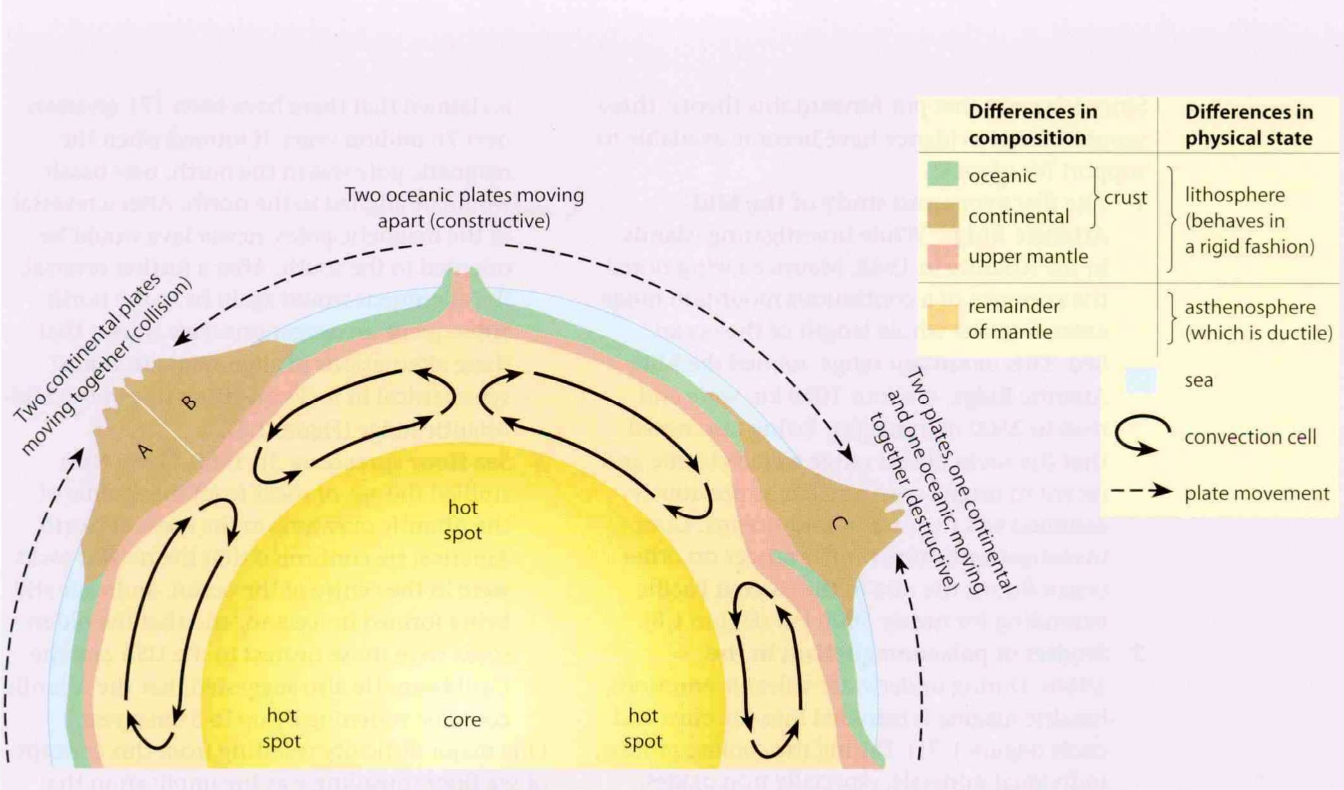


Figure 1.6
How plates move

Figure 1.7
Differences between continental and oceanic crust

	Continental crust (sial)	Oceanic crust (sima)
Thickness	35–40 km on average, reaching 60–70 km under mountain chains	6–10 km on average
Age of rocks	very old, mainly over 1500 million years	very young, mainly under 200 million years
Weight of rocks	lighter, with an average density of 2.6	heavier, with an average density of 3.0
Nature of rocks	light in colour; many contain silica and aluminium; numerous types, granite is the most common	dark in colour; many contain silica and magnesium; few types, mainly basalt

The theory of plate tectonics

The **lithosphere** (the Earth's crust and the rigid upper part of the mantle) is divided into seven large and several smaller **plates**. The plates, which are rigid, float like rafts on the underlying semi-molten mantle (the **asthenosphere**) and are moved by currents which form **convection cells** (Figure 1.6). Plate tectonics is the study of the movement of these plates and their resultant landforms.

There are two types of plate material: **continental** and **oceanic**. Continental crust is composed of older, lighter rock of granitic type. Oceanic crust consists of much younger, denser rock of basaltic composition. However, as most plates consist of areas of both continental and oceanic crust, it is important to realise that the two terms do not refer to our named continents and oceans. The major differences between the two types of crust are summarised in Figure 1.7.

Plate movement

As a result of the convection cells generated by heat from the centre of the Earth, plates may move towards, away from or sideways along adjacent plates. It is at plate boundaries that most of the world's major landforms occur, and where earthquake, volcanic and mountain-building zones are located (Figure 1.8). However, before trying to account for the formation of these landforms, several points should be noted.

1 Due to its relatively low density, continental crust does not sink and so is permanent; being denser, oceanic crust can sink. Oceanic crust is being formed and destroyed continuously.
2 Continental plates, such as the Eurasian Plate, may consist of both continental and oceanic crust.
3 Continental crust may extend far beyond the margins of the landmass.
4 Plates cannot overlap. This means that either they must be pushed upwards on impact to form mountains (AB on Figure 1.6) or one plate must be forced downwards into the mantle and destroyed (C on Figure 1.6).
5 No 'gaps' may occur on the Earth's surface so, if two plates are moving apart, new oceanic crust originating from the mantle must be being formed.

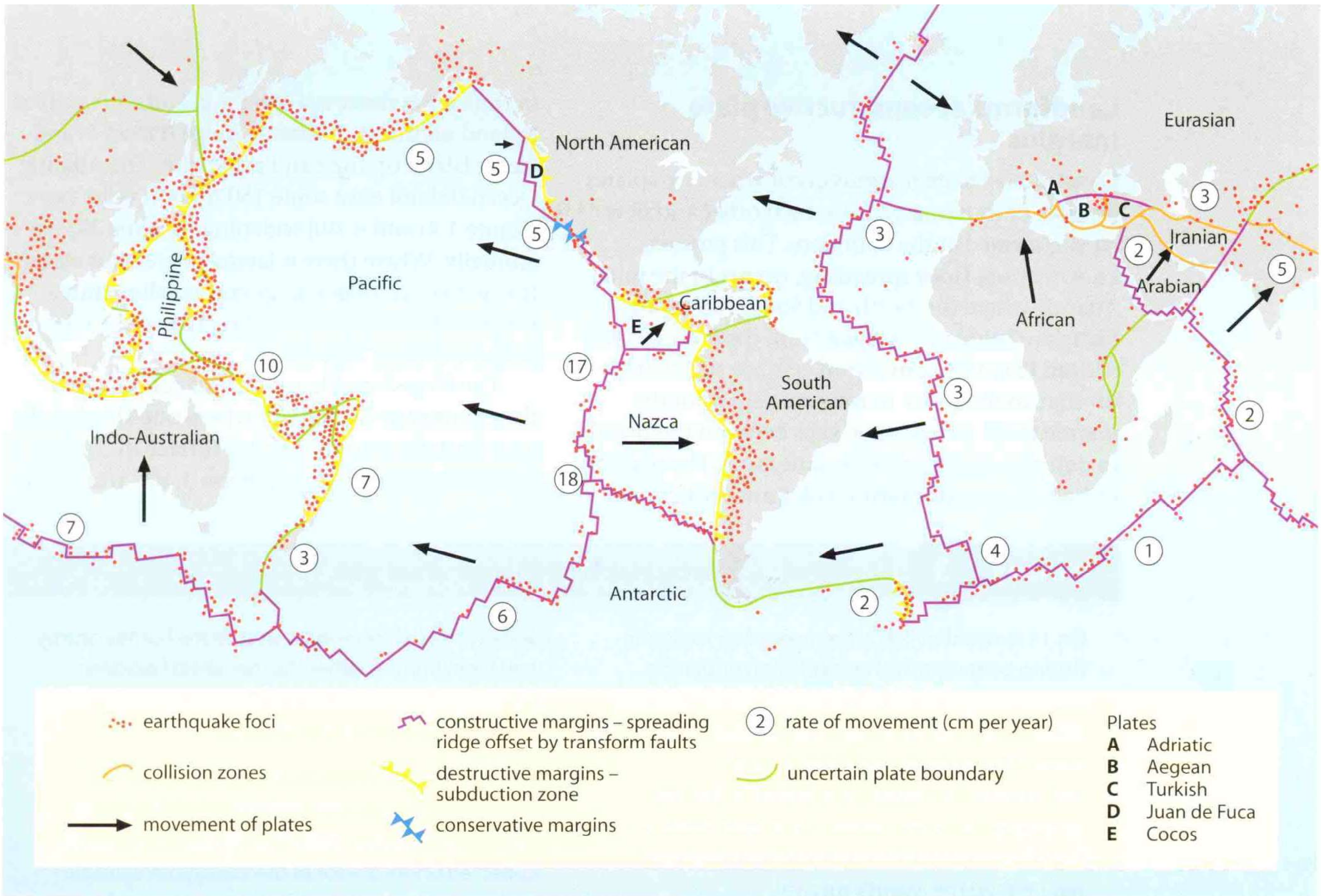


Figure 1.8

Plate boundaries and active zones of the Earth's crust

6 The Earth is neither expanding nor shrinking in size. Thus when new oceanic crust is being formed in one place, older oceanic crust must be being destroyed in another.

7 Plate movement is slow (though not in geological terms) and is usually continuous. Sudden movements are detected as earthquakes.

8 Most significant landforms (fold mountains, volcanoes, island arcs, deep-sea trenches, and batholith intrusions) are found at plate boundaries. Very little change occurs in plate centres (shield lands). Figure 1.9 summarises the major landforms resulting from different types of plate movement.

Figure 1.9

The major landforms resulting from plate movements

Type of plate boundary	Description of changes	Examples
A Constructive margins (spreading or divergent plates)	two plates move away from each other; new oceanic crust appears forming mid-ocean ridges with volcanoes	Mid-Atlantic Ridge (Americas moving away from Eurasian and African Plates) East Pacific Rise (Nazca and Pacific Plates moving apart)
B Destructive margins (subduction zones)	oceanic crust moves towards continental crust but, being heavier, sinks and is destroyed forming deep-sea trenches and island arcs with volcanoes	Nazca sinks under South American Plate (Andes) Juan de Fuca sinks under North American Plate (Rockies) Island arcs of the West Indies and Aleutians
Collision zones	two continental crusts collide and, as neither can sink, are forced up into fold mountains	Indian Plate collided with Eurasian Plate, forming Himalayas African Plate collided with Eurasian Plate, forming Alps
C Conservative or passive margins (transform faults)	two plates move sideways past each other – land is neither formed nor destroyed	San Andreas Fault in California
Note: centres of plates are rigid...	rigid plate centres form a shields lands (cratons) of ancient worn-down rocks b depressions on edges of the shield which develop into large river basins	 Canadian (Laurentian) Shield, Brazilian Shield Mississippi–Missouri, Amazon
...with one main exception	Africa dividing to form a rift valley and possibly a new sea	African Rift Valley and the Red Sea

Earthquakes and Seismology

ZiW, 2012-10-24

Earthquakes are tremors or ground movements caused by shock waves. They have long been a source of both fascination and terror for humans. Pliny the Elder, in AD 200, wrote that earthquakes were Mother Earth's way of protesting against those people who mined for gold, silver and iron.

We now understand that major earthquakes normally occur at boundaries. Plate movement causes stress to build up within the crustal rocks until the rocks break along the line of a **fault** or cracks in the earth's crust. The actual movement of the material may be only a few centimetres but the sudden release of seismic (earthquake) energy can be enormous.

The point at which the rocks break within the crust is the **focus** of the earthquake. This may be some distance below the surface and the seismic energy emitted from the focus travels in all directions as **seismic waves**. The point on the earth's surface above the focus is the **epicentre** (Figure 1). An earthquake is likely to be more powerful the longer the time that stress has had to build up and the closer the location of the focus of the seismic energy to the surface.

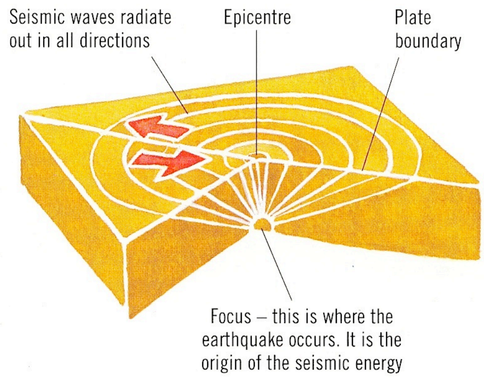


Figure 1 **Focus of an earthquake**

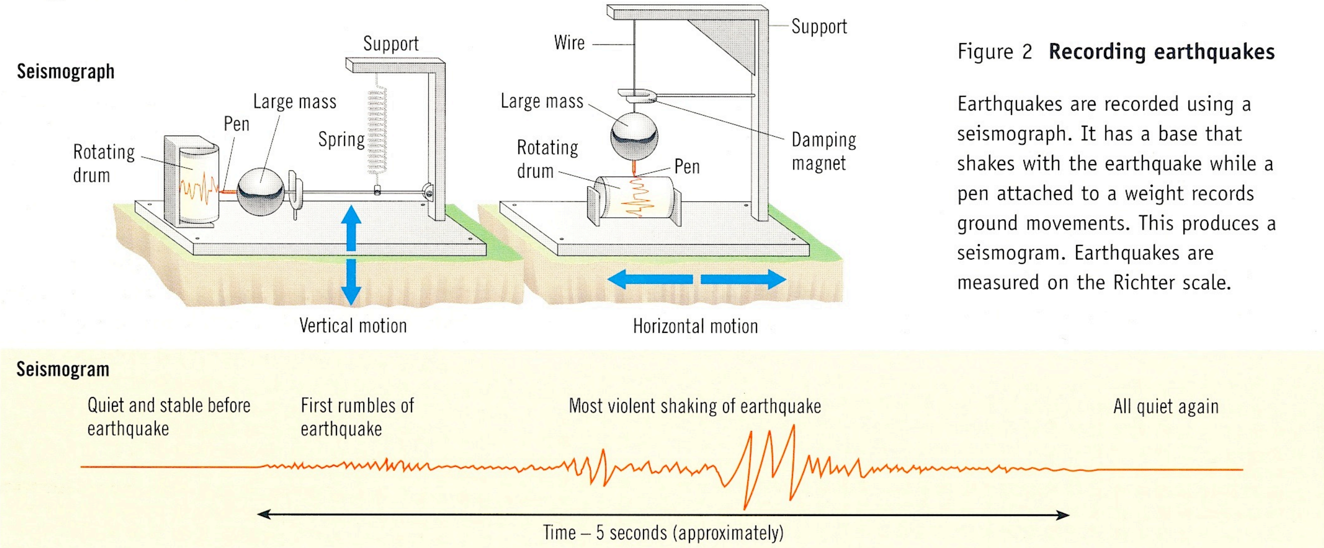


Figure 2 **Recording earthquakes**

Earthquakes are recorded using a seismograph. It has a base that shakes with the earthquake while a pen attached to a weight records ground movements. This produces a seismogram. Earthquakes are measured on the Richter scale.

What makes an earthquake hazardous?

Many thousands of earthquakes occur each year but only a few are centred near populated areas and are strong enough to cause loss of life. There are a number of immediate or **primary effects** from the violent shaking of the ground during an earthquake. Buildings may collapse killing people inside them, shattered window glass may shower on to streets below and huge cracks may open in the ground. Roads and railways may be damaged. Services such as mains water and electricity may be cut off.

The primary effects of earthquakes can also generate other problems or **secondary effects**. A large number of deaths occur after an earthquake when food and water are in short supply. The ability of a country to cope with secondary effects will often determine the final death toll. Secondary effects include:

- fires, set off as gas or oil leak from fractured pipes
- disease, brought about by lack of medical care and clean drinking water
- tsunamis, which are huge waves caused when earthquakes occur under the sea. The waves can travel at 1000 km per hour in open water; they slow to about 65 km per hour close to land when they reach up to 15 metres in height.

The Richter scale

Richter scale	*Effects*	*Average annual occurence worldwide*
Under 3.5	Detected only by seismographs	300 000
3.5 – 5	Felt by all hanging objects; trees sway	55 000
5 – 6	Walls crack; becomes hard to stand	800
6 – 7	Chimneys and tree branches fall; houses collapse	120
7 – 8	Many houses and bridges collapse; ground opens wide	18
8+	Total destruction	1

Source: S. Chapman et. al. (1999): Complete Geography. Oxford University Press, Oxford. