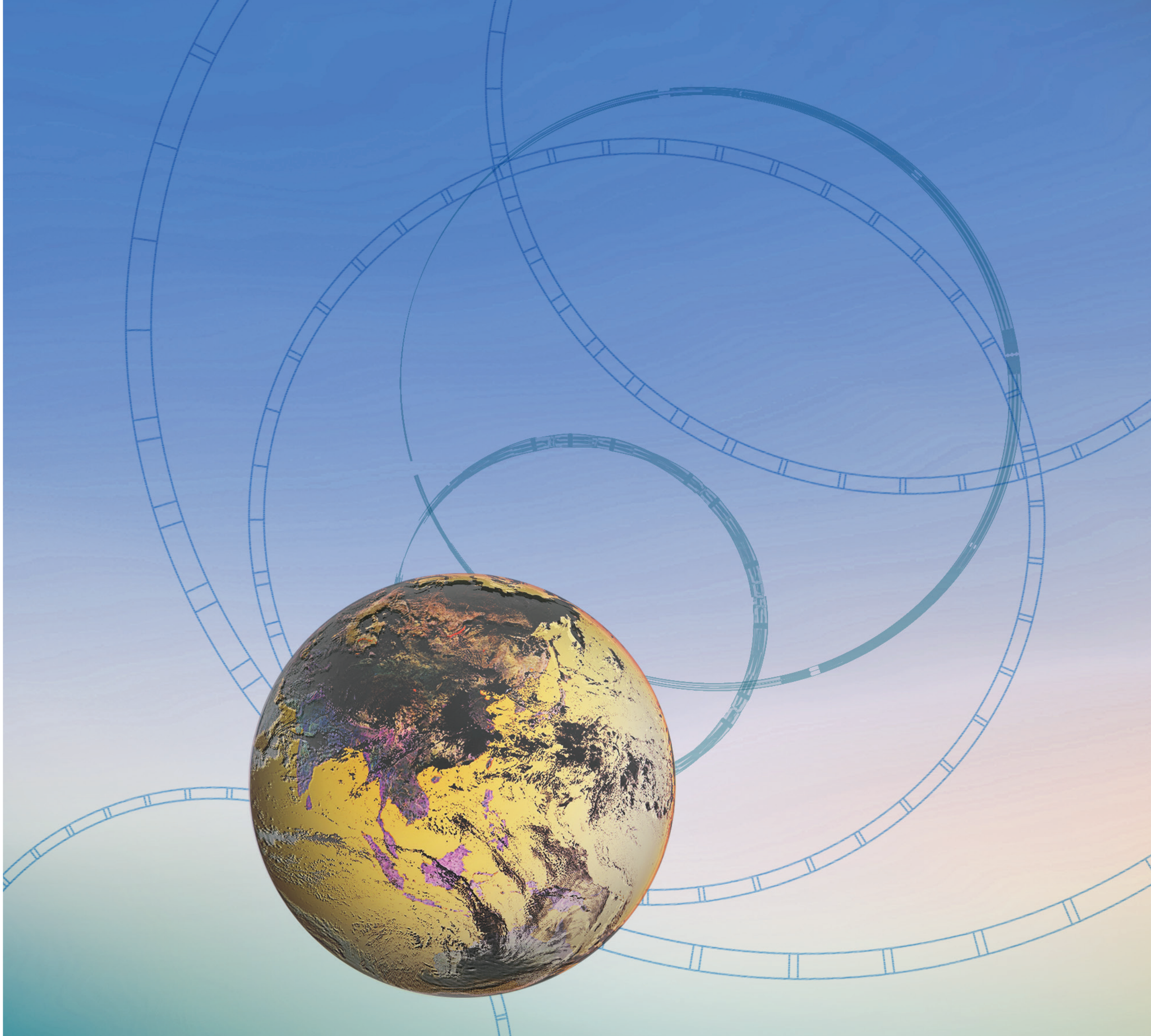

Framework on Geosciences
literacy principles

GEO
SCHOOLS

GEOschools

GEOschools is a European Union project supported by the Lifelong Learning Programme which brings together geoscientists from universities, museums, geoparks, teaching training institutions and educators which can best "translate" geosciences into language and learning opportunities that can be understood by school students.

GEOschools

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GEOschools

"Framework on Geosciences literacy principles"

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Prologue

“Geoschools – Teaching Geosciences in secondary schools”
A project of the European Union within the Lifelong Learning Programme –Comenius

Introduction and general remarks

One permanent, nevertheless burning problem and goal of the international geo-scientific community is: to inform the public about the great value of knowledge of the Earth for the well-being of future generations and to promote science-based solutions for Earth related problems, including ‘Earth science education’.
One of the goals in Earth science education is getting young people excited about our planet Earth.

Thus, the **GEOschools** project is focusing on themes like:
- Bridging the gap between scientific knowledge and school knowledge in geosciences.
- Increasing the knowledge of teachers and Improving the ability of students in valuing and appreciating geosciences.
- Reinforce educational skills of geosciences in European school environment.
- Providing a consortium on research and initiatives on geo-scientific didactics and
- Triggering school education for sustainability (that should lead to a better understanding and ‘wiser’ use of the Earth).

The partners of the Geoschools project were: the University of Athens *(Michael Dermitzakis, Georgia Fermeli)* and the Committee of Geosciences Didactics of the Geological Society of Greece *(Anastasia Koutsouveli)*, Greece; the Universities of Zaragoza *(Guillermo Meléndez)* and Alcalα *(Amelia Calonge)*, Spain; the University of Palermo *(Carolina D’Arpa and Carolina Di Patti)*, Italy; the Naturtejo European & Global Geopark *(Carlos Neto de Carvalho and Joana Rodrigues)*, Portugal and the Krahuletz Museum in Eggenburg *(Fritz Steininger)*, Austria.

The project is divided in five main chapters with 32 products delivered as results of this project. These five chapters are:

- Curriculum comparison research
- Interest research
- An electronic School Geosciences Dictionary (lexicon) containing 25 to 40 terms described in 6 different languages (English, German, Greek, Italian, Portuguese and Spanish) with eight main subjects as there are: (Chrono-) Stratigraphy, Geological Risks; Geomorphology; Hydrology; Mineralogy; Palaeontology; Petrology and Tectonics.
- An electronic Booklet on the: “Framework on Geosciences Literacy Principles”
- Five electronic Teaching modules on specific subjects.
- An interactive multilingual Website (English, German, Greek, Italian, Portuguese and Spanish), all the results of other chapters can be found under the adress: http://geoschools.geol.uoa.gr.
- Besides the website an e-Newsletter was and still will continuosly issued.

Apart from the internal sessions, within the project several scientific papers and presentations have been produced or presented at selected national and international congresses (e.g. EGU, Vienna) by the participants. The envisaged public publication policy is well developed; there are a number of public publications and public events for the geoscientific colleagues and community and to attract the interest of society.

The Booklet: "Framework on Geosciences Literacy Principles":

Treats topics which have been most estimated by students and teachers. It is devided into 15 Chapters with several subchapters. For each chapter you will find keywords, the main text, short main dexterrities / skills and a bibliography.
The following chapters can be found in the booklet besides an interoduction:
The Position of Earth in Cosmos; The Earth; Paleontology; The measure of time; Tectonics; Earth is changing; Natural hazards; Natural resources and mankind; Human activities alter the Earth; Geodiversity, Earth protection and sustainable development; Earth yesterday, today and tomorrow; Geological maps; Brief geologic history of your region; Geology in every daylife.

Fritz F. Steininger
Krahuletz-Museum, Austria

GEOschools

"Framework on Geosciences literacy principles"

Athens – GREECE

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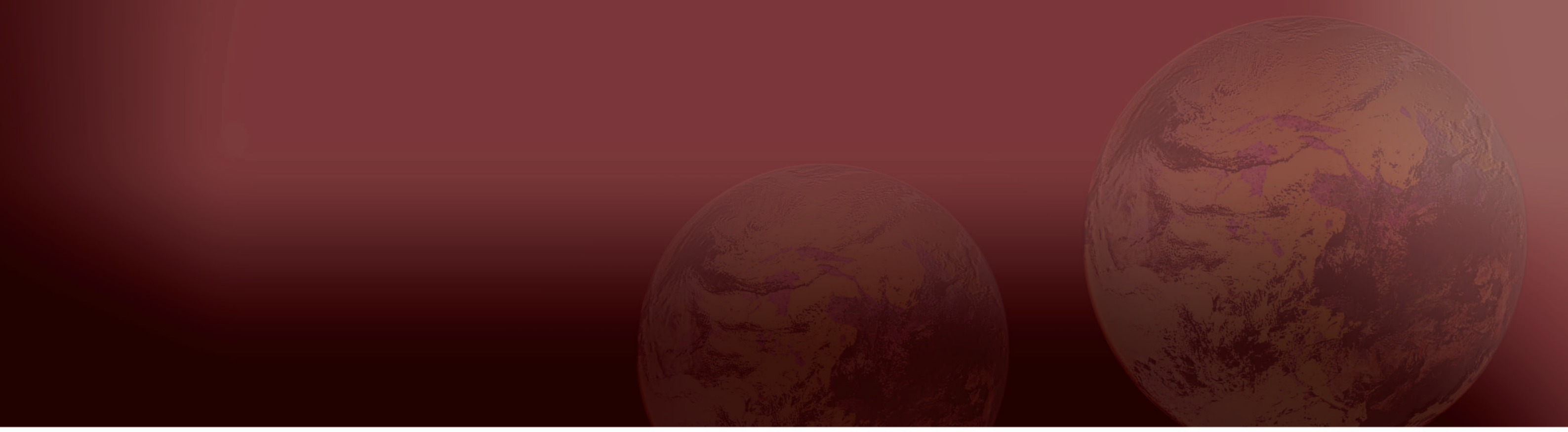

Framework on Geosciences Literacy Principles

Introduction

This guide is the proposal of the GEOschools project for a common framework for Geosciences Literacy at a European level. It is intended to help develop the scientific literacy of European secondary education students.

The booklet is based on a Comparitive Analysis of geoscience curricula in the partner countries (Austria, Greece, Italy, Spain and Portugal), the results of an “Interest Research” survey involving around 1,750 students and 60 teachers in these countries, combined with specific proposals by the project partners. A supporting bibliography is also included.

The GEOschools Literacy framework is summarized in 14 separate chapters, each including a brief description of the main themes of the subject, the intended learning outcomes as well as keywords and a bibliography.

WHY we should teach geosciences in compulsory (primary and lower secondary school) and higher secondary school education

Remarkably, even today, a debate continues on the necessity for geoscience teaching and some curriculum developers still appear uncertain as to whether they should include geosciences within compulsory and higher secondary school education. But even though this is an old question, the answer remains so clear: as global citizens, students need to understand and appreciate the materials and processes that make up their home planet, the Earth, and the way it can affect their lives.

It is also clear, that a good knowledge of geosciences is often lacking by a broader society and there is a gap in understanding between geologists and the public. This is one more reason for developing geosciences within national school curricula.

Geosciences link the biotic (i.e. living) and the abiotic (i.e. non-living) environment and are the key science to understanding the history of the Earth and the evolution of life on it. Evidence for continental drift, the evolution of life, climatic and sea-level changes, as well as volcanism, earthquakes, mountain building, erosion and other landscape changes and processes are recorded in the rocks, minerals, fossils and other geological materials all around us.

Students, as future citizens, need to be taught the basic geoscientific knowledge that they need for their everyday lives. They live on and use the Earth’s resources; they witness the Earth’s dynamic processes and they need to understand about natural hazards and how to protect themselves and their families.

Studying geosciences can also expand a student's interest in the natural phenomena all around them and provides them with opportunities to seek explanations. It engages them at many levels, linking direct practical experience with scientific ideas. They will also understand how the geosciences contribute to the search for the natural resources which are crucial to industry, commerce and improving the quality of human life. Through this process, they will also develop high level observational and interpretative skills, learning to question and discuss the issues that may affect their own lives, society and the future of our planet.

According to many educational researchers, geoscience teaching can develop a wide range of skills, underpinned by some key concepts and processes. These include understanding the Earth as a complex system through the spatial reasoning, direct field observations, analysis of datasets and the historical perspective that make the geosciences a distinctive and empowering curriculum subject:

Geoscientific thinking (retrospective reasoning and the historical approach)

Studying geology requires retrospective reasoning and a historical approach to interpret geological events. Frodeman (1995) observed that the distinctive features of geological reasoning as an interpretive and historical science are that it ...*offers the best model of reasoning for confronting the type of problems we are likely to face in the twenty-first century* and listed examples such as global warming, resource assessments and risk assessments.

In addition, Baker (1996), in attempting to summarise geoscience methodologies, wrote that: *The science of geology has long concerned itself with the real-world natural experience of the planet we inhabit. Its methodology more directly accords with the commonsense reasoning familiar to all human beings. Because its study focuses on the concrete particulars of nature rather than on abstract generalisations, its results are also more attuned to the perceptions that compel people to take action, and to the needs of decision makers who must implement this action*.

A fundamental aspect of the study of Geology is the Geological Record, a body of knowledge often perceived to be separate from the "natural" or biological components of the biosphere. Nevertheless, although approaches to environmental problems and processes may assume that the same basic factors operated in past and present day environments, the methodological process in Geology for the reconstruction of past environments can function differently. Geology may use some uniformitarian principles as a tool for geological interpretation of the past and to reconstruct the History of Earth, the methodological approach of Geology is based on the observation, the empirical testing and the logical interpretation of the Geological Record, including the rocks and fossils (Meléndez *et al.,* 2006; Meléndez *et al.,*2007).

In this context, the classic geological principle that the *"present as a key to the past",* is not always the case, and sometimes the situation is effectively the opposite. Many biological and environmental problems, as well as predictions on the future of climatic change, glaciations, geological risks and catastrophic events – including their consequences for life such as extinctions, ecosystem change and species renewal – can be better understood with a clear knowledge of past processes and events as can be interpreted from the geological record. This apparently opposite approach to Earth processes and their consequences for human populations establishes Geology as a fundamental scientific discipline with an enormous potential to help society face and solve environmental problems, literally *"the past as a key to the present"* (Meléndez *et al.,* 2006; Meléndez *et al.,*2007).

A holistic approach to the Earth system

Geosciences, more than any other branch of science, are concerned with developing a holistic perspective on our planet, including dealing with interactions between land, water, the biosphere and the atmosphere. This perspective means that geoscientists can readily support many interdisciplinary studies and procedures. The complex Earth system is dominated by feedback between these among component parts and the processes that characterise each of them. The interpretation of both positive and negative feedbacks are important for understanding this Earth system (Kastens *et al*., 2009).

Spatial thinking

Spatial thinking in geosciences requires a number of skills such as recognition, description, classification, locational and communicational, followed by mental manipulation and interpretation of what has been observed in order to deduce the properties, processes and prospects of an area (Kastens and Ishikawa, 2006).

Geology is arguably the most visual of the sciences, with visualization taking place at a variety of scales, ranging from the rock outcrop to the regional and back down to the microscopic. Many geologists have the ability to mentally transport themselves rapidly from one scale to another, using observations at one scale to constrain a problem that arose at another scale – and then back again. For instance, observations from the rock outcrop can be used to construct a regional geologic framework, which in turn feeds back and guides what additional features should be looked for at the outcrop (Frodeman, 1996).

The understanding of geological time including of large-scale geological events in time and space

The concept of "deep time", as originally developed by the great Scottish pioneer James Hutton in 18th Century, has fundamentally altered the perception of our place within Earth history. The concept of geological time introduces two key features into geological thinking:

a) The concept of very long periods of time between low-frequency but high-impact events and

b) the potential for such events in the future – as evidenced by their occurrence in the past - which are not possible to prevent or change, but only to prepare for – and hence reduce their impact (if negative) to the natural environment and our society (Kastens *et al.,* 2009).

Geoscientific fieldwork

In order to acquire a good understanding of geology, students need to explore geology *in situ*, acquiring a first-hand experience in the field. Geology is by definition a science which uses an empirical approach to help understand and interpret complex phenomena, which can be remote in time and space. Even for relatively simple geological concepts, it is most effective to demonstrate them within the school grounds, or close to the school, instead of attempting to describe them with words, drawings, models, etc. in a classroom (Meléndez *et al.,* 2006; Meléndez *et al.,* 2007).

Field work is fundamental for the geosciences. It expands students' curiosity about geological phenomena and processes and offers them opportunities to question and discuss after observation, testing and reasoning. Field based learning offers students an opportunity to see the world differently and develop, little by little, a more informed view of their "geoenvironment". Teachers and students collaborate closely and though appropriate guidance (such as mentoring) students (through *observe-test-reasoning*) develop an informed vision and understand of the Earth's complexity.

WHAT European citizens should know (i.e. knowledge) and do (i.e. dexterities/skills) and how they should relate (i.e. behavior/attitudes) to the geosciences

(- At the end of the Primary school
- At the end of Lower secondary school (= i.e. as European citizen)
- At the end of Higher secondary school)

One of the main aims of the GEOschools project is to investigate the interest that secondary school students have in the geosciences content of their courses and the teaching strategies used. In particular, the results of the GEOschools "Interest research" survey have shown that students show a higher interest in those topics which have a potentially higher social impact or profile, such as mass extinctions, dinosaurs, geological hazards and disasters and the origins and evolution of life (including of humans). These results provide an evidence base to justify why curriculum content and teaching strategies can be made more effective through developing such "interest topics", instead of trying to follow an excessively rigid or academic, development of teaching programs.

The challenge that the geosciences face, as a scientific discipline, is how to combine a well-structured and conceptual teaching programme, whilst maintaining links with attractive and interesting topics, i.e. making Geosciences something relevant to daily life (or, in other words, deconstruct the most spectacular and interesting topics, to extract the basic scientific concepts that lie behind). Fundamentally, this is about how to build effective and enjoyable learning thorough good, academic teaching practice, with students able develop a unique set of skills, combining geological knowledge with spatial and visualisation skills.

The 14 chapters of this guide describe what students should know and do, and how they should relate, as European citizens, to the geosciences. To face the challenges of the present and the future, modern citizens should be literate in natural sciences and in the context of the geosciences, be able to:

- Demonstrate a knowledge and understanding of the basic principles, models, laws and terminology of the Geosciences.
- Know how and where to find and access scientifically credible information about the Earth at a national and international level.
- Recognise their responsibilities concerning geodiversity and Earth resources as local, national and international citizens.
- Understand planet Earth as a system.
- Appreciate geodiversity and geoheritage as a key theme within local sustainable development programmes.

- Know how to predict and mitigate the impacts of natural hazards and evaluate the most appropriate measures for changing circumstances.
- Demonstrate an ability to apply geoscientific knowledge in the real world and take appropriate decisions.
- Describe and explain basic geoscientific phenomena and procedures in familiar and unfamiliar contexts.
- Interpret, evaluate and synthesize geoscientific data from a range of sources and in a range of contexts.

HOW to teach geosciences

The challenge and the question that arises next is: How can educators, capitalize on the existing interest of school pupils in the geosciences in order to make geoscience teaching more effective, comprehensive and attractive? And as part of this question, a consideration of the teaching strategies which can transform geoscience knowledge and thinking into school knowledge, whilst demonstrating the links with biotic features of the environment as well as relationships with society and everyday life.

The GEOschools "Interest research" study has also shown that teaching strategies are very important for generating a high level of interest between students and teachers, as these were one of the three most selected topics within the research. In particular, students chose "Experiments", "Simulations" and "Fieldwork" as the most interesting teaching strategies amongst the 17 listed.

The Geosciences' laboratory is the Earth and the field is the place where students should ideally be taught, but with support from active learning in the classroom (including through problem-solving and project activities). Through such teaching strategies, school students can learn how knowledge and understanding in the geosciences are rooted in evidence.

Taking into consideration student preferences, experimentation and simulations could be used in geoscience teaching in order to develop and evaluate explanations and encourage critical and creative thought. Visualizations (static, animated or interactive) are appropriated for teaching about large scale events through time and across geographical space. 3D geological models are especially useful and can provide an aid enabling students to observe, manipulate and interpret geological features and processes. Such models offer students an opportunity to instantly switch from two dimensional to three (or even four, including time) geological views. This multidimensional perspective can be very difficult to demonstrate through more traditional teaching methods, even through field work. Nevertheless, the best and most appropriate way to teach geosciences is the study of a geological feature in situ. Such study can help develop an understanding and awareness of more complex geological processes, even on a global scale.

Educational geotopes are appropriate tools for field work. As geological sites identified for their educational value, and set in both rural and urban environments, then can play an key role in geoscience teaching, often showing the link between ecology and geology, as well as with human activities and generally increasing an awareness for geoconservation (Fermeli and Meléndez, 2011).

Educational geotopes can cover a variety of geological themes and process and in order to succeed in their educational aims, they need to be supported by:

a) Appropriately trained educational specialists, able to engage in developing local environmental education projects, and

b) educationally robust and flexible modules that can be used effectively in a wide variety of settings (Fermeli and Meléndez, 2011).

The future of geosciences in Europe and the world

In recent years, interest in geoscience education has increased, as evidenced by the greater number of sessions dedicated to this theme in educational initiatives and congresses worldwide, as well as in educational and geoscience journals and conference proceedings. At the same time, national and international bodies have developed discussions about learning and teaching and the assessment of practice in the Geosciences at the K-12 stage. Despite this increase in interest, however, much still needs to be done to improve the effectiveness of geoscience education for the future.

Today, a wealth of geoscience knowledge is available, for instance through the internet, and it is crucial for geoscientists to help make this information accessible and understandable, including "investing" in education to provide the next generation of geoscientists that society needs. It is necessary, therefore, to start teaching geosciences in schools and increase the interest of school pupils in the key geoscience concepts, theories and skills that effective global citizens should possess.

In the past, however (and in some countries this continues), geology has often had a minor role in school curricula, which has created serious concerns amongst the geological community. In particular, a substantial reduction in geological content of secondary school curricula can lead to a drop in the number of geology students in universities and hence a lack of geologists in society where they are increasingly needed (Meléndez *et al.,* 2006; Meléndez *et al.,* 2007).

Whilst working within schools is crucial, it is first necessary to convince educational policy makers and communicate effectively with the general public in order to reverse any such trend. In this context, it is important for geoscientists to look outward and avoid becoming isolated from Society and regionalised rather than internationalised. However, inadequate geoscience content in school curricula continues to make an understanding between geologists and the public if not impossible, still very difficult - and hence Society pays a cost through inappropriate decision making concerning geological matters.

Geosciences are playing an increasingly important role in the understanding of the Earth and are becoming more and more multidisciplinary and oriented towards solving the great challenges facing modern society. In this context, we should consider the Earth as a system in which geoscience research and teaching needs to be prepared to deal with much greater complexity, hence linking and integrating with the other natural sciences: physics, chemistry, and biology. Such an approach could be a valuable tool for creating a greater social and political interest in and concern for the geosciences, as well raising the interest and enthusiasm of secondary school teachers and students about the Earth.

Education is the key for a sustainable future and it is well known that the future lies in the hands of children and the future of geosciences lies in their hands too.

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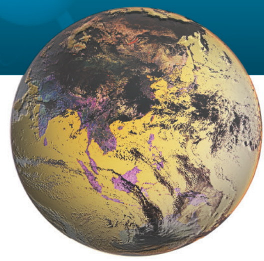

CHAPTER 1

The Position of the Earth in the Cosmos

Key words: Cosmos / Universe, Galaxies, Stars, Planets, Moons, Asteroids, Meteorites.

Introduction

When we watch all those stars on the sky, watch a meteorite falling or see the sun glowing we often ask ourselves: How far is all of this from planet Earth, and how old are all these objects and how did they all come into existence? Most of the answers below tell us distances and dimensions we can barely imagine – and many are still not precisely known. Nevertheless, we now know quite a lot about what we call the Universe – or the Cosmos – and you will find some very brief answers to these questions.

1.1. The age of Universe

The Universe began with the famous “Big Bang”. According to recent studies using the “Hubble Outer Space Telescope”, this happened some 13.75 Billion years ago.

1.2. The development of the Universe

With the “Big Bang”, the time, space, light and matter of our Universe was born - Einstein‘s theory of relativity providing a mathematical model for how all these facets are related. The question: “*What was before?”,* is simply not relevant, because before the “Big Bang” we have no information at all. The Universe itself has no centre, it expands as everything in it moves away from everything else. At the moment the diameter of the Universe has been calculated as 12 billion light years, each of these light years representing around 9.5 to 10.12 billion kilometres), The Universe, however, might be larger still, and it cannot be proved that it is indeed not infinite.

Another philosophical question is whether the Universe will at some time collapse. However, as gravitational forces may not be strong enough to reverse the continuous expansion of the Universe, it is probably unlikely that this will happen.

1.3. Galaxies

Matter is very unequally distributed across the Universe: There is only 1 atom in every 5 m^3 on average in the Universe, with 1,000,000 atoms per 5 m^3 in galaxies. For comparison, the air we breathe has around 130,000,000,000,000,000,000,000,000 atoms per 5 m^3 . We also find concentrations of matter in stars, and these stars are usually organised into larger structures, such as "Star systems" (such as our own "Solar System") and "Galaxies". Galaxies have an age of about 12 billion years. This concentration is due to the gravitation attraction between all matter.

The time between the origins of the Universe and the origins of the first galaxies is around 1 to 2 billion years: This time is called the "Dark-Age" of the Universe, because there were no stars to "illuminate" it. Galaxies have different shapes, most known are "Spiral-Galaxies" and "Elliptical Galaxies", however, there are also "Irregular Galaxies" which have no centre. Galaxies are not equally distributed in Universe; many form clusters, the largest known cluster comprising more than one thousand galaxies. The closest cluster to us is known as the "Virgo-Cluster", and our spiral-galaxy - the "Galaxis" or "Milky-Way" is on the edge of this cluster, as is the "Andromeda-Galaxy", which contains about 100 billions of stars and can sometimes be seen with the naked eye in the night sky. Our star, the Sun, and our solar-system, are part of the "Milky-Way" galaxy, situated towards its outer rim, the Sun being the centre of our planetary system. The distance to the "Andromeda-Galaxy" is about 2,000,000 light years, but the nearest star to us – excepting our own – is around 3 light years away and our sun-system has a diameter of only 0.002 light years. Our solar-system has an age of about 4.6 billion years.

