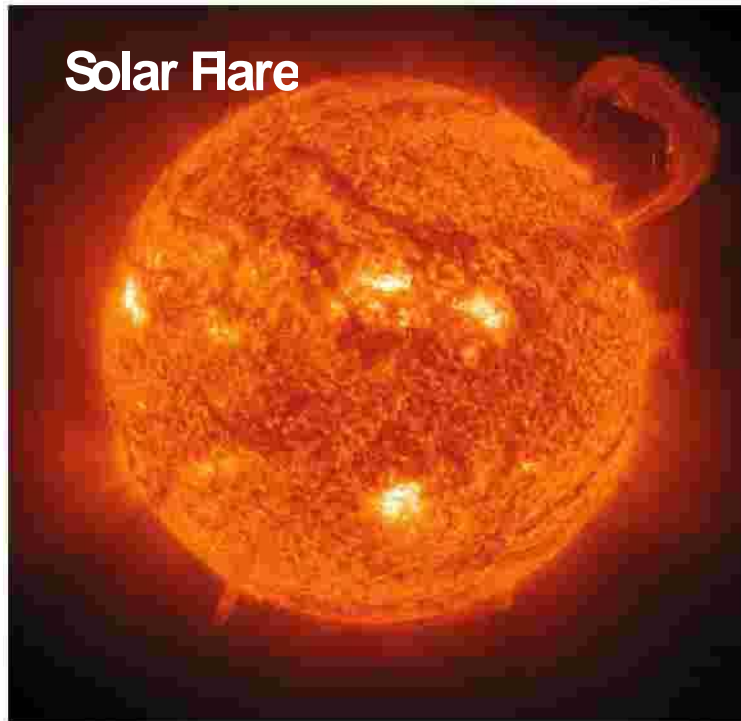
The Plan for Today

Important Earth Science Concepts

- This is a science course, and an **Earth Science** course, even though there are no prerequisites. So you will need some basic concepts. In this class we commence with some ideas connected to energy, and then move into Geology.
- Energy in the Universe
- The essential structure of the Earth and the concept of the Lithosphere (the outermost region of silicate planets).
- Minerals, rocks, and some key aspects of Earth Sciences.
- The “Rock Cycle” and Plate Tectonics; reasons for the dynamic nature of Earth.

Energy in the Solar System – Some Concepts

- Obviously, there is energy on (or in) the Earth, and there is energy in the Solar System. Where does this come from, and how do we make use of it as scientists?
- It is equally obvious that we cannot yet visit all places, so the data and information that comes from remote sensing methods is very important. These methods are largely sense/analyze energy.
- So, let us quickly look at some ‘major points’ about energy – which should be familiar to you.

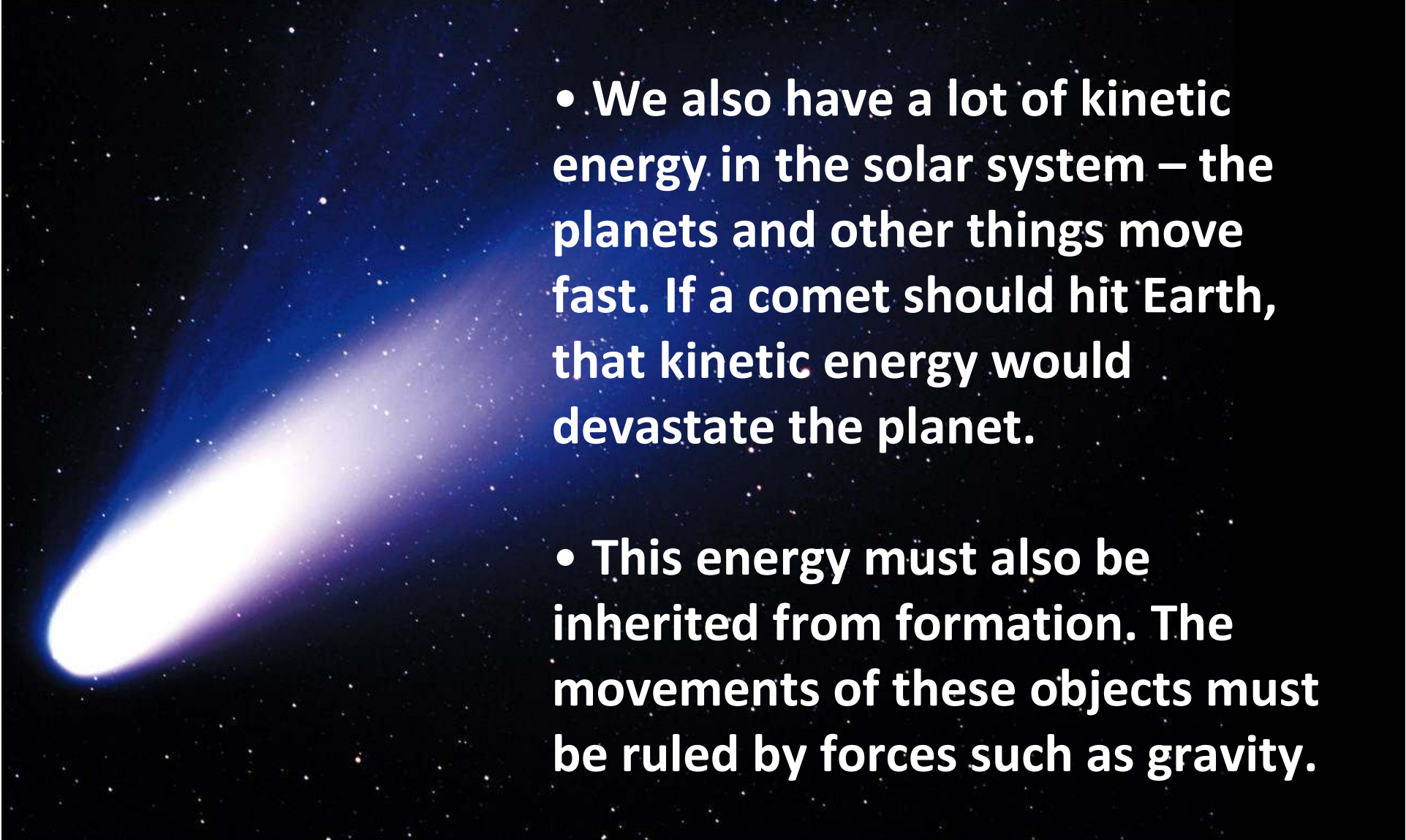


- The most obvious energy source is the Sun. Its energy ultimately comes from Nuclear Fusion – it turns hydrogen atoms into helium. We can ‘analyze’ its energy output... It tells us a lot about processes.

- Planets have internal energy as well, although some have lost most. This is both leftover from formation and produced by radioactive decay (fission),



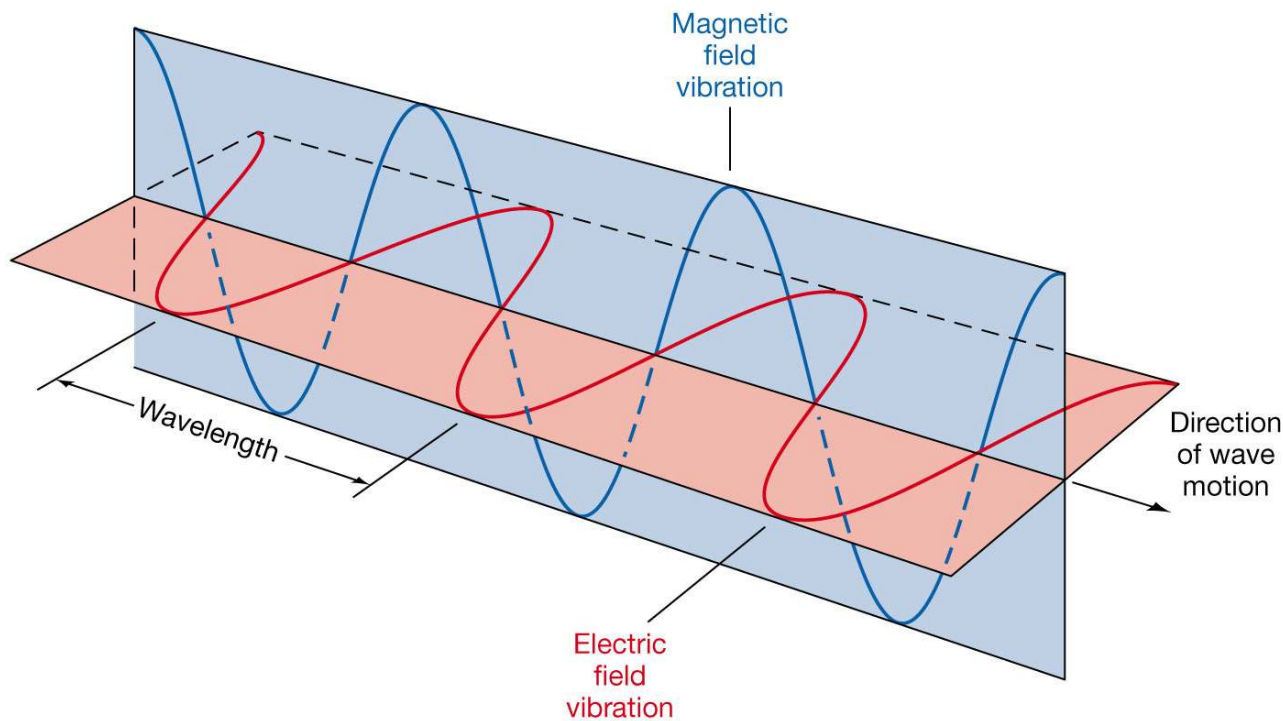
Energy in the Solar System – Some Concepts

- 
- A bright comet streaking across a starry night sky. The comet's head is a glowing white and yellow sphere, with a long, diffuse tail of blue and purple light trailing behind it. The background is a dark, deep blue space filled with numerous small, white stars.
- We also have a lot of kinetic energy in the solar system – the planets and other things move fast. If a comet should hit Earth, that kinetic energy would devastate the planet.
 - This energy must also be inherited from formation. The movements of these objects must be ruled by forces such as gravity.

Later, we'll discuss laws of motion and gravitation....

The Electromagnetic Spectrum

- The most obvious and most useful energy that we deal with is **Electromagnetic Energy** or Radiation. The Solar energy is the most obvious example.
- EM energy is produced by many processes – combustion, radioactive decay are just two examples. It is in many ways a contradiction – we describe it as a wave-form with a frequency and a wavelength; but at other times we think of tiny ‘energy packets’ called photons. For now, we’ll stick with the concept of waves. It makes things a bit easier.
- The analysis of electromagnetic spectra from various types of solar system objects is fundamentally important to our knowledge, and it always will be.

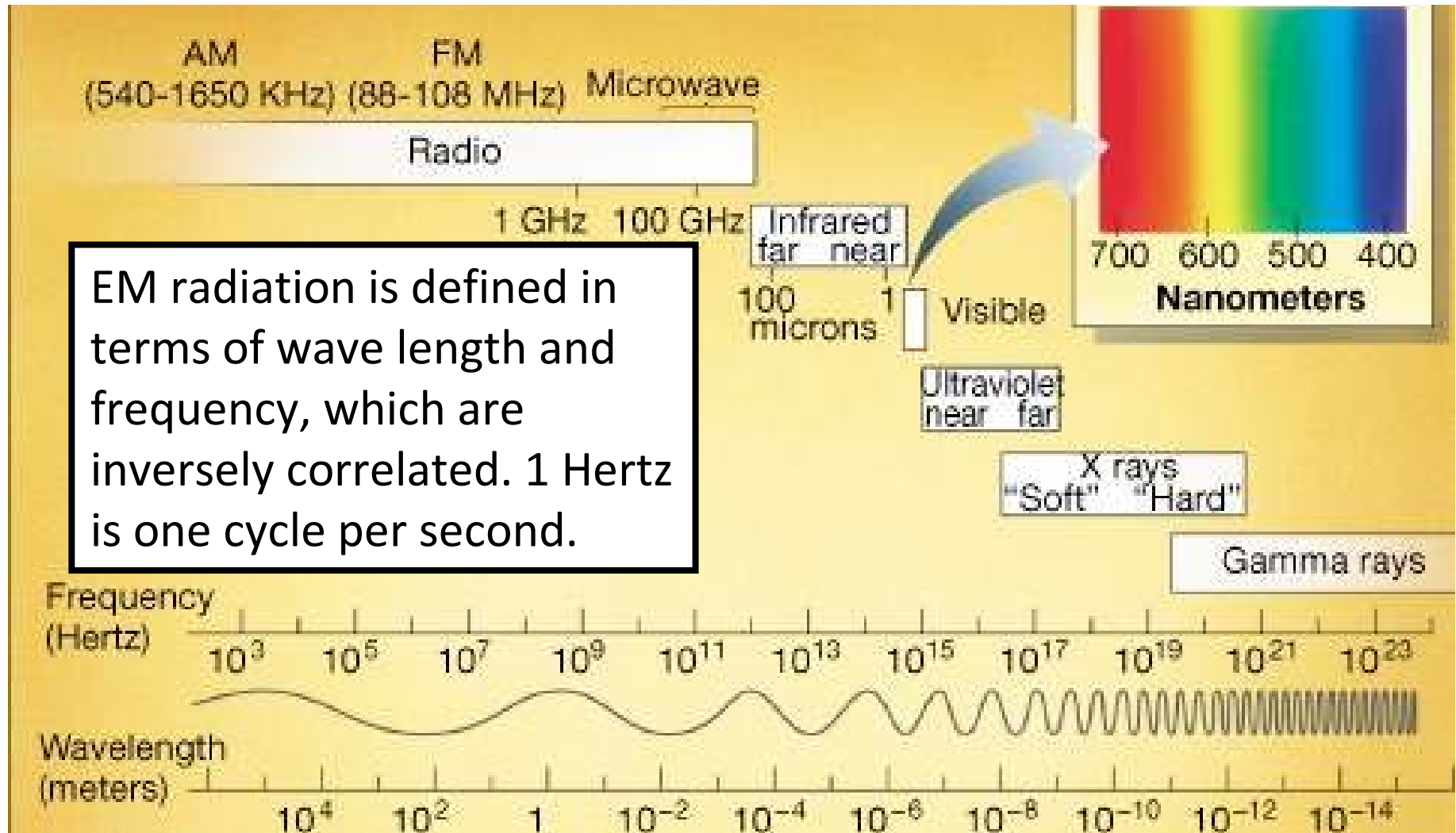


• **Frequency and Wavelength are opposites. If there is a long wavelength, there is a low frequency, and vice-versa.**

- EM radiation has two components – electrical and magnetic – that vibrate at right angles. It is described by two measures.
- **Wavelength** is the distance between wave crests. **Frequency** is a measure of how many wave crests pass a spot in a given time.
- **EM radiation propagates at the speed of light (3×10^8 m/s)**

Important Regions of Electromagnetic Spectrum

(you should have a general idea of these)



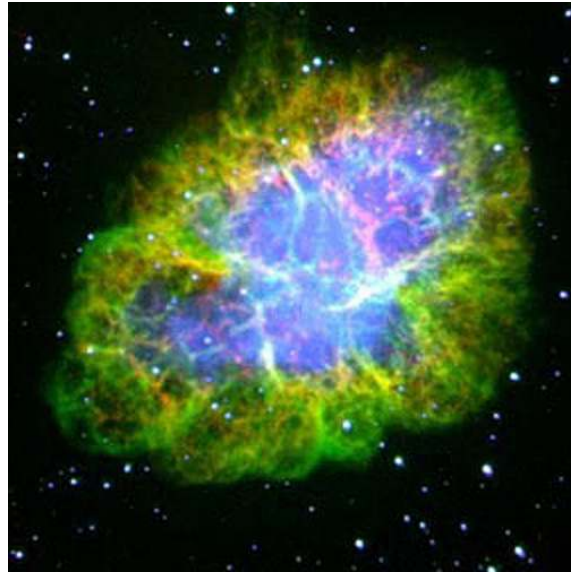
- As the wavelength gets shorter, EM radiation is more energetic.
- Visible light is a very small region in the middle of the spectrum.

Using The Electromagnetic Spectrum

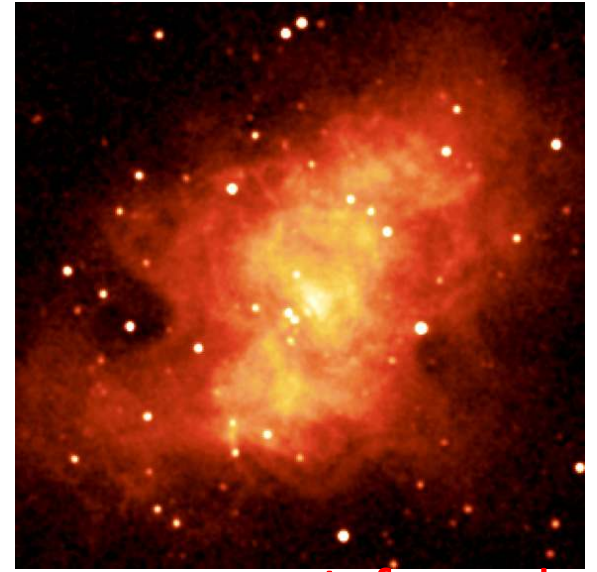
- Objects produce a range of frequencies. The Sun gives us UV and infra-red as well as visible light. Also some X-rays.
- There is a relationship between the temperature of a radiant surface and the frequency/wavelengths emitted. So we can figure out the temperature of a distant star!
- Objects show different features in different regions of the EM spectrum – we can see Venus' surface with 'radar'.
- Atoms, ions and molecules will absorb energy in defined ways, and will also emit energy in defined ways. So we are able to use these features (spectra) to find compositions.
- All these methods fall into the general heading of **SPECTROSCOPY** – and we will make much use of this.



X-ray



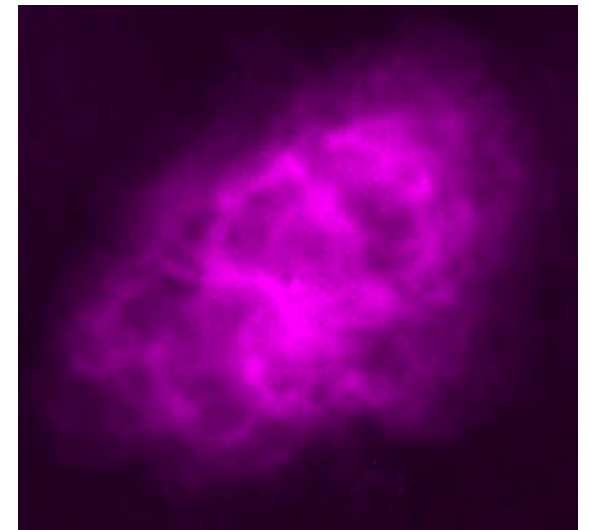
Visible



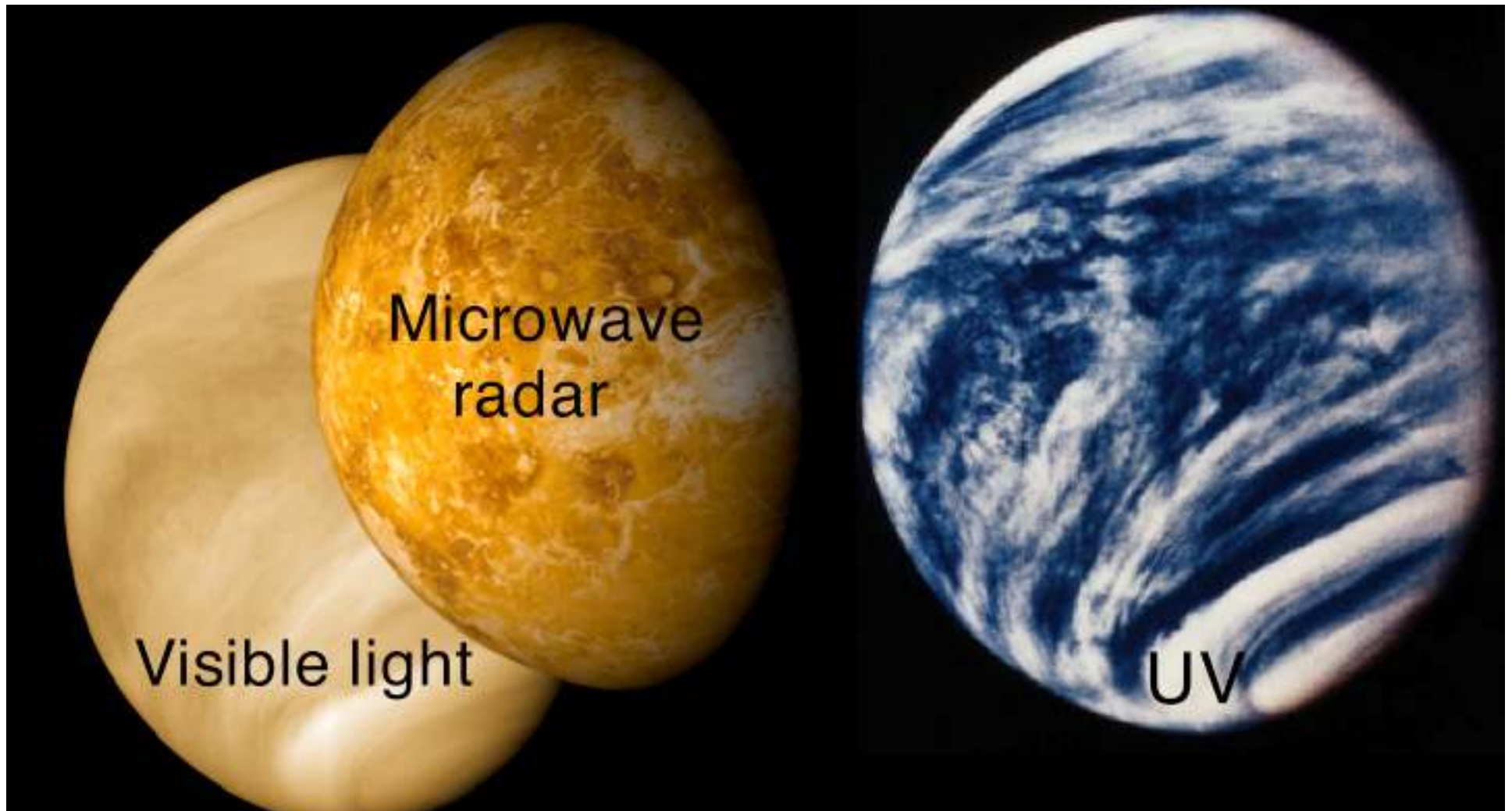
Infra-red

- This is an example of different images of an area known as the Crab Nebula. It is 6000 light years from Earth.

- The detailed spectral analysis can tell us about compositions and sizes of stars, rotation rates, and possibly even if they have planetary companions.



Radio



Cloud cover masks the surface of Venus as seen in visible light. Radar and UV portions of EM spectrum improve the image. Radar gives best image of surface, UV gives best image of clouds. In all cases, the EM energy is reflected energy, originally from the Sun. Such methods are vital because it's not likely that we will ever set foot on Venus.....

From atoms to molecules – making minerals

- We discussed atomic structure in Part 1. Two or more elements can combine chemically to form a **compound**.
- **Minerals** are simply chemical compounds that occur in nature; some are simple, some are more complex.
- A **molecule** is the smallest unit into which a compound can be divided and still retain all the physical and chemical properties of that compound. Minerals also can be defined as molecules. For example, a molecule of quartz has a silicon atom and two oxygen atoms (SiO_2).

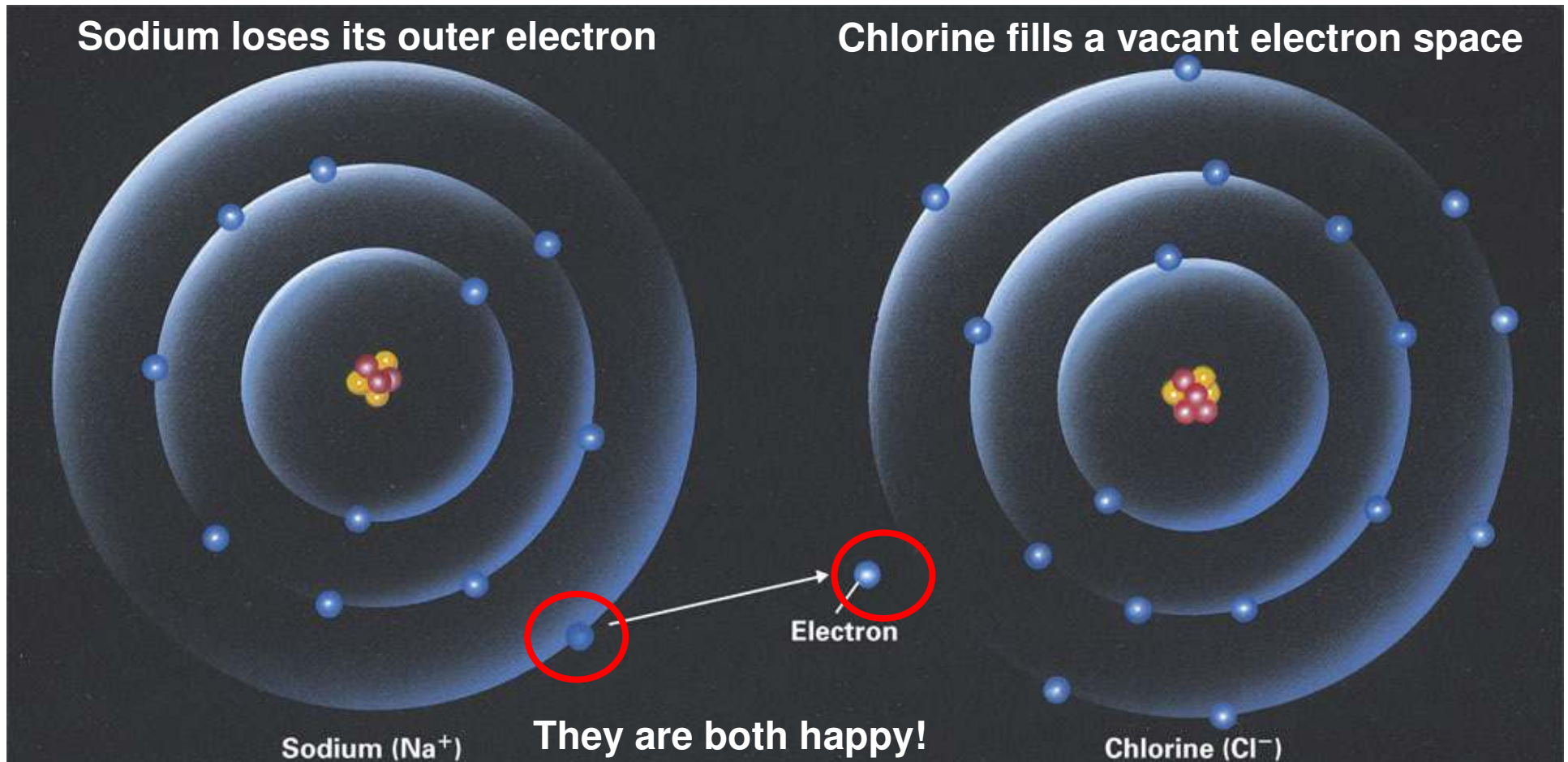
How do atoms combine to form molecules?

- By various types of **chemical bonds – the most important are IONIC and COVALENT.**
- **But these are not the only factors to consider**

Bonding Types – A Summary

- The chemical bonds that hold atoms together in molecules are mostly electrical in nature.
- Ionic bonds form generally between metals and non-metals, and involve the transfer of electrons. The metal (e.g., Na) loses an electron by giving it to the non-metal (e.g., Cl). The result is NaCl (salt or the mineral 'halite'). Another example is quartz (silicon dioxide, or SiO₂)
- Covalent bonds are where two elements 'share' an electron, so that they each have a full electron shell.
- The majority of natural minerals are **Ionic Compounds**. They involve metals and non-metals. In some cases, the latter are organized into groups to make a polyatomic ion. For example, CO₃²⁻ is the **carbonate** ion. Many minerals on Earth are carbonates; we also have sulphates, sulphides....

Opposites Attract – the making of an ionic bond

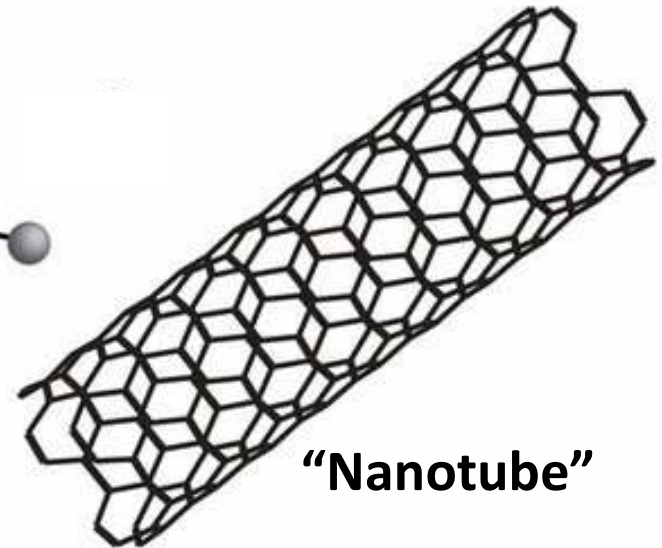
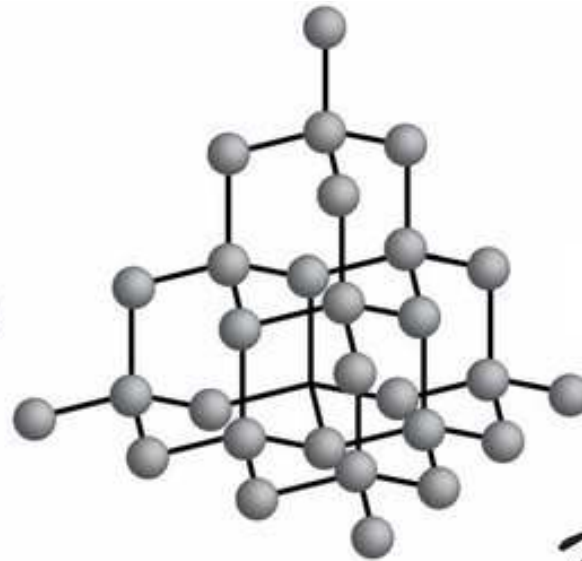
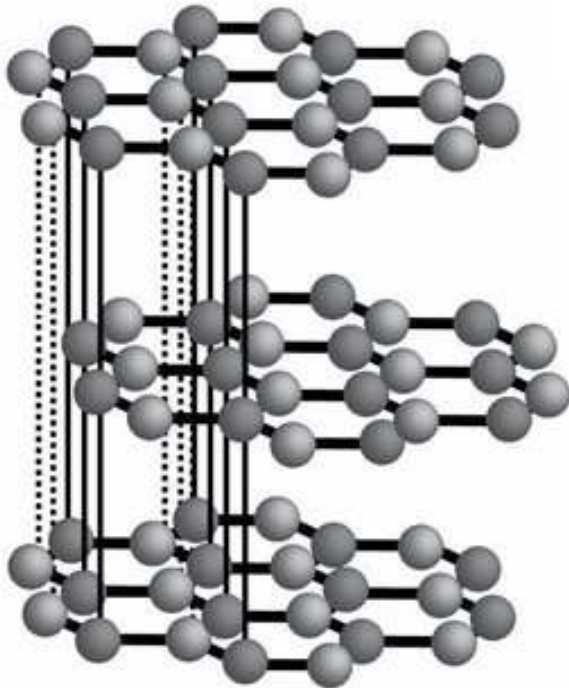
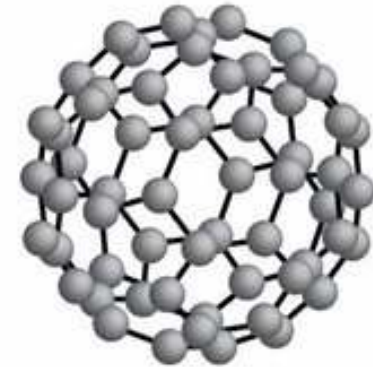


One **Na⁺** cation attracted to one **Cl⁻** anion produces one electrically neutral, ionic compound called sodium chloride (**NaCl**). Sodium chloride is the chemical name for the mineral known as **halite** (or common table salt). We mine it as “rock salt” – used on the roads.

Sharing Electrons – Covalent Bonds in Minerals

Diamond – a continuous 3D network of carbon atoms with covalent bonding linking all atoms

“Bucky Ball”



“Nanotube”

Graphite – sheets of carbon atoms with covalent bonding are held together by weaker (VdW) forces

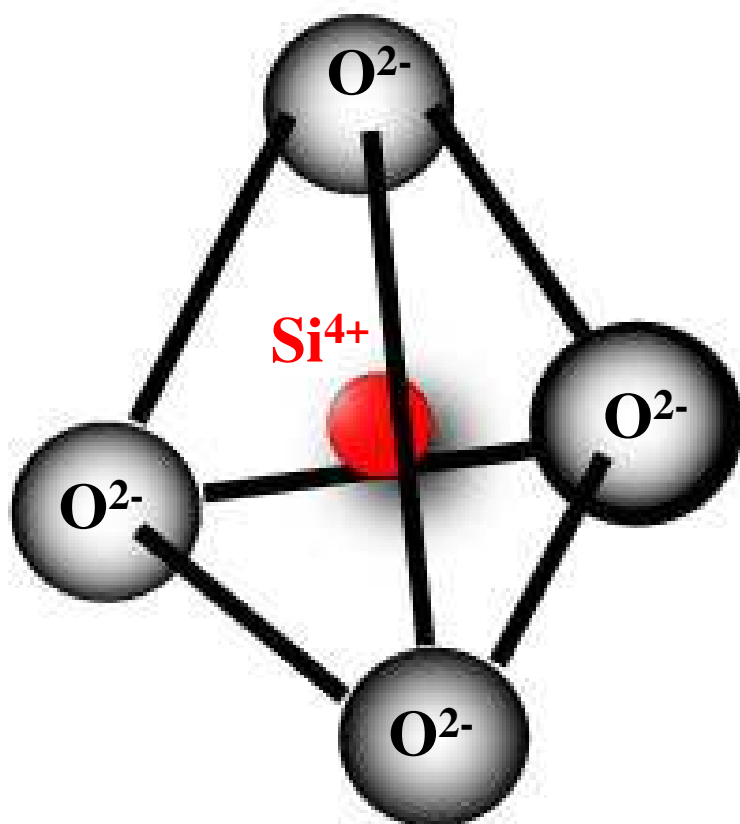
Graphite and Diamond are natural minerals made of carbon. Bucky Balls and Nanotubes are artificial.

Minerals and Rocks – What Makes a Planet?

- In the previous example we talked about atomic bonding and used common salt as an example. Salt is a familiar foodstuff, but it is also a natural mineral, called 'halite'.
- Minerals are naturally occurring chemical elements or (more often) chemical compounds. Minerals come together to make rocks, by various mechanisms. The Earth has several thousand minerals, but other planetary objects in our system are much less varied. We also find very similar minerals on all terrestrial planets, as far as we know.
- The most common minerals are generally silicates – combinations of metals and the silicate ion (SiO_4). There are thousands of silicates. They build rocks, and planets.

Silicate Minerals – are defined by the **silicate tetrahedron**

- All silicate minerals are based on the “**silicate tetrahedron**”, the fundamental building block of all silicates, which consists of one silicon cation (**Si⁴⁺**) surrounded by four oxygen anions (**O²⁻**) as shown schematically in this "stick" figure.



A tetrahedron is a 4-sided polyhedron. There are no stick-like connectors in an actual silicate tetrahedron. They are included in the figure to emphasize the 4 sides of a tetrahedron (3 sides leaning against the top O²⁻ anion, and a 4th side on the bottom of the tetrahedron).

Net charge on the four O²⁻ anions and the one Si⁴⁺ cation in the tetrahedron
= 4 x (-2) + 1 x (+ 4) = - 4 (i.e. 4 minus)

Silicate Minerals as Natural Polymers

- “Polymers” are complex molecules that can be joined up in to produce materials of great strength and durability. Diamond is a polymer. Most organic compounds are polymers. Plastics – universal in our modern world – are all polymers.
- Silicate minerals are *natural* polymers in which the basic SiO_4 unit is combined with other SiO_4 units in a wide variety of geometric patterns – for example, chains, rings, sheets, 3D networks, etc. **These are very stable and durable compounds.**
- These basic units are then combined with various cations (positive ions) to balance the charges in the molecule. In nature, cations with similar size and charge characteristics can **SUBSTITUTE** for one another (e.g., Fe and Mg, or Na and K). So natural minerals **vary** in composition. They generally do not have fixed compositions like the chemicals in a laboratory.

Minerals in the Solar System.....

- There are thousands of different minerals seen on Earth, but other planets seem less diverse.
- But their rocks *are* made of familiar minerals.
- Some important ones to remember are **olivine** and **pyroxene** (both are Mg-Fe-silicates). These make up most of the terrestrial planets in a bulk sense, although not all of their surfaces.
- Remember also **plagioclase** (Ca-Na-Al-silicate). This is the most abundant mineral in the crust of the Earth, and likely common elsewhere.
- Other common minerals like **quartz** (SiO₂) and **orthoclase** (K-Al-silicate) seem rare elsewhere.



Olivine and Pyroxene –
essentially Mg-Fe-Silicates

(not always like these
photos; colour varies)

“Labradorite” – a type of plagioclase



“Anorthosite” – plagioclase-rich rock

- **Plagioclase** is a Na-Ca-Al silicate. It is very common in Earth rocks, especially those of igneous origins. Labradorite is a type of plagioclase, and represents a specific composition that can interfere with the wavelengths of reflected light. It is a rare form of a very common mineral.

Anorthosite is a rock type consisting largely of Ca-rich plagioclase. It is very widespread in Labrador and on the Moon

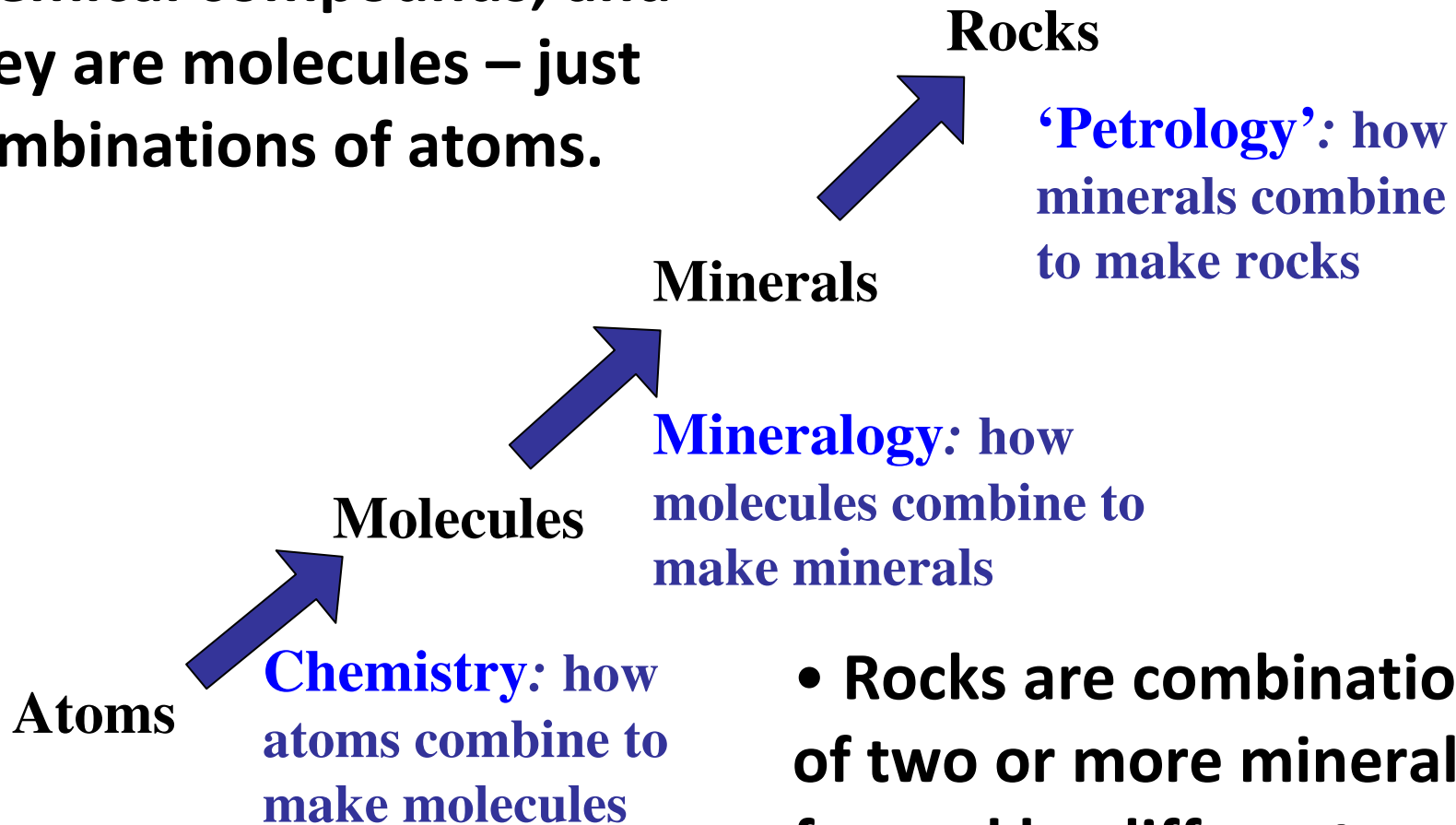


- Quartz is a simple mineral (Silicon Dioxide – SiO_2). Orthoclase and other similar minerals are Potassium Aluminum Silicates. These resemble Plagioclase and all belong to the feldspar group

A mixture of quartz, plagioclase and orthoclase forms the common rock type **Granite**, seen widely on the continents of Earth. There is little evidence of this rock type on the other planets.

What are Minerals compared to Rocks?

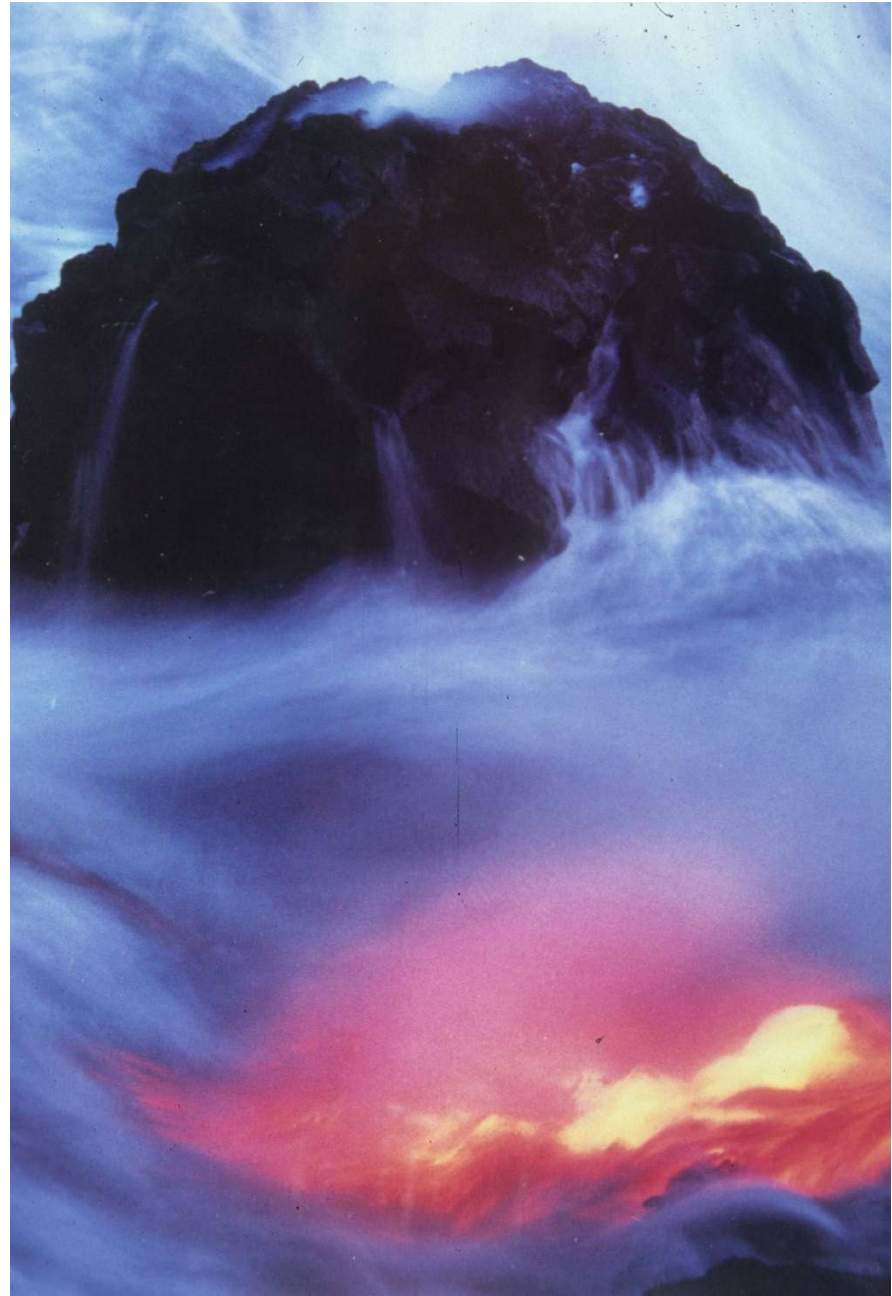
- Minerals are natural chemical compounds, and they are molecules – just combinations of atoms.



- Rocks are combinations of two or more minerals, formed by different natural processes.

Rocks in the Solar System

- As you might expect, ‘terrestrial planets’ are made up of rocks, and (so far) it seems that the rocks on them are familiar from Earth.
- However, it does not (so far) seem that other planets contain the diversity of rock types that we know on Earth. Or the diversity of minerals.
- We know that the rock type known as **Basalt** is **very** widespread. This is a common volcanic rock that erupts in many places (eg. Hawaii). It is common on the Moon, Mercury and Mars.
- A Basalt contains **olivine, pyroxene and plagioclase** (plus a few other minor minerals). A lunar basalt looks the same as an Earth basalt.



Igneous rocks that form on the surface of the Earth are most familiar to us – we know these as lavas. There is no doubt that other planets have volcanoes.

Definitions - The three large families of rocks are defined by the processes that form them.

- 1. Igneous Rocks:** form when molten rock (lava or magma) cools and crystallizes (solidifies). There are many different types of igneous rocks on Earth, and they dominate silicate planets.
- 2. Sedimentary Rocks:** form by cementing together loose material (sediment) that has been derived from other rocks, or by precipitation from water, or by accumulations of shells and organisms. There are some sedimentary rocks on Mars.
- 3. Metamorphic Rocks:** form from other rocks as a result of elevated temperature and pressure or reactions. Common on Earth – but we are much less certain about them elsewhere.

to repeat – THERE ARE MANY DIFFERENT TYPES ON EARTH!

Igneous Rocks – A few other important concepts

Igneous Rocks: can be divided into two main types that we call volcanic and plutonic. A volcanic igneous rock (a lava) erupts on a planetary surface (on Earth, often underwater). Basalt is the most common but other types exist. A plutonic rock cools slowly at great depth and will form larger crystal masses. Granite and anorthosite are plutonic rocks.

Magmas are the deep version of a lava. Essentially, a lava is a magma that gets to the surface. Lavas build volcanoes, but these differ in type and behaviour. Some volcanoes on Earth are explosive in eruption style, but we have less evidence of this elsewhere.

Volcanic activity involves fluids and vapours. Volcanoes on Earth are important sources of volatile compounds like water, CO₂ and Sulphur. These come from deep within the planet, and we would expect this to be true on other planets.

Volcanoes are abundant in the Solar System, but many are extinct: We think that Venus has active volcanoes, but we have never seen one erupt. Mars has several enormous volcanoes, but they are probably extinct. Volcanic activity was once intense on the Moon and Mercury, but these planets now appear to be dead.

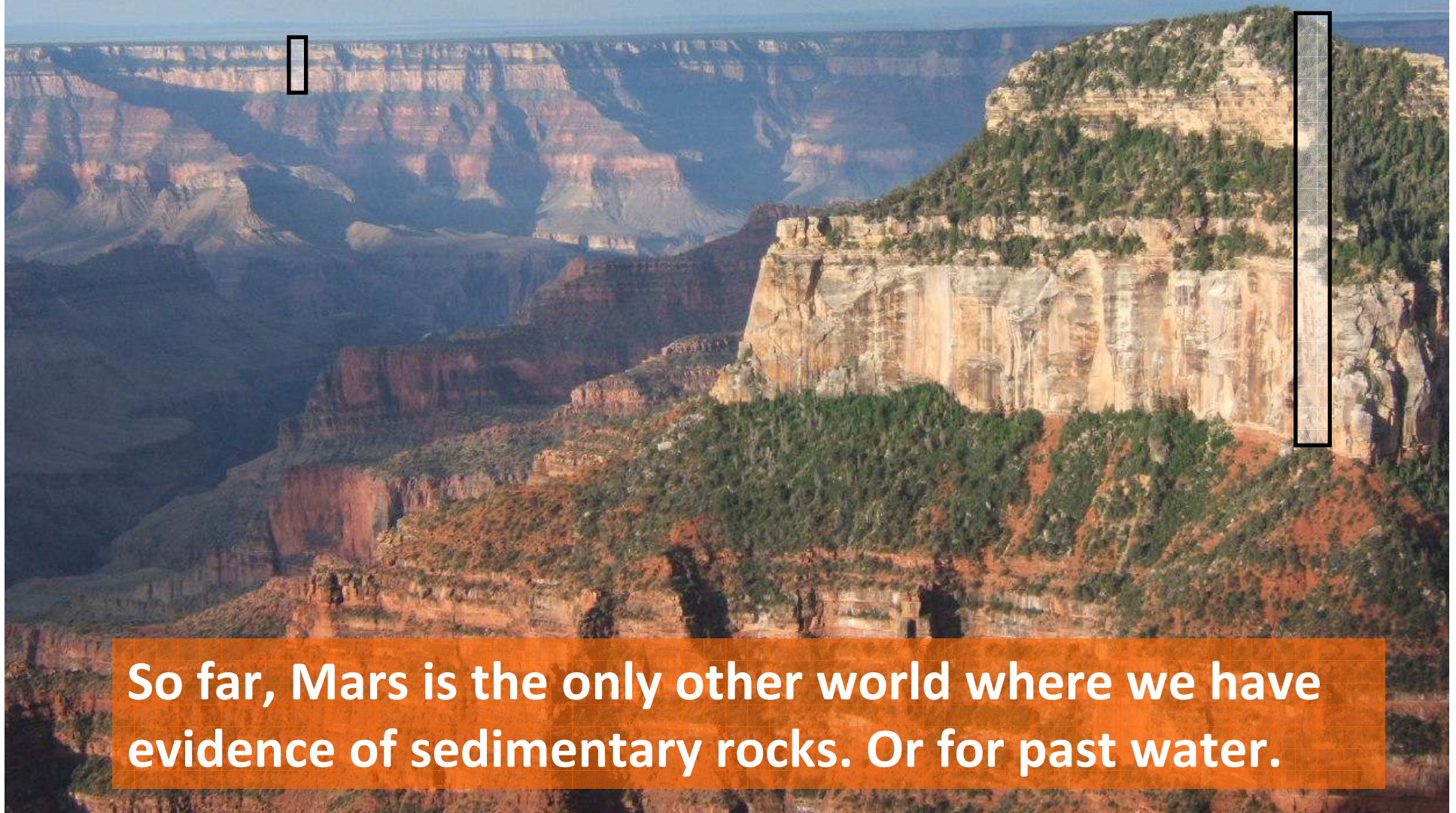


- The most familiar type of volcano is called a “stratovolcano”. These tend to have large and explosive events, and are formed by viscous (sticky, thick) lavas. There is no evidence yet of any elsewhere than Earth. Maybe on Venus?

- Shield volcanoes are broad mountains formed by hot fluid basalt eruptions. e.g., Hawaii – and Olympus Mons (on Mars). These lavas had low viscosities.



Sedimentary rocks – you should know a bit about these already, notably that they form layers or beds that can be traced. You don't have to go to the canyon to see this! An essential fact about most sedimentary rocks is that they formed in **water-rich settings.**



So far, Mars is the only other world where we have evidence of sedimentary rocks. Or for past water.



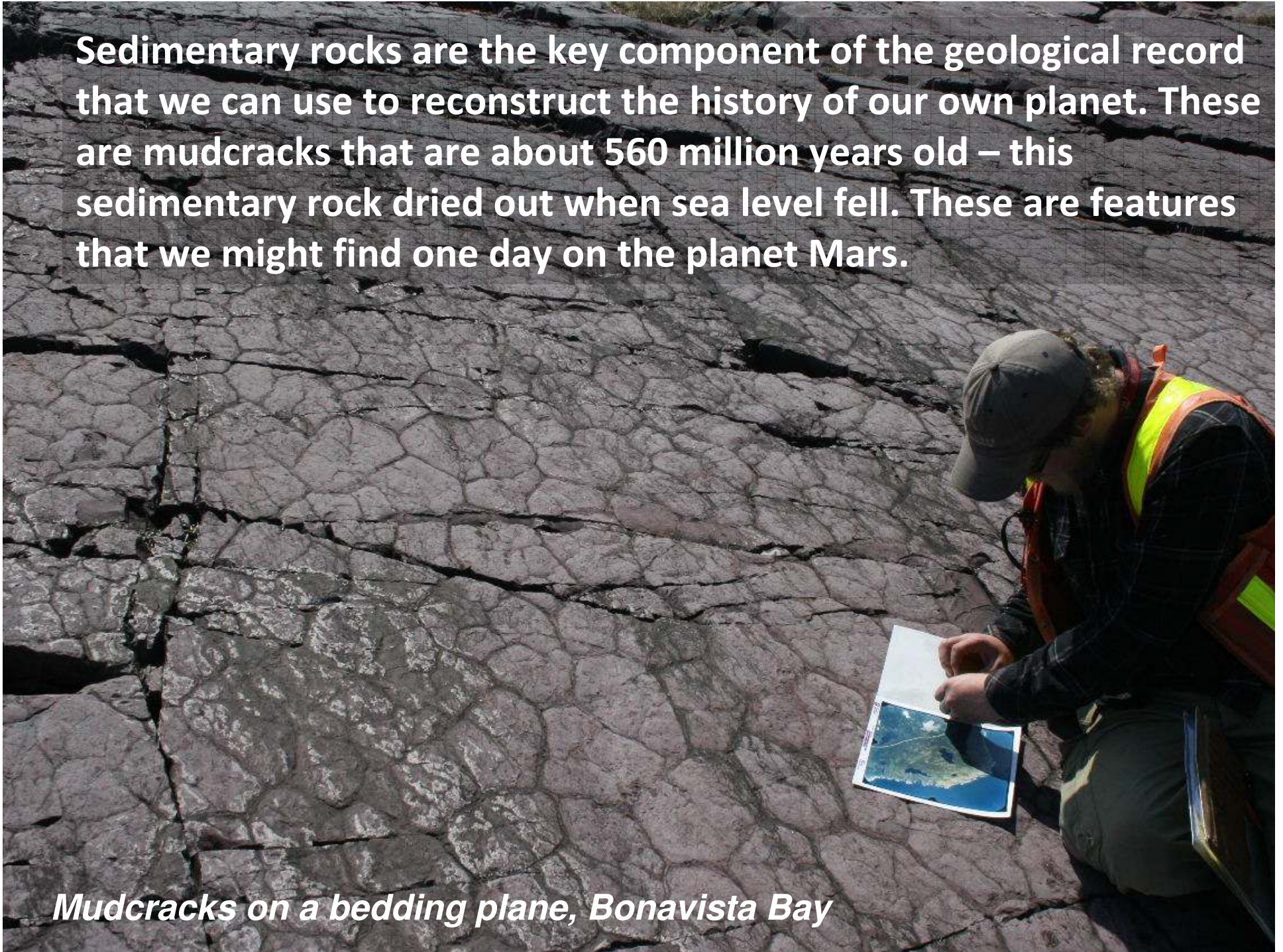
Sedimentary rocks on Earth collectively give us a “geological record”. Ancient sedimentary rocks are typically tilted because the Earth is a dynamic planet. These ones are about 450 million years old (450 Ma).

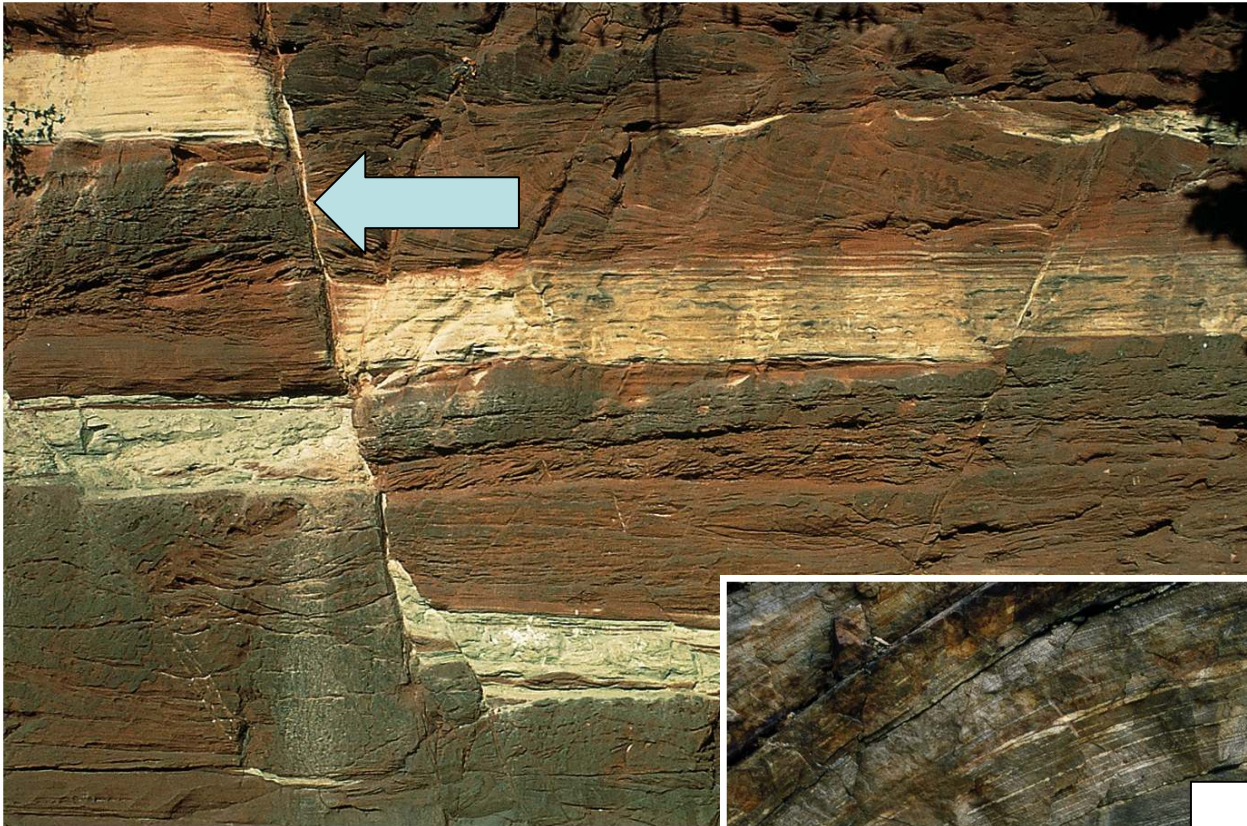


There is abundant evidence of the dynamic geology of the Earth – these are sedimentary rocks that have been crumpled and ‘folded’ in the processes that formed the Appalachians of eastern Canada. Earth is an active, dynamic place.

Sedimentary rocks are the key component of the geological record that we can use to reconstruct the history of our own planet. These are mudcracks that are about 560 million years old – this sedimentary rock dried out when sea level fell. These are features that we might find one day on the planet Mars.

Mudcracks on a bedding plane, Bonavista Bay





In this photo, a small fault (break) affects a bedded sequence of sedimentary rocks. It must be younger than any bed that it affects – this is obvious!

Figure 10.2a
Landform Slides

In this photo, two 'dykes' of basalt cut through folded sedimentary rocks. If you could 'date' a dyke, it would give a minimum age for deposition and folding.

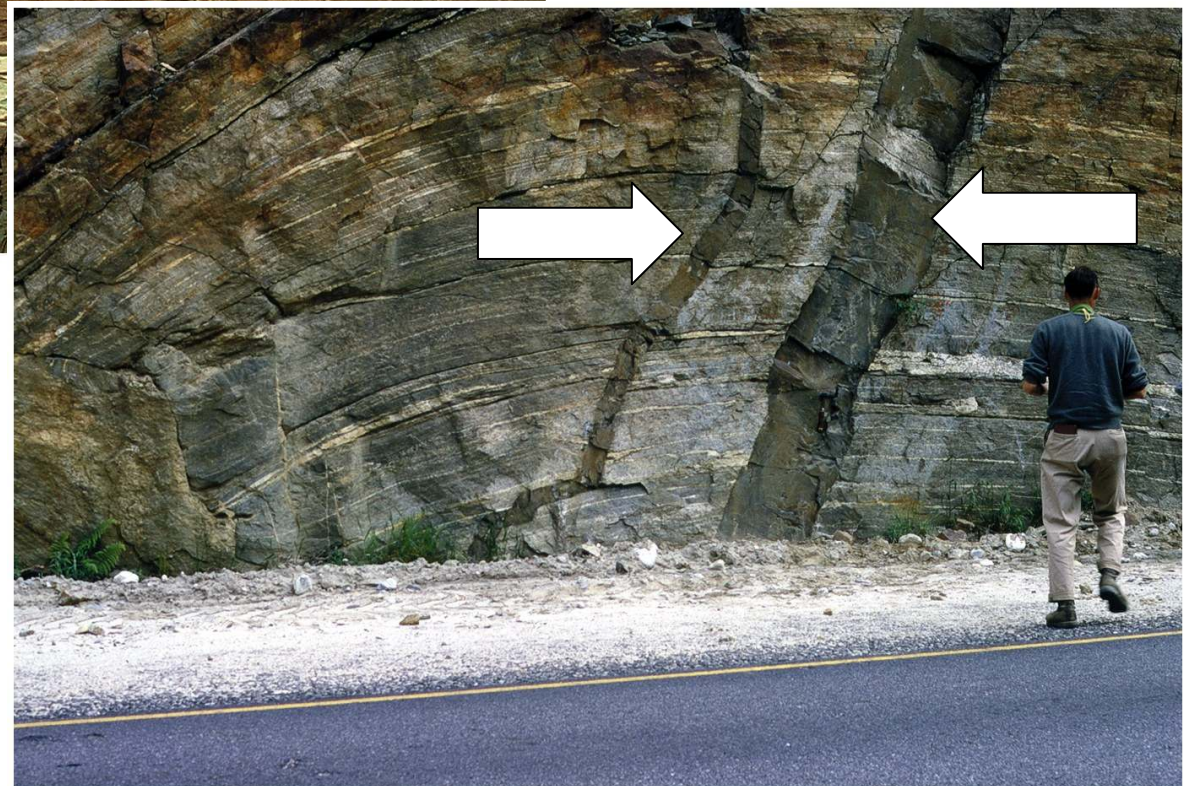
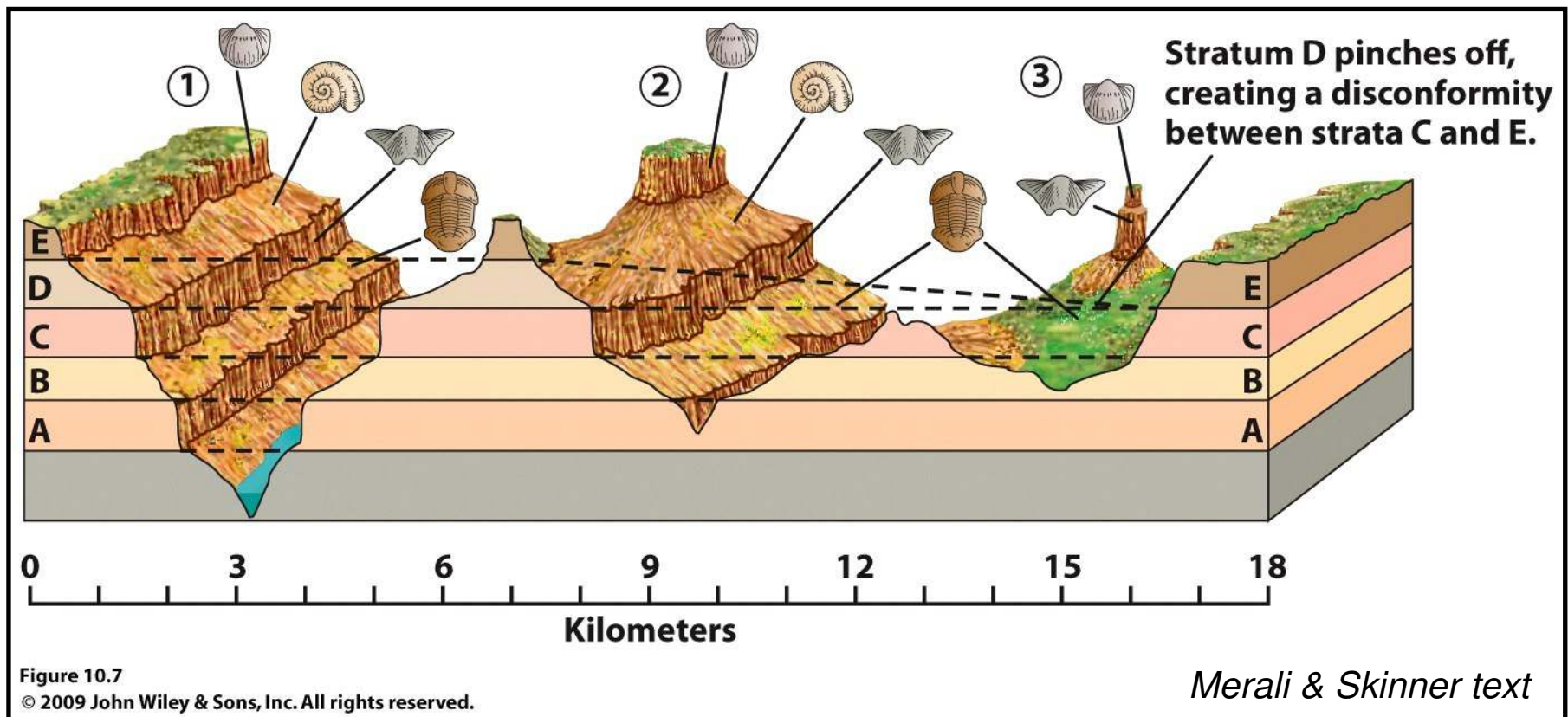


Figure 10.2b
Courtesy Lee Gerhard

Merali & Skinner text



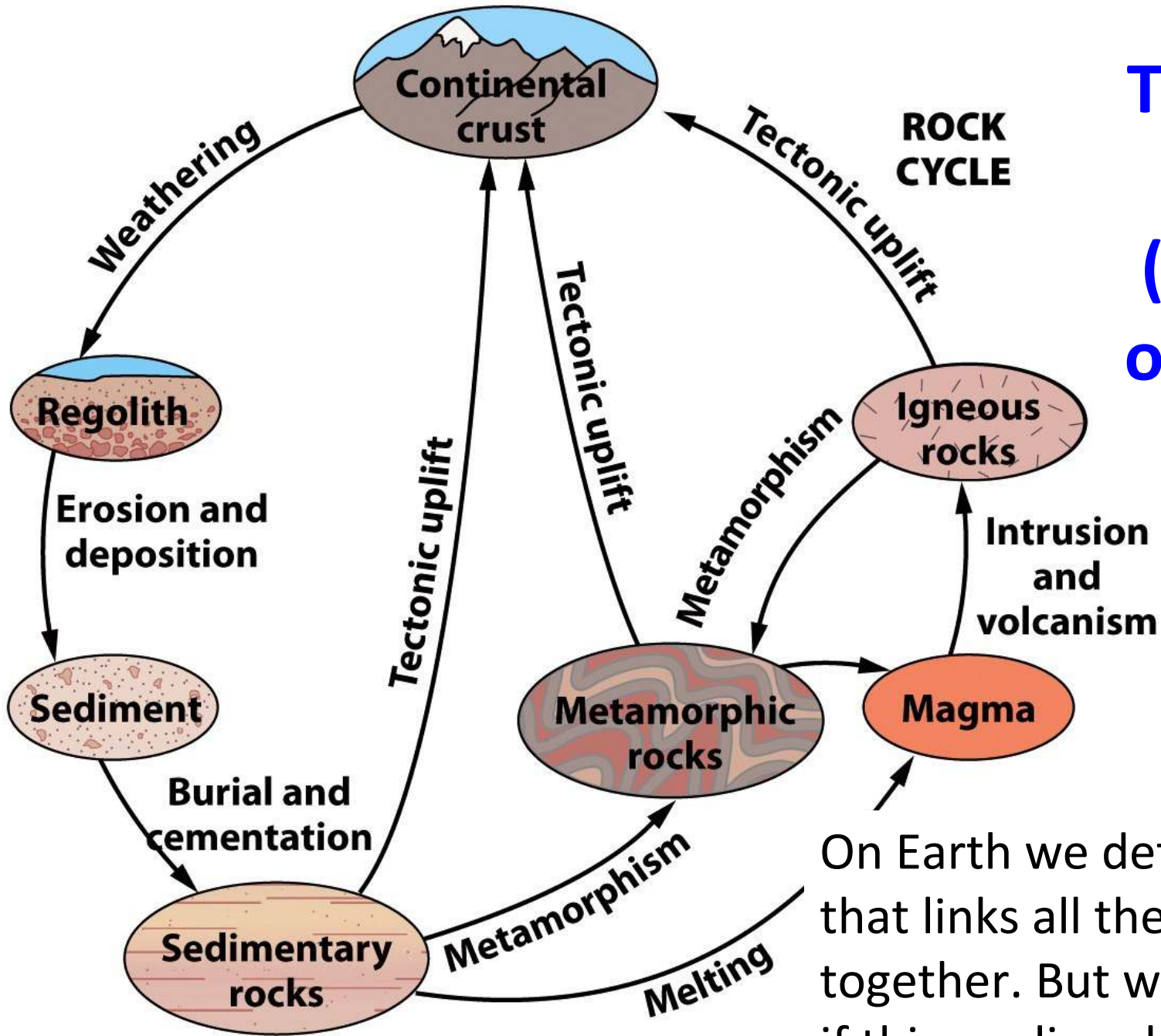
- On Earth, we have another way of linking events in time. We can use fossils, which record the evolution of organisms. If two rock layers contain the same distinctive fossils, they must have formed in the same time interval. The study of fossil assemblages is critical in stratigraphy.
- If we eventually discover fossils in Martian sedimentary rocks it will surely be the most important of discoveries!

Some metamorphic rocks are pretty amazing, and they have incredibly complex histories – like this one from Labrador, which is more than 3 billion years old – but a lot younger than the Earth.



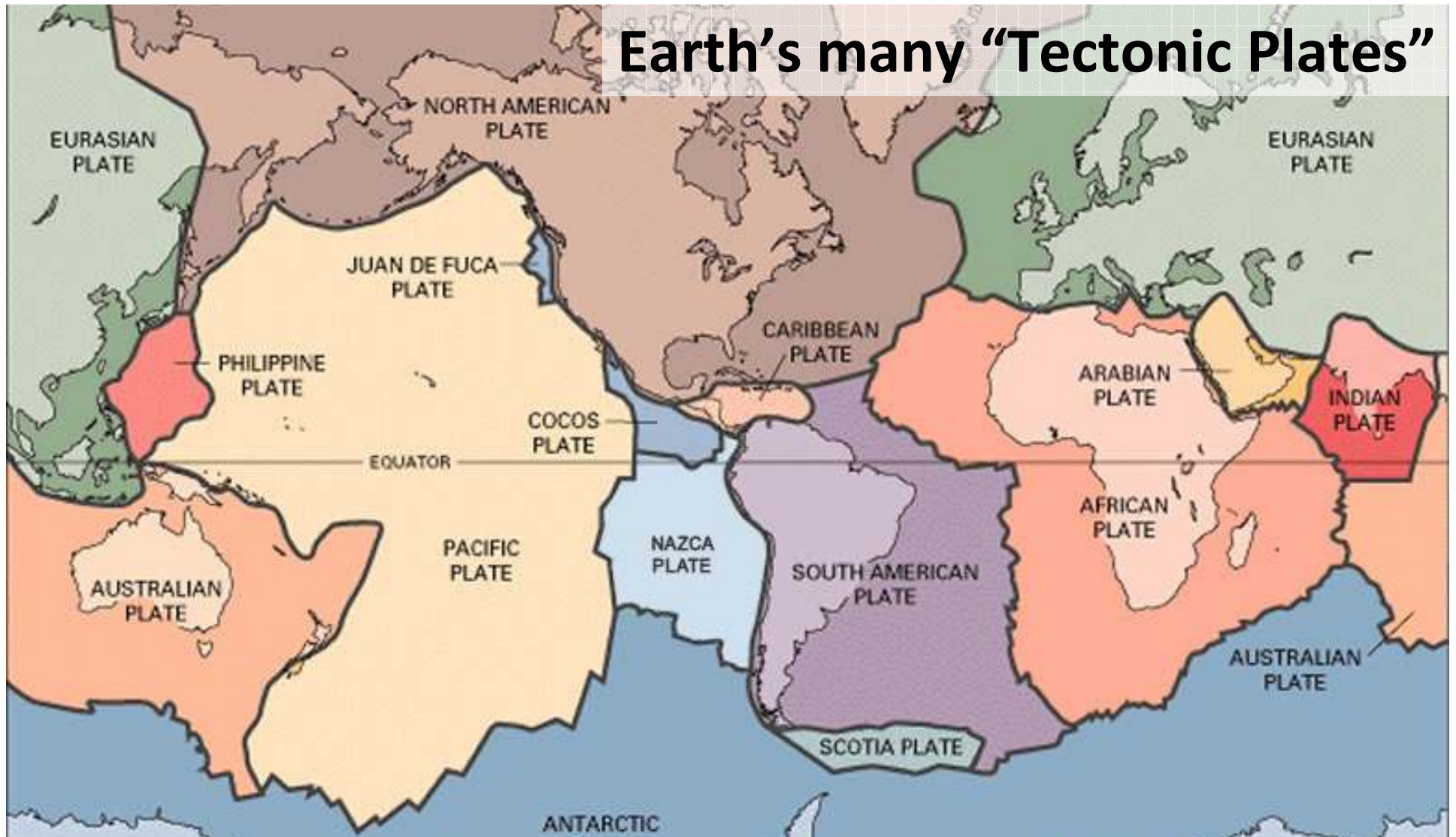
This example was originally an igneous rock of some kind. It was placed under enormous pressure at high temperatures (> 800 C) which caused it to start melting and make a 'granite' (pale stuff).

The Rock Cycle (as seen on Earth)



On Earth we define a 'cycle' that links all these types together. But we don't know if this applies elsewhere....

Earth's many "Tectonic Plates"

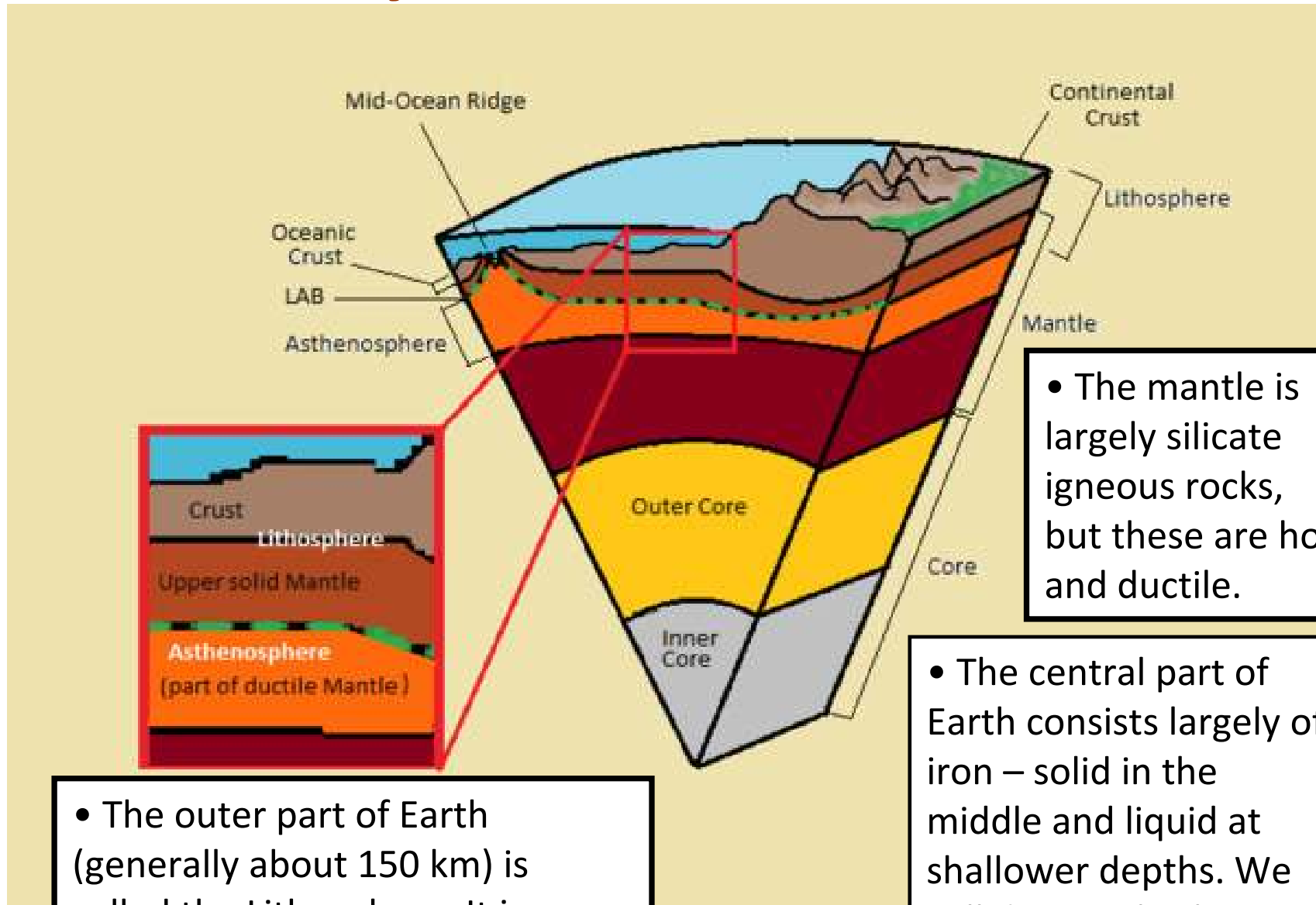


The Earth is a dynamic planet, because its outer shell is in constant but very slow motion. The 'boundaries' of these tectonic plates are where many geological processes are focused, e.g., volcanism, metamorphism, mountain building.

So, Why is the Earth a Dynamic Planet?

- You have probably figured out that Earth is unique. Why is it an active planet?
- The first reason is that it has lots of internal heat – left over from its formation and also from radioactive decay in the interior regions.
- Smaller planets will cool much more rapidly as they have high surface area to volume ratios.
- The second reason is that the materials (rocks) that make up the Earth's surface and those inside the planet behave very differently. This is the concept of the **Lithosphere**. An Important word!

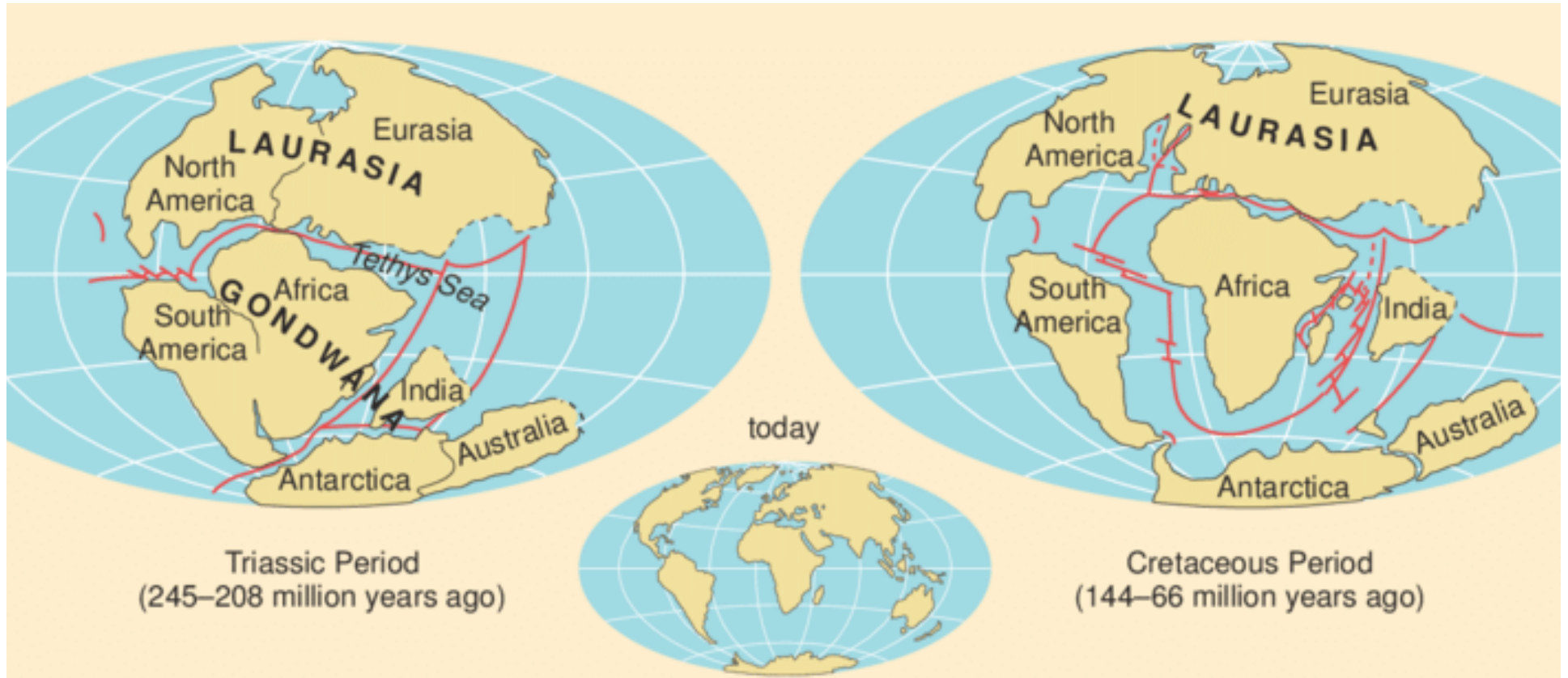
A Summary of Earth's Internal Structure



Why is the Lithosphere Important?

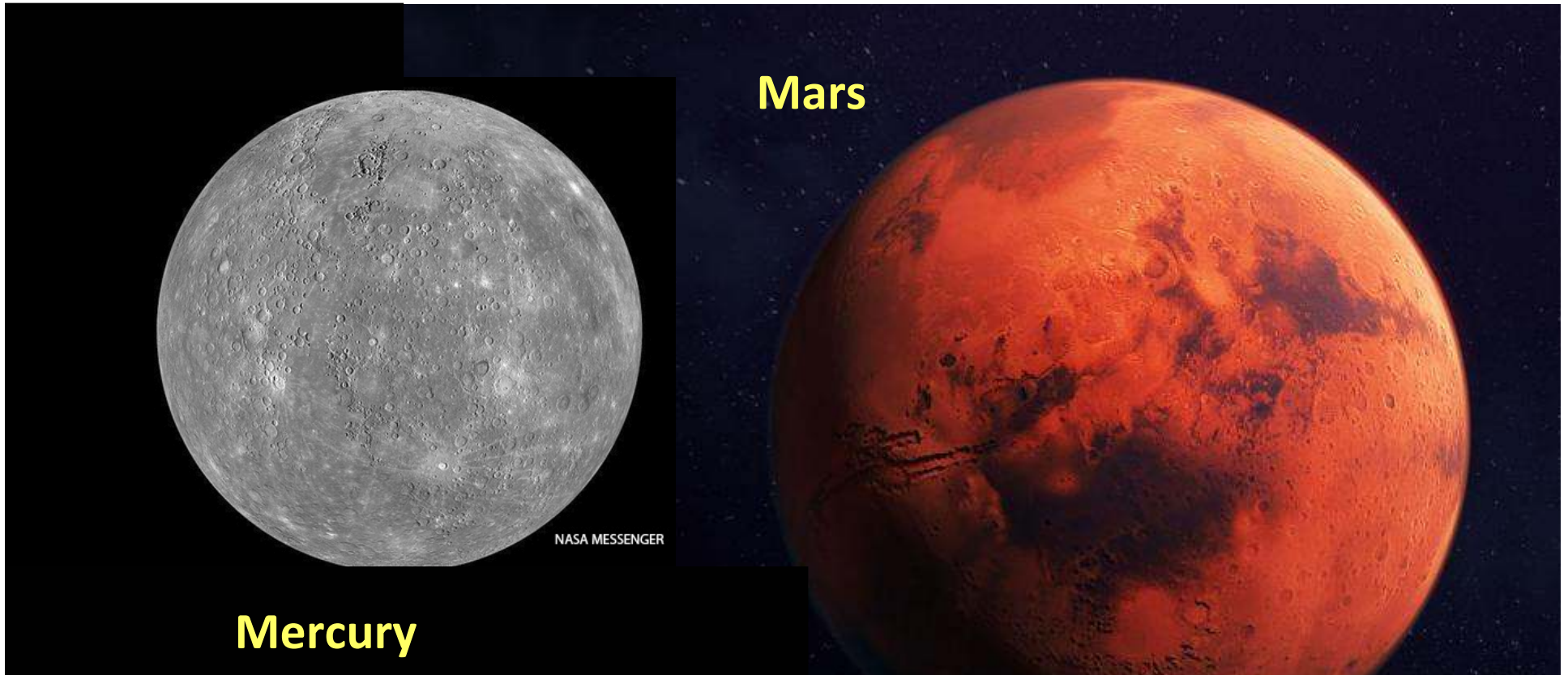
- The outer region of the Earth behaves in the style of a 'brittle solid' – i.e., it generally breaks rather than flows. This includes the crust and part of the mantle. It is the part we are familiar with.....
- The deeper regions of the mantle are hot, under great pressure and (on Earth) contain some water. This allows them to be ductile and they will actually flow on long time scales.
- On Earth, the lithosphere is thin, so heat can easily break through it, and it can break and move in response to underlying flow of the mantle. This allows the motion of tectonic plates, a.k.a Continental Drift! This may not occur elsewhere. For example, the Moon, Mercury and Mars have **thicker** lithospheres.

Continental Drift in Action – Pangaea



About 250 Ma, all the continents were fused together to form the most recent supercontinent (Pangaea). Since then, the Atlantic and Indian Oceans have formed, continents have drifted far apart, and the Pacific Ocean continues to shrink.

Do Other Planets Have Lithospheres?



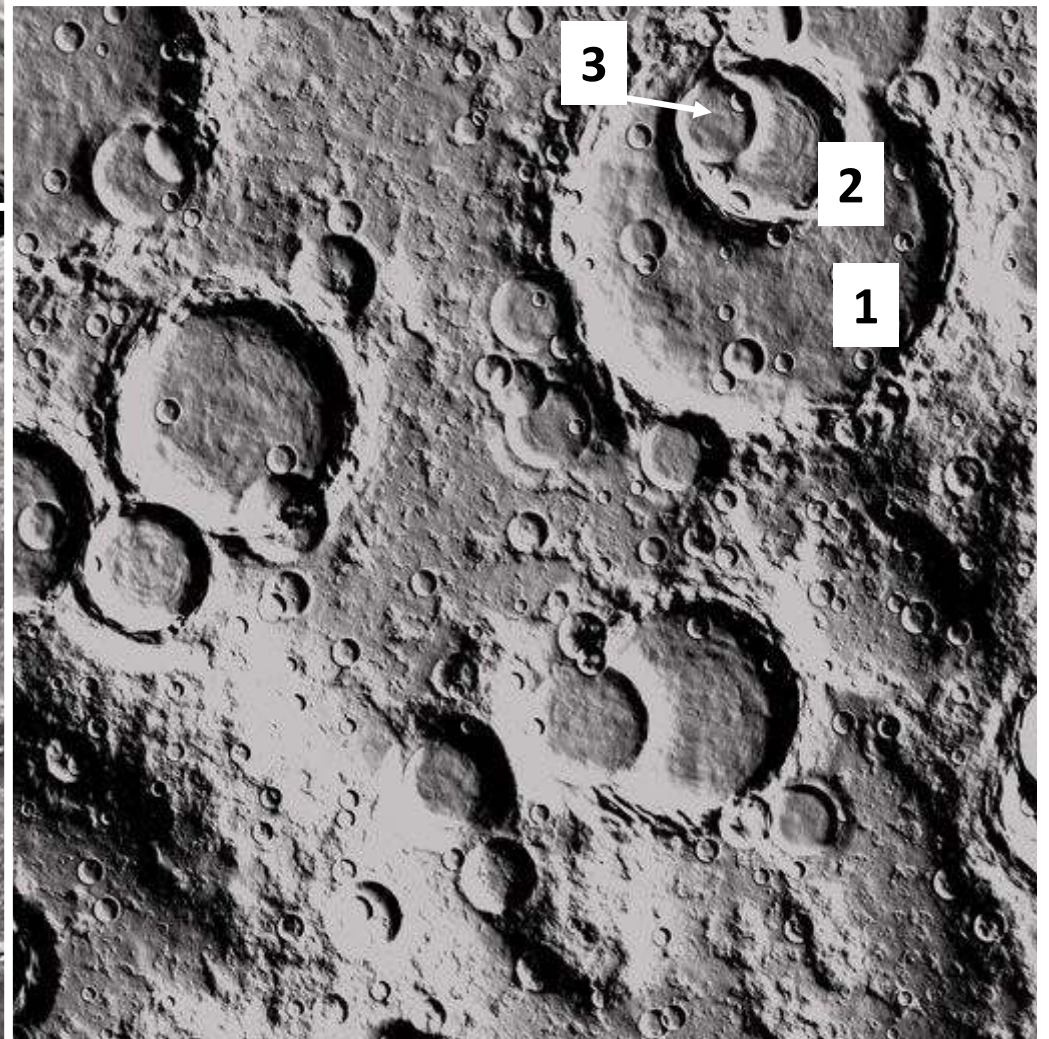
- Yes, they do. We're sure of this. But smaller planets like Mars and Mercury have VERY THICK lithospheres because they are colder inside. These lithospheres are too strong and thick to be mobile like Earth's. These worlds have lost heat. We're not sure about Venus. In theory, it's similar to Earth, but the absence of water is a big problem.

Earth's Moon



- The surfaces of smaller planets are essentially made of impact craters, which can also provide some sense of chronology by superposition.

These surfaces are ancient and unchanging!



Surface Processes on “Solid” Planets and Moons

- The terrestrial planets (and some moons of the giant outer planets) are the only ones with real ‘surfaces’, but processes will vary widely from place to place.
- Dynamic surfaces like Earth’s are one extreme – the other is the battered, cratered surfaces that we see on Mercury and the Moon. The dominant process here is impact cratering on **all** scales. The density of craters provides a general measure of the age of surfaces – fewer craters means a younger formation.
- In the outer planets, materials are familiar but strange. At -140 C , ice behaves like rock – volcanoes erupt water instead of lavas. Solid gases can flow like an ice glacier would do on Earth. So, a cold Jovian moon like Europa has a fairly dynamic, young surface.

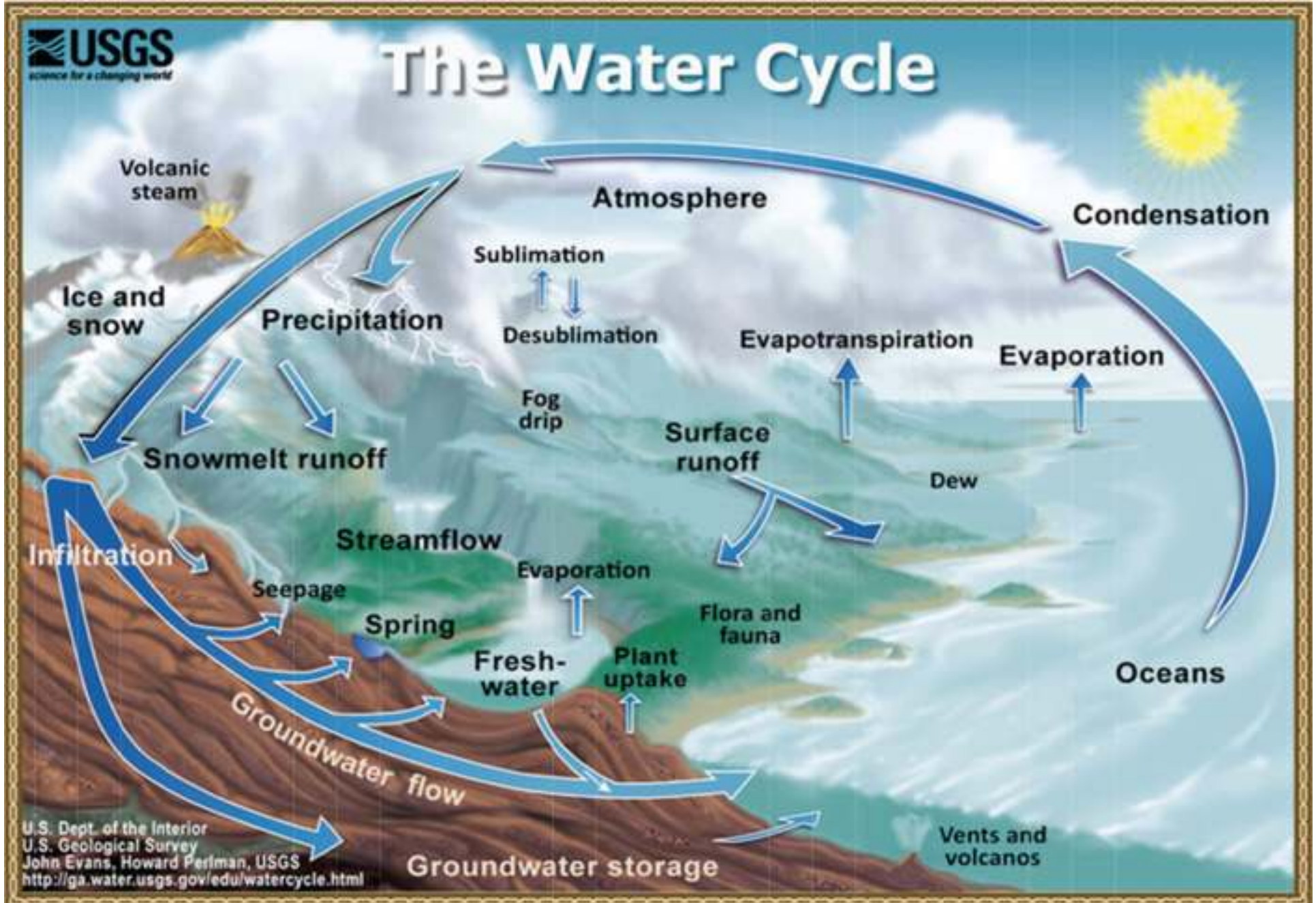
The Earth System Concept – A New Paradigm

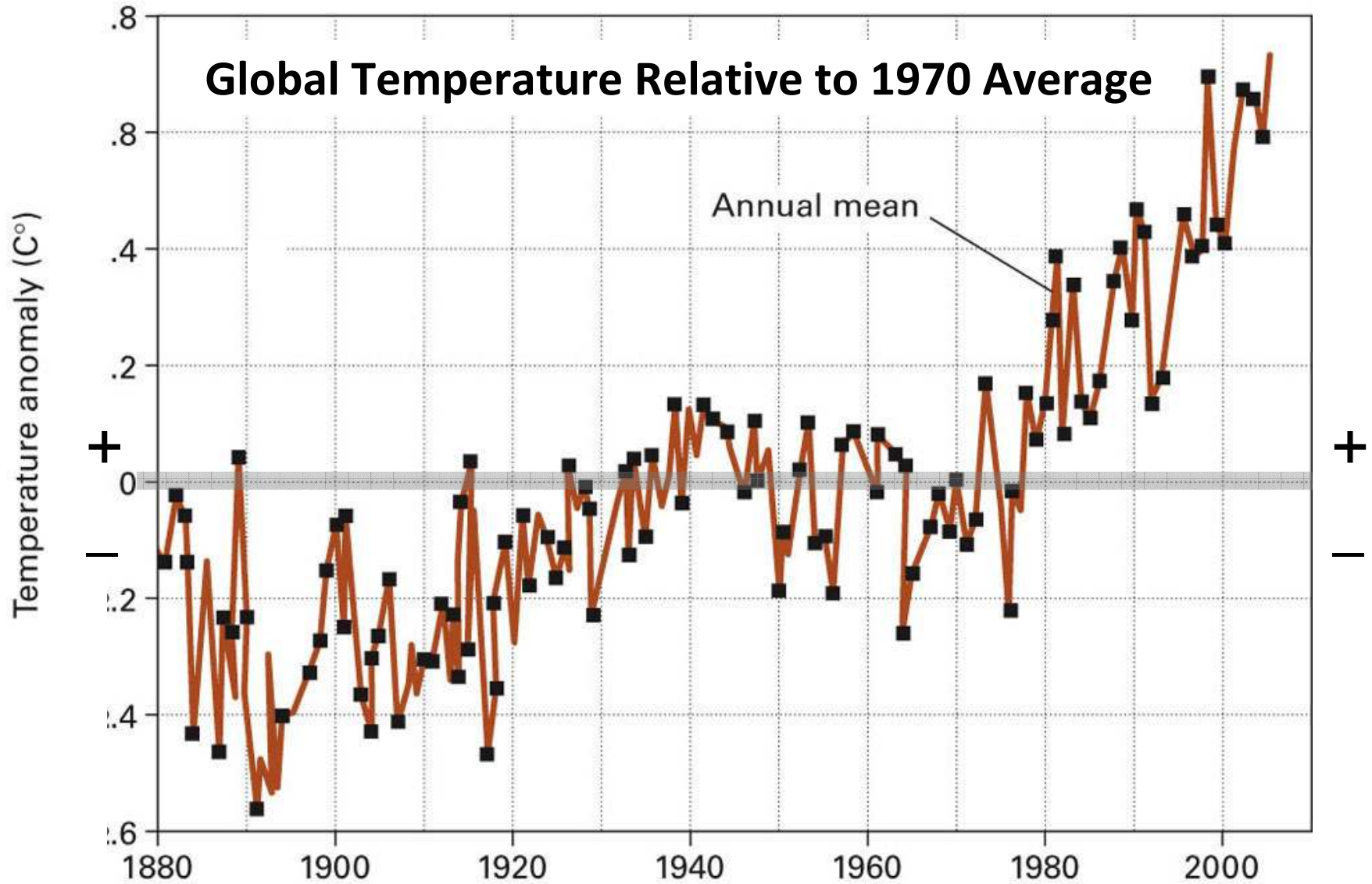


Earth as an Evolving Planetary System

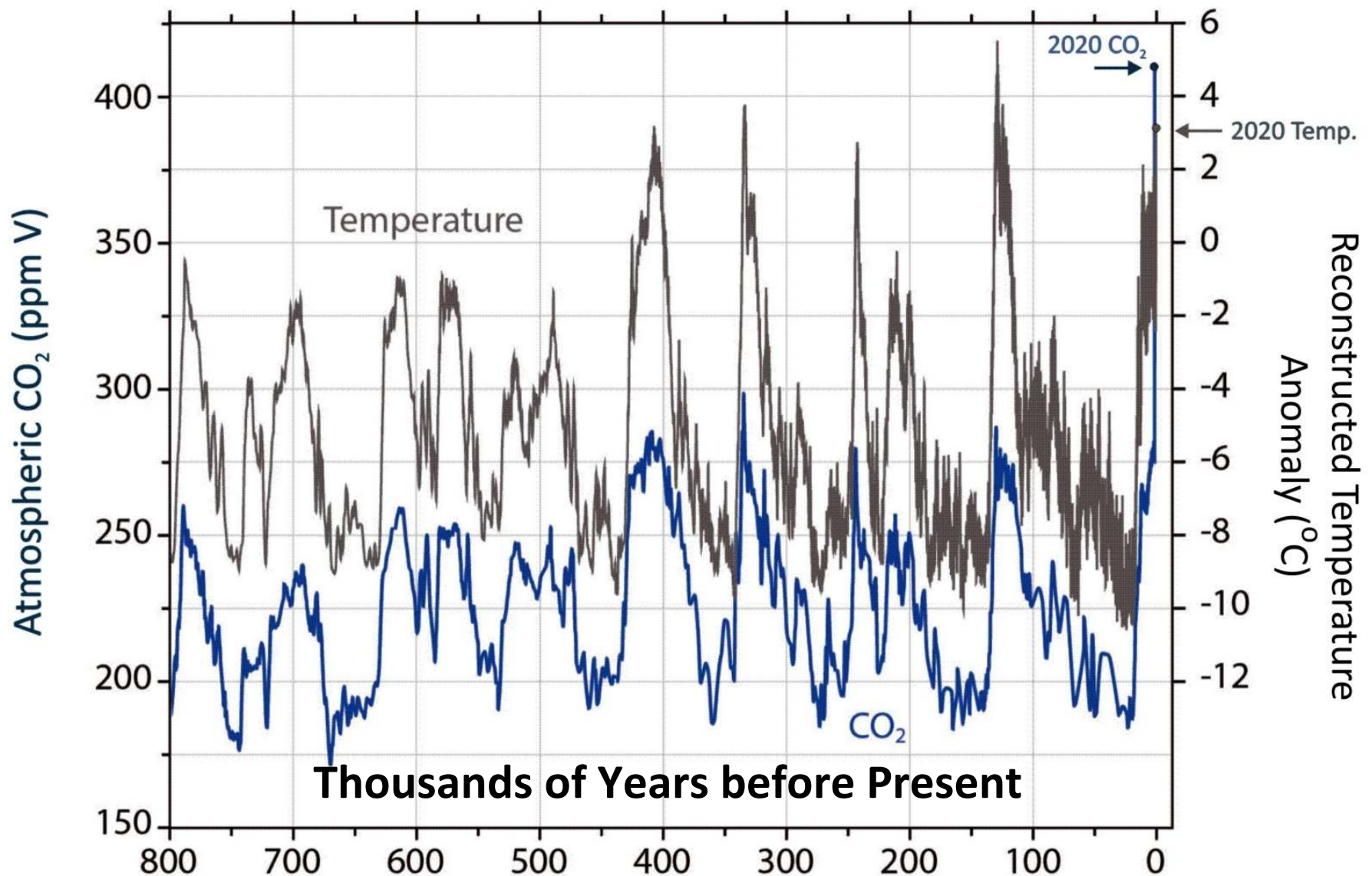
- The complex interactions of biosphere, atmosphere, hydrosphere and lithosphere maintain the surface environment of Earth.
- The biosphere has had a massive impact on the evolutionary path of the entire system, and it likely even influences internal processes.
- This is a delicate balancing act that has worked for > 4 billion years and counting.
- We think of Venus and Mars as distinct 'planetary systems' but these must have evolved on different paths through deep time. There is no reason to assume that what we see now is what once was.

The Water System is a good example of such interactions



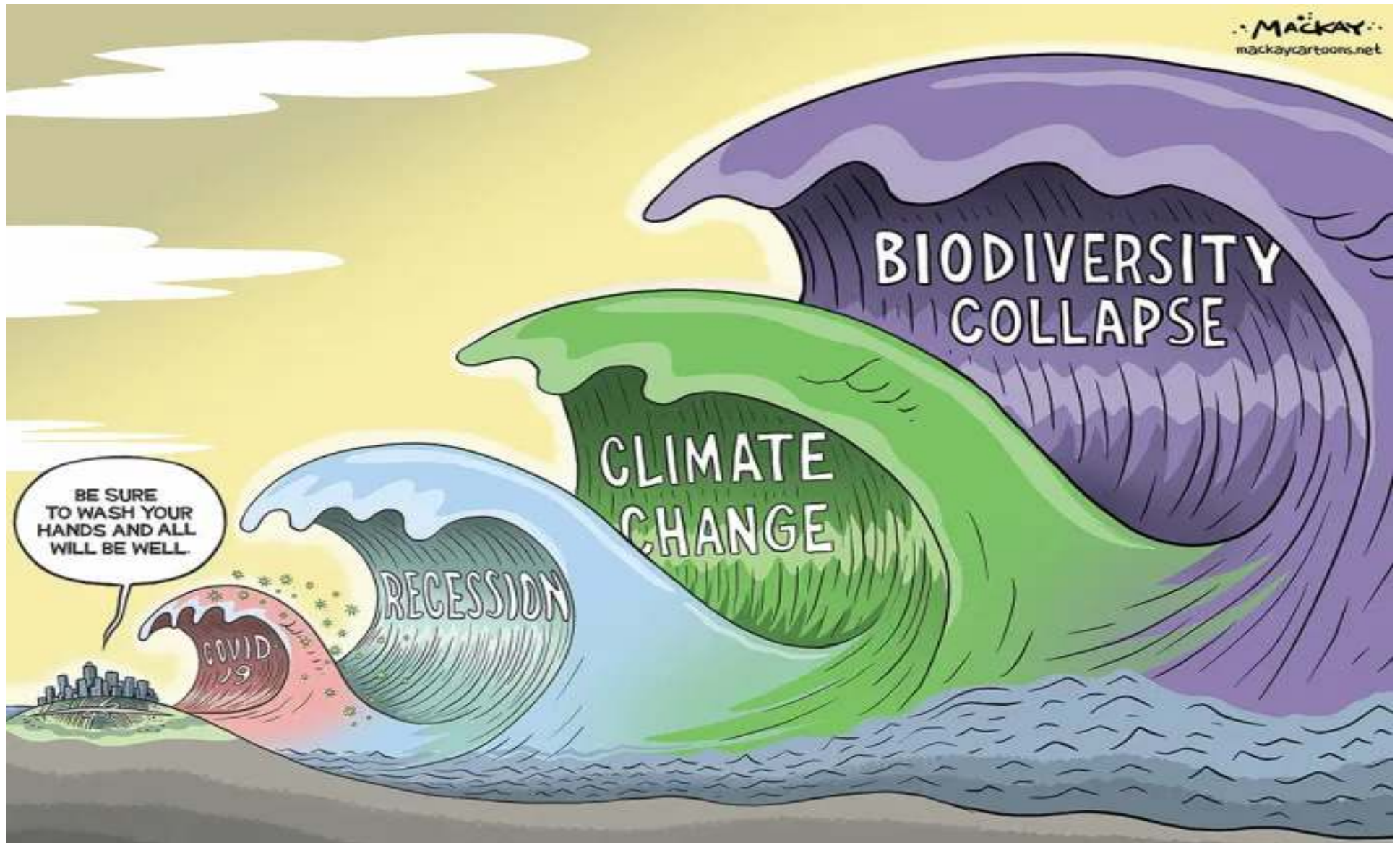


Global Temperature Change – Measurements suggest that there has been a rise of about +0.8 °C in the annual mean temperature from 1960 to the present day. This may not seem like much, but it is of significance. Changes of 2°C or less define the differences between our climate and an ice age.



This graph shows the relationship between global temperatures (based on data from ice cores) and the concentration of CO₂ in the atmosphere (from gas bubbles in the ice). How can we deny that a relationship exists here?

The Earth System is Changing at a Very Rapid Pace.....



Illustrating the potential impact of changes in the biosphere.

What's This?

How does it happen?



One of several topics for the next class.

Summary Slides – Some Key Points from The Class (Module 2 – Part 2)

- Summary slides are not provided for this class as it represents background. Elsewhere, these will provide a summary of the really important ‘take-home’ points from classes. However, don’t assume that this is the limit on what we expect you to learn from the class, because some of the details in individual topics should also be absorbed. It’s a guide to key concepts only.
- This is background Earth Science material and you can find it in many sources. The Seeds and Backman text has some information in Chapter 11 (The Earth) but we will use more of this later. Concept Art pieces on ‘The Active Earth’ and ‘Volcanoes’ are also useful. Introductory Earth Science textbooks provide plenty of material relevant to topics summarized in Part 2 of this module. Older textbooks may not emphasize modern views of the “Earth System”.