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.

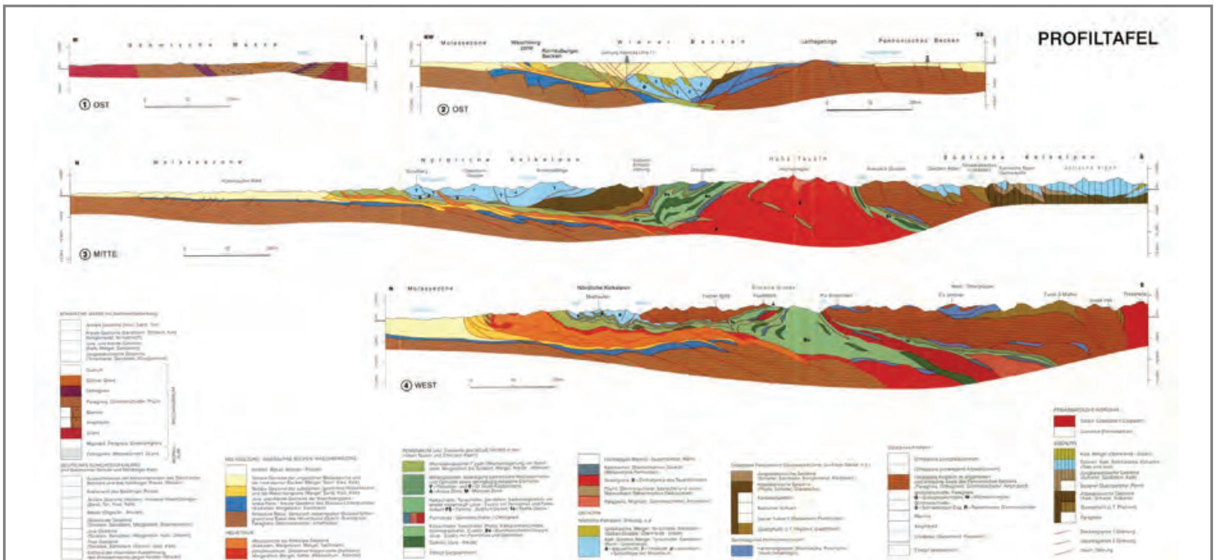

Fig. 1

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

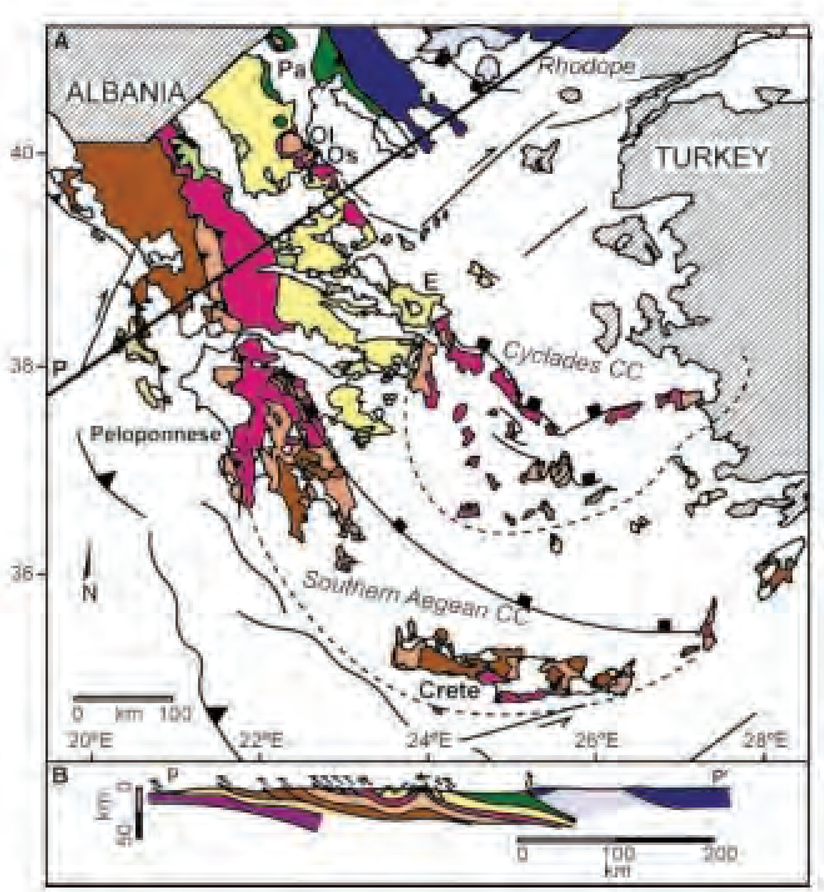

Fig. 2: A: *Geological map of Greece by Bornovas and Rontogianni-Tsiabaou (1983) modified by Jolivet et al. (2004) and van Hinsbergen et al. (2005).*
E-Evia; Ol-Mount Olympos; Os-Mount Ossa; Pa-Paikon window; CC-core complex.
B: *Schematic cross section of Aegean nappe stack along profile P-P9 (By van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

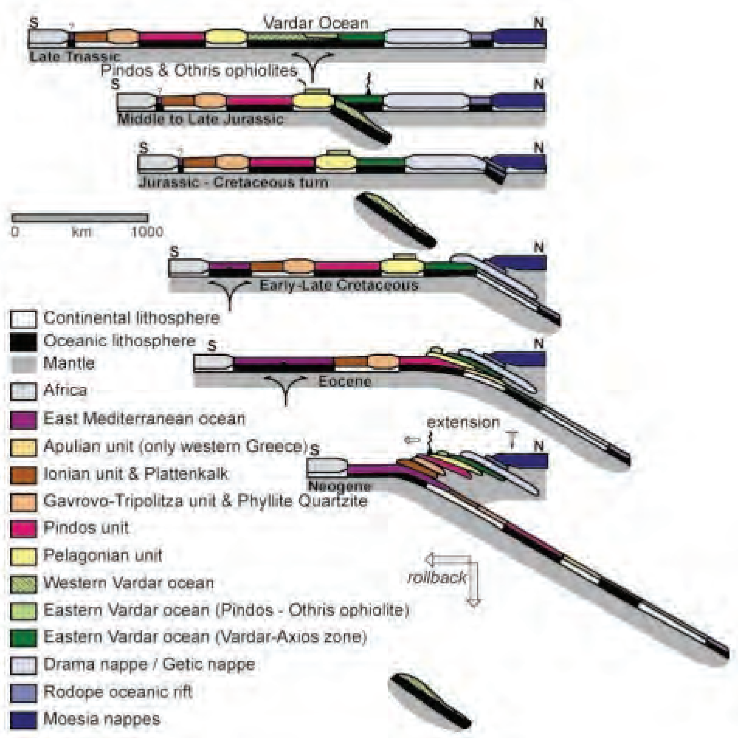

Fig. 3: *Schematic overview of development of nappe stack and subduction during Alpine orogeny in Greece. (By van Hinsbergen et al. 2005).*

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.

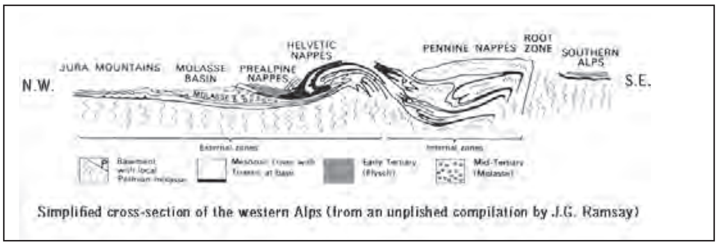
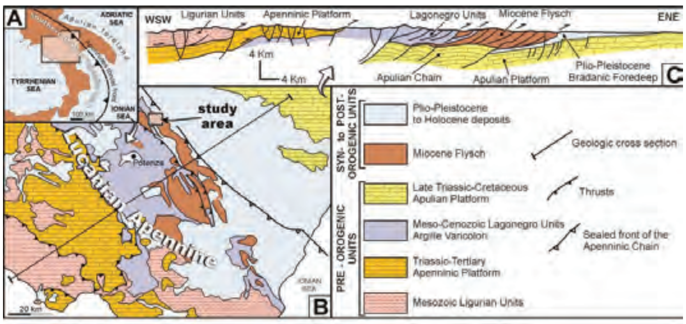


Fig. 4: *Cross section of Alps*



From D. Chiarella D. and Longhitano S. G.
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Fig. 5: *Cross section of Appennines*

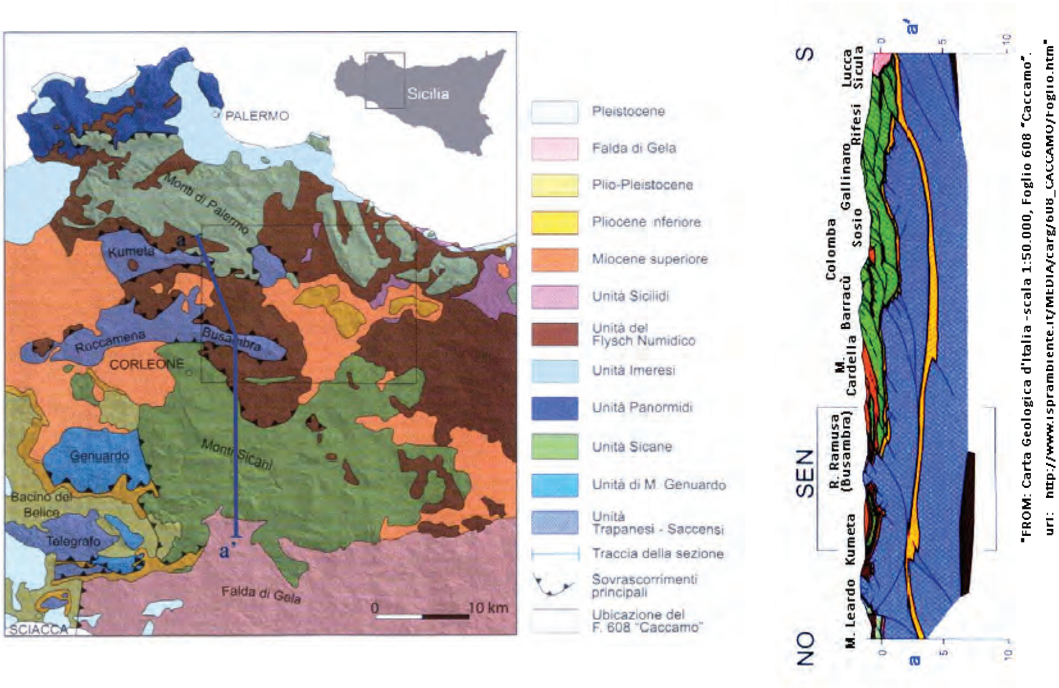

Fig. 6: *Cross section of Sicily*

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.

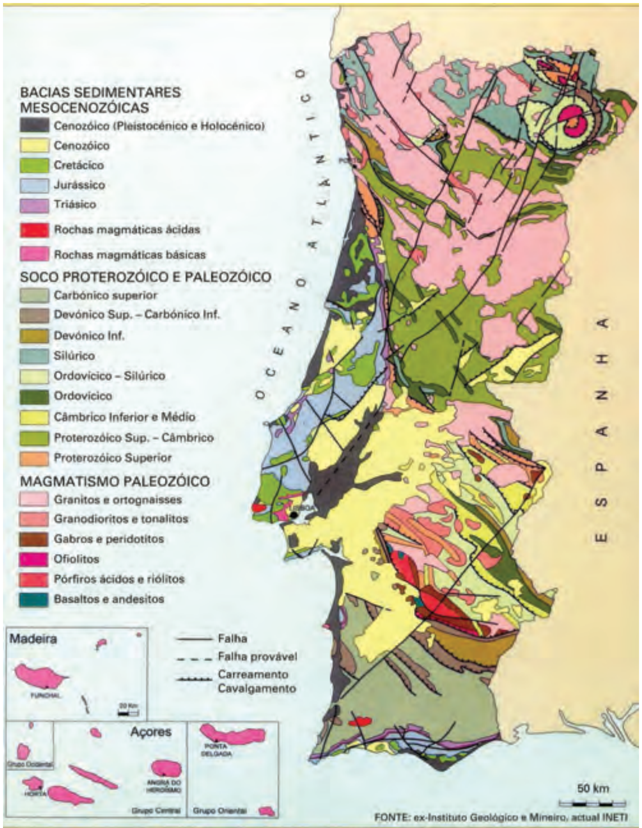

Fig. 7: *Simplified geological map of Portugal (Source: LNEG)*

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-últssia, 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-Gerκs-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.

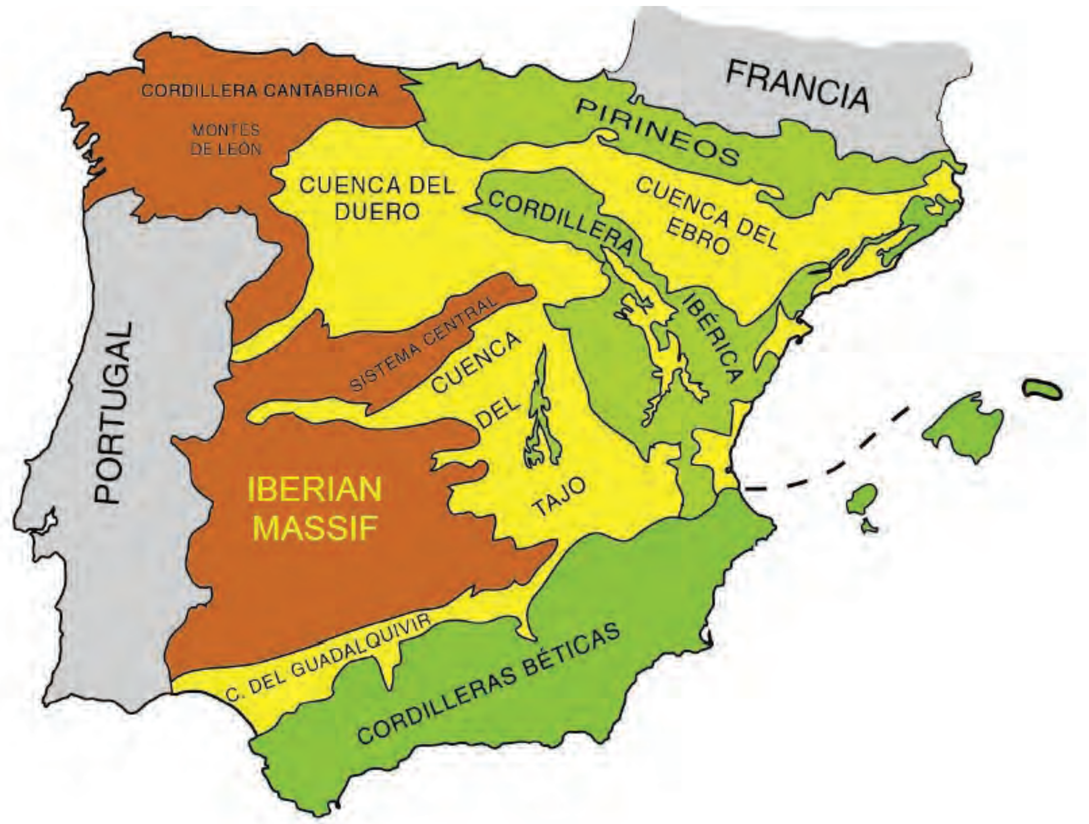

Fig. 8: Main structural units of Iberia. The Iberian Massif (Paleozoic, Brown) occupies most of the Iberian plate, being partly covered by Tertiary (continental) basins, in yellow and by recent orogenes forming mountain systems (in green). The older primitive "Hesperian" Massif", Precambrian, would form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

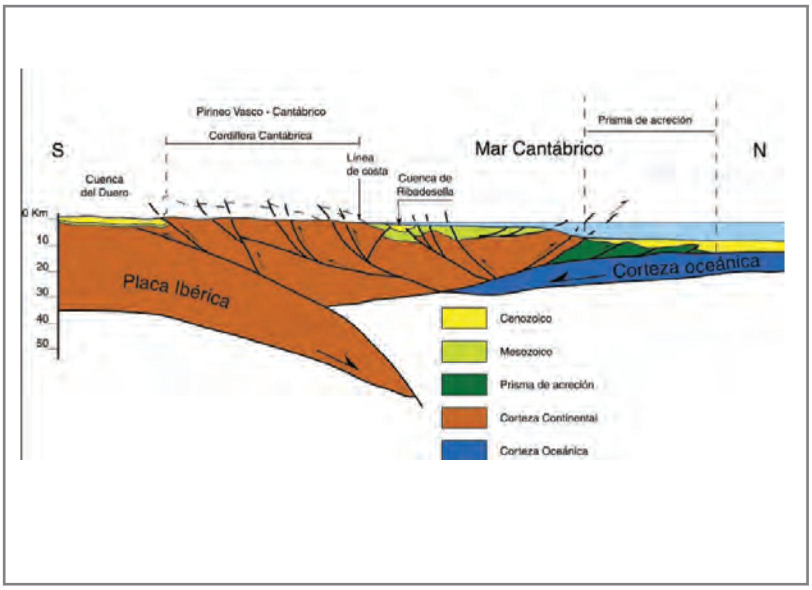

Fig. 9: *The Cantabrian orogene (Cantabrian Cordillera) in the North of Spain: The compression of Iberian block by the approaching of the African plate has led to the fragmentation and subduction of the continental crust and, at the same time, the subduction of oceanic crust in the North, rsulting in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

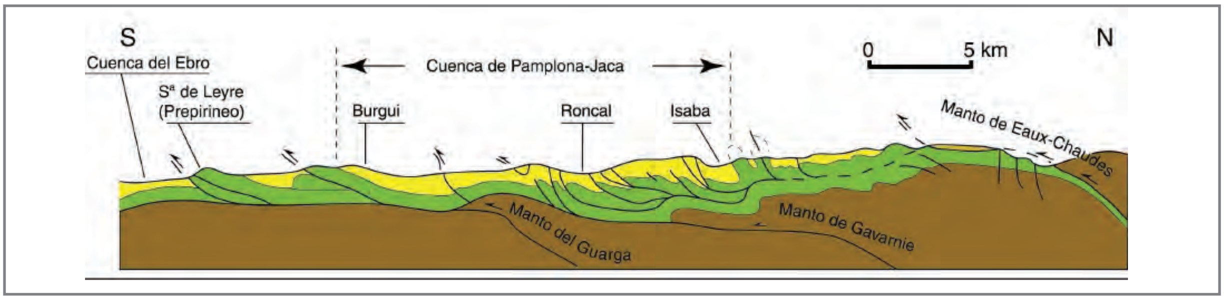

Fig. 10: *The Pyrenean orogene: In Surface, the Mesozoic and tertiary cover, pushed by the crust thrusting has moved southwards forming large nappes and sliding on detachment levels, normally on the clay intervals of the Upper Triassic.*

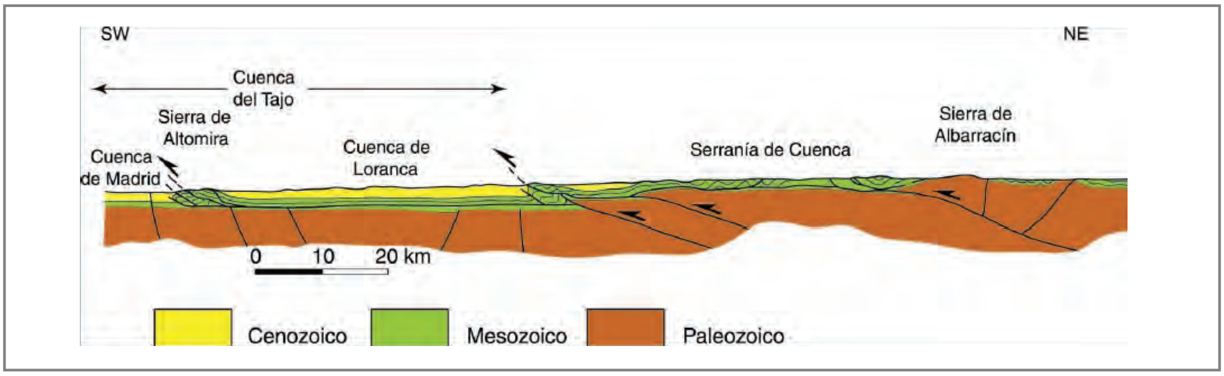

Fig. 11: *Iberian orogene: Block tectonics resulting from the pushing of African plate in a different direction and superimposed to an already existing system of Paleozoic basement fractures has led to a series of short term basement thrusts and the detachment and folding of the Mesozoic and Tertiary 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.*

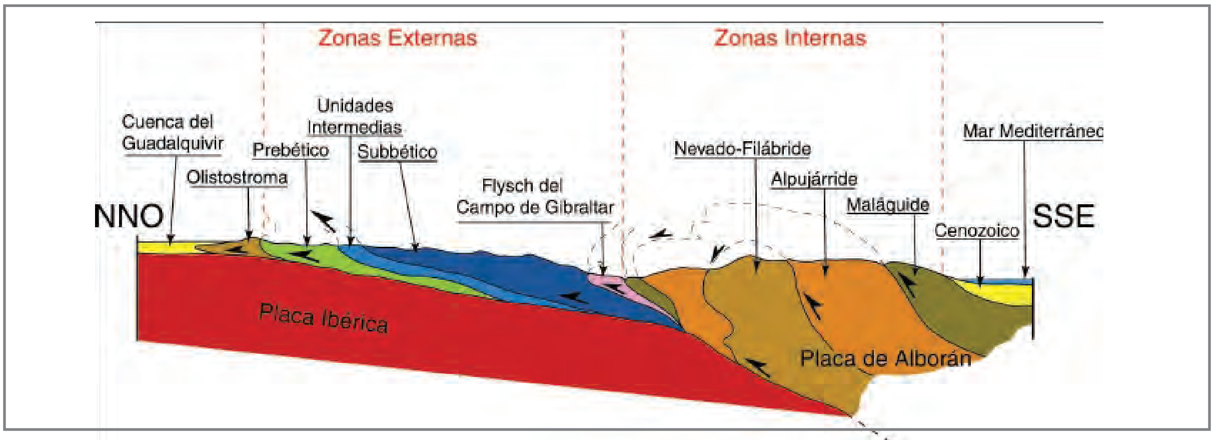

Fig. 12: *Baetic orogene: The violent compression of African plate against Iberia in Miocene times from SE to NW led to the thrusting and piling up of many external and distant orogenic units on the southern margin of Iberia, and the subduction of this part of the Iberian bock. The piling up of nappes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

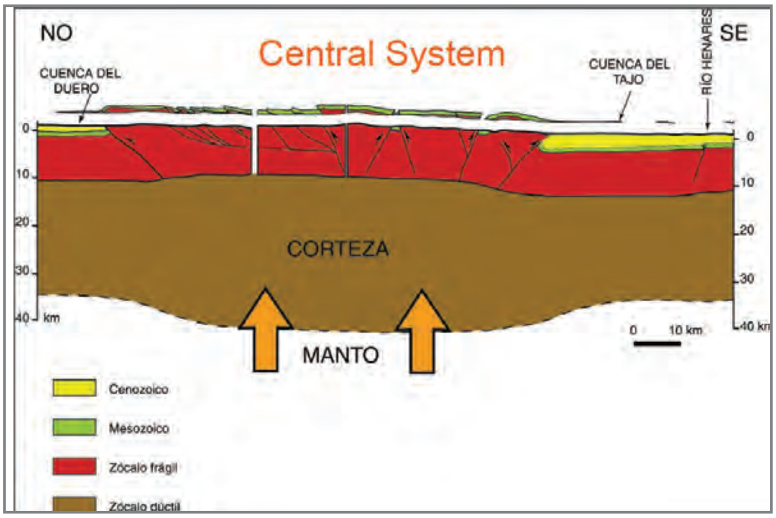

Fig. 13: *The Central System: The compression of the Iberian block in Miocene times led to the deformation, folding and thickening of the crust itself (crustal, or lithospheric folds) and to the uplifting of big granite blocks, to form the so-called Central System. In the margins, both N and S, the Mesozoic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