1.4. The "Galaxis" or "Milky-Way"

Galaxis is a greek word which means 'Milky-Way'- the blurred ribbon of light which can be seen on a clear night crossing the sky and which represents a side view of part of our galaxy, made up of millions of distant stars. The Galaxis is a flat disc with a diameter of about 100,000 light years and around 16,000 to 30,000 light years deep. It contains around 100 billion stars, organised within spiral "arms" galaxy linking to its centre. The stars in their spiral arms rotate around the centre of the Galaxis every 100,000 years to 200 million years. At the outer rim of one of the spiral arms of the Galaxis, about 30,000 light years from its centre, is our home with our star the Sun and its orbiting planets. Above and below the disc of the Galaxis there are numerous spheres of star clusters, and our galaxy itself forms part of "Virgo-Galaxies-Cluster".

1.5. Stars, Planets, Moons, Comets, Asteroids (or Planetoids) and Meteorits

A **star** is a ball of gas, composed typically of 99% hydrogen and helium, held together by its own gravity. Stars originate from gas clouds, mainly composed of hydrogen, which collapse under their own gravity, forming "Globuls" - discrete dust and gas clouds. These "Globuls" then contract over around 10 to 15 million years to form stars. The surface temperatures of stars can range between 3,000 to 20,000 degrees centigrade, whilst within larger stars, temperatures can reach millions of degrees. Stars are often organised as double stars or within star clusters and can be classified in "Supergiants", "Bright Giants", "Giants", "Dwarfs" and "White dwarfs". Some have planets like our Sun. People have long perceived patterns in the stars visible from the Earth, imaginatively linking these patterns to myth and legend, such as the "signs of the zodiac".

Planets are very closely linked to their stars and originated at the same time. Some have remained primarily as gas-balls, but others collapsed under their own gravity and develop into rocky planets. All planets have a nearly rounded form and orbit around their star in broadly circular – or slightly elliptical - orbits. In our planetary system, the "Solar-System", we find the "Inner Planets" - the rocky planets Mercury, Venus, Earth and Mars - and the "Outer Planets", the "Gas-Giants" Jupiter, Saturn, Uranus and Neptune. The inner and outer planets are separated by the asteroid-belt, a band of rocky and icy debris, left over from the formation of the solar-system. Planets may have rocky moons like our own planet's Moon, or moons made up by frozen water and gases. Planets within our solar system are called "Planets", whereas outside of our solar system they are called "Exoplanets" or "Exosolar Planets".

Comets are masses of dust and ice, sometimes with a rocky core, with a diameter of a few kilometres and a characteristic orbit within our solar system. When a comet passes near to the Sun a portion of this frozen material evaporates, forming a glowing head called the coma. Because of the solar wind – particles emitted by the Sun which stream into space - some comets also form a tail pointing away from the Sun, that can extend for millions of kilometres. Within the ice that makes up comets, such as the famous Halley's Comet, there can be up to 25% organic molecules. Some scientists have speculated that such molecules may have contributed to the origins of life on Earth, but others strongly disagree.

Asteroids (or Planetoids) are rocky left-overs from the origins of our solar system. Ninety-nine percent of them are found in the asteroid-belt, the largest ones, however, are concentrated in the "Kuiper-belt", which lies outside of the orbit of Neptune. Around 507,271 asteroids have so-far been identified within the asteroid-belt and they orbit the sun like the planets. Some, however, have distinctly exocentric orbits, meaning that they may cross the orbits of planets, such as our own, and sometimes even collide with the planets. The results of these collisions can be quite devastating and it is believed that an asteroid hit the Earth 65 million years ago causing mass extinctions. Asteroids are classified by spectral analysis according to their chemical composition and their surface characteristics.

Meteorites are mainly fragments of asteroids, less than 10 km in diameter. We know today, however, that some very rare meteorites originated from the Moon and from the planet Mars, and were broken off during a collision with another meteorite or asteroid, before being attracted to Earth by our own planet's gravity. Meteorites and meteoritic material is continuously hitting the Earth. Most of these are "Rocky-Meteroites" (also known as "Chondrites"), and they are as old as our solar system; "Achondrites", however, also fall and these are largely composed of iron and nickel. Meteorites are captured by the gravity of the Earth, and due to friction with the atmosphere they heat up and glow - usually disintegrating and disappearing in a trail of light. These 'Shooting-Stars' are usually all we see of a meteorite, as most vaporise in the Earth's atmosphere before anything can reach the ground.

1.6. The geological activity away from planet Earth

Geological activity on other bodies in our solar system is recorded on the surface of the rocky planets and moons and even on the surface of some of the frozen ice moons. However, most of these bodies are nowhere near as active as Planet Earth.
For instance Mars, although half of the size of the Earth, probably still has a core of iron and a

mantel of melted rocks and a crust. But it is “cold planet”, apparently with nothing like the Plate Tectonics activity we see on Earth. Mars can divided into two hemispheres, like the Earth. The southern hemisphere is covered with impact craters, the northern is a rolling hill country; the border between the two being the “Janus-Head”, a steep feature around 6 km in height. Impact craters on Mars reach diameters of around 2,300 km and a depth of 7 km. Volcanos, such as the great “Olympus Mons”, can reach a height of 24 km and a diameter of 500 km. Canyons such as the “Valles Marinensis”, can be 4,000 km long, 600 km wide and 7 km deep. We know quite a lot about Mars, as its surface has been photographed in detail by orbiting probes, and even sampled directly by rover-vehicles landed on its surface.

In contrast, although “Europa” - a moon of planet Jupiter - has a core of iron and rock, it is covered by a 100 km thick layer of water, the uppermost 30 km of which is frozen. Around 3 km below the surface there are liquid “salt lakes”, but below the ice layer there are 70 km of liquid water.

Intended learning outcomes:

- Understand the origins and age of the Universe.
- Understand the organisation of galaxies and stars.
- What is the “Milky Way”?
- Read about our solar-system and its planets.
- What are and where do we find asteroids and meteorites?

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CHAPTER 2

The Earth

Key words: Earth, Moon, oceanic crust, continental crust, mantle, core, lithosphere, asthenosphere, rock, mineral, rock cycle, igneous rock, magma, metamorphic rock, sedimentary rock, soil, soil profile, pedogenetic processes, parent material.

Introduction

The Earth is a rocky planet, the only one in the Solar System where life is known to have developed. The Earth, whose age has been estimated at 4.6 billion years, has a natural satellite, the Moon. The solid Earth's structure consists of three concentric shells of different composition and thickness: the Crust, Mantel and the Core. The Crust is the outermost of these layers and the most dynamic part of the planet – and on which all live exists. The Crust is made up by rocks, which are formed by aggregates of one or more minerals.

Different processes give rise to a wide variety of rocks and minerals. The alteration of rocks and minerals by weathering, chemical agents or living organisms leads to the formation of soil, which is essential for the development of most terrestrial life on our planet.

2.1. The age of the Earth

Planet Earth originated, along with the other planets of our Solar System, within a nebula - a mass of gas and a dust - around 4.6 billion years ago. This date has been determined through several different lines of evidence. The oldest rocks which have been found so far on Earth have been dated using radiometric dating methods (see Chapter 4.3) to around 3.8 to 3.9 billion years ago. Some of these very early rocks are sedimentary, and incorporate minerals derived from even older rocks, which have been dated themselves as as old as 4.1 to 4.2 billion years - just as the primordial crust of the early Earth was solidifying. We also have evidence, however, of materials formed right at the beginning of the solar system, at the same time as the Earth, and these exist as lumps of rocks drifting in space which occasional fall back to Earth as meteorites (see Chapter 1). These rocks have also been dated, and they provide a date for the first formation of a rocky planet Earth, some 4,550 million years ago.

2.2. The evolution of the Earth

The Earth, unlike the other planets, underwent significant further evolution, not just as plate tectonic processes were established and its surface largely recycled over 1000s of millions of years, but also due to the development of life. During its initial accretion as a result of solid ma-

terials colliding together in the early solar system (including as meteorites), the Earth's surface was largely molten because of the effects of these impacts of (see Chapter 1) and extreme volcanism. A chemical differentiation produced the concentric shells of increasing density which now represent the crust, mantle and core and cooling allowed the crust to solidify. Gasses emitted by the volcanoes produced a primitive atmosphere with almost no oxygen. These gasses included water vapour and carbon dioxide, some of which had been brought by asteroids and comets. As the surface of the Earth cooled, water vapour condensed into clouds, which were raining off and formed the oceans. From at least 3.5 billion years ago, photosynthesis by primitive organisms – mainly cyanobacteria - produced oxygen and began to change the chemical composition of the original atmosphere – state the composition of the original atmosphere. As a result more and more sophisticated life forms could evolve.
So we can say that the Earth has three solid shells and on top of them we find the hydrospere, biosphere and atmosphere.

2.3. Internal Structure of Earth (Crust – Mantle – Core)

The structure of the Earth is made up by three concentric shells, each with a characteristic composition and physical properties. From the surface inwards they are: the Crust, with a thickness of few 10s of km at the most; the Mantle, the intermediate part, which extends to 2,890 km in depth; and the Core, with an outer fluid part and an inner solid part to 6,360 km depth (i.e. the centre of the Earth). The Crust and Mantle are made up of rocks rich in silicates (i.e. containing silicon and oxygen); the core, however, is made up of a nickel-iron alloy. These different shells are separated by discontinuities – the Mohorovičić, Gutenberg and Lehmann, respectively, which can be identified by seismic waves.

2.4. More on the internal structure of the Earth

As well as chemically, it is possible to distinguish the internal structure of the Earth through its physical properties, as demonstrated by the way seismic waves pass through the various layers. Thus, from the outside to the inner core we can distinguish: lithosphere, asthenosphere, mesosphere, plus and outer and an inner core. The lithosphere is formed by the crust and part of the upper mantle. The asthenosphere is a band of the mantle between 70 and 250 km depth, which is partly formed of molten material and is hence less rigid then the lithosphere. The mesosphere is a solid portion of the mantle located between the asthenosphere and the outer core. The latter, unlike the layers immediate above and below, is liquid, as the inner core is solid.

2.5. Continental and oceanic crust

Continental and oceanic crust are profoundly different in thickness, composition, age and origin. Oceanic crust forms the "floor" of the oceans. It has an average thickness of around 6-7 km, an age no more than 180 million years and a more uniform composition consisting of silica-poor basalts and gabbros covered by thin sediments. Continental crust underlies the continents and their continuation below sea level. It has an average thickness of 40 km, but can reach 70 km beneath mountain ranges. The composition of continental crust is more heterogeneous, with a predominance of rocks with a general silica-rich composition similar to granite. The age of continental crust occasionally approaches 4 billion years.

2.6. The Moon

The Moon is the Earth's only natural satellite and a rocky body with a spherical shape. It is one of the largest satellites in the Solar System and, unlike the Earth, is devoid of a hydrosphere and atmosphere. Its radius is about 1/4 of the Earth, the mass is 1/81 and the force of gravity on the Moon 1/6 of that on the Earth. The gravitational pull of the Moon affects the Earth, most significant by creating tidal cycles. Although the Moon may appear bright in a night sky, this is due only to the reflection of sunlight. The Moon has complex and simultaneous movements (i.e. rotation and revolution) and the Sun, Moon and Earth are periodically aligned. When the Moon is between the Earth and the Sun it is known as a solar eclipse, when the Earth is between the Sun and the Moon it is known as a Lunar eclipse.

2.7. The forming of minerals

Minerals are solid substances, typically inorganic and characterized by a defined chemical composition. In a mineral, atoms are arranged in an ordered structure or lattice known as a crystalline structure. The genesis of minerals can take place in a number of ways, typically through processes of crystallization from a liquid. This can be through the cooling and crystallization of a molten magma, precipitation from a hot aqueous solution during igneous or metamorphic processes, evaporation of aqueous solutions (including from seawater), sublimation of a gas directly into a solid and transformation in an essentially solid state from one material to another due to the effects of temperature or pressure (especially at depth). There is also the group of organic minerals that can be formed by the decomposition or restructuring of organic molecules derived from plants and animals after burial in sediments.

2.8. How to test and describe a mineral

Minerals can be studied and classified on the basis of their chemical composition, crystalline structure and related physical properties. The main properties which can be tested are: density, hardness, cleavage along planes of crystal weakness, lustre (i.e. "sheen"), colour, fracture, malleability, ductility, fluorescence and light refraction angle. According to chemical composition, minerals can be divided into eight main families or groups. Among these, the most widespread and numerous in the Earth's crust are silicates. They consist of mainly of oxygen linked to silica in combination with metals such as iron, magnesium, aluminum or potassium. Other important mineral families are carbonates, formed by carbon linked to oxygen usually in combination with calcium, but sometimes including magnesium; oxides, containing oxygen combined with metal elements; sulphides, metals combined with sulphur and sulphates, where oxygen is also combined with sulphur and linked to a metal (most commonly calcium in a rock-building sense).

2.9. How minerals make rocks

A rock is a solid aggregate of one or more minerals. According to their origins, crustal rocks are divided into three categories that are the result of three different formation processes: igneous, sedimentary and metamorphic rocks. Igneous (or magmatic) rocks derive from the solidification of magma which is produced by melting materials deep in the crust or even in the mantle. Sedimentary rocks are derived from the deposition and accumulation of inorganic and organic materials on the Earth's surface. These rocks are often stratified and may contain fossils. Metamorphic rocks are formed from pre-existing rocks, which have been subjected to high temperatures and pressures which can lead to their structure and composition being profoundly changed.

2.10. Different types of rocks

Igneous rocks are classified into "intrusive" or "extrusive" (or volcanic) rocks depending on whether the cooling and crystallization of the magma is, respectively, at depth or on the Earth surface. Sedimentary rocks can be divided into three main groups according to the origins of the material of which they are formed: clastic rocks are formed by the accumulation of fragments of other rocks; biogenic sedimentary rocks, result from the accumulation of fossil remains of organisms, such as shells or organic structures (such as woody material that can form coal); chemical sedimentary rocks are derived from precipitation of salts from supersaturated waters. Metamorphic rocks can be formed in two main ways: by "Contact" metamorphism, caused by temperature changes that affect the rock surrounding a hot magma rising through the crust and through "Regional" metamorphism, caused by increases in temperature and pressure within igneous or sedimentary rocks – or even pre-existing metamorphic rocks – buried deep in the Earth's crust, for instance as a result of continental collision during plate tectonics.

2.11. Examples of characteristic rocks

Examples of igneous rocks are granite (see 2.16), obsidian and basalt. Obsidians are extrusive rocks formed by the very rapid cooling of lavas – for instance on flowing into the sea – to form a volcanic "glass". Basalts, are the most common extrusive rocks, and form the ocean floor; they are formed by the cooling of magmas rich in minerals containing iron, magnesium and calcium. Granite, however, is an intrusive igneous rock formed from the crystallization of a rock rich in silica, its large crystals being the result of slow cooling several kilometers underground. Sedimentary rocks, include a very wide range of types, including clastic rocks which vary from fine grained mudrocks, to coarser sandstones to pebbly conglomerates. There are also "carbonates", which include limestones formed from the remains of shells and plankton, and evaporites, such as salt and gypsum, formed as salty lakes or enclosed seas evaporate. Among the most widespread metamorphic rocks are finely splitting slates, layered schists and banded gneisses, which often represent the results of, respectively, low, medium and high temperatures and pressures on muddy sedimentary rocks.

2.12. The Rock cycle

Igneous, sedimentary and metamorphic processes are not independent of each other but can be linked within a single Rock Cycle, in which the materials of the Earth's crust are continuously rearranged and recycled, a process driven by plate tectonics. A first stage creates igneous rocks through intrusive or volcanic processes. When such rocks reach the Earth's surface, weathering and other sedimentary processes cause their breakdown, followed by transport and accumulation of the resulting debris to make sedimentary rocks. As these sedimentary rocks are buried deep within the Earth's crust, the increase in temperature and pressure can cause them to recrystallize to form metamorphic rocks – and ultimately if they are buried deep enough, they can melt to form new igneous rocks. The latter can rise to the surface, become exposed, and so the whole process begins again.

2.13. Soil types and buildup

Soil forms from the outermost surface of the Earth's crust where it is exposed to the atmosphere (i.e. on land). It is the interface between the lithosphere, hydrosphere and biosphere. Soil typically consists of rock particles and organic material (such as humus) with different proportions depending on the soil type. Water content is also important. Most soils can be divided in layers known as "horizons". The most commonly identifiable horizons are a surface organic-rich horizon, a horizon of leaching below (in which muddy or sandy components are predominant) and a lower "illuviation" horizon, where very fine clay particles accumulate. Soils originate when surface rocks or other deposits are broken up by weathering, including both physical breakdown (for instance through freezing), as well by chemical processes or by living organisms. These are known as pedogenetic processes and they can be very slow, with the formation of only one cm of soil every hundred to a thousand years on average.

The main factors that influence the formation of soil are the composition of the original rock (known as the "parent material"), the climate, living organisms and the geomorphology of the surrounding area. As a result of the numerous factors involved, a very wide variety of different soils can be formed. For example in tropical regions, where the soil organisms and bacteria can be very active, organic material can be rapidly decomposed meaning that the humus layer can be very thin or absent. In contrast, in temperate regions where the microbial decomposition is reduced, the uppermost humus layer of the soil can be more developed and the soil may be more fertile. Soils can be very variable in thickness, from a few cm to several metres, depending on these factors. Soil grows from its uppermost level down into the rock, the parent material.

2.14. Soil zones and life in and on the soil

A well-developed soil with horizons differing in composition and physical properties, has a characteristic vertical "soil profile". It is an invaluable resource because it supports and provides nutrients to plants and other autotrophic organisms. Plants, in turn, as well as producing organic molecules, assimilate other essential elements from the soil making them available to animals, including ourselves. Living organisms such as bacteria, fungi, plants and animals facilitate the decomposition of organic remains, contributing to soil fertility and promoting the mixing and aeration of the soil itself.

2.15. Soil uses by humans

The history of the use of soils by humans is focused on activities related to survival, economic development and characteristics of the soil itself, and people have used the soil for many purposes. Over time, however, the pressure on this resource has intensified, often without taking into account the diversity of soils, their function and their potential - as well as their vulnerability.

The transformation from a “natural” use of the soil, such as forests and wetlands, into a “semi-natural” use such as agriculture, or even an “artificial” use, such as for construction and industry, has led to the loss of fertile soils. Further negative impacts, include land fragmentation, biodiversity loss, changes in the hydrological cycle and changes in microclimate. Little is often done to counter or mitigate this situation, in large part due to a lack of awareness within society – at all levels from decision makers downwards – about the importance of soil, and why it is necessary to safeguard its functions.

2.16. How sand, granite or marble is formed

Sand is a clastic sedimentary rock composed of individual sedimentary grains ranging from 2 mm to 1/16 mm in size. It is formed as a result of fragmentation, transportation and deposition of fragments produced as a result of chemical alteration and physical disintegration of a pre-existing rock. Granite is an intrusive igneous rock rich in quartz and is formed as a result of the slow cooling of a magma within the Earth’s crust, typically at depths between 1.5 and 50 km. Marble is a metamorphic rock composed mainly of calcium carbonate ($CaCO3$). It is formed by the metamorphic action of temperature and pressure on sedimentary limestone or dolomite, which causes complete recrystallization into a welded mass of calcium carbonate crystals (i.e. of the mineral calcite or rarely dolomite), destroying original sedimentary structures such as fossils and sedimentary layering in the process.

Intended learning outcomes:

- Knowing the age of the Earth.
- Understanding the main stages that led to the formation of the Earth.
- Describing the internal structure of the Earth.
- Describing the characteristics of the Moon and the minor bodies of the Solar System.
- Explaining the differences between minerals and rocks.
- Describing the processes of mineral formation.
- Being able to identify the most important features of the minerals.
- Describing the processes of rocks formation.
- Describing the rock cycle.
- Defining what soil is, how it forms and what are its characteristics.

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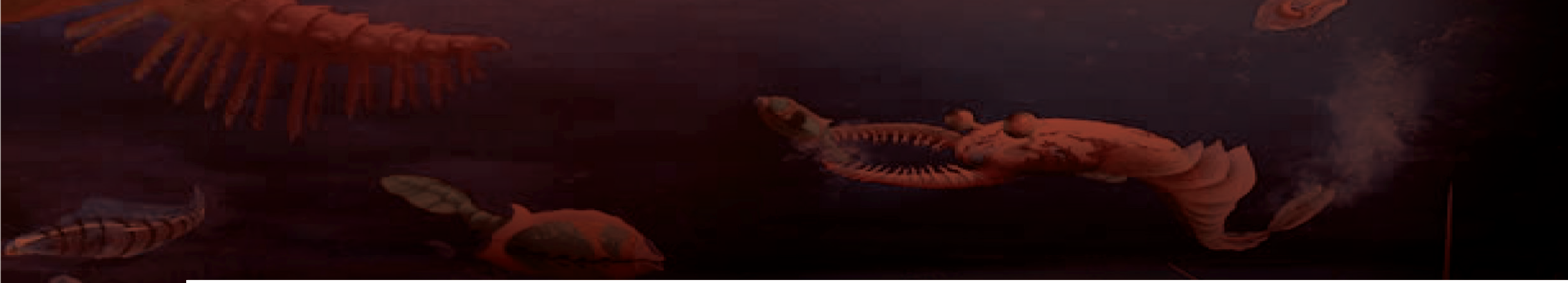

CHAPTER 3

Palaeontology

Key words: Fossil record, palaeontology, evolution, life on Earth, extinctions, fossil groups.

Introduction

Palaeontology is the study of the fossil record through geological time. It is the study of life on Earth and the evolution of all biological groups from their origins until the present day – and it also includes studies of the relationship between life and its physical environment through time. The study of palaeontology, therefore, requires a detailed knowledge of and training in both biology and geology. Palaeontology aims to explain the origins of life on Earth, subsequent evolutionary development and changes, as well as the extinction of biological groups.

The concept of evolution has a major importance for education far beyond its origins as a scientific theory. Evolution underpins the process of biological change and the origins and radiation of the different living organisms that have made up the biosphere through time. Just as the world around us is in a permanent state of change, so is the biosphere and the biological groups, that inhabit the planet's surface. But even a quick look at different types of organisms reveals striking similarities between different species, and palaeontologists and biologists have demonstrated that such similarities can be explained by evolutionary relationships, which can be proved through studying the fossil record.

Although a separate scientific discipline, Palaeontology still has close relationships with other geological disciplines, especially stratigraphy (including biostratigraphy), sedimentology, geodynamics, paleogeography and geochemistry, as well as with most aspects of classical and modern biology, from taxonomy, evolutionary studies, population genetics, to the geographic distribution of species (i.e. biogeography) and to ecology and interrelationships with environments. However, despite these close links with other Earth and life sciences, Palaeontology is has its own unique body of knowledge, subjects of study and research methods. This is the fossil record, and the fossil record, together with the sedimentological and stratigraphical record, is a part of the geological record. Sedimentology is a key facet of palaeontological study as fossils – with very, very few exceptions - are preserved in sedimentary rocks. Although fossils are often referred to as "*petrified organisms*", this can be misleading, as most represent only the remains of hard inorganic skeletons and shells, or evidence of biological activity such as burrows and footprints. Only a few very rare specimens represent the whole organism, such as insects in amber and mammoths preserved in permafrost. The processes that preserve these remains are called "*fossilisation*" and the branch of Palaeontology that studies fossilisation is called *taphonomy*.

3.1. When and how Life appeared on Earth

Fossils document the origins and evolution of life on Earth over thousands of millions of years. As they are preserved in sedimentary rocks formed at the same time as the organisms they record were living, they can provide information on the age of these rocks - this is the branch of palaeontology known as biostratigraphy - and on the ecology, environments, climate and geography of past periods of Earth history.

The oldest fossils identified so far, date from around 3,500 million years, but chemical evidence of life processes goes back perhaps 100 million years further. These very early fossils represent bacteria, including photosynthetic cyanobacteria (often incorrect know as blue-green *algae*), the simplest unicellular living organisms. During most of this early existence of the Earth, life consisted only of unicellular organisms, initially simple bacteria which are '*prokaryotes'* without a central nucleus regulating the cell, and then, from around 2,500 million years ago, '*eukaryotes*' with a true differentiated nucleus. With the latter the main biological and metabolic processes of life today originated, including sexual reproduction which enabled the sharing of genetic material between individuals, hence providing the opportunity for much greater evolutionary development. This was manifested as the first evidence of multicellular organisms some 1,200 million years followed by whole communities of strange leaf and jelly-fish like animals around 650 million years ago. The first animals with shells and skeletons appeared around 550 million years ago, but it was not until only around 90,000 years ago that our own species, *Homo sapiens* appeared and the history of human civilization is limited to the last 7 to 6 thousand years or so, a time that represents only 0.004% of Earth history.

3.2. Evolution of life

Biodiversity, i.e. the diversity of life forms and biological groups as we see it today, is the result of 1000s of millions of years of evolutionary processes. Why know much less about biodiversity in the past, however, as the fossil record only provides brief glimpses. The variety of fundamentally different 'designs' for animals (i.e. 'body plans') in the early Palaeozoic Era of geological time (from around 550 million years) was higher than today, although at species level, overall diversity is certainly higher now.

The early evolution of life caused dramatic changes in the composition of Earth's atmosphere. Significant free oxygen was not present in the atmosphere until oxygen-producing cells - such as photosynthetic cyanobacteria - evolved. The diversity of groups preserved as fossils in the fossil record has allowed paleontologists to infer and partly reconstruct the different patterns of evolution that followed through time. Fossil evidence indicates that a wide variety of life forms have existed in the past and that most of these forms have become extinct. Human existence, however, is still very, very brief compared to the span of geological time and the time range of most groups of organisms recorded in the fossil record.

Evolution is the organic process of change affecting all the living organisms that make up the biosphere and leads to changes in numbers and distinct types of organisms through geological time. Both external (environmental) and internal (genetic) factors are responsible for these changes, but the main evidence which shows us that biological groups have changed through time are the fossils that we find. When fossil organisms are compared to living forms, we can see that many things have changed. Some fossils show us organisms that once lived on Earth but have disappeared, such as trilobites, dinosaurs or ammonites; and others reveal the ancestors of life forms that are familiar today, such as clam shells, primitive mammals and early birds.

3.3. How fossils are formed

Fossils are the remains or traces of activity of ancient biological organisms, including animals and plants, and the traces or impressions of living things from past geological ages, or the traces of their activities, such as burrows and footprints. The process of fossilisation is a dynamic, complex process in which the remains of the organism or trace fossil are modified by external, environmental factors (e.g. microorganisms, sedimentary and geochemical processes, etc.) which affect and interact with it from the very moment of death to the stage at which it is recorded as a fossil entity and stored in the fossil record. Fossils have been found in every continent on Earth wherever sedimentary materials, such as clay, silt and sand, have been transported and deposited in sedimentary basins by processes such as water and wind, and hence the remains produced by living organisms can be buried and preserved.

Although it is generally only the hard, skeletal parts of organisms that are most easily fossilised, the reality is that many organic structures produced by animals, plants and other organisms can become fossils under certain conditions. Normally, in oxygen-containing surface environments, organic material will be rapidly destroyed by decay and in oxygen-rich environments, such as shallow marine platform environments, it is most likely only mineralized skeletal remains, will survive – but sometimes even then only as internal molds, where the shell has been filled with sediment or mineral before being dissolved by waters in the sediment after burial. However, in certain oxygen-deficient environments, the organic material of the soft parts can be partly replaced by minerals such as pyrite and phosphate compounds before it rots away entirely.

Fossils of hard mineral parts (such as bones or teeth) were formed as follows:

- The living organism produces remains and/or evidence of its activity during life. These remains can concentrated on or within a sedimentary substrate (i.e. 'accumulation') or can be moved across or within the substrate - which can involve significant lateral transport, including by sedimentary processes such as currents, or with minimal lateral transport (i.e. 'resedimentation'). During these *biostratinomical processes*, the remains will change their original properties (e.g. by disarticulation of skeletons or bivalve shells, fragmentation, infill, encrusting, concentration or dispersion, dissolution, etc.
- Eventually, if the remains are not completely destroyed, they can be buried by sediment accumulating around them.
- Over time, more and more sediment covers the remains and they are subjected to *diagenetic* processes, as the soft sediment is converted into a geological deposit, such as mudrock, sandstone or limestone. These processes can include, dissolution, compaction, early mineralization of any surviving organic material or cementation of cavities or infill of the remains.
- These processes can take place over a relatively long period of time, before the sediments is fully lithified (i.e. 'hardened') to form a rock. For instance the cavities in bone or wood can be filled with minerals deposit from water in the sediment, becoming harder and more rock-like as a result. The process of fossilisation, therefore, typically involves the dissolving and replacement of the original minerals in the remains by other minerals, including where the calcium carbonate shells of some molluscs are replaced by a different and more stable form of calcium carbonate (i.e. calcite replacing the original aragonite mineral of the shell).
- All these *diagenetic* processes can eventually lead to the formation of fossil remains, which can be mineralised skeletal parts (i.e. *permineralised bone*), a cemented infilling of a shell (i.e. *internal mold*) the imprint of the remains in the substrate (an *external mold*) or the consolidated (i.e. *lithified*) impression of the organism's burrow or footprint (i.e. *trace fossils*). Much, much more rarely, however, the mineral can replace and hence preserve certain soft parts, such as calcium phosphate replacing muscle fibres.

- The fossil has the same shape as the original object, but is chemically now a rock, even if some of its original mineral shell or skeleton may remain.

Fossils are generally, but not only, found in sedimentary rocks, as volcanic eruptions can also engulf living organisms in ash or lava. For instance, there are many records of trees preserved in volcanic deposits, although often only as a burnt-out tube. However, there are famous records of animals also being preserved in volcanic deposits, such as some of the Roman populations of Pompeii and Herculanium, preserved in ash flows produced by the eruption of the volcano Vesuvius.

3.4. Some examples of 'Precambrian', Paleozoic, Mesozoic and Cenozoic fossils

Geological history can be reconstructed by observing sequences of rock types and fossils at different localities and then correlating them where their fossil content matches, to build up a composite story of the history of life on Earth. The characteristics of rocks indicate the processes by which they formed and the environments in which these processes took place. Fossils preserved in these rocks provide information about past environmental conditions. Geologists have divided Earth history into time units based upon this fossil record, a discipline of Palaeontology known as *biostratigraphy*:

- The **Precambrian** is a general term for all of Earth history, prior to the first abundant appearance of shelly fossils at the base of the Cambrian Period of geological time around 550 million years ago. Relatively few fossils are found in Precambrian rocks because of this lack of hard bones and shells. The most typical fossils are banded limestone structures formed by prokaryotic cyanobacteria known as *stromatolites.* These are known from the mid Precambrian, i.e. the Archaean Eon. Under certain conditions, microscopic remains of the actual bacterial cells are also preserved, as well as single celled eukaryotes in the later Precambrian (i.e. the Proterozoic Eon). At the end of the Proterozoic, during the period known as Ediacaran, a remarkable biota, including strange leaf-like and jellyfish-like soft-bodied multicellular organisms developed. These were first found at Charnwood Forest in central England in Europe, but are better known from Ediacara in Australia. The apparent lack of any anatomical differentiation has led some palaeontologists, to propose that these animals represent an entirely separate branch of living organisms, the '*Vendobionta'* which apparently did not survive the end of the Precambrian.
- The **Palaeozoic Era** begins with the appearance of organisms with hard parts around 550 million years ago. Marine invertebrates became abundant and diverse throughout the seas of the world at the beginning of this Era, followed very soon by the first vertebrates, primitive fish. Towards the middle of the Palaeozoic, land plants evolved, and the colonisation of land began. Many of our fossil fuels, especially coal, were formed of the remains of the earliest equatorial forests from the late Palaeozoic, which were made up of giant, tree-sized primitive plants such as club mosses, horsetails, and ferns. Invertebrates soon followed the plants onto land, and insects evolved – and vertebrates followed the insects and the first amphibians evolved, eventually giving rise to the first reptiles.
- Into the **Mesozoic**, many new species evolved following a mass extinction at the end of the Palaeozoic. Seed-bearing plants colonised dryer areas of the land, initially dominated by Gymnosperms, including cycads and early conifers, but in the later Mesozoic, the first flowering plants (i.e. Angiosperms) evolved (but did not become dominant until the later Cenozoic Era). Dinosaurs evolved and dominated the land, and giant marine reptiles occupied the seas and others took to the air. The first mammals appeared, but remained small and insignificant whilst dinosaurs ruled the Earth, and the first birds appeared. The extinction of the dinosaurs at the end of the Mesozoic, however, allowed terrestrial and marine mammals to diversify in the following Cenozoic Era.

- The **Cenozoic** is the era of modern life, with mammals, birds and flowering plants very rapidly coming to dominate terrestrial ecosystems and the seas being dominated by the groups of animals which are still very familiar today, such as advanced fish and molluscs.

3.5. Why species go extinct

Extinction is the process in which groups of organisms (ultimately species) die out. If the rate of reproduction of any species is less than the death rate over time, extinction will inevitably result. Extinction is a natural result of evolution and natural selection. Species go extinct when they are unable to adapt to changes in the environment or compete effectively with other organisms. Most extinctions - perhaps up to 95 per cent of all extinctions - occur as a 'background' over time. These extinctions are not caused by major catastrophes or dramatic climactic changes, but by small changes in climate or habitat, depleted resources and competition.

3.6. About mass extinctions

A mass extinction is a relatively sudden or rapid, global decrease in the diversity of life. Mass extinctions have occurred periodically throughout the existence of life on Earth. To qualify as a mass extinction, such events or phases must:

- Occur all over the world.
- A large number of species must go extinct.
- Many types of species, not necessarily closely related, must go extinct.
- The extinctions should be clustered over a short period of geological time (note that a few million years is very short in terms of geological time).

The five largest mass extinctions in Earth's history occurred during:

- The late Ordovician Period (around 438 million years ago): 100 families extinct, including more than half of all bryozoan and brachiopod species.
- The late Devonian Period (around 360 million years ago): 30% of animal families extinct.
- At the end of the Permian Period (around 245 million years ago): 50% of all animal families, including 95% of all marine species (including trilobites) and many terrestrial plants die out.
- The late Triassic (around 208 million years ago): 35% of all animal families die out, including many terrestrial animals.
- At the Cretaceous-'Tertiary' (i.e. Palaeogene Period) boundary (around 65 million years ago): About half of all recorded species died out, including the dinosaurs, pterosaurs, plesiosaurs, mosasaurs, ammonites, many families of fish, clams, snails, sponges, sea urchins, and even plankton.

Besides these major extinction events, many minor extinctions phases have occurred through Earth's history. Today, within the Holocene Epoch of the Quaternary Period, a large number of extinctions are occurring – could this be another mass extinction?

3.7. Why dinosaurs disappeared

As with all other living organisms, many dinosaur species perished as background extinctions throughout the Mesozoic Era. However, despite remaining the dominant animals on land during the Cretaceous Period, the entire group became extinct in the global mass extinction event that took place at the end of that period around 65 million years ago.

Intended learning outcomes:

- Understand, the scope of the science of Palaeontology.
- Describe the process of fossilisation.
- Understand the different types of information contained in the fossil record.
- Understand how fossils can be interpreted by comparison with modern organisms.
- Distinguish the different types of study of the fossil record that are possible.
- Know the main fossil groups from the Precambrian, Palaeozoic, Mesozoic and Cenozoic and how fossils can, therefore, be used to date rocks.
- Know about the five mass extinctions.

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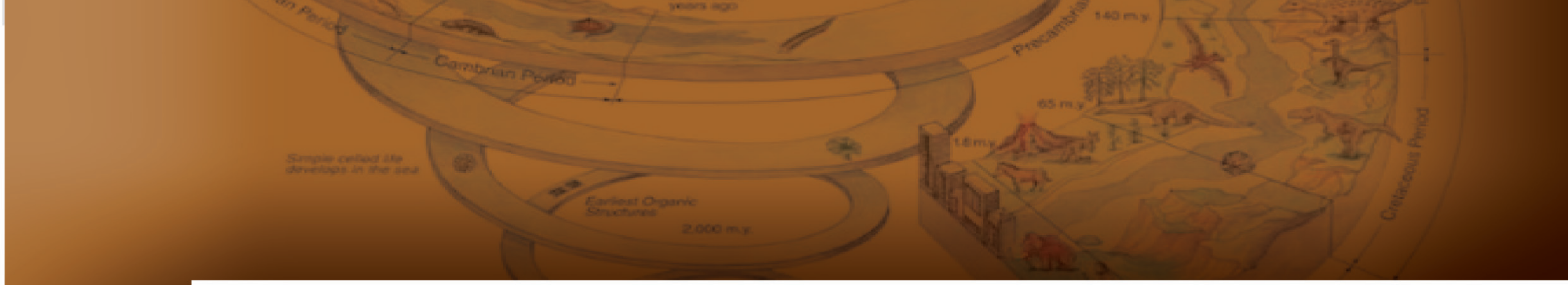

CHAPTER 4

The measure of time

Key words: Chronostratigraphy, radiometric dating, biostratigraphy.

Introduction

For easily communicating the age of the rocks and other geological materials we find on planet Earth, we need a stable and internationally agreed sequence of named time units, into which the history of the planet can be divided. Such a sequence is known as Chronostratigraphic time scale (see 4.1) and the definitive version of this is the 'International Stratigraphic Chart' produced by the International Subcommission on Stratigraphy and available at www.stratigraphy.org. All the rocks making up the crust of planet Earth – and the processes that created them or affected them after their initial formation – can be related to this time scale and their relative age stated. Correlation with this timescale is carried out using a range of methods including lithostratigraphy, biostratigraphy, isotope stratigraphy, radiometric dating, magnetostratigraphy, event stratigraphy, cyclostratigraphy, seismostratigraphy, sequence stratigraphy, tectonostratigraphy and tephrochronology (see also 4.2 and 4.3).

4.1. What is the Chronostratigraphic Time Table

The chronostratigraphic time scale divides the time which has passed since the first formation of the Earth, some 4.6 billion years ago, into a series of named time units, based on geologic rock-sections (for all but the oldest rocks). The basic chronostratigraphic unit is the 'Stage'. Stages are grouped together into Series, series into systems (which are equivalent to 'periods'), systems in erathems and erathems in Eonothems.

The lower boundary of a chronostratigraphic unit is defined at a fixed level in a rock sequence, at a 'type locality'. This sequence forms a standard reference for the unit and the locality is known as a '**G**lobal **S**tratigraphic **S**ection and **P**oint', or GSSP. The top of the unit is equivalent to the base of the next, younger chronostratigraphic unit, correlated from its own GSSP. For instance the Zanclian and Piacenzian stages make up the Pliocene Series, the Pliocene and the Miocene series together comprise the Neogene System; the Neogene together with the Paleogene and Quarternary systems make up the Cenozoic Erathem and the Cenozoic with the Paleozoic and the Mesozoic erathems comprises the Phanerozoic Eonothem.

4.2. How determine the age of strata by studying fossils

We can use various correlation methods to establish the relative age of rocks around the world and correlate them with the international time scale. These include matching rocks of a distinctive type (or 'lithology') or similar fossil contents, or by using actual dates in millions of years derived from the study of certain radioactive isotopes of certain elements that they might contain. 'Biostratigraphy' is a correlation method using fossils and is used to date most sedimentary rocks. If we find fossils in a rock, we usually know from studies elsewhere their age relative to the chronostratigraphic time scale, and hence we can demonstrate that our samples must belong to the same named chronostratigraphic units, such as a system or stage (or sometimes an even finer time division, known as a 'chronozone' or 'biozone').

Biozones are relative time divisions recognized solely by their fossil content. The difference between successive biozones is often a consequence of evolutionary changes in the selected 'indicator' fossil, each successive biozone being equivalent to the time interval through which a named species lived. Sometimes, however, changes in ecology can mean that biozones can be recognized by changes in the relative abundance of certain species through time or even different assemblages of fossil species.

4.3. How determine the age of the Earth by using radiometric methods

Radiometric dating uses the fact that radioactive isotopes of different elements (known as "parent-isotopes"), decay to form a specific "daughter isotopes" at a fixed rate known as the elements 'half-life'. The parent isotope is incorporated into the crystal structure of a mineral in an igneous or metamorphic rock when it forms, after which it decays to its "daughter" isotope at a constant rate. By analyzing the relative amounts of both parent and daughter isotopes in a sample of the rock or mineral, for instance using masspectrometry, it is possible to calculate the age of the sample using the known half-life for the decay of the parent to the daughter isotope. This date is quoted in years, for instance millions of years, but as there may be experimental errors, this date is known as a 'radiometric date', rather than an 'absolute date', as it may change slightly as analytical techniques improve.

Intended learning outcomes:

- Know how rocks and geological events may be dated, both relatively and in terms of radiometric dating.
- Know what is meant by an "a geological time scale".
- Understand the principles of stratigraphy.
- Interpret a Chronostratigraphic timescale.
- Know the age of the rocks of your region.

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CHAPTER 5

Tectonics

Key words: Continental drift, plate tectonics, subduction, obduction, Mid Ocean Ridges, Atlantic Ocean, Mediterranean Sea, continents, folds, faults, earthquakes, volcanoes.

Introduction

At the beginning of the 20th Century the geologist Alfred Wegener proposed the theory of continental drift to explain the dynamics of the Earth's surface, based mainly on an observation of the apparent fit of the coasts of some continents - in particular western Africa and eastern South America. He believed then that continental drift was driven by both external factors (e.g. the rotation of Earth) and internal factors (e.g. geothermal energy).
His theory was highly controversial but after the second World War, the combination of oceanographic (i.e. sea bed structure) and palaeomagnetic and radiometric dating studies of sea floor rocks – as well as studies on palaeogeography and fossils – gave a much more comprehensive evidence for continental drift. This ultimately led to the establishment of plate tectonics as a theoretical framework for Earth Sciences in the late 1960s and early 1970s. A key and influential publication from this time was written by Dewey and Bird and published in 1972 and described the different types of plate movement and collision.

5.1. How the "Theory of Continental Drift" became the "Plate Tectonics"

Alfred Wegener proposed the **theory of continental drift** in 1912 based on a study of continental coastlines and attributed movement of the continents to both external and internal forces acting on the Earth. After many years of discussion, the theory was proven in the late 1960s and early 1970s through studies of palaeomagnetism, radiometric dating, palaeogeography and the distribution of fossil groups (i.e. palaeobiogeography).
Plate Tectonics is the unifying term with which Continental drift and related aspects of the evolution of the Earth's crust are known today, having been confirmed and established as the framework within which many aspects of the Earth Sciences can be placed. It is now known that the surface of the Earth is made up of vast, essentially rigid slabs of crust known as plates, which are always in dynamic movement with respect to each other.

5.2. What is seafloor spreading?

The ocean floor is being continuously renewed by the production of basaltic volcanic rocks along lines known as 'Mid Ocean Ridges'. The main factors responsible for this volcanic activity and the creation of new oceanic crust are:

1) The release of pressure as ocean crust is thinned by stretching at Mid Ocean Ridges, which allows the mantle below to rise and melt, and, more locally.

2) Processes related to the interaction of the lower part of the Earth's mantle and the outer core, which leads to localised heating and melting of the mantle and the rise of molten magma in what are known as *'Mantle plumes'*.

The process of seafloor spreading, which occurs at Mid Ocean Ridges, however, is driven by great convection currents, which develop in the mantle, with hot material rising and colder material sinking. This is the force that pulls the continents apart or pushes them together, making them collide, crumpling them in the process to form mountains such as Himalayas, the Alps or the Pyrenees.

Mid Ocean Ridges begin to form when these convection currents diverge at the surface and pull the crust apart creating 'Constructive Plate Margins', whilst 'Destructive Plate margins' are where plates are moving together, as heavier oceanic crust sinks below lighter continental crust in what are known as 'Subduction Zones'. When all of this oceanic crust has been consumed by subduction continents collide and the great mountain ranges are formed. Due to the broadly spherical shape of the Earth, however, in places these plates are simply sliding past each other in what are known as 'Conservative Plate Margins'.

As a consequence, continents have been changing their position through time and aggregated or disaggregated as convection currents have pulled them apart or made them collide. Similarly, oceans have been opening and closing through time as convection currents have caused Mid Ocean Ridges to develop, creating new ocean crust, or destroying ocean crust in subduction zones, leading to volcanic and tectonic activity – the latter as sinking material is melted to produce magma which rises to the surface. The latter produces volcanic 'Island Arcs', such as in Indonesia, where ocean crust sinks beneath ocean crust, or mountain belts with active volcanoes where oceanic seafloor is subducted below continental crust – which is crumpled in the process – as in the Andes and Rockies of the south and north Americas respectively. The compressed, deformed and uplifted materials are called 'Orogenes' and they form mountain ranges as they rise.

5.3. Geophysical, Geological, Palaeontological and Palaeoclimatic evidence for Continental Drift and Plate Tectonics

Background: Fundamentally, the concept of continental drift and plate tectonics states that the Earth's crust is formed by thick, less dense continental blocks composed of granitic, metamorphic and sedimentary rocks and denser oceanic plates, formed of Fe-Mg-enriched rocks - the latter forming the ocean floor, but also underlying continental crust. Both types of plates move and displace each other as they are pushed together (i.e. accretion) or split apart (i.e. rifting) by forces generated in the upper Mantle (the *Asthenosphere*), by convection currents. The history of planet Earth, therefore, from the moment of the crystallization of a first solid crust, has been on one side a story of the accretion and collision of continental plates and on the other, of generation and destruction of oceanic plates. Displacement of these oceanic plates would push the continental plates and make them collide, but, as oceanic plates are denser, they can also sink below continental plates through the process of *subduction*.

Main evidence: Scientific support for the Plate Tectonics theory has come from geophysical, geological, palaeontological, palaeoclimatic and geodesic studies. This evidence has demonstrated that although many continental masses are now far apart, millions of years ago they were united, forming a single supercontinent known as Pangaea. This supercontinent began to split up over 200 million years ago, forming the separate continents we know today. Evidence of this split and subsequent movement comes from radiometric, palaeomagnetic, palaeontological, petrological and stratigraphical studies.

5.4. About the position of the continents through time

Studies in Geophysics (including palaeomagnetism and radiometric dating), fossils, palaeoclimatic indicators and other geological data have been crucial for demonstrating that the continents have not been in the same position through Earth History. As iron-bearing minerals, such as magnetite, are common in basaltic and other igneous rocks and retain the orientation of the magnetic north pole in the moment of the formation of the rock, geophysicists can reconstruct the former position of a continent or oceanic plate by comparing the present day magnetic orientation of the minerals with their original orientation. In addition, a comparison of stratigraphical successions and fossil assemblages of similar age on different continents can also enable a palaeogeographic reconstruction of the original position, and evolution through time, of each continental block. For this reason, fossils are also essential tools for plate tectonic studies.

It is clear that the continents have been continuously changing their relative positions through time, indeed oceans and continents have been in a permanent state of change and evolution throughout the history of Earth. Aggregation of continental masses from the consolidation of the first crust through the Archaean and Proterozoic eons led to the formation of a first big supercontinent, known as Rodinia, around 700 million years ago. From the early Cambrian Period, around 600 million years ago, this large continent began breaking up into smaller continental masses, the different continental blocks being initially dispersed during the Early Palaeozoic Era. In the later Palaeozoic, however, they were re-aggregated again into a new large continental mass, the supercontinent 'Pangaea'.

From the early Mesozoic Era, from the Triassic Period onwards, Pangaea in turn started disaggregating into smaller continental fragments as new oceans (including the Atlantic, Indian and Tethys oceans) opened. From the Cretaceous, however, the Tethys, which had separated the continents of Laurasia and Gondwana, started closing as the South Atlantic Ocean opened and started pushing the African continent in the opposite direction. The Mediterranean Sea is effectively all that's left of this ocean.

5.5. About plate tectonics and building mountain ranges

Oceans have formed when continents have been pulled apart by the development of a Mid Ocean Ridge, for instance the Mid Atlantic ridge, which extends from the Arctic, through Iceland, to southern latitudes close to Antarctica.

Mountain ranges have formed when continents have collided, or where an oceanic plate has been subducted below a continent. These processes lead to the folding and uplifting the continental margin including the thick sedimentary sequences deposited in the marginal sedimentary basins, leading to the formation of mountain ranges.

5.6. About folds

Folds are the result of the deformation of rocks by a compressive force. They can take place in every sort of rock but they are most likely to be seen in layered rocks, such as sedimentary rocks or some metamorphic rocks.

When sediments are subject to high pressures by the weight of further sediments accumulating above them in sedimentary basins, they undergo *compaction* and become *lithified sedimentary rocks*. When sedimentary rocks are subjected to lateral compression by tectonic forces – typically over a long period of time and in combination with some heating during deep burial - the elastic limit of the rocks can be exceeded and they can become plastically deformed. This is known as ductile deformation. However, many folds develop in rocks which are nearer to the surface and can be more angular due to a more brittle deformation.

Anticlines and synclines are basic fold types and the main structures that can be formed as a result of both brittle and ductile deformation. They are especially visible in sedimentary rocks although they can also develop in metamorphic rocks as they undergo tectonic deformation.

An *anticline* is a fold in which the younger strata are to the outside, whilst the older rocks form the core or the internal part of the fold. Anticlines can be recognized by their typical 'A'-shape.

A *syncline* is an opposite structure, being a fold in which the younger strata form the internal part of the structure whilst the strata to the outside are older. It can be identified by a typical 'V' or 'U'-shape. Where the relative age of the layers within the fold cannot be determined, 'A'-shaped folds are known as *antiforms*, and 'U'-shaped folds are known as *synforms*.

As both anticlines and synclines affect stratified rocks that once were horizontal, they can form a distinctive pattern on a geological map, at varying scales from many kilometres to only a few 10s of metres (any smaller would be difficult to record on a map). The line that follows the *hinge* of the folded beds is the *fold axis*, whilst the geometrical plane that symmetrically dissects, or divides, the folded structure into two, is the *fold plane*. The sides of a fold, in which the beds are inclined in opposite directions, are called the *limbs* of the fold. In a symmetrical fold, the fold plane is vertical, i.e. it forms a 90° angle with the horizontal surface. However, as a result of intense tectonic efforts in one dominant direction, the folds can be pushed beyond the vertical plane and then the fold plane is *inclined* with respect to the orientation the dominant pressure. In such cases the fold plane shows a *vergence* in this direction. The vergence of a fold provides crucial information about the direction of the forces that formed it.

If this compression is particularly strong and continues for a longer period of time, the whole structure can be pushed over to a virtually horizontal position, forming a *recumbent fold*, where one limb now overlies the other. In such cases, the limb that lies below shows an *inverted* stratigraphic sequence, with the younger beds below and the older beds above. Recognising that a stratigraphic sequence is inverted is extremely important for geologists as it indicates that the beds have been intensely folded, and recent erosion has destroyed the upper part of the fold structure, leaving only the lower inverted limb preserved. As compression continues, a fold can even be detached from its base and displaced along a sub-horizontal fracture plane to the point that it can be pushed over more recent, even relatively less-deformed, materials. This process is called *overthrusting*.

Thrusted beds forming sets of folded stratigraphic units, which can be classified as tectonic units are called *thrusts*. These thrusts can be completely detached and displaced from the point where they were formed, even for tens or even hundreds of kilometres. They form *allochthonous* (= transported) tectonic units, known by the Swiss term *Nappe*. Thrusted nappes are common, major tectonic structures in many mountain ranges whereas the consequence of plate collision, they can be displaced for many kilometres in both directions relative to the mean sense of plate movement. This is classically the case of the Alps, where important thrusted units have been detached and displaced in divergent directions to form different marginal (or ‘external’) mountain ranges such as the Subalpine chains in Provence (France), the French Jura and the Swiss Jura. In the Hellenides, in Greece, the external structures of the Pindos Mountains and many other mountain ranges have been detached and thrusted to the east and southeast for many kilometres, and similar phenomena are also seen in the Betic ranges (S. Spain), Cantabrian mountains (N. Spain) and Pyrenees (NE Spain and SE France).

5.7. About faults

Faults and fractures: When rocks are submitted to forces that exceed the limits of ductile deformation they undergo brittle deformation, i.e. they can break along fracture surfaces known as faults. Different types of folds and faults are some of the most important tectonic structures that can affect all the rocks of the Earth’s crust.

‘Joints’, however, are fractures affecting rocks in which blocks on either side have not been displaced. Joints can be generated by different forces, but most are formed as a consequence of decompression when rocks become exposed at the Earth’s surface by erosion. They can also be formed as a result of changes of temperature affecting the rocks in the surface. Such changes, for instance freezing and heating, can make the rocks contract and expand, leading to fracturing. The increase of the volume of water as it freezes to form ice, can be a very important factor in high mountain areas where it contributes to fracturing of the rock as it opens up such joints. Faults, however, are fractures along a plane in which the blocks on both sides do undergo displacement by the effect of extensional, compressive, or laterally opposed forces.

When rocks are affected by extensional forces, they can break to form what are called *normal* or *gravitational* faults. In a normal fault, the displaced block moves down long the fault plane so that the younger beds of the sunken block (or *downthrow side*) appear at the same level as the older beds of the other, relatively uplifted block. At a minor scale, normal faults can undergo displacements of only a few centimetres or metres, but they always reflect a state of extension of the surface rocks. At a major scale, normal faults can affect major units of the Earth’s crust, resulting in the active subsidence of sedimentary basins at the margins of continents, as well as the relative uplift of adjacent blocks. The latter structures are known as *Horsts* (i.e. uplifted blocks) and the former, *Grabens* (i.e. sunken blocks).

In some cases, the vertical fault plane can bend at depth becoming horizontal. These extensional curved faults are known as *listric* faults. Sliding along the plane of a listric fault will result in the tilting of the faulted block, leading to inclination and sinking of the strata close to the fault plane (i.e. the proximal area), with a corresponding uplift further away (i.e. in the distal area). Listric faults and tilted blocks can be identified when geologists record different thickness of sediments for the same stratigraphic interval in different locations, with the thicker sequence representing more proximal areas where there has been more subsidence and the thinner more distal areas with less subsidence or even relative uplift. Listric faults are fundamental tectonic elements controlling the shape and the evolution of sedimentary basins throughout Earth history.

A reverse fault is a fracture affecting the rocks of Earth crust in which the displaced block moves upwards along the fault plane, so that the lower, older beds of the uplifted block are pushed and emplaced above the younger beds of the down-thrown block. A reverse fault is formed when rocks are subject to strong lateral compression by tectonic forces. At a small scale a reverse fault can show only a small overlap of the uplifted block over the downthrown *block.* At a larger scale, however, reverse faults can become the sliding surface of overthrusted structures (see above) - and at a much, more extreme scale, large tectonic nappes displace large slices of crust and folded stratigraphic units on large, low angle reverse fault surfaces.

Other tectonic processes associated with faults: Quite commonly, a sedimentary basin that has been formed by subsidence and filling with sediments along normal or listric faults, can be subsequently subject to lateral compression if the former extensional regime turns into a compressive stage. In such case, the sedimentary rocks can be compressed, pushed and thrusted above the margins of the basin following the same fault planes that are now reversed, acting instead as reverse faults. This process is known as *tectonic inversion*, and is a common process in the evolution of **orogenes** and the formation of mountain ranges. This shows that the displacement of large masses of rocks can follow the same fracture plane in both directions, as they constitute significant *weakness zones* of the crust, when can be reactivated, even in an opposite direction.

Strike-slip faults: Strike-slip faults are formed when two large blocks of Earth crust are pushed horizontally in opposite directions along an essentially vertical plane. Such faults can lead to the displacement of crustal blocks over large distances, generally as a consequence of plate movements. At a smaller scale, however, strike-slip faults can lead to an oblique collision of smaller bocks within a compressive regime. The combination of both types of movements is known as either *trans-tension*, if it results in a stretching movement, or *trans-compression* if it leads to an oblique collision of these blocks.

Transform faults also belong to this category of faults. These are major fracture lines that develop in the ocean floor perpendicular to the Mid Ocean Ridge, along which the ocean floor is slowly spreading. Quite commonly, continental blocks can also be displaced relative to each other for long distances along transform faults, a famous example being the San Andreas Fault on the western coast of North America.

5.8. Why and how Earthquakes occur

Earthquakes occur when masses of land move along a fault plane. This displacement can be caused either by extensional movements, for instance in a sedimentary basin which is slowly sinking or *subsiding*, or by compressive movements, for instance associated with plate collision, or by sliding, movements along active *strike-slip* faults (such as the San Andreas).

Although earthquakes can be of very different degrees and magnitude, depending on the displacement of the blocks and the size of the fault itself, they are always connected with tectonic activity, and the abundance and intensity of earthquakes in an area gives a direct expression of the intensity of the tectonic movements in that area.

5.9. How volcanoes are formed

Plate margins are the parts of the lithosphere where geological activity is most intense. This activity can take place in many different ways and one important type is volcanism. Volcanism can take place both at the plate margins or in areas close to destructive margins, as well as associated with other major fractures of the lithosphere.

Volcanic activity takes place when a melted rock (i.e. magma) ascends to the surface. Depending on the different types of rock and the temperature of the magma, there are different types of volcanic activity. Generally, basic lavas (i.e. rich in minerals of Fe and Mg) are more liquid and the eruptions are less violent (e.g. along Mid Ocean Ridges, such as in Iceland or above mantle plumes such as Hawaii), whilst acid lavas (i.e. more rich in silica) are more viscous and eruptions generally more violent and explosive (e.g. above subduction zones, such as in the Andes and

along island arcs such as Indonesia).
The main components of a volcano are: the magma chamber, where the melted rock concentrates, the volcanic vent where the magma ascends to the surface, and the external volcanic crater, where the melted rock is ejected to the surface. A repeated sequence of volcanic eruptions can create a cone of lava and ash around the crater. After many years of successive eruptions, some volcanic cones can reach several thousand of metres in height, as it is the case with Teide, Vesuvius and Etna.

5.10. Why the distance between Europe and North America is increasing?

North America and Europe are getting progressively further apart as the Atlantic Ocean, which separates them, is slowly enlarging.
At the end of the Permian Period, around 250 million years ago, all continents of the planet were united together to form the supercontinent Pangaea. However, this continental mass began to break up through a process of *rifting* and oceanic crust started developing between each section of continental crust, pulling them apart. Firstly, a northern block (Laurentia), which would become N America, separated from another large block (Eurasia), which would eventually become the present day Eurasian continent, and both masses separated from a southern continent (Gondwana), which originally included, South America, Africa, Australia, India and Antarctica.
Through this process, both the northern and the central Atlantic oceans were formed. Subsequently, from the Late Jurassic (around 145 million years ago) and during Cretaceous times, the progress of rifting led to the large continent of Gondwana fragmenting into smaller blocks and what is now South America, Africa and Antarctica started being pulled apart. As the oceanic plates created between them are still pushing the continents away, North America and Europe continue to move further apart, and similarly are South American and African continents.

5.11. Why is the Mediterranean Sea is slowly closing? Will it eventually disappear?

The Mediterranean Sea is all that remains of the once great Tethys Ocean, which separated the Eurasian continent from the continent of Gondwana from the beginning of Mesozoic Era (i.e. Early Triassic times, some 250 million years ago) the Tethys ocean started opening at the end of Paleozoic Era in the Late Permian Period by a series of lines of rifting, which established an area of oceanic crust between the continents, pushing Eurasia and Gondwana apart. As Tethys developed, its margins developed extensive carbonate platform margins, sections of which are now preserved across southern Europe, from Iberia, across France and Italy to Austria and beyond.
From Cretaceous times onwards, however, as the South Atlantic Ocean started to open, the African continent moved slowly in an opposite sense (i.e. counter-clockwise) and started closing the Tethyan Ocean. During the Cenozoic Era, as the African continent approached Eurasia, the sedimentary sequences accumulated along both continental margins were strongly folded and pushed over the continental margins. This continental collision gave rise to the Alpine Orogeny. In some areas, however, the force of this collision led to slices of the oceanic plate being pushed up onto the continents through a process known as *Obduction*. These slices are preserved in the Alps, in Greece (in the so-called *Hellenic Arches*), in the Betic Cordillera (S. Spain) and in Cyprus (the Troodos Massif).

Today, the Mediterranean Sea is just a small remnant of what the Tethyan Ocean used to be, but it still retains areas of true oceanic sea floor on its bed. The constant rate at which the African plate continues to move towards Europe, (several centimeters every 100 years), however, indicates that the Alpine Orogeny is far from over - indeed, in the next 50 to 100 million years the African Plate will eventually entirely close the Mediterranean Sea and collide against Europe.

Intended learning outcomes:

- Describe briefly the theory of plate tectonics and recognise its importance for the Earth sciences.
- Know about seafloor spreading.
- Know that the continents have changed their relative positions through geological time.
- Understand the relationship between mountain building and plate tectonics.
- Describe the building of mountain ranges.
- Refer to the main types of tectonic structures (e.g. folds, faults etc.).
- Know why and how earthquakes and volcanoes occur and the connection between them.
- Realise the consequences of seafloor spreading, mentioning specific examples.
- Know that plate margins are the parts of the Earth's crust where geological activity is most intense.

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CHAPTER 6

The Earth is changing

Key words: Geomorphology, landscapes, landforms, dynamic systems, weathering, erosion, drainage systems, coastal dynamics, sea level changes, desertification, climate change, global warming, Palaeoclimatology.

Introduction

On a very dynamic Earth landscapes evolve. Natural landscapes are a complex interaction between landforms produced through erosion and sedimentary processes and the control of plate tectonics and climate. The evolution of landscapes is controlled by a balance between tectonic uplift (or subsistence) and climate change. Geomorphology is the branch of Earth Sciences that studies landscape forms and their evolution.

6.1. The Earth as a dynamic system

Earth is a dynamic planet because its composition in different layers or “spheres” moving and interacting each other. Loss of Earth’s internal heat energy drives moving of plate tectonics that influences all of the structure features of our planet.

6.2. How landscapes are changing

Landscapes are dynamic systems determined by tectonics, erosion, climate and the geodiversity of the bedrock. Changes such as mountain uplift or subsidence, the motion of lithospheric plates, opening or closing of ocean basins and sea level changes, as well as rock response to tectonics or weathering agents, can take millions of years.

6.3. About the interaction between the lithosphere, hydrosphere, biosphere and atmosphere

Geological landscapes result from the interaction of the Earth’s different subsystems. The main components affecting the climate system are the atmosphere, hydrosphere, lithosphere and biosphere.

6.4. About major landforms (mountains, plains, plateaus, hills, valleys, coasts, etc.

Landforms are natural physical features of the Earth's surface formed as a result of the interaction between major constructive geological processes (tectonics, volcanism, etc. and surface destructive processes (weathering, erosion, etc). The scale of landforms ranges from few metres or hundreds of metres (e.g. sand dunes) to hundreds of kilometres (e.g. mountain belts).

6.5. About weathering

Weathering is the effect of all the chemical and physical processes that break up and decay minerals, rocks and other geological materials on the surface of the Earth into fragments of various sizes, or soluble minerals. Weathering processes include heat, water, pressure and organisms.

6.6. About erosion

Erosion is the set of processes that loosens *in situ* rocks, soft sediments and soils, leading to their *transport* to another location where they may be deposited as layers of sediment. Agents of erosion agents include flowing water, glaciers, wind and gravity.

6.7. How water shapes landscape

Water reacts chemically with many minerals, typically altering them into more soluble or weaker materials and thus contributing to the weathering of rocks, as well as changing soil properties. Rain water flows down slopes, eroding gulleys and then valleys, hence shaping the land. Waves and sea currents shape coastal areas. Freezing water breaks rock as it expands to become ice and glaciers and ice sheets shape mountains and high-latitude lands with a powerful grinding action as they move.

6.8. How mountains are eroded and worn down

Erosional agents such as flowing water, ice and wind can act intensively on a mountain. Different resistances of different rock types to weathering and erosion, as well as tectonic discontinuities such as major faults, will dictate the shape of the mountain.

6.9. About river basins

Beyond the glaciers and ice sheets, river drainage systems are responsible for the physical weathering and erosion of mountains and ultimately sedimentation in lowlands or the sea. Rivers evolve from a fast flowing ‘youthful’ stage in the mountains towards a slow moving ‘mature’ stage in the lowlands depending on tectonic uplift rates and sea level changes. Erosion and sedimentation is largely dependent on climatic factors such as rainfall and vegetation cover.

6.10. How rivers and sea waves alter landscapes

Rivers are a balance between the actions of erosion, transport and sedimentation. These factors create a longitudinal equilibrium profile for the riverbed, whose shape is dependent on changes in water flow, geological characteristics, sediment characteristics and depositional processes - as well as tectonic factors and changing sea levels. The highest rates of erosion take place in the faster flowing upper reaches of the river and sedimentation takes place mainly in the lower reaches, such as on mature flood plain areas and in estuaries. River sinuosity depends on the rate of erosion and sedimentation in the river margins which can lead to the development of meanders.

6.11. About coastal dynamics (beaches, cliffs, cliff retreat, coastal evolution)

Sediments deposited in estuaries and river deltas are redistributed by sea waves and currents along the coast. Beaches are usually temporary accumulations of such sediments. Eroding coastlines result where waves are the major erosive agent, leading to shoreline retreat as the eroded sediment is moved away by currents.

6.12. How shorelines are changing

Sea level changes related to continental movement (including marine transgressions and regressions) and the rate of river sediment input into coastal areas are the main processes responsible for coastal evolution. Raised marine terraces (i.e. above present day sea level) and coastal sedimentary deposits document the past evolution of shorelines. Knowledge of these changes is very important for the management of human activities in coastal areas where more than 600 million people live today.

6.13. About desertification

Deserts are arid regions and comprise around one third of the Earth’s land surface. The very low rainfall prevents significant plant growth. Wind processes are the major factors which shape desert landscapes. There are “hot” rocky and sandy deserts and “cold” deserts as in Polar regions. Desertification is a consequence of climate change that may transform semi-arid lands into deserts. The unrestrained growth of human populations and consequent agriculture expansion – including greater demands on water supply – may result in the expansion of deserts.

6.14. About climatic change

Climate change is a significant and lasting change in the distribution of weather patterns over time. Forcing mechanisms include oceanic circulations, variations in solar heating of the Earth's surface, plate tectonics and volcanic eruptions - as well as major human impacts on natural systems.

6.15. About climate changes through History of Earth

Palaeoclimatology, or the study of the geological record of past climates, can help separate natural variations of climate from human-induced effects. To understand global patterns of natural variability in space and across time can help predict more accurately phases of global cooling (for instance leading to a Glacial period) or warming. On a more local scale, modelling geological hazards related to short-term climate change may help prevent or reduce the risk of loss of life or property with the improvement of land management plans.

6.16. About climatic changes in your region through geological time

The rocks and landforms of Europe record many climate changes through geological time. Three major phases of Ice Ages before our present phase are recorded in some of the older rocks across Europe, the oldest around 580 million years ago during the latest Precambrian, immediately preceded the first burst of Metazoan life in the seas, the second was around 150 million years later, at the end of the Ordovician Period (450 million years ago), and the third around 290 million years ago during the Carboniferous Period. The latter, however, is recorded in Europe mainly as massive changes in sea level which affected low lying areas (i.e. as a result of polar ice repeatedly freezing and then melting). At this time, however, Europe itself was dominated by equatorial forest and swamps which produced the Carboniferous coal deposits so important for industrial development in many countries.

Desert deposits dominate central and northern Europe in the Devonian and Permian-Triassic as continental drift took the region through desert latitudes first to the south, and then to the north of the equator. Deep weathering of the Carboniferous-Permian Variscan Mountain Belt under tropical climates during the Jurassic Period contributed to the plateau-like landscapes which are characteristic from the Iberian Massif. Cenozoic climates with semiarid conditions and torrential rains lead to the current erosive shapes of these major plateaus.

However, in parts of more northern Europe, sub-tropical weathering had a major effect in reducing more ancient topographies during the Cenozoic. Some of the most major changes across central and northern Europe occurred during the most recent ice ages of the Quaternary Period, with their alternating phases of warm, temperate climates and frozen permafrost or ice sheet covered phases. These phases created deep river valleys incised into upland areas and plateaus and the glacial U-shaped valleys in some of highest mountains. Tectonic and climate changes are also responsible for shaping coastal areas during the Quaternary, for instance producing raised marine platforms above modern sea level during warmer interglacial periods when ice melted.

Intended learning outcomes:

- Understand landscapes as a result of Earth Dynamics.
- Recognise major landforms.
- Understand the difference between weathering and erosion processes.

- Understand coastal dynamics and their importance for world populations.
- Understand the difference between “hot” and “cold” deserts and the human role in desertification.
- Develop an informed opinion on Global Warming and its relationship with Climate Change.
- Develop an understanding of the geological evidence for climate change and an appreciation of the possible causes within an Earth System context.
- Recognise that natural processes lead to changes in the environment.

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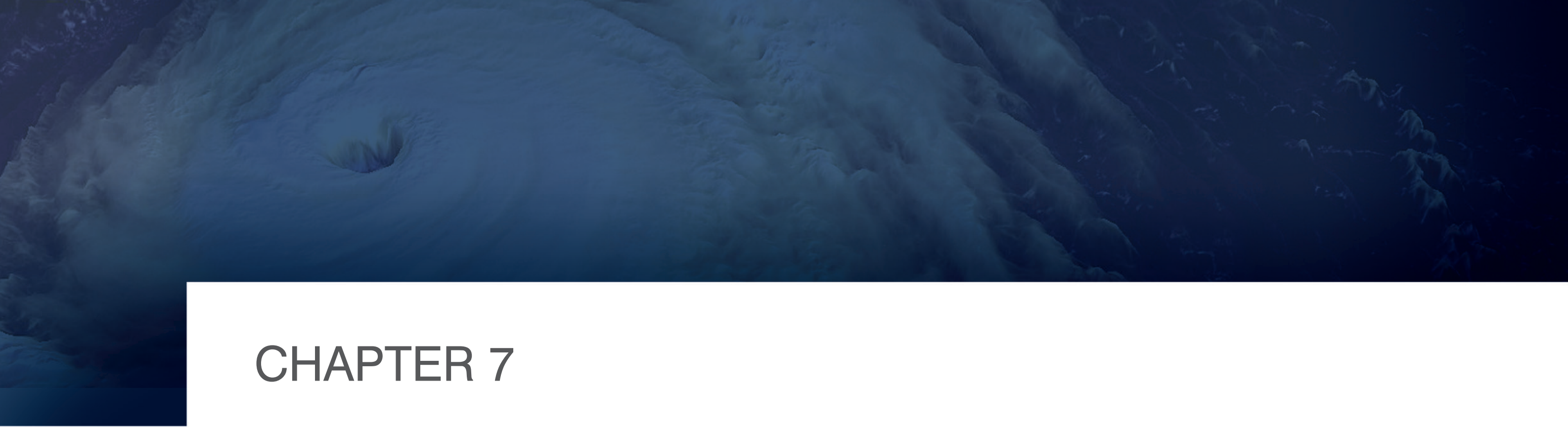

CHAPTER 7

Natural Hazards

Key words: Earthquake, tsunami, volcano eruptions, landslides, storms, floods, droughts, historical eruptions.

Introduction

Natural Hazards are phenomena or processes that can potentially affect human beings and their activities. Natural hazards can pose a significant danger to people, their properties and the environment they live in. It is important, therefore, to understand about natural hazards, as well as the risks associated with them, to help protect communities form their effects.

7.1. About earthquake risk and the protection of communities

An *Earthquake* is a sudden shaking of the Earth's crust caused by the sudden release of slowly accumulated strain in the bedrock, and which can cause significant damage to human structures. In ancient societies there were different myths and legends which tried to explain earthquakes. For instance for the ancient Greeks the giant Enceladus was responsible for earthquakes and for the Japanese it was a whale.
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The risk of earthquakes depends on:

- The local geological conditions of the area (e.g. solid rock or loose consolidated deposits, proximity of active fault zone).
- Distance from a potential epicentre.
- The type of building construction in the area and building regulations (and their enforcement).
- The population density of the area.
- The preparation of the population for emergencies.

The study of earthquakes is called seismology. To reduce the potential hazards of an earthquake, it is necessary to develop very strict building codes and include geological risk zoning and vulnerability mapping into building planning systems. This is because the majority of deaths from earthquakes are due to the collapse of human constructions.

7.2. About tsunami

Tsunamis are very large waves that can travel very quickly across the sea and can cause extensive damage along coastal areas, sometimes for thousands of kilometres. Tsunamis are usually generated by plate movements, undersea earthquakes, volcanic eruptions and land-slides, and much more rarely by meteorite impact. Tsunamis are very destructive and cause considerable damage to ships, harbours, coastal installations, buildings and constructions near the coast, as well as the death of many people. They can also affect the aquatic fauna and flora in the coastal environment.

In the open sea, tsunamis are not dramatically higher than normal waves, as they are usually only about 1m high. However, as they travel towards the land and come nearer to the coast, they increase in height as the depth of the sea water decreases. Tsunamis transfer a huge amount of energy and they can reach a speed of 800km/h in the open sea, slowing down when they reach the coast as the water depth shallows. The speed of tsunamis depends on water depth rather than on the source of the wave. Typically, shortly before a tsunami wave hits the coast, the sea level near the shore drops, exposing the sea floor. According to NOAA (National Oceanic and Atmospheric Association of USA), *"...the largest tsunami on record rushed past Ishigaki Island, Japan, in 1971. It was an incredible 84.7 meters high tsunami wave. While it caused little damage, the giant wall of water relocated a 750-ton block of coral 2.4 kilometers inland".*

7.3. What happened in Japan after the Earthquake and tsunami of March 2011

On March 11, an earthquake of amplitude nine on the Richter scale, led to a huge tsunami, and 50 aftershocks, which destroyed extensive areas along the NE coast of Japan, from Chiba to Aomori (Honshu). The epicentre of the earthquake was located about 373 km NE of Tokyo. It was reported that at least 15,703 people died, 5,314 injured and 4,647 people were missing. 130,927 people were displaced and at least 332,395 buildings, 2,126 roads, 56 bridges and 26 railways were destroyed or damaged by the earthquake and tsunami (source *USGC-Earthquake Hazard programme*).

7.4. About volcanic eruptions and the risks and benefits of the volcanic activity

Volcanic eruptions are the ejection of igneous material from inside the Earth (lava, ash, pyroclastic flows, and associated gases) via a vent or fissure to the surface.

There are at least 1,300 volcanoes - perhaps more than 1500 - that are potentially active or have erupted in past 10,000 years. Some estimates of young seafloor volcanoes, however, exceed a million.

Although volcanoes threaten communities close to them, they can also bring some benefits, such as:

- Very fertile soils supporting agriculture.
- Creating new land areas (such as the island Nea Kammeni of the Santorini complex islands in Aegean Sea, Greece).
- A source of geothermal energy.

- Precious gems and volcanic sulphur.
- Providing decorative and light weight material for buildings.

Volcanologists study and record current volcanic activity using scientific instruments, including seismographs to detect the earthquakes that almost always precede eruptions. They also study past volcanic activity. The results of these studies are very important and help develop plans for those who live nearby and who may be affected by any future eruption.

7.5. What happened in Pompeii after the Vesuvius eruption of 79 A.D.

The violent eruption of the volcano *Vesuvius* in August A.D. 79 was described by the Roman writer Pliny the Younger, who was an eye-witness. The ash and the pumice produced by the eruption covered areas up to around 30km from Vesuvius, including burying the Roman city of *Pompeii* and killing thousands of people. Some days before the eruption, small earthquakes took place. The old mountain was destroyed by the eruption and in its place a new one was created from the volcanoes products and the remains of the old dome. Pompeii was rediscovered during the 18th century and excavated. The area around Vesuvius remains one of the most dangerous volcanic areas in the world because of its density of people and settlements - the last eruption of Vesuvius took place in the 1944. Today Pompeii is a National Park and open to visitors.

7.6. About the eruption of the volcano of Santorini in the Late Bronze Age and its impact on the cultures and civilizations of the time

Santorini is a caldera-type volcano situated in the Aegean Sea and it is the most active volcanic centre in the South Aegean Volcanic Arc. Volcanism in Santorini began around two million years ago with the extrusion of lava from vents around the Akrotiri area. The five islands of the Santorini volcano formed from a variety of eruptions over a long period of time.

The Thera, Therasia and Aspronisi islands form a broken circle and they are the remnants of a formerly large single inland called in ancient time *Stroggili* (= “round”). Their present topography is the result of the Minoan eruption that happened between 1645-1625 B.C. Since that time, two further islands (Palaea Kammeni and Nea Kammeni) have grown up from erupted lava in the middle of the Caldera. Palaea Kammeni appeared during the eruption of 197 B.C. and during the volcanic activity of 1707 Nea Kammeni first appeared. The latest volcanic dome was created during activity in 1950.

Thera is the largest island with spectacular 300m high vertical cliffs on the inside of the caldera. These cliffs reveal the stratified deposits of many different eruptions through the last 500,000 years. The most important and famous eruption, however, of the Santorini volcano took place in the Late Bronze Age, between 1645-1625 B.C. It was a Plinian explosion so huge that the eruption column is estimated to have risen to around 30km and the ash was spread all around the Eastern Mediterranean (ash from this explosion has found in Egypt, 800 km away). Several metres of pumice blocks and ash covered the island area. Archaeological excavations near the area of Akrotiri have revealed the ruins of a Minoan town with very well preserved frescos and paintings, as well as many craft items. A tsunami around 30m high was generated by the eruption and reached the coast of Crete and destroyed the Minoan culture, the dominant civilization in the Mediterranean at this time. Historians believe that this volcanic eruption changed the political landscape of the ancient world. After this eruption the island was uninhabited for the next 300 years.

Many earthquakes followed this great eruption and caused the internal collapse of the crater, which created the current geological caldera, which measures 12 km by 7 km, is 400 m depth and surrounded by 300 m high cliffs.

7.7. About landslides

Landslides are downwards movements of slope-forming material such as rocks, soils and artificial fillings under the influence of the gravity. They can occur in any terrain, where conditions allow gravity to overcome the forces of friction. Typically, mountainous areas are most at risk from landslides, but they can occur also in lowland areas where slopes developed in relative weak materials are developed, or have been de-stablised by road construction, excavation for buildings or in active quarries and opencast mines. Coastal areas can also be at a high risk from landslips as coastal erosion undermines coastal slopes and cliffs. The primary cause of a landslide is the saturation by groundwater of the slope material, leading to a loss of cohesion meaning that they can flow more easily. Other factors that affect slope movement are the gradient of the slope and its degree of consolidation.

Landslides are often related to:

- Volcanic activity
- Seismic activity
- Coastal erosion
- Tectonic conditions in the area
- Differences in lithologies within the slope
- Weathering and extreme climatic conditions or weather conditions
- Wildfires

Human activity can also be a very important factor due to de-stabilising of slopes by engineering works or construction or changes in ground water systems.
The amount of material moved during a landslide can be enormous. In some cases the volume of the slope material is so huge that entire villages can subside or be buried (e.g. in 1963 at Mikro Horio, Karpenissi-Greece where 13 people were killed).
Mitigating landslide hazard: 1) Avoid construction on steep slopes in weak geological materials or in areas at risk from natural erosion (e.g. due to rivers or the sea), 2) Install surface and deep draining to remove excess groundwater, 3) Reduce or control surface rainwater runoff, 4) Applying engineering techniques to stabilise slopes (e.g. following on from a thorough study of the geological, hydrological and geotechnical conditions of the area).

7.9. About floods

Floods are one of the most common natural hazards and they can be either *coastal* or *river floods* depending on their causes.

Coastal floods often happen when the sea overflows coastal land due to a storm event, or more rarely a tsunami. Events causing coastal flooding include:

- Storm events, often seasonal
- Exceptionally high tides
- Sea level rise due to a climatic change
- Tsunamis
- Local tectonic activity

A combination of exceptionally high tides and storms often causes coastal flooding; exceptionally, however, tsunamis can cause flooding many hundreds of metres inland. In such cases, the seawater moves inland with such a huge force that it crushes everything in its path. Coastal flooding can lead to many social, economic and environmental impacts in the affected area.
River floods are the most common floods and they occur when the river flow is high and the water overtops the river banks and covers the land around. Factors causing river floods are:

- Heavy rainfall
- Permeability of rocks
- Topography of landscape
- Dam overflow or dam collapse
- The melting of ice and snow during the spring.

Every year river floods are responsible for damage to property and agricultural production and the loss of human life.

7.10. About droughts

Drought is a period when there is not enough rainfall for an unusually long period of time, which affects the hydrological equilibrium of the area. During a drought, streams dry up, soils dry out, the level of groundwater sinks, plants die and there is not enough water for people and animals. Sometimes droughts are related to high temperatures which increase evaporation and water loss. When these phenomena continue for an unexpected long period, settlements and the general environment are put at risk.
There are 4 types of Drought: 1) *Meteorological drought* (decrease of rainfall), 2) *Hydrological drought* (decrease of water reserves), 3) *Agricultural drought* (impact on the agricultural production) and 4), the more dangerous type, *Starvation drought.*

7.11. About storms

The term storm includes many weather phenomena such as rainstorm, snowstorm, thunderstorm, hailstorm, windstorm, tropical cyclone, whirlwinds and tornados. Storms can have negative impacts on people and properties as they can cause flooding, block road and other transport systems, lead to wildfires and create dangerously powerful storm waves in coastal areas. Whirlwinds and tornados are some of the most dangerous natural phenomena because of their particular characteristics, such as very low atmospheric pressures which lead to very strong winds. Atmospheric pressures can drop to 100 mbar and the wind speed can rise to 230 km/h, and sometimes to 400 km/h, in a tornado.

7.12. What we can do to avoid being exposed to Natural Hazards

School education should aim to develop a “culture of prevention”. Students (i.e. future citizens) can be made aware of natural hazards. As adults, they may be able to take preventive measures and avoid activities that could destroy the balance of ecosystems and harm the natural environment. In this way they will be able to reduce the risk of turning natural phenomena into the natural disasters which cause enormous losses of human lives, infrastructure and property.

7.13. How we can defend against geological risks

Natural Hazards related with the geological processes include:

- Earthquakes – and secondary effects such as tsunamis and aftershocks (smaller earthquakes)
- Volcanic eruption (lava flows, tephra, pyroclastic flows and gases)
- Landslides
- Rock falls
- Floods (river/coastal)
- Droughts
- Salinisation of water supplies

Geological hazards will never go away. A prepared society, however, can make them less damaging, by preparing emergency plans and instructions for citizens to follow when they strike. Learn, share, join together and be ready to reduce geological risks to our society.

Intended learning outcomes:

- Know about different types of natural hazards (e.g. earthquakes, volcanic eruptions, etc.).
- Describe the causes and dangers associated with specific natural hazards (e.g. earthquakes, tsunami, volcanic eruptions, etc.).
- Know about historical and recent large-scale natural disasters and their impacts on human society, infrastructure, property and the environment.
- Know how to be ready to prevent, confront and mitigate the impacts of natural hazards in varying circumstances.
- Be aware of natural hazards and establish a "culture of prevention".

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CHAPTER 8

Natural resources and mankind

Key words: Fossil fuel, coal, oil, reservoir rock, geothermal energy, renewable resources, raw material, karst, cave, artesian springs, gravity springs, drilling, underground water.

Introduction

Modern human life is dependent on energy for lighting, heating, powering industry, transportation and communication. Most of this energy comes from rocks, from the fossil fuels stored in the rocks of the Earth's crust. These fossil fuels are: a) Coal formed from fossil plants, b) Oil formed from fossil animals and c) Natural gas which can originate from both sources. These are characterised as fuel fossils, because they contain energy trapped by living organisms in the past. Coal, oil and gas remain the dominate resources on the global energy market, although the demand for energy increases continuously.

Man is always searching for new geological sources such as geothermal energy (section 8.6.) and methane hydrates. Methane hydrates, also known as "methane ice" consist of methane chemically combined with water. They are often found in the seabed in areas where continental plates meet at depths of 500 - 1,000m. It has been suggested that their energy reserve is twice as that of coal, oil and natural gas combined. Methane hydrates were found for first time in 1971 in the Black Sea and they could help meet future energy needs.

8.1. How coal deposits were formed

Coal is a sedimentary rock formed from the remains of trees and other plants under special environmental conditions – for instance under hot and wet tropical climates in areas of swampy ground. The processes necessary for dead plants to be preserved and altered into coal are:

- The quantity of plants must be enough so that a thick deposit can build up.
- The dead plants must accumulate under hot and wet conditions, such as in a swamp, where little oxygen is available and hence they do not rot.
- The plant remains have to be buried by other sediments, such as sands, clay and silts. The weight of these sediments squeezes and compacts the underlying organic remains.
- Chemical changes take place slowly, water and gases escape and the remaining material becomes richer and richer in carbon, leading to long-term preservation.

The amount of concentrated carbon in coal is dependent on the types of plant and the duration and the depth of burial. Coal can classified into four categories (the '*coal series*') according to the thermal capacity of the concentrated carbon:

1. *Peat*: This has a low thermal capacity (40-50% carbon and 50-60% water content) and was mainly formed during the Quaternary Period and continues to form to the present day.
2. *Lignite*: With a good thermal capacity (70% carbon and 20-30% water content). Lignite in Europe mainly dates from the Palaeogene Period to the Lower Quaternary Period (i.e. the Pleistocene Epoch). There are also deposits of Cretaceous lignite in Europe.
   In Greece lignite is the most important source of Energy. Two lignite deposits are mining, the lignite deposits of Ptolemais (N. Greece) formed during the Pliocene period and those of Megalopolis (S. Greece) formed during the Early Pleistocene period.
3. *Bituminous coal*: This has a very good thermal capacity (75-90% carbon, 2-7% water content) and in Europe was mainly formed during the Carboniferous Period, although there are smaller deposits of Jurassic and Palaeogene age.
4. *Anthracite*: This has the best thermal capacity (92-98% carbon content) and is relatively hard and the best quality coal. It was mainly formed during the Carboniferous Period, where tectonic conditions were favorable (i.e. warming during deep burial).
   Most of the coal deposits in W. Europe and N. America were formed around 300-280 million years ago during the Carboniferous Period.

8.2. How the oil is formed

Oil is formed in sediments under the sea when large amounts of dead plankton (i.e. billions of organisms!) become incorporated into sea-floor sediments as they die and sink to the seabed. These sediments, under favorable conditions, can be the source rock for oil and gas. This process usually happens in the fine muds of off-shore regions, where there is little oxygen and hence the organic remains do not rot away. The best areas are sedimentary basins, in which the sediments have been buried deep enough to mature and generate oil, but which have not been intensively deformed by an orogeny, only folded enough to produce trap structures to hold the oil. Oil and gas usually tends to move away (i.e. migrate) from the source rock, through porous rocks such as sandstones. These porous, permeable rocks can be the reservoirs for holding oil and gas. But over these porous rocks there needs to be a seal, a sedimentary unit with low permeability blocking their escape from the reservoir rock.

Oil has become the most important source of energy today, because it has a high energy content, is relatively abundant, can be processed into a range of products (tar, diesel, paraffin, etc.) and can be easily transported. In addition, oil is the raw material for many chemical products, plastics and artificial fibres such as nylon.

Every day, people consume about 88 million 'barrels' of oil globally. Natural gas, however, is used mainly as a fuel for heating.

8.3. Why oil is so expensive

The oil is trapped at depth in rocks and the research, drilling, extraction and refinement needed to use this resource is very expensive. In parallel, the price of oil follows economic trends of supply and demand - and as the demand for oil is still increasing, especially from emerging markets such as China and India, as no other abundant and safe alternative is usually available. Political and other economic reasons also play a role in determining the price of oil.

8.4. What is the difference between coal and oil?

Both coal and oil are fossil fuels formed million years ago from decaying plants or animals. The main differences are the organic source material and whether they were formed in the sea or on land. Coal was normally formed in wet areas on land from dead plants and is a solid material; oil, however, was formed in the sea from planktonic animals and protists and is liquid.

8.5. About renewable resources (e.g. geothermal energy)

Renewable resources of energy come from wind, sunlight, water flow and geothermal heat extracted from inside the Earth. The geothermal resources of the Earth are generally limited to areas near the boundaries of tectonic plates, but they are potentially sufficient to supply the energy needs of humanity. However, only a small amount of this energy may be exploited, because the exploitation of deep resources is very expensive. This energy, however, is sustainable and environmentally friendly and in many cases could replace fossil fuels. It requires only limited areas of surface land and its application in home heating, agriculture; desalinisation and industrial processes can be very efficient and successful.

Geothermal energy has been well known since ancient times (Palaeolithic epoch) as hot springs have been harnessed for bathing as well as in Ancient Roman times. From the beginning of 20th century, geothermal energy has also been used to generate electricity. Since then, many technologies have been developed to better exploit heat from the Earth.

In Greece, due to its geographical position, has many opportunities to develop geothermal resources, in places such as Milos, Nisyros, Santorini, Lesvos islands, Platy, Thermopyles and Soussaki. In many others regions, investigations have also had positive results.

More examples:

Natural resources of Austria

The main natural resource in Austria is water, providing drinking water and the driving power for hydroelectric power plants. Austria has only limited amounts of other mineral resources, however, such as crude oil and natural gas, iron ore and few rocks for building stones. Most rocks are used for the production of aggregate, including the production of cement. Gravels are extracted from river deposits. The most precious resource, however, are the fertile soils (e.g. Löss or loess).

Natural Resources of Italy

Water: Providing drinking water and water for hydroelectric power plants. Water for electrical energy is mainly used in the north of Italy.

Oil: Drilling for oil in Italy has taken place both on land and on the sea-bed. Apart from Basilicata, which is historically the area with most oil-wells (70% of national oil is extracted from oil-fields in Val d' Agri, Basilicata), there are also concentrations of oil-wells in Emilia Romagna, Lazio, Lombardia, Molise, Piemonte and Sicily.

Methane: Methane (i.e. natural gas) is extracted almost exclusively in the south of Italy.

Coal and lignite: There are several coal deposits in Sardinia, whilst there are lignite deposits in Calabria, Basilicata and central Italy. There is no on-going mining activity at present.

Geothermal energy: At present geothermal energy represents 10% of the energy from renewable sources in Italy, but it is predicted that the figure might soon double. It is exploited mainly in Tuscany.

Metalliferous minerals: In Sardinia, where the oldest rocks in Italy are found, deposits of sphalerite (zinc sulphide) and galena (lead sulphide) are exploited. The iron deposits mined on the island of Elba are almost exhausted. Monte Amiata, an ancient volcano, is still rich in minerals containing mercury. In Val Graveglia (Liguria) manganese is mined. Gold is also to found in Italy, albeit in small quantities - the sands in the rivers Ticino, Sesia, Dora, Adda and Orba contain some gold and were exploited at the time of the Roman Empire.
Materials for building and ornamental stones: Italy is the major world supplier of pumice, which is obtained principally from the island of Lipari. There are significant porphyry quarries in Trentino, tufa quarries in the south of Italy, granite in Sardinia and alabaster in Sicily. Italy is also an important producer of marble. Italy is also the second largest producer in Europe of crude steel and cement.
Wind energy and photovoltaic energy: At present there is an increase in photovoltaic energy production in Italy; in 2012 amounting to 18.3 TWh. Wind energy represented 13.1 TWh in 2012 covering 9.6% of national electricity supplies. Puglia and Campania lead wind-produced energy, accounting for 5% of their area's own electrical energy consumption and 50% of total wind energy generated in Italy.
Salt: Common salt (sodium chloride). In Italy there are various salinas, the largest of which is in Sicily (Trapani), which extract salt from sea-water. There are also salt-mines that extract Messinian rock salt at Realmonte and Petralia (Sicily), the latter being the largest salt-mine in Europe.

Natural Resources of Portugal

Exploitation of natural resources in Portugal goes back to the Lower Palaeolithic with the extensive mining of flint from sedimentary rocks near Lisbon and quartzite cobbles from the fluvial terraces. The natural resources of Portugal can be divided into metalliferous minerals (16 different metals have been mined historically), industrial minerals (14 mined and 8 quarried), ornamental rocks and energy and hydrogeological resources.
Gold (and to a lesser extent silver) was widely exploited from at least the Bronze Age until the 1980s, but with a climax during the Roman times (1st -3rd centuries B.C.), from large placer, open cast and subterranean mines. Tin (from cassiterite) was also mined, mostly from placers, from the Bronze Age and peaking during the 20th Century for the canning industry. As well as tin, this metallogenetic province also yielded tungsten, which was extensively exploited between the 1930s and 1950s for ferberite and scheelite - including as one of the main sources of tungsten for Nazi Germany. Panasqueira mine is still operating as one of the most important in Europe. The most important mine today, however, is Neves-Corvo, extracting copper, tin and zinc from the Iberian Pyrite Belt.
Important industrial minerals are gypsum, feldspar, lithium (Portugal is the world's 5th most important producer), quartz and rock salt (halite). The most important industrial rocks are, in order: limestone and granite aggregates, common sand, limestone for cement, clays (ball clay and china clay) and specialist sands. Ornamental and building stones are very important, with 150 different commercial types, including marbles (that have been quarried from at least 370 A.D. in Alentejo), slates and schists, limestone breccias, limestones, diorite and gabbro, granites, porphyries, quartzite, volcanic rocks in the Azores and Madeira archipelagos and serpentinites and nephelinic syenite from the Monchique pluton. Mineral and spring waters are mostly distributed in the Iberian Massif and represent a value of 290 million €/year globally.
Energy resources are scarce representing still 58,3% of the total electricity produced in 2013 by renewable sources such as hydroelectric (28,9%), wind (23,2%), biomass (5,3%) and solar (0,9%) power plants. The production of electricity in country's mainland, based on renewable energy sources, was in 2013 more than 29TWh. Geothermal resources are locally important in the Azores archipelago (20% of the electricity consumed) and uranium was mined between 1951 and 2001 at an average of 143t/year, during the climax in the 1980s, for export. Portugal has the

most important uranium reserves in the EU.
In 2009 there were 1009 mining concessions operating in Portugal, about half of them related with ornamental and building stones. However, the 5 mines exploiting metals still represent 45% of the profit taken by the mining industry in Portugal, representing more than 1100 million € annually and providing work for around 9000 people (in 2010).

Natural Resources of Spain

Natural resources in the Iberian plate are abundant and have been intensively mined since early Iberian times (1000 to 200 B.C.) - before the Romans invaded. Metallic minerals were mainly exploited, mainly haematite, sphalerite, cinnabar, cassiterite, chalcopyrite and galena, in the search for iron, copper, tin, mercury and lead. Gold and silver, as native metals, were also intensely mined. The arrival of Romans in Iberia led to agreements with native tribes in different regions and a more effective, ordered and intensive mining system. Most of the main mining areas of these times have remained active until recently and many of them continue in production. The most important metal ores are associated with intrusive processes related to the Caledonian and, especially, the Variscan orogenies. The successive collision of different continental plates against the continent of Laurentia led to the subduction of the Rheic Ocean between, below the continental block and compression of the continental crust above. This lead to the intense local generation of magma which as it rose produced a hydrothermal phase leading to the generation of enormous mineral resources. The successive phases of the Variscan Orogeny appear today as concentric, parallel bands of different metamorphic units forming the Iberian Massif in SW Iberia and S Portugal. The large band of mineralisation known as the 'Iberian Pyritic Belt' (*Faja Pirítica*) formed at this time and holds what may be the most important metal ore concentration in Europe. A later, lateral migration of hydrothermal fluids that contaminated the continental crust further east led to the formation of the enormous mineral deposits of cinnabar, the main mineral of mercury (Hg) in the region of Almadén (SE Iberia). Large mining operations in these areas are still active today.
Gold mining has been active for a long time in Iberia, the main sources for gold being mainly of sedimentary origin. Post orogenic (i.e. Alpine) alluvial sediments of Oligocene-Miocene age have been mined for gold in NW Iberia (Galicia) in the fluvial deposits of river Sil, in the NW part of the province of Leon and in the southern margin of the Cantabrian mountains, where large amounts of gold were concentrated. The exploitation of these materials by the Roman technique known as "*Ruina Montium*", which provoked the collapse of a hillside by the injection of water at high pressure, led to the formation of a unique landscape in the area known as "*Las Médulas*", which has now been listed as World Heritage. Native silver has also been the subject of intense mining from Roman times to the late 18th Century. The most important sites were also along the Iberian Pyrite Belt, from SW to NW Iberia and the boundary with Portugal, in what is traditionally known as the "Silver trail".
Coal mining has been very active in the Upper Carboniferous rocks of the Cantabrian Mountains. The origin of the enormous coal deposits of Asturias and León (N Iberia) was the large concentration of plant remains in internal or coastal sedimentary basins at equatorial latitudes, during the closure of the Rheic Ocean. Coal mining traditions in Asturias go back to the 18th and 19th centuries, although it probable that some working took place long before, in pre-Roman times. Production of lignite has also taken place from Mesozoic rocks of Lower Cretaceous age in the Iberian Range. This 'brown coal' formed from large amounts of continental plant remains which accumulated on the eastern Iberian margin when it was temporarily emerged (this includes the "*Escucha Formation*" of Teruel Province).
The search for petroleum in Spain has for long not been very successful, despite the apparent potential of Upper Jurassic-Lower Cretaceous sediments, including the presence of folded units as potential oil traps. The reason is probably the intense folding which affected the area, which

led to the migration and/or disappearance of existent oil reservoirs. Nevertheless, some good reserves have now been found and developed from Upper Jurassic deposits of North Castilla (in the region of Bureva, N. Burgos and adjacent areas), in the Cantabrian Sea, off the Mediterranean coast near Tarragona and, more recently, in the Cenozoic basin of the river Guadalquivir (S. Spain).

8.6. About soil, rocks and minerals providing essential metals and other materials for agriculture, manufacturing and building

Soil is the product of weathered rocks and composed of rock particles associated with organic materials which have been altered by physical, chemical and biological processes. Soil is the essential basis for agriculture.

Minerals and metals are exploited from specific ore deposits in mines or quarries and provide the raw materials for society. Some specific minerals for the construction of electronic and mechanical devises are very rare and only present in low percentages.

8.7. About raw material

A raw material is a material in its primary state as harvested, mined or quarried and before its refinement for use. Examples of raw materials are: wood, bauxite, iron ore, iron, gold, silver, kaolin (china clay), oil, etc.

Any country that has raw materials in abundance can be economically strong internationally as it has the possibility to export these raw materials to other countries, as well as covering its own needs.

8.8. About the sustainable exploitation of geological resources

Sustainable exploitation of geological resources such as metals, industrial minerals, water, fossil fuels, etc., can help to ensure the availability of these resources for future generations. Geoscientists support global cooperation and collaborative research that can help wisely manage raw materials and human resources.

8.9. Why and how water is stored as underground

Rainfall, melting snow and ice either flows on the Earth's surface as streams and rivers, or is absorbed by the soil into the ground where, depending on the geological conditions, it can be stored underground in rock fractures and in pores between the grains that make up geological formations (e.g. sandstones).

Underground water is the source for aquifers, springs and wells. The upper surface of groundwater is the water table.

8.10. How caves and other underground landforms are formed

Caves are underground karstic formations. Karst formations are limited to areas where solu-

ble rocks such as carbonates (limestones and dolomites) and sulphates (gypsum and anhydrite) are present. As these rocks are easily dissolved and hence eroded by water, shallow holes, sinkholes and caves can be formed.
A cave is a natural underground hole, into which a man can enter. As the water flows in a cave, it erodes and washes away the rock and hence it becomes larger and larger. To form a cave, hundreds or thousands of years, or even millions, are needed, depending on the nature of the geological formation. During this long period of time, slowly dripping water from the fractures in the ceiling of cave can lead to deposition of dissolved calcium carbonate as beautiful structures such as stalactites (hanging from the cave roof), stalagmites (growing from the cave floor) and columns, when stalactites and stalagmites meet.

8.11. About water management

As water supplies become more and more intensively used, interest in how they are managed grows intensely. An important step for the sustainable use of water resources is to find a balance between human needs and what is needed for natural environments.
The management of water resources is very important for human life, but is very difficult in practice due to the planning needed to develop and distribute these resources, whilst balancing the competing demands for water and ensuring its allocation on an equitable basis. This management has to take into account hydrological, chemical and ecological processes in relation to human activities.
Major problems include: 1. Human overuse of water resources for agriculture and urban areas and its ecological consequences, 2. Pollution control and water allocation and 3. Economic and financial management.
Growing uncertainties over global climate change make management decisions more difficult, meaning that new management strategies will need to be implemented in order to avoid any bad decisions in the allocation of water resources.

8.12. About springs

A spring is any natural site where water flows to the surface of the Earth from underground. There are two categories of spring: gravity springs and artesian springs.

There are three types of *Gravity Spring*:

- *Gravity depression springs* occur when the ground surface dips below the level of water table in a geological formation. This type of spring may dry up seasonally.
- *Gravity contact springs* occur when the infiltration of water into a permeable geological formation is restricted by an impervious geological layer and the water is directed to the surface. They often appear as small water holes or seeps on hillsides. This type of spring is usually a good water source.
- *Fracture and tubular springs* occur in geological formation affected by tectonic movements. They are formed when water comes though faults, joints and fissures in rocks. Their discharge is usually concentrated at one point and they are a good water source.

Artesian springs occur when water under pressure is trapped between two impervious geological layers; there are two types:

- *Artesian fissure springs* occur when water under pressure reaches the surface through a fissure or joint. They are similar to gravity fracture springs and they are a very good water source.

- *Artesian flow springs* are formed when a confined aquifer flows underground and appears at a lower elevation. They occur on hillsides and are very good water source.

8.13. Why underground water is sometimes salty in areas near the coast

The need for water in society today is always increasing and this can lead to the over extraction of groundwater. But when the pumping of water from an aquifer is faster than it can be recharged naturally, the system will be out of equilibrium and any further ground water has to be pumped from deeper and deeper levels, or can be drawn into the aquifer laterally.

If the over extracted aquifer is near the coast, this pumping can eventually draw salt water from the sea into the freshwater aquifer causing contamination (i.e. salinisation) of the previously drinkable (i.e. potable) freshwater resource. Many areas near the coast have problems with the salt water intrusion as a result of over extraction.

8.14. Why in some regions does drilling for underground water have to go deeper and deeper?

The quality of groundwater in shallow wells is quite sensitive, while in deep wells the quality changes more slowly – hence they are usually for community supplies. An aquifer depending entirely on rainfall for replenishment, is affected in years of severe draught, and as a result pumping of groundwater has to go to deeper and deeper levels, meaning that the water extraction is more expensive.

In addition, it might not be possible for the aquifer to recharge to its former water level and storage capacity, as the porosity and the permeability of ground may have changed due to compaction as the water was removed. This lost volume is sometimes visible at the ground surface as permanent subsidence.

Intended Learning Outcomes:

- Understand how fossil fuels are formed.
- Know about renewable energy sources.
- Recognise the importance of soil, rocks and minerals for agriculture, manufacturing and building.
- Appreciate the value of raw materials for countries in an international, economic context.
- Be aware of the sustainable exploitation of geological resources.
- Demonstrate knowledge and understanding of underground water and its importance for humanity.

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CHAPTER 9

Human activities alter the Earth

Key words: Human activities, landscape, environment, building, public works, quarries, mines.

Introduction

Since the first stages of human evolution, people have used our planet Earth not only as a habitat to survive in – like all other species – but also to obtain useful materials and sources of energy. An increasingly intensive use of the planet, however, has resulted in physical, chemical and biological changes to the environment that affect both the resources essential to life and the activities of human society. Large constructions (e.g. dams, docks, roads, bridges, factories, etc.), damming of rivers, cutting through mountains, removal of natural vegetation, for example, change the landscape and interfere with natural processes and can cause serious damage to nature.

9.1. How human activities change the Earth

People are part of the natural environment but often act negatively when human activities oppose or ignore the evolutionary processes that regulate the balance between the constituent parts of the Earth system. There is an imbalance between the rapid growth of human populations and the increased use of resources necessary for their subsistence, because of the tendency to satisfy immediate needs without taking into account long term effects. Humans are the only species able to build and use machines to exploit natural resources and shape the Earth's surface, hence making changes to landscapes in a few years, which would take nature thousands. Humans, therefore, can be considered to be the most important agent able to modify landscapes.

9.2. About public works and landscape changing

Public works are one of the factors with the highest potential environmental impact. Public works often include large scale construction projects which have an impact on humans, animals, vegetation, soil, water, air, climate, landscapes, material assets, cultural and historical heritage and other aspects of the environment and their socio-economic interactions. Public works involve ever increasing land use, high energy consumption and emissions of harmful substances.

In addition, in some areas, there can also be an absence of or disregard for the rules and regulations designed to safeguard and protect the natural environment and landscape. Economic and commercial interests are often behind the use of inappropriate sites for development, such as protected areas, areas subject to high levels of natural risk (e.g. landslides, earthquakes, tsunami, etc.) and contaminated areas - as evidenced by recent disasters worldwide.

9.3. How large-scale constructions (roads, bridges, etc.) change the landscape

Communications infrastructure, such as roads, railways, highways or tunnels are often the public works that have most impact on the ground, especially when they affect areas such as steep hillsides, mountains and coastal areas, leaving highly visible "scars", as well as potentially creating various kinds of slope instabilities. Damage is not only linked to effects on the profile of the natural slope, but often includes the accumulation of debris on the slopes or into the valley below. This accumulation of rocky materials is usually highly damaging to native vegetation, as well as degrading the geomorphology and aesthetics of the slope itself.

Any artificial basin which accumulates water artificially for removal elsewhere alters the natural balance of rivers and the groundwater-table and can also have significant ecological impact. The exploitation or overexploitation of underground fluids, especially water, but also oil and gas, through the sinking of wells may also produce various negative phenomena, including subsidence of the ground surface. Other harmful effects can include permanent lowering of the water table, changes of the ground level or the sea bed, changes to drainage systems including both surface (i.e. rivers) and underground, alteration of groundwater chemistry, contamination, etc.

There are also major problems associated with the construction of ports or coastal defenses. These works can significantly modify sea bed sediments, the morphology of the seabed, wave and currents action and hence may strongly influence the future evolution of the surrounding coastline. Possible consequences include speeding up coastal erosion in adjacent areas, leading to a disappearance of beaches and retreat of the land leading to threats to property and habitats.

9.4. How quarries and mines alter the Earth's surface

Quarries are sites where bulk geological materials are extracted as a resource for construction, agriculture (e.g. lime production) and ornamental uses. Typically, mines are areas where more restricted mineral deposits, for instance in veins or layers are extracted. These minerals include coal, metal ores and gemstones.These deposits can either be worked underground using vertical shafts and tunnels, or extracted in large surface excavations known as 'opencast' workings. Whether they are above ground or below ground, mines can have a major impact on natural environments, including:

- Increasing slope instability, leading to collapses and rock falls.
- Disfigurement of a natural landscape, including both through direct excavation and through the tipping of waste materials.
- Destruction of natural habitats, forcing either the migration or the disappearance of the species of animals and plants that inhabit them.
- Interference (including contamination) of surface and ground water systems.

- Production of large volumes of waste materials.
- Air pollution, including dust production.
- Noise pollution through the use of machinery and blasting.

At the end of extraction phase, such sites may be simply abandoned, without appropriate restoration to other uses or to nature and many may become waste disposal sites, or even illegal dumps, leading to further environmental issues. Although some mines and quarries may become important sites for viewing and learning about geology and geological heritage, unless they are well managed, some can still potentially affect the health and quality of life of people living near the works, the natural landscape, the soil and subsoil, air and water quality and flora and fauna.

9.5. How can we minimise the impact of mining and quarrying

Studying the interactions between the natural environment and human activity is fundamental for the protection of landscapes and the Earth's resources. In addition, it is essential to try and put into practice techniques which allow the recovery of damaged natural landscapes and processes. For example the restoration of former quarries and mining areas is becoming a common practice, even long after their closure. The procedures adopted include restoring the original landscape by infilling to the original land surface, the transformation of the quarry site into a nature reserve (including geosite), use of underground facilities, development of recreational, touristic or educational use of the area (including development of parks), flooding to form lakes, etc. In some cases, abandoned quarries are used as landfill sites for waste, which can contribute to their infill and return of the area to a former ground level.

The impact of human activities can be further reduced through:

- Increasing awareness of environmental issues.
- Developing a respect for nature through education.
- A more effective state regulation of potentially environmental damaging activities.
- More sensitive management and safeguard of natural resources.
- Development of a more sustainable use of the environment and landscape.
- Adopting land use planning systems which respect and conserve key natural resources.

9.6. How human activities can destroy the evidence of the history of Earth

All landscapes and ecosystems on Earth today are the result of natural processes taking place over hundreds, even sometimes thousands, of millions of years and for this reason, they are evidence of the geological history of Earth and must also, therefore, be considered to be an environmental asset. From the first appearance of human societies, people have contributed to the story of the Earth, but in the last few centuries this activity has become so intensive that it has begun to destroy some of this natural heritage. Human activities, such as intensive agriculture, large-scale industrialisation and urbanisation, pollution, deforestation, alteration of natural waterways and construction of canals, dams, roads and buildings, changes the natural landscape, destroying or significantly modifying natural features - hence contributing to this ongoing disappearance of the remains and traces of the natural history of our planet.

Intended learning outcomes:

- Explain why people are considered to be important modifying agents of the landscape.
- Describe human impacts on nature.
- Explain how human activities change the landscape.
- Explain how quarries and mines alter the Earth's surface.
- Know how to minimize human impacts on the environment and landscape.
- Appreciate the value of nature.

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CHAPTER 10

Geodiversity, Earth protection and sustainable development

Key words: Geotope, geodiversity, geological heritage, geoparks, geoconservation, nature protection, biodiversity, sustainable development.

Introduction

Geodiversity is the natural diversity of rocks, minerals, fossils, landforms, physical processes, soil features and their assemblages, relationships, properties, interpretations and systems. Geodiversity is part of the Earth's natural heritage and supports sustainable development by many ways, especially by attracting large numbers of tourists who wish to visit, enjoy and admire the dramatic and remarkable landscapes and geological formations that are witnesses to the history of the Earth.

Geodiversity can be considered as the main link between people and their culture and landscapes, through the interaction of biodiversity with aspects of geodiversity such as soils, minerals, rocks, fossils, active natural processes and the human, built environment. According to Gray (2004), active conservation of geodiversity is a measure of a civilized and sophisticated society that wishes to conserve elements of the planet that are both valued and threatened.

10.1. What is a *geotope*?

Geotopes (*or geosites*) are the geological and geomorphological sites and features that represent significant moments in the history of the Earth and are important witnesses of the long evolution of our planet, or demonstrate the active physical and geological processes that continue to evolve the Earth's surface. *Geotopes* can be considered as documentary evidence of the Earth's evolutionary process which have a special importance for science as well as for society as a whole. *Geotopes* are many and varied and their age can vary widely. We can see them in the countryside, in mountains, on coasts, in river systems and in cities. The qualities that a natural physical feature should ideally show to be identified as a geotope are rarity/or representativeness (of larger scale features), scientific value, naturalness (for a process-related geotope) as well as ideally a conservation status and, in many cases, an educational value linked to accessibility.

10.2. What is geological heritage?

Geotopes – both recognised and yet to be identified - constitute our *geological heritage***.** The most important and the most representative geotopes should be identified and selected for conservation using appropriate legislation and policy and planning procedures. This is our duty for future generations.

10.3. How Geological Heritage is studied and why it should be protected

Geology is essentially a field-based science and the existence of well exposed geological features is critical for scientific study, educational use and recreational enjoyment. Geological heritage should be conserved because, firstly, it can be valued in many ways and, secondly, because it is threatened by a great variety of human activities. Geological heritage provides us with a means of studying and understanding both the history of our physical planet as well as the evolution of life. It records billions of years of history, during which time the Earth formed and evolved. Rocks, fossils and minerals record how continents have drifted, how life has evolved, how climates and sea-levels have changed and how natural processes such as volcanism, mountain building and erosion have shaped and continue to shape the landscape.

10.4. What is a Geopark?

Geoparks are (usually) nationally protected areas containing a number of geological heritage sites of particular importance, rarity or aesthetic appeal. Their interest may, in addition to geological, include ecological, archaeological, historical, or cultural features. Such Earth heritage sites or areas can contribute to an integrated concept for conservation, education and sustainable development of a region.

Geoparks achieves their goals through a three-pronged approach: Conservation, Education and Geotourism. They should also foster scientific research and cooperation with universities and research institutes, stimulating a dialogue between the geosciences and local populations.

10.5. What is the meaning of geoconservation?

Geo*conservation* (i.e. geological and geomorphological conservation) is the conservation of geology in its natural setting. This includes the conservation of rocks, fossils, minerals and natural processes. But it can also include museum specimens, building stones, geological data, maps, and art. In other words, Geoconservation deals with the conservation of non-living parts of the natural environment, including geological deposits and features, landforms and soils.

10.6. About nature protection and conservation

Nature protection and conservation have a long history. Some of the earliest attempts at conserving natural features were carried out by George Catlin in 1830 and Henry David Thoreau in 1850 and in 1864, George Perkins March formulated the first modern concept that man has to live with nature (Gray, 2004). Their efforts succeeded in 1864, when the Yosemite Valley in California, USA, became the first protected nature conservation area, followed by the world's first National Park at Yellowstone in 1872, also in the USA.

In the later 20th century, international bodies, such as IUCN, UNESCO and UNEP became more involved in nature protection with various initiatives and projects. For effective nature conservation systems, however, it is important that legal frameworks are adapted to meet local and national needs. In the last few decades many countries have also established legislation and

spatial planning systems and developed funding mechanisms to meet these needs. As a result, regulations for the conservation, management and protection of geotopes and often now available at many levels from state and regional authorities to local communities.
In various countries, geoconservation is also now incorporated into conservation policy and environmental protection as an essential environmental component. Connecting geoconservation to ecological and species (i.e. biodiversity) conservation provides a more holistic approach to nature conservation. In Europe the concept of geoconcervation is widespread, although public awareness is still not at the level of biodiversity or other forms of conservation, such as archaeological and historical.

10.7. About sustainable development and geoheritage

Geological heritage is a part of the Earth's natural heritage and supports sustainable development by many ways, especially by attracting large numbers of tourists to dramatic and attractive landscapes and geological formations which are witnesses to the history of our planet. Initiatives like Geoparks stimulate local socio-economic development through the promotion of a quality-assured label linked with the local natural heritage and encourage the creation of local enterprises and cottage industries involved in geotourism and geoproducts.

10.8. About protected areas and geology

Even today, in protected areas such as Natural Parks, Cultural Parks and NATURA 2000 sites, an awareness of geoconservation is often missing, even when the links between biodiversity and geodiversity are obvious. Crucially, however, geoconservation can provide a fundamental background for biodiversity conservation, as geodiversity provides the variety of environments and conditions which directly influence biodiversity.

10.9. About the geological heritage of your area

To know about and value *local geological heritage* and its role in maintaining biodiversity creates a positive attitude towards nature as a whole. For this reason, geotopes are excellent tools for education for both teaching geology and raising awareness of the need for environmental protection. This raising of awareness can also help reduce the risk of inadvertent damage to or loss of important geological and geomorphological features.
An experiential approach to the study of geological features in place creates an understanding which can facilitate greater understanding of global and more complex geological processes. In this way, as well as raising awareness of geology and geological heritage, maintaining geotopes as part of broader nature conservation programmes can play an important role in the education of a general public.

Intended Learning Outcomes:

- Demonstrate knowledge and understanding of the basic terminology of geodiversity.
- Be aware of geodiversity and geoconservation.
- Recognise that an understanding of geodiversity and geoconservation should be a precondition for broader nature consecration strategies.
- Be able to identify links between geoconservation and biodiversity conservation.
- Identify the links between geodiversity and biodiversity.

- Know where to find legislation for geoconservation at a national and international level.
- Recognise ones responsibilities for geoconservation issues as a local, national and international citizen.
- Appreciate geological heritage as a parameter for local sustainable development.
- Understand planet Earth as a system.

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Environment and Heritage Service Northern Ireland: www.ehsni.gov.uk

European Geoparks: www.europeangeoparks.org

GeoConservation Commission: www.geoconservation.com.

Global Geoparks: www.globalgeopark.org

Natural England: www.naturalengland.org.uk

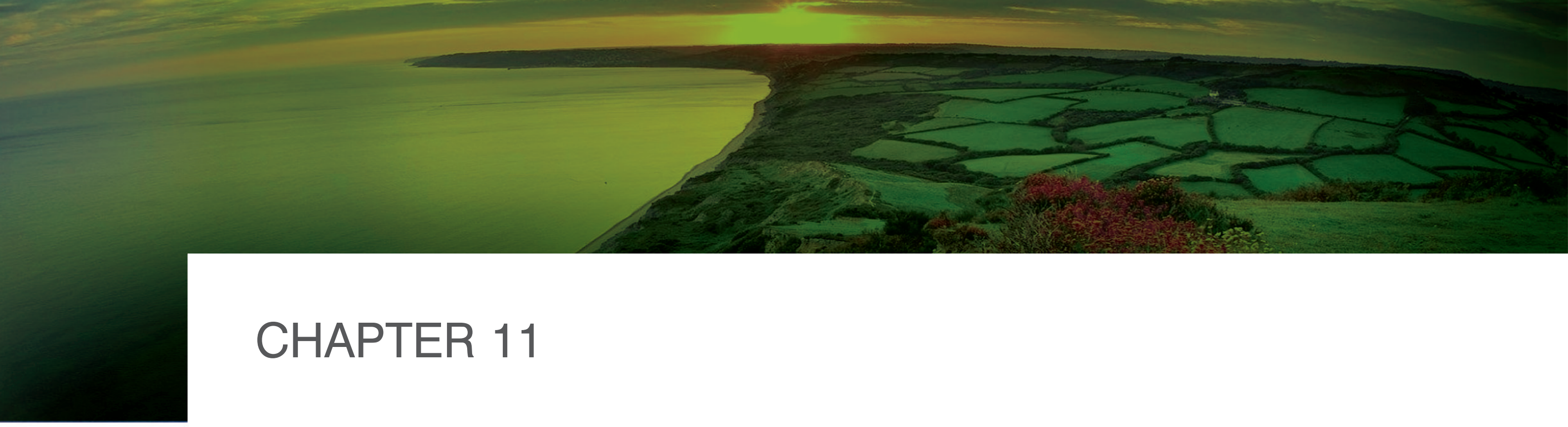
Natural Resources Wales [formerly Countryside Council for Wales]: www.naturalresourceswales.gov.uk

ProGEO: www.sgn.se/hotell/progeo

Scottish Natural Heritage: www.snh.org.uk

UK RIGS: www.ukrigs.org.uk

UNESCO, Earth Science Division:
www.unesco.org/science/earthsciences/geological_heritage



CHAPTER 11

Earth yesterday, today and tomorrow

Key words: Human distribution, land management, environmental change, climate change, global warming, mineral exploitation, exploitation of soils, exploitation of water, pollution.

Introduction

We live on a dynamic planet, where geological processes are continuously active and human interactions with natural systems can cause negative effects, even increasing potential risks to human populations. To avoid such scenarios, it is necessary to understand the dynamics of the Earth system and to learn how to sustainably live and interact with the planet by developing and respecting environmental management regulations.

11.1. The Earth before dawn of humans

The Earth was formed around 4,550 million years ago, but modern humans did not evolve until around 200,000 years ago. Life had appeared on the Earth by around 3500 million years ago under water and in the sea, evolving into many different types of organism, and eventually becoming widespread on land after around 400 million years ago. Climates and environments have changed due to the dynamics of the Earth's crust and small variations in the Earth's orbit, which have influenced the way landscapes are shaped by geomorphological processes.

11.2. Palaeoclimates and the impact of lithospheric dynamics on climate change

Ancient climates are recorded in rocks and testify to the dynamics of the tectonic plates that make up the Earth's surface. Mountain Belts are built up through the collision of these plates and are responsible for important changes in regional temperature and rainfall levels. Plate tectonics is also responsible for connecting and closing oceans and consequently influencing the distribution of heat, and hence climates, across the planet by changing major oceanic current systems. For instance, there are remains of glacial deposits dating from the end of the Palaeozoic Era in Antarctica, Australia, India, South Africa and South America which provide evidence that these continents have moved through time.

11.3. Human occupation and land management problems in drainage basins, coastal areas and on slopes

Depending on the geological and climactic characteristics of the region, human occupation and activities have the potential to increase fluvial erosion and flooding, as well as increasing coastal erosion, slope erosion, landslide risk and groundwater pollution. Geologists can predict and help prevent the geological risks associated with these natural phenomena and establish appropriate land management systems.

11.4. Human beings as agents for environmental change

Human beings have developed the ability to transform their environment to improve its suitability for human society. Such technological development implies environmental impacts that may also adversely affect the quality of the environment, for instance by building large hydroelectric stations and changing drainage basins, building in coastal areas and on alluvial flood plains and hence increasing the risk of flooding, deforesting mountain areas and provoking landslides, overexploiting of natural resources, etc.

11.5. Global warming

The development of our modern society has been dependent on the burning of fossil fuels for industry, transport and electricity production. This process releases large amounts of CO_2 to the atmosphere that can have a greenhouse effect and consequently contribute to raising the average temperature of the Earth.

11.6. Exploitation of minerals, ornamental rocks and other geological raw materials

The geological resources that we use to make everyday objects and for buildings and other constructions are considered to be essential raw materials. Due to their localised distribution in the Earth's crust, however, most of these are non-renewable resources. The most commonly used are sand, clays, and hard rocks such as sandstone, limestone and marble.

11.7. About environmental pollution

In modern societies, pollution affects water resources, the atmosphere and soils. Only a fundamental change of attitude can help reduce this pollution, with the implementation of environmental measures such as reducing the burning of hydrocarbons, improved refuse and waste water management and the protection of water reservoirs. Pollution is a major threat to the health and stability of the ecosystems of our Planet and is consequent a very real threat to life, causing disastrous reductions in the numbers of many species, as well as potentially seriously affecting human life.

11.8. About the exploitation of soils

Although agriculture is the most ancient human practice of soil exploitation, it can also be the most damaging. De-forestation, over-cropping, use of fires and intensive grazing can all contribute to stop the regeneration of the nutrient content of soils.

11.9. About the exploitation and pollution of water resources

Water is a very important resource but can vary in its quality. Groundwater geological reservoirs, or aquifers, can store water which can be made accessible for human use. Unfortunately, however, the growth of global populations can increase water pollution across increasingly larger areas, including in both coastal regions and inland drainage basins. The source of this pollution is mainly from agriculture, industry and urban sources – including both human and runoff.

11.10. What regional and global environmental changes should be expected in the 21st century?

Although modern societies are growing faster and faster and human impacts on the environment are increasing, human consciousness about the environment is also beginning to change. Nevertheless, human pressure on the planet and on its geological resources is causing irreversible changes that could very seriously damage human health. Fortunately, however, people can now understand how they affect the planet and how to respect the dynamics of the Earth's systems through sustainable land management and development policies.

Intended learning outcomes:

- To understand the Earth as a global and dynamic system.
- Recognise the role of humans in the Earth system.
- Identify ways to manage planet Earth sustainability.

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CHAPTER 12

Geological maps

Key words: Mapping geology, scale, key, cross section.

Introduction

We can study the geology of an area either in the field **and**/**or** using a geological map. Geologists record in the field the variety of geological features and rock and deposit types present, often representing many millions of years of geological evolution, and interpret them, presenting the results as a geological map. By reading this map, people can learn about the geological history of the mapped area. This map shows the distribution of rocks, deposits and geological structures at the Earth‘s surface – the geological foundation of the mapped area.

12.1. Know how geologists present geological information as a map

By reading a geological map we can be learn about:

- The age of the rocks present and, sometimes even the fossils and minerals they contain.
- The distribution of the rock types present and the position of structures such as faults, folds and unconformities.
- The relationship between older and younger rocks.
- The mineral deposits that rocks may contain.
- The location of many physical features, such as landslides, quarries, springs, caves, **waste-dumps** etc.

12.2. Know about topography and relief

Geological mapping is normally presented as an overlay to a topographical map of the study area. The construction of every geological map, therefore, follows the same basic rules as for the use of a topographical background, including inclusion of a scale and a key (sometimes known as a ‘Legend’). The scale of the map is the ratio of the distance between two points on a map and the real distance between the corresponding points on the Earth’s surface. For example, a scale of 1/50,000 means that 1 cm on the map represents 50,000 cm – or 500m – on the Earth’s surface.

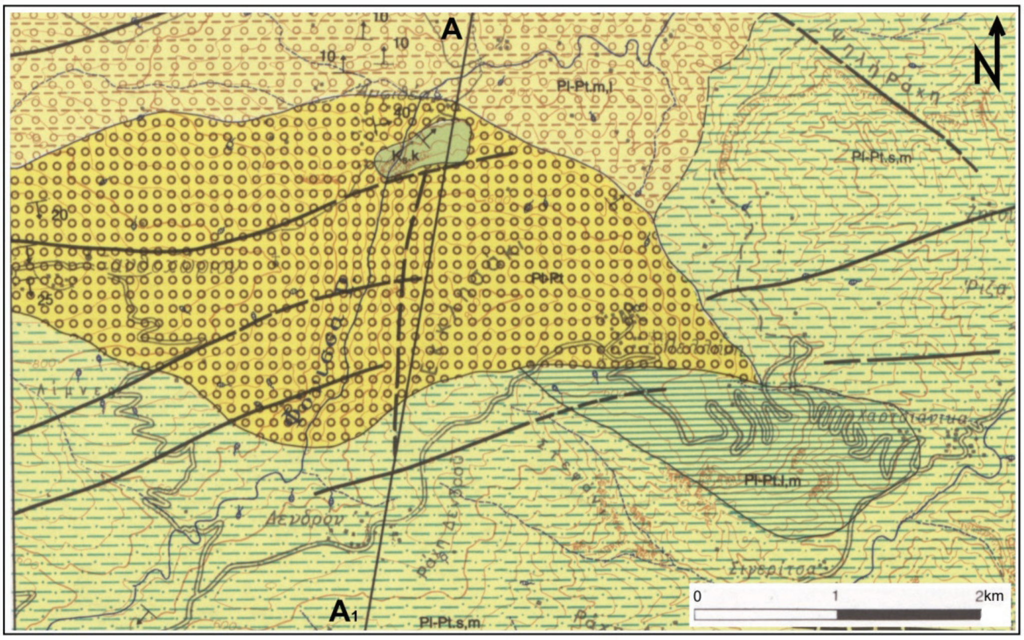
12.3. National and international geological maps

Many countries have national Geological Survey's, often producing local maps at a scale of between 1/50,000 and 1/100,000. This mapping can be compiled together to produce a national map, often at a scale between 1/500,000 and 1/1,000,000 depending on the size of the country. For international or global geological mapping, the scale will be smaller - for instance an International Geological Map of Europe has been produced at 1/1,500,000 and the World Quaternary Map (i.e. recording the distribution of rocks formed during the last 1.8 million years) has a scale of 1/5,000,000. Larger scales of 1/25,000, 1/10,000, 1/5.000, 1/1.000 and even 1/500 are very useful in applied geological studies, where greater detail is needed (e.g. for the construction of roads, dams, landslip monitoring, etc.).

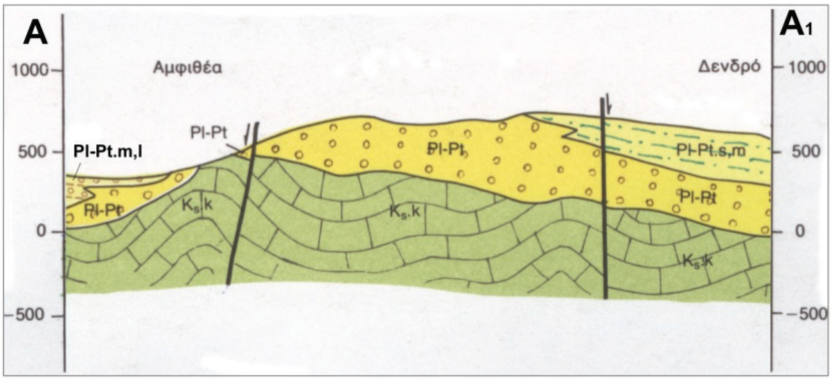
12.4. Know about geological structure

A geological map always has an accompanying key, which explains the abbreviations, symbols, patterns and colours shown on the map. Every marked outcrop of rocks will usually have a special symbol or abbreviation that will usually combine the rock type and geological age, for instance: Mc = 'Miocene conglomerate', Jm = 'Jurassic marble' or CPS = 'Creedy Park Sandstone Formation'. These keys also usually show an idealized geological succession or 'column' for the area, with the rocks and deposits present in chronological order, i.e. with the oldest at the bottom of the column and the younger in their correct order above. The different rock-types shown on the legend are usually marked by a number on the map.

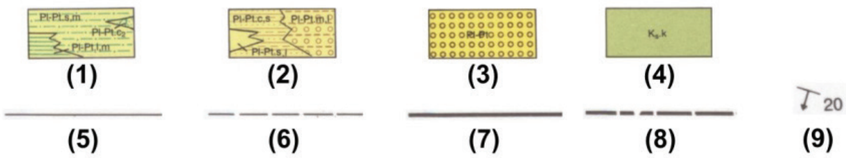
GEOLOGICAL MAP



CROSS SECTION



LEGEND



Excerpt from the "Xylokastron Sheet": part of the geological map of Greece

Key: 1. Sandy marls (Lower Pleistocene), 2. Sandstones and conglomerates (Upper Pliocene), 3. Conglomerates (Upper Pliocene), 4. Limestones (Cretaceous), 5. Geological boundary (observed) 6. geological boundary (inferred, i.e. covered), 7. Fault, 8. Fault (inferred), 9. Dip and strike of beds (i.e. the angle of slope and direction of the geological layers).

Although a conventional printed or digital geological map shows a two dimensional view of the surface of the mapped area, a third, or vertical dimension is provided by geological cross-sections. These cross sections are constructed from the mapped geological information between two points on the map, including information about the shape of the land surface (i.e. the topography), the types of rocks present and their thickness and dip direction, as well as faults and other geological structures.
To construct a cross-section two scales are used - a horizontal scale which is usually the same as the map's scale and a vertical scale that can vary depending on requirements. Typically, however, this latter scale is expanded relative to the horizontal scale to allow more detail to be included, for instance the inclusion of relatively thin but important geological units.
By reading a geological map it can be easy to interpret the past history of the area, by determining 1) the geological events or processes that are recorded and 2) the sequence through time in which these events or processes happened. Three very important principles can help users work out this sequence:

- *The Law of Superposition:* i.e. The rock that lies above another is expected to be younger than the one below (this is always true for sedimentary rocks which have not been overturned by major tectonic events).
- *The Law of Cross Cutting Relationships:* A rock or structure is older than the rock or structure that cuts it across.
- *The law of Inclusions:* A rock *fragment* included in another rock is always older than the host rock.

Geological maps are the main archive of knowledge about the surface of the terrestrial Earth and a fundamental tool for further research and exploration. One of the first true national geological maps published in Europe – with rocks types ordered by their relative geological age – was produced by the canal engineer William Smith for England, Wales and southern Scotland and published in 1815.

Geological Maps are very useful to the our society for applications such as:

- Searching for ground water resources
- Prospecting for mineral or energy resources
- Assessing natural risks
- Looking for building materials
- Locating sites suitable for waste disposal
- Assessing soil quality for agriculture
- Informing dam, road and other major construction projects.

12.5. See the geology of a region from the air

In areas where access might be difficult, geological mapping can be carried out using aerial photographs. Historically these have been taken from aircraft flying at a fixed height in a series of parallel transects. The first aerial photographs, however, date from 1860 and were taken of the city of Paris from a balloon. Today, in addition to aeriel photographs, satellite images are also used, including the well-known ”Landsat” images. Interpretation of satellite images, however, requires special computer processing techniques. Some images are produced by governmental organisations, although commercial companies are also involved. As with aeriel photographs, the early use of satellite imagery was often military, but now they are also used for meteorological, geophysical, telecommunication, landuse and natural resources studies.
This type of survey is known as ‘remote-sensing’ and both aircraft and satellites are still used. Images are recorded with photographic cameras, polyspectral and thermal scanners and radar (microwaves). In geology Landsat and other comparable images can be very useful, for instance for:

- Research into and prospecting for natural resources (e.g. metalliferous and other mineral deposits, hydrographic systems, etc.).
- Identification of fault-zones and landslides areas.
- The selection of sites for major constructions such as dams, bridges, harbours, etc.
- Investigating and monitoring landscape scale change.

Classically, a field geologist would use a simple range of tools to make a geological map, for instance a topographic base map of the region, a notebook, some coloured pencils, a geological hammer, a combined compass and inclinometer for measuring slope angles, magnifying lenses and occasionally an altimeter. Today, however, some of these tools have been replaced or at least supplemented by laptops or netbooks for note taking, GPS devices for determining precise locations and GIS (i.e. Geographic Information System) applications for plotting locations and records. Despite all this technology, however, it is the experience and accuracy of the field mapper that remains the key determining factor as to whether the geological map produced will be reliable, even credible.

Intended learning outcomes:

- Understand the underlying principles of geological mapping.
- Recognise the importance of time and scale in geology.
- Visualize geological data in two and three dimensions (including using cross-sections).
- Recognize the importance of different types of geological maps.
- Describe the basic steps needed to compile a geological map.

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CHAPTER 13

A brief geological history of your region

Key words: Geological history, Austria, Greece, Italy, Portugal, Spain.

a. AUSTRIA

13a.1. Know a brief geological history of your country

The northernmost part of Austria, the Bohemian Massif, mainly consists of granite, gneiss and schists and is part of the Variscan Mountain belt which formed from around 350 to 320 Million years ago. It is overlain by Upper Carboniferous to Permian lacustrine sediments which are known from a locality on the Bohemian Massif (Zöbing) and also in deep boreholes. These deposits are followed by marine Jurassic to Middle Miocene sediments and then by Upper Miocene to Quaternary continental and fluviatile sediments of the 'Molasse-Zone'.
Northern Alpine units comprising various tectonic nappes of the Calcareous Alps (mainly calcareous slope, reef and basin sediments of Triassic to Lower Cretaceous age) were tectonically emplaced onto the Bohemian Massif and the 'Molasse-Zone', with a 'Flysch-Zone' in front (comprising Upper Cretaceous to Lower Eocene deep water sediments). These nappes rest on the Central Alpine units (mainly of Proterozoic and Palaeozoic age). To the south there are equivalents of the Northern Calcareous Alpine units in the Southern Calcareous Alps. Sunk into these Alpine units are Neogene basins such as the Vienna Basin, the Graz **B**asin and the Klagenfurt **B**asin (see section 13.2).

13a.2. See a general cross-section of your country showing the main geological units

The sections provided show the main tectonic units which make up the geology of Austria.

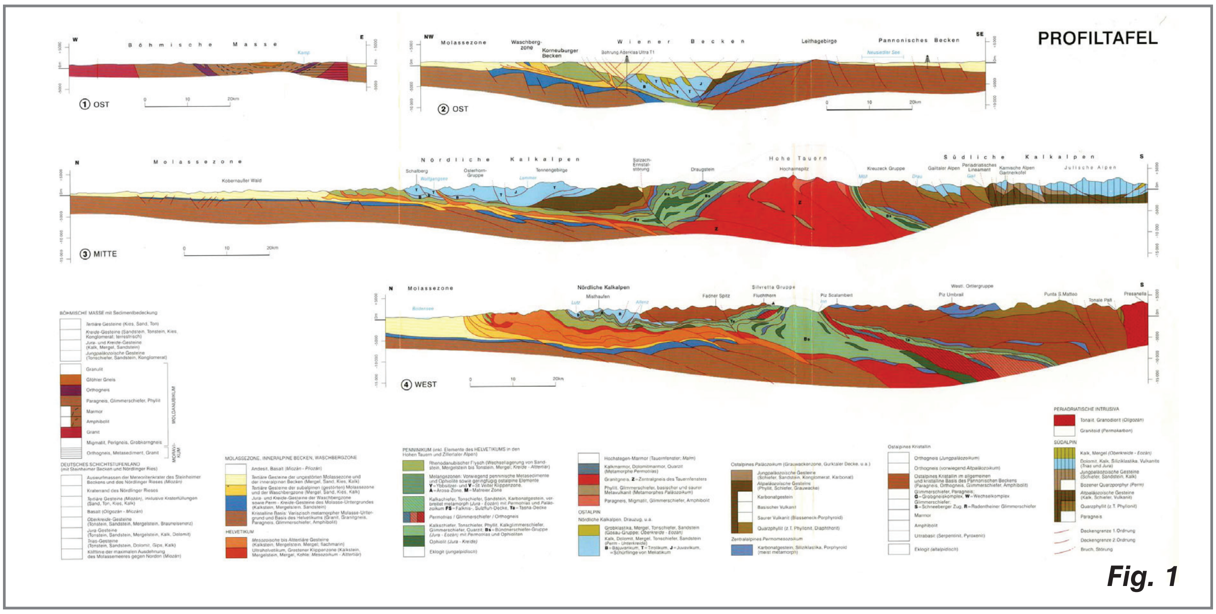

Fig. 1

13a.3. Learn about the geological evolution of your country from Pangaea onwards using geological maps and discussion

The geological evolution of Austria from Pangea onwards is described in the book edited by H.G. Krenmyr in 2002, entitled *Rocky Austria.- Eine bunte Erdgeschichte von Österreich* (Geologische Bundesanstalt, 64 Seiten; 1 Geol. Karte. – Wien (F. Berger, Horn). The main geological units are also discussed above.

13a.4. The age of the oldest rocks of your region

The oldest whole-rock dated unit known in Austria is the "Dobra-Gneis" from the Moravikum/ Bites-Unit of the Variscian belt of the Bohemian Massif. It has an age of 1.380 million years and belongs to the Neoproterozoic Era. The oldest radiometrically dated minerals, however, are zircons from a quarzite from Drosendorf (Bohemian Massif, Drosendorf-Unit) and have an age of 3.4 billion years.

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b. GREECE

13b.1. Know a brief geological history of your country

The geological history of Greece is very complicated as it is related to the geological evolution of the Mediterranean and Europe, as well as active geological processes, such as 'neotectonics' and volcanism. In particular, the interaction between the Eurasian and African continent has intensively affected the geological structure of the area over the last 200 million years.
The rocks which dominate Greece can been grouped according their age and tectonic history into three main categories:

1. *Pre-alpine rocks.* These were deposited before the Triassic Period (when the Alpine 'geosyncline' began to develop) and have been affected by older orogenic events, such as Hercynian folding and represent the substratum for alpine sedimentation. The oldest sediments in Greece are of Silurian age and outcrop in Kos, Chios, but usually the Pre-alpine rocks are metamorphic to semi-metamorphic and of Upper Palaeozoic age. These rocks include the Rhodope and Serbomacedonian massifs in north east Greece which are dominated by metamorphic and plutonic rocks – the most extensive area of these types of rocks in Greece. They were partly metamorphosed and faulting again during the Alpine compression.

2. *Alpine rocks.* These rocks were deposited from the Triassic to the Neogene (Lower Miocene) periods, when the last phase of the Alpine orogeny took place, and the Hellenides mountain chains were formed. Flysch represents the youngest Alpine depositional phase and was deposited as the mountains developed.

3. *Post-alpine rocks.* Deposited after the Alpine orogeny, these are molasse and clastic rocks sedimentary rocks of Neogene and Quaternary age.

Three main phases of intense tectonic activity are recorded in Greece. The oldest dates from the Upper Jurassic to the Lower Cretaceous and is linked to the closure of the Tethys ocean. The second took place during Palaeogene and early Neogene and the third, or youngest, is the neotectonic activity that began in the Middle Miocene and continues to the present day (e.g. in the Arc of Aegean sea).

The Alpine geology of Greece has been described in terms of geotectonic zones and *massifs*, because the Pre-alpine basement of Upper Palaeozoic age consisted of an alternation of submarine ridges and deep troughs formed as a result of Hercynian folding. Across these submarine ridges and troughs, different palaeogeographic environments and sedimentary conditions are represented. Every geotectonic zone shares a common geological history (i.e. environment of deposition, faulting and folding history, etc.) and maybe a hundred kilometres or more long and up to several kilometres thick. Depending on their location within the internal or external arc of the Hellenides chains, these geotectonic zones are known as either *internal* or *external geotectonic zones*. The succession, or sequence, of massif and geotectonic zones from east to west is the following:
Internal geotectonic zones: a) Axios or Vardar zone, b) Pelagonian zone and c) Subpelagonian zone. Their main characteristics are i) the presence of opholites, ii) transgressive sedimentary formations of Middle to Upper Cretaceous age and iii) they have been affected by two orogenic phases, Upper Jurassic-Lower Cretaceous and Palaeogene-Lower Neogene.
External geotectonic zones: a) Parnassos–Giona zone, b) Olonos-Pindos zone, c) Gavrovo–Tripolitza zone, d) Ionios zone and e) Pre-apoulian or Paxoi zone. The main characteristics of these

zones are i) continuous sedimentation from the Triassic to the Neogene (i.e. Lower to Middle Miocene) periods and ii) they have only been affected by the Palaeogene-Lower Neogene orogenic phase.

Post-alpine rocks are dominated by molasse: very thick, post-orogenetic, clastic formations and Neogene-Quaternary formations deposited in the basins formed as a result of neotectonic activity during the Miocene. The latter are usually clastic formations of marine, brackish, lacustrine or continental origin and are widespread across Greece. They include deposits recording two remarkable events that took place during the evolution of the Mediterranean sea: 1) the almost completely drying up of the sea as a result of tectonic activity which closed the Straits of Gilbratar around 6 million years ago (the 'Messinian crisis') and 2), sea-level fall to a level considerably lower than today during the cool interval of the last glacial period (from around about 110,000 to 20.000 years ago). Some lacustrine Neogene and Quaternary formations also include lignite deposits of great economic value.

13b.2. See a general cross-section of your country showing the main Geological units

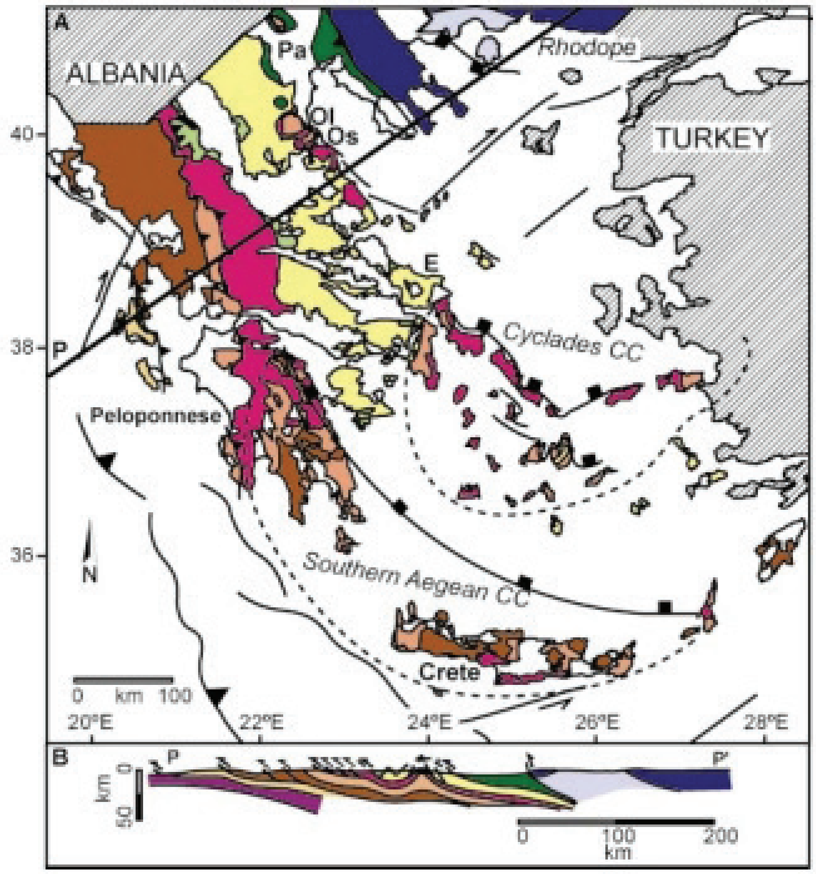

Fig. 2: *A: Geological map of Greece by Bornovas and Rontogianni-Tsiabaou (1983) modified by Jolivet et al. (2004) and van Hinsbergen et al. (2005).*
E-Evia; Ol-Mount Olympos; Os-Mount Ossa; Pa-Paikon window; CC-core complex.
B: Schematic cross section of Aegean nappe stack along profile P-P9 (By van Hinsbergen et al. 2005). See next Figure 3 for key.

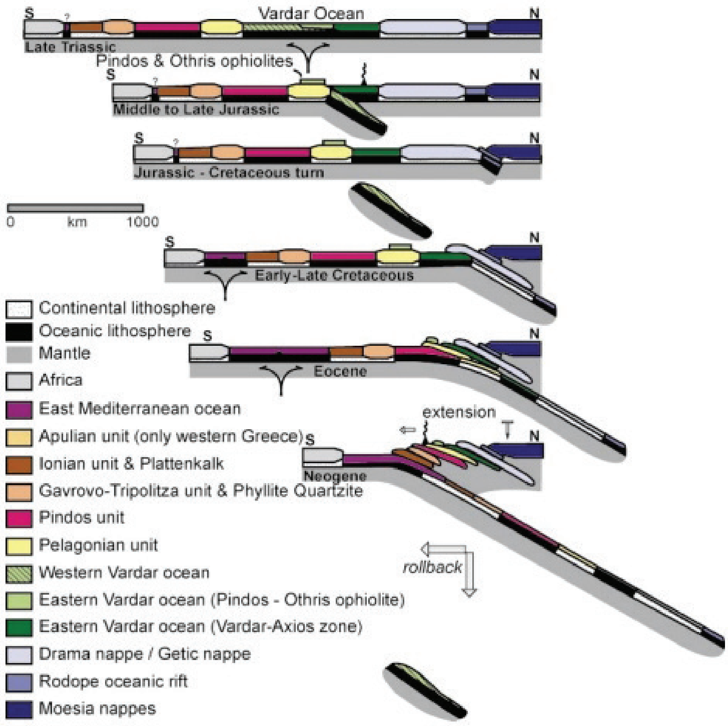

Fig. 3: *Schematic overview of development of nappe stack and subduction during Alpine orogeny in Greece. (By van Hinsbergen et al. 2005).*

13b.4. The age of the oldest rocks of your region

The oldest rocks in Greece are found in the Florina Terrane in NW Greece and are late Neoproterozoic crustal rocks varying in age from 699±7 to 713±18 million years ago. They outcrop over an area of around 20X100 kilometres.

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c. ITALY

13c.1. Know a brief geological history of your country

Italy can be divided into seven major geological regions , from north to south these are: the Alps, the Padan plain, the Apennines, Puglia, the Calabrian-Peloritan Arc, Sicily and Sardinia.
The *Alps* are made up of four different structural elements with different rock types reflecting their different origins. There are ophiolites and flysch from the former Tethys Ocean and polymetamorphic schists and intrusive basic and acidic rocks from the late Palaeozoic. There are also eclogites and blue schists linked to metamorphism connected with subduction.
The *Padan Plain* extends as far as the southern limits of the Alps and comprises great swathes of Palaeogene-Neogene and Quaternary sediments which formed after the neighbouring mountain chains developed.
The *Apennines* have a nappe structure in which four distinct units can be recognized, each with a characteristic stratigraphical-structural successions, some of which continue underneath the Padan Plain. The sediments of the stratigraphical-structural units are of Mesozoic and Palaeogene-Neogene age.
Puglia is a stable region with a continental crust of normal thickness, covered by around 6 km of evaporates and shallow water limestones that laterally pass into deeper water carbonate sediments on the eastern slope of the Gargano.
Sicily occupies a sector of the central-western Mediterranean and is a segment of the Alpine system that developed along the boundary of the African and European plates. This chain links the African Maghrebides with the southern Apennines, through the accretionary wedge of Calabria forming the so-called *Calabrian-Peloritan Arc*. Nevertheless, although they have features in common, there are also numerous structural and paleographical differences between each geological region. For instance, analysis of Sicilian sedimentary successions shows that those of Palaeozoic-Paleogene age represent the sedimentary covering of a distinct paleogeographical region that developed in the Tethys Ocean and on the African continental margin before collision and deformation.
The core part of the *Calabrian-Peloritan* domain, however, consists of pre-Alpine (including Variscan) igneous and metamorphic rocks (granite, gneiss, mica schists, phyllite, etc.) which are sometimes associated with Mesozoic sedimentary successions. Chaotic ‘Flysch’ deposits rich in olistoliths, have tectonically slid over these sequences, and outcrop near the southern crust of Calabria.
The last geological region is that of the *Sardinian-Corsican block*, which mainly belongs to the European foreland of the Alps. The rotation that placed Sardinia in its present position took place between the Oligocene and the Miocene. Most of Sardinia is made up of Palaeozoic rocks, including limestones, mudrocks and sandstone that were deformed during the Caledonian and Hercynian orogenies and later covered with Mesozoic and Palaeogene-Neogene sucessions. Some of these rocks underwent a regional metamorphic phase that slightly altered the southern part of the island, whereas towards the north, metamorphism was more intense and mica schists, gneiss and granites formed.

13c.2. See a general cross-section of your country showing the main Geological units

These sections show the main tectonic units that make up the geology of Italy.

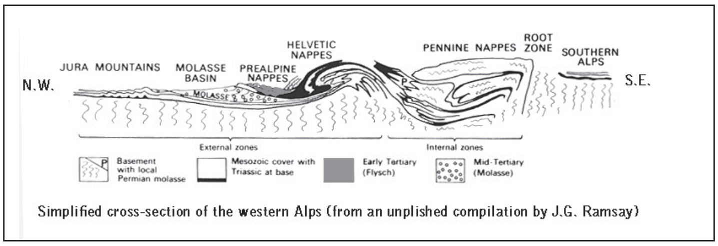
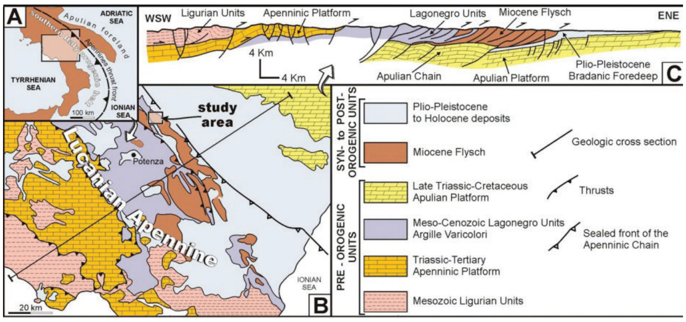


Fig. 4: *Cross section of Alps*



From D. Chiarella D. and Longhitano S. G.
Journal of Sedimentary Research, December 2012, v. 82, p. 969-990, published online December 14, 2012

Fig. 5: *Cross section of Appennines*

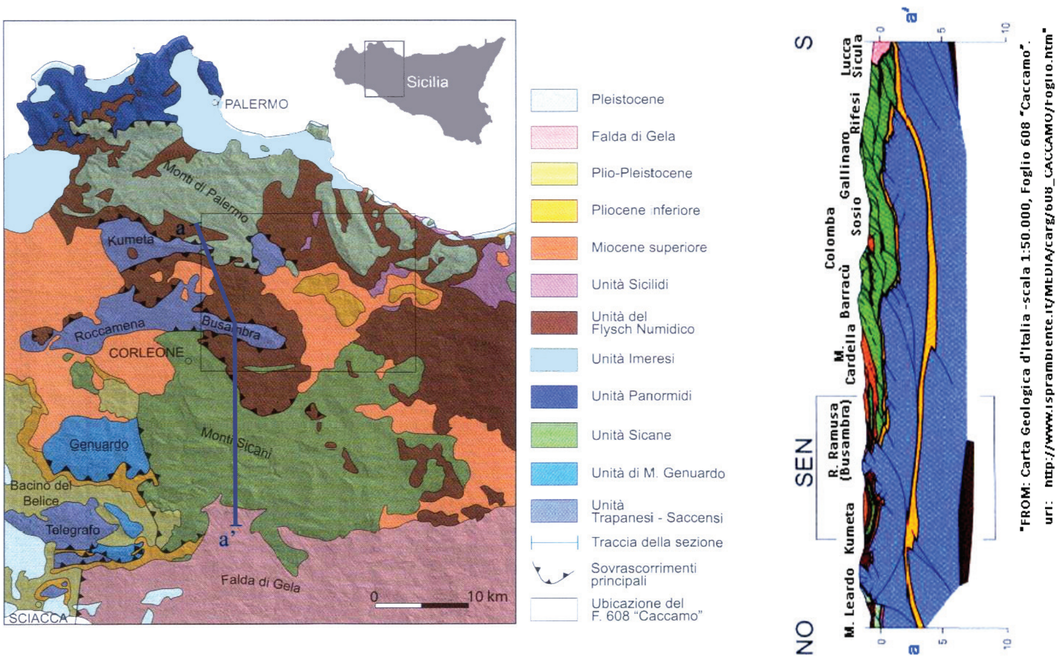


Fig. 6: *Cross section of Sicily*

13c.3. Learn about the geological evolution of your country from Pangaea onwards using geological maps and discussion

At the end of the Palaeozoic, around 250 million years ago, all continents were grouped together as the supercontinent of Pangaea. Within reconstructions of this supercontinent it is possible to recognise Africa, central and northern Europe, Australia, the Americas and Antarctica - but there is no trace of Italy. Indeed, most of the future Italian territory was scattered around the edges of the African and European continents, where they faced each other across the Gulf of the Paleotethys. These areas include a compact block on the southern edge of the European continent and a small portion that was being formed in the ocean, firstly of the Paleotethys in then in the Tethys.

Four major phases led to the formation of Italy as we define the country now:

- A phase of crustal extension as the Tethys formed,
- A compressive phase that led to the disappearance of the Tethys Ocean, the formation of the Alps and the compression of materials deposited on the edges of the African and European continents,
- A new phase of crustal extension that led to the separation of Sardinia and Corsica from Europe and triggered the formation of the Apennines,
- A further phase of crustal extension characterised by the opening of the Tyrrhenian Sea and the completion of the development of the Apennines.

(For more detail see the textbook by Alfonso Bosellini (2005), listed in the bibliography below).

13c.4. The age of the oldest rocks of your region

Metamorphic rocks, of probable Precambrian age, outcrop in a number of areas across Italy. Fossiliferous rocks of Lower Cambrian age (around 500 million years ago) are present in eastern Sicily (near Taormina) and in Sardinia (the “Nebida Formation”).

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d. PORTUGAL

13d.1. Know a brief geological history of your country

Precambrian and Palaeozoic sedimentary, metamorphic and magmatic rocks are very well represented as part of the Iberian Massif. This Massif is composed of several crustal segments (or 'zones') which represent different palaeogeographic regions that were joined together during the Cadomian and Variscan orogenies. The main part of the Iberian Massif belongs to the Central Iberian Zone and the Ossa-Morena Zone that were joined during the formation of the Gondwana supercontinent. They are mainly marine sedimentary rocks which record the breaking up of Gondwana and the development of the Rheic Ocean and range from shallow water, fossil-rich quartzites, shales and carbonates (later metamorphosed into marbles) to deep sea mudrocks, turbidites and fan conglomerates. The origin of these terranes in extreme southern latitudes means that they show evidence of Late Ordovician glaciations.

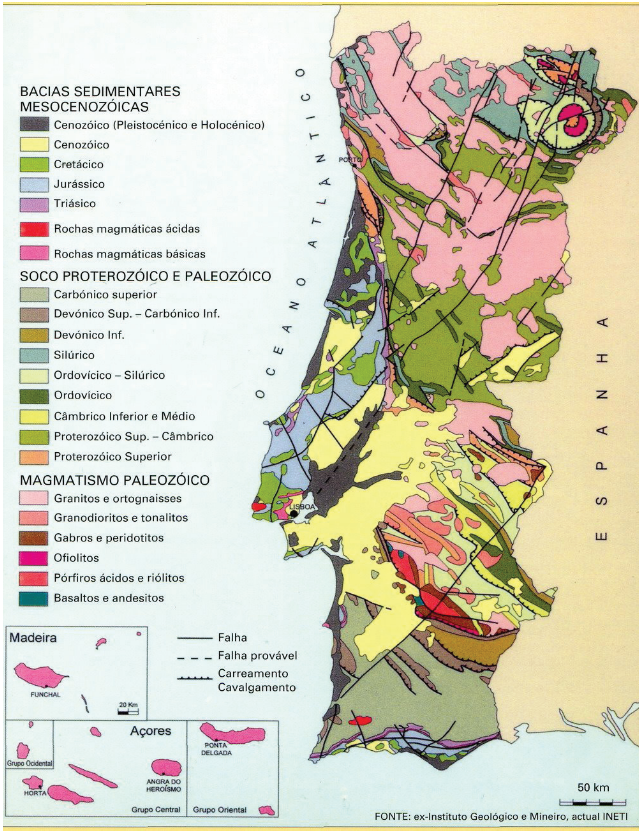

Fig. 7: *Simplified geological map of Portugal (Source: LNEG)*

The South-Portuguese Zone and the allochthonous terranes of Morais and Bragança joined the Central Iberian and the Ossa-Morena zones later, during the closing of the Rheic Ocean which lead to the development of the Variscan-Hercynian-Appalachian mountain belt and the formation of the supercontinent Pangaea. The collision of the Laur-ússia, Huno and Gondwana lithospheric plates after the Middle Devonian, lead to the extensive deformation of earlier sedimentary sequences and uplift which created mountains. This phase also lead to the emplacement of very deeply-sourced mantle-derived gabbro and peridotite rocks (the Alochthonous Terranes of Morais and Bragança) as well as regional metamorphism which formed green schists and gneisses and intense magmatism with the formation of granitic rocks. Hydrothermal circulation linked to this activity led to the development of hydrothermal quartz-rich veins with economically-important minerals. Small intramontane basins developed during the Carboniferous and were filled by lacustrine and fluvial sediments rich in plant debris, leading to the formation of coal deposits.

During the Mesozoic, rifting which formed the Lusitanian and Algarve basins, recording the birth of the North Atlantic. The development of Cenozoic volcanic islands such as the Azores are connected with the evolution of this ocean. On mainland Portugal, however, Cenozoic deposits in the major river basins cover older rocks. For more information on this later geological history of Portugal, see section 13.3 below.

13d.3. Learn about the geological evolution of your country from Pangaea onwards using geological maps and discussion

The later evolution of Portugal in the context of the Iberian microplate is related to the break-up of Pangaea, the opening of North Atlantic and the evolution from the Tethys Ocean to the modern Mediterranean Sea in the south (due to the sequential collision of the African plate with Eurasia and the resulting Alpine Orogeny). Migration of the Iberian microplate northwards during the Mesozoic and Cenozoic is also responsible for the intense climate conditions that led to deep weathering and subsequent major erosion of the Variscan mountain belt leading to peneplanation.

Rifted basins such as the Lusitanian and Algarve basins developed with the opening of Atlantic and Tethys respectively. Detrital sediments coming from erosion of the Iberian Massif and carbonates produced mainly by marine biological productivity (within palaeoequatorial latitudes), filled these basins during and after the major rifting events. Subsequently, tectonic inversion developed with the onset of Alpine Orogeny after the Eocene. Many earlier faults, such as Vilariŋa active fault, were reactivated as reverse faults and some continental basins and drainage systems, such as those of the Douro, Tejo, Sado and Guadiana rivers, developed. These basins were subsequently captured by Atlantic rivers as a response to regional tectonic and global climate changes during Quaternary glaciations.

In the triple junction between the Eurasian, North American and African plate in the Mid Atlantic Ridge, the Azores volcanic islands developed and have remained actively moving away from each other since the Miocene. Volcanism in the Madeira islands, off the North African coast, started around 10 million years ago and finished 6,500 years ago and was caused by a strong thermal anomaly underneath the lithosphere. Glaciers shaped the landscapes of the highest and northernmost mountains of Portugal, such Peneda-Gerĸs-Cabreira and Estrela, during the Quaternary ice ages.

13d.4. The age of the oldest rocks of your region

The oldest rocks in Portugal are gneisses in the Bragança Massif (north east of the country) with an age of around 1,000 million years.

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e. SPAIN

13e.1. Know a brief geological history of your country

The Iberian Peninsula forms a continental block, or micro plate, at the south west limit of Europe. It is attached to the European (or Eurasian) continental plate along the Pyrenees mountain range. The Iberian microplate is, however, a complex aggregate of many small crustal fragments (or *terranes*) which, from the late Precambrian (Proterozoic) to Neogene times, have been added to a primitive nucleus during successive orogenies (Fig. 8).
The oldest nucleus of the Iberian block is formed of high grade metamorphic and some igneous rocks (the "Hesperian Massif"), and forms the western and north western parts of the peninsula - mainly outcropping out in the regions of Extremadura and Galicia. Attached to this nucleus is the Hercynian Massif (or "Iberian Massif"), which formed at the end of the Carboniferous and includes many metamorphic and sedimentary 'belts' ranging in age from Cambrian to Carboniferous - as well as the granitic intrusions that form the core of the Pyrennean and Central Iberian mountain systems. Trilobites, archaeocyathid sponges, brachiopods, graptolites, cephalopods and a wide range of echinoderms and corals are the main fossil groups of Palaeozoic marine rocks, whilst a large variety of fossil plants are present in continental rocks of Carboniferous age.
Remains of Permian deposits form scattered outcrops of red conglomerate and sandstone with volcanic rocks formed during the early rifting of the supercontinent of Pangaea. Triassic rocks outcrop extensively as red sandstones ('Buntsandstein'), dolomites ('Muschelkalk') and clays rich in salt and gypsum deposits ('Keuper'). Both Permian and Triassic sequences formed as the result of the erosion of the Hercynian massifs that formed at the end of Carboniferous times.
Later Mesozoic, Jurassic and Cretaceous rocks form predominantly marine sedimentary sequences, with carbonates and occasional mudrock intercalations – although some non-marine deposits are also present (in particular of latest Jurassic and early Cretaceous age). These rocks were deposited in subsiding sedimentary basins at the margins of the Iberian block and developed as a result of the fragmentation and break up of the Hercynian basement. A repeating succession of marine transgressions and regressions led to an alternating sequence of marine and short continental intervals in which the remains of many invertebrate and vertebrate groups form an exceptional record of the history of life during the Mesozoic. These remains include ammonites, belemnites, sponges, brachiopods, bivalves, echinoderms, corals and marine vertebrates (including reptiles), whilst in continental environments, dinosaurs and plant remains are the most important fossil groups.
The Mesozoic Era ended with the impact of a large meteorite that led to the extinction of many marine and terrestrial groups, amongst them dinosaurs, ammonites, belemnites, and many members of other groups such as foraminifera and bivalves. This mass extinction opened the door to the expansion of many groups of terrestrial and marine animals, especially mammals, but also many groups of invertebrates and plants.
During the Cenozoic Era (from 65 million years ago to the present day) the anti-clockwise movement of the African plate against Europe led to the closure of the former Tethys Ocean, the remnants of which are the present day Mediterranean Sea. This movement also led to the formation of most of the main mountain ranges of Iberia, either as a result of uplift (i.e.'re-activation') of the Hercynian basement and folding of the overlying Mesozoic cover (as in the Pyrennean, Cantabrian, Iberian, and Central Iberian Systems), or as a result of folding and emplacement on

the continental margins of sedimentary sequences deposited on the ocean floor, for instance in the Betic Ranges.

After the main compression phase passed, successive extension phases led to the development of generally continental (or occasionally temporarily marine) sedimentary basins (Fig. 8), the main being the Ebro, Calatayud-Montalbɑn, Duero, Tagus and Guadalquivir basins, with various, smaller, internal basins such as that of Guadix, the Catalonian basins (Vallıs-Penedıs) and a series of N-S oriented Palaeogene-Neogene basins along the eastern part of Iberian block (Jiloca, Teruel, Alfambra, Libros, etc.). All these sedimentary basins are relatively undisturbed and are mainly filled with lacustrine sediments which yield many continental fossil remains, especially mammals, plants and insects. Some of these successions are also important as formal reference sections (i.e. “stratotypes”) for intervals of Palaeogene and Neogene time.

Finally, during the glacial and interglacial periods of more recent Pleistocene times, the Iberian block records some of the earliest hominid inhabitations of Europe, with pre-Neanderthal species such as *Homo heildelbergensis* and *Homo antecessor*. Key localities such as Atapuerca, Orce, Guadix, Torralba, the Vallés basin in Catalonia, and Málaga provide an internationally important record of the expansion of early human populations across Iberia during Quaternary times.

Fig. 8: Main structural units of Iberia. The Iberian Massif (Paleozoic, Brown) occupies most of the Iberian plate, being partly covered by Tertiary (continental) basins, in yellow and by recent orogenes forming mountain systems (in green). The older primitive “Hesperian” Massif”, Precambrian, would form part of the western part of Iberian Massif and some old parts of Portugal.

13e.2. See general cross-section of your country showing the main Geological units

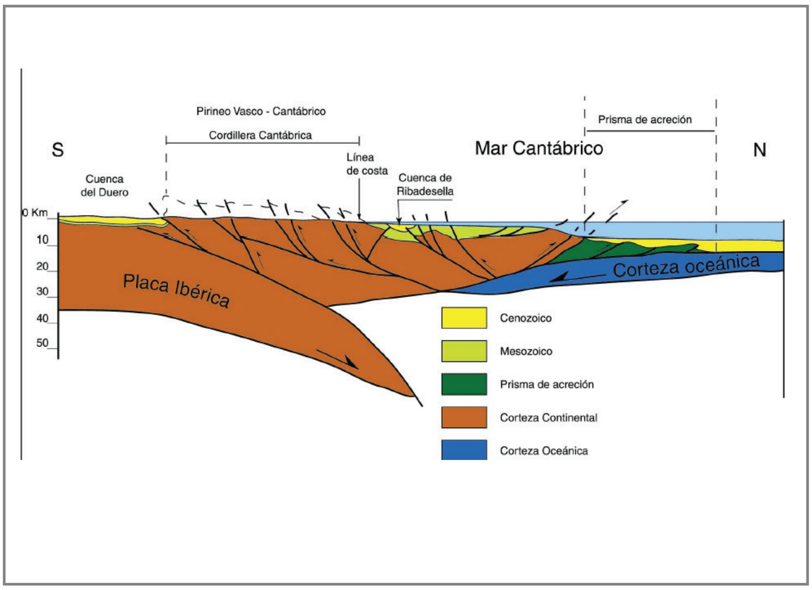

Fig. 9: *The Cantabrian orogene (Cantabrian Cordillera) in the North of Spain: The compression of Iberian block by the approaching of the African plate has led to the fragmentation and subduction of the continental crust and, at the same time, the subduction of oceanic crust in the North, rsulting in complex thrust structures, the folding of Mesozoic cover (in green) and the development of a subsident, thick tertiary basin (yellow) at the South.*

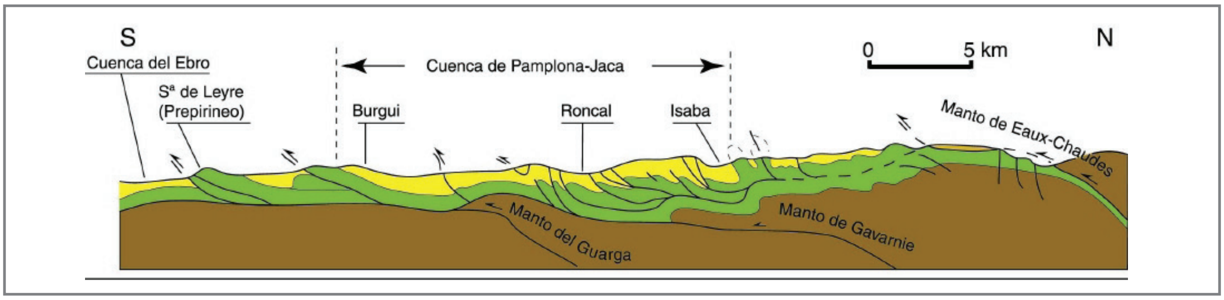

Fig. 10: *The Pyrenean orogene: In Surface, the Mesozoic and tertiary cover, pushed by the crust thrusting has moved southwards forming large nappes and sliding on detachment levels, normally on the clay intervals of the Upper Triassic.*

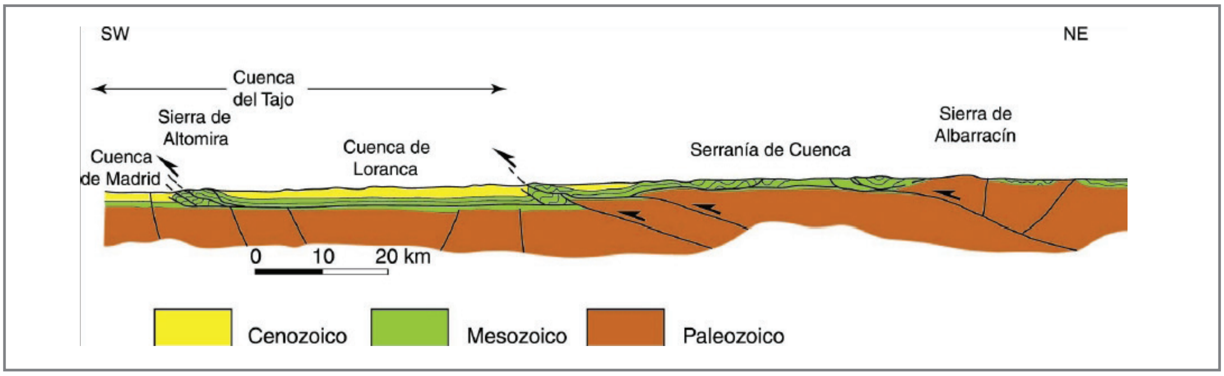

Fig. 11: *Iberian orogene: Block tectonics resulting from the pushing of African plate in a different direction and superimposed to an already existing system of Paleozoic basement fractures has led to a series of short term basement thrusts and the detachment and folding of the Mesozoic and Tertiary cover. In the NE, similar processes but in a different direction, have led to the tilting and folding of the Catalan coastal range, which, for most authors is just a divergent branch of Iberian range.*

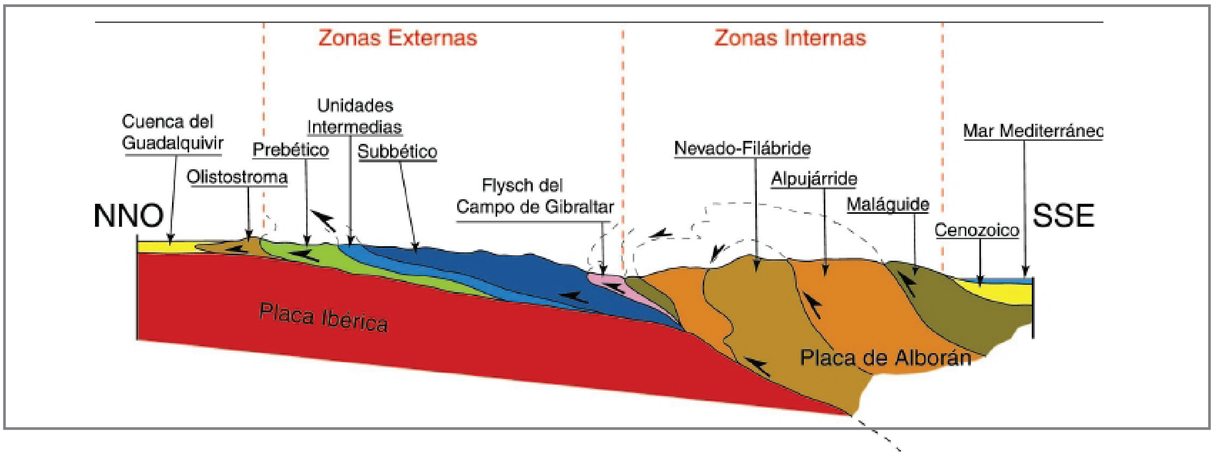

Fig. 12: *Baetic orogene: The violent compression of African plate against Iberia in Miocene times from SE to NW led to the thrusting and piling up of many external and distant orogenic units on the southern margin of Iberia, and the subduction of this part of the Iberian bock. The piling up of nappes to the north led to the sinking of Iberian plate and the development of the tertiary basin (Foreland basin) of Guadalquivir.*

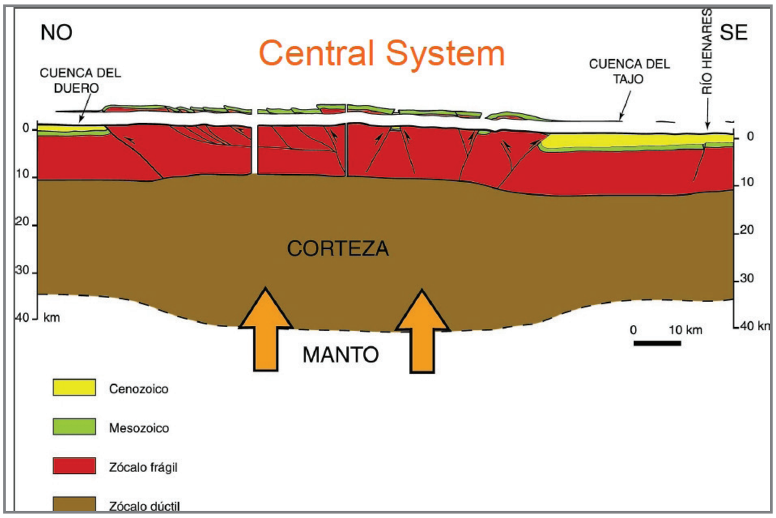

Fig. 13: *The Central System: The compression of the Iberian block in Miocene times led to the deformation, folding and thickening of the crust itself (crustal, or lithospheric folds) and to the uplifting of big granite blocks, to form the so-called Central System. In the margins, both N and S, the Mesozoic cover was deformed and Tertiary continental basins (Duero and Tagus) were developed.*

Intended learning outcomes:

- Know a brief geological history of their country.

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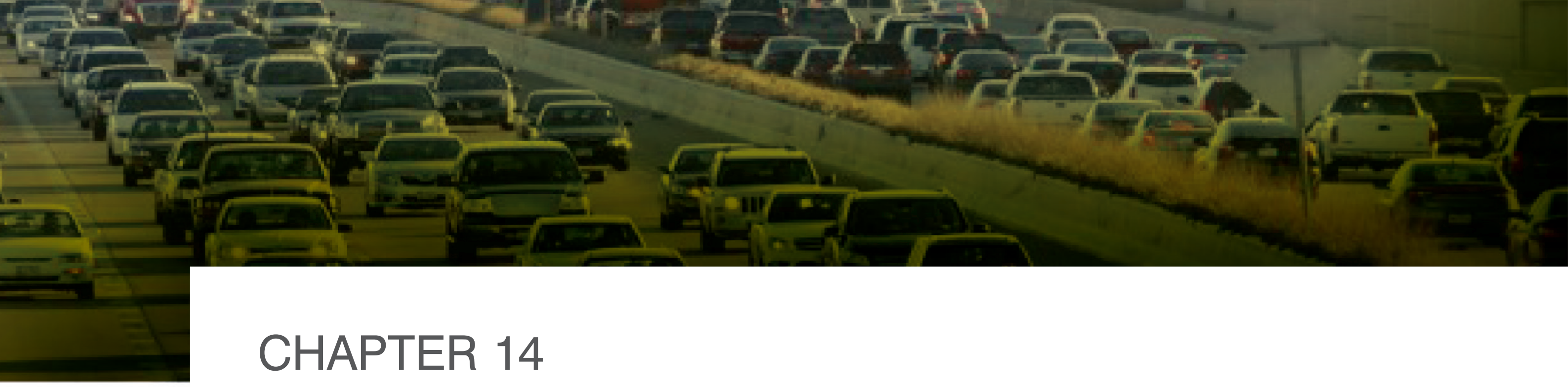

CHAPTER 14

Geology in everyday life

Key words: Resources and humanity, geology in everyday life, sustainable development, geo-tourism.

Introduction

Geology is all around us! Nearly everything in our daily life is directly or indirectly connected to the lithosphere – the solid geological surface layers of our planet. Geology in everyday life can be obvious – just think about fossil fuels and building stones. But sometimes it can be hidden and unexpected – who would think about geology in food and clothes? Knowledge of our links to geology is also important for understanding and assessing climate-change-related geohazards in the future. Geology can also be very strongly linked to recreation and leisure when it comes to climbing and hiking and even just visiting a beach – and developing this theme leads to *geotourism*, where opportunities to impart geological knowledge and awareness to a broad public are identified, including to help safeguard natural heritage and geodiversity for future generations.

14.1 Geological resources for Humanity

When discussing the use of geological resources for our society, most people will think of mining and fossil hydrocarbon exploration and exploitation. In addition, our need for geological-sourced building materials is also enormous and represents more than just stone for building, as we also exploit gravel, sand and clay for the building industry. The consumption of a typical European exceeds 1,100 tons of natural resources over 70 years, including more than 460 tons sand and gravel, 245 tons of rock, 166 tons of fossil fuel, 145 tons coal, 40 tons of iron, 13 tons of salt, 8 tons of wood, 6 tons of gypsum, 4 tons of phosphates, 2 tons of sulphur, and 1 ton each of aluminum, potassium, and copper. These resources are processed by industry and used by us in our daily lives in the form of many common products.

Coal and lignite (i.e. 'brown coal') are other geological resources which are important to a modern society, as sources of energy. Most of this energy in Europe was captured around 300 to 330 million years ago by enormous equatorial swamp forests. Similarly, crude oil and natural gas are fossil organic compounds, typically formed from planktonic marine organisms that lived millions of years ago. All these materials are still crucial for much of our modern industry, transport systems and energy production. Products of the petrochemistry industry, which transforms oil and gas into useful products, literally surround us everywhere, even our clothes and shoes may

be at least partly made from oil, if 'man-made' materials such as fibres (e.g. polyester or nylon), plastics or synthesized rubbers have been used. Plastics, in particular, are almost exclusively produced from fossil hydrocarbons.
Without oil refinement, around 700,000,000 cars globally would stop working – but the car itself, of course, is also largely made from geological sources: steel, aluminum, magnesium and other metals are used for the motor, framework and bodywork, rubber and plastic for tyres, seats and cables and sand for the window glass. Another important geological resource, which plays a major role in our society without much public awareness, are phosphates. Phosphates extracted from geological deposits are fundamental for global agriculture as fertilizer. Geology also provides resources such as stone, metals, minerals, glass, for art and sculpture, paints, architecture as well as for pottery and jewelry.
Although this more or less random list of examples is far from complete, all have something special in common – they are all non-renewable resources and their availability is constantly declining. Peak oil production – the time when a maximum rate of hydrocarbon exploitation is reached (to be followed by only declining production rates) – may have already passed; peak phosphate production will be reached within the next few decades.

14.2. Geology in Everyday Life

It might be surprising to consider our human bodies as reservoirs. Nevertheless, we contain considerable amounts of chemical elements. The origin of the quantitatively most important ones, such as oxygen, carbon, nitrogen and hydrogen, are the atmosphere and hydrosphere. As components of the biological structure of our bodies, they are mainly available to us only through food uptake as only plants and certain bacteria are able to fix carbon by photosynthesis. All the other elements we contain are derived from the lithosphere and are thus "incorporated geology". Bones and teeth are made from the phosphate mineral apatite. To produce our skeleton we need calcium and phosphorous, which become available to life by the weathering of minerals in rocks. Similarly, iron – an essential component of our blood pigment haemoglobin – is also lithosphere-derived. Most of these geochemical elements pass into our bodies in food and drinking water.
Some geological raw materials are even used by the food industry. Consumers are not usually aware of this as ingredients can be masked by codes, such as by the E-numbers applied to food additives in Europe. Typical examples are gypsum (E 516), chalk and limestone (E 170) and even quartz sand (E 551) among numerous others. These additives are found in bakery and dairy products and are used as acidity regulators, anti-caking agents and for surface treatment. Up to 10g/kg of "rock" may be added to some sausages and soft cheese. Of course, geology in daily life is much more than this: baby powder[1], toothpaste [2], beer filters [3], cat litter [4], eye glasses [5], mobile phones [6] ... and the ceramic cup [7] from which you may sip coffee and the spoon[8] you stir it with can all be made from geology (Geological materials used: [1]talc, [2]chalk, [3]diatomite,[4] bentonite,[5] quartz sand,[6] rare earth elements,[7] kaolinite,[8] silver, steel, even plastic derived from crude oil).

14.3. Geological Tourism (Geotourism)

Geology also surrounds us on a much larger scale as topography and landscape are primarily products of geology and climatic processes (although without education, the nature of the geological processes which have produced such landscapes will be poorly understood by most people).

Geotourism has become a key theme in the recent years, mainly as a result of increasing concerns amongst in the scientific community and greater awareness in a broader society about natural heritage, including geological heritage and geodiversity. There can also be economic drivers behind the development of geotourism, as some local and regional administrations try and make nature, including landscapes and geology, contribute to local economic development. The development of the European Geopark Network, in particular, reflects this process, and the increasing number of protected geodiversity sites features are obvious evidence of this growing social concern which combines the nature conservation, geology and tourism development.
Geoparks have a great potential for disseminating knowledge about geology. According to the charter of the European Geopark Network, these are defined areas with a spectacular geological heritage and a sustainable economic development strategy (see also Chapter 10). Geoparks, therefore, include touristic locations in which visitors can be introduced to Earth history in both a local and an international context. Whilst the production and sale of local goods inspired by this geological heritage is encouraged in European and UNESCO geoparks, the sale of geological objects such as fossils is strictly prohibited to avoid unsustainable and destructive exploitation. Positive support from local people comes from the sustainable economic development that geoparks encourage, which results in a raised awareness of the importance of geosciences for society.

Intended learning outcomes:

- Recognise the importance of geological resources for Humanity.
- Demonstrate knowledge and understanding of the importance of geology in everyday life.
- Appreciate geodiversity.
- Appraise geotourism potential within local Sustainable development programmes.

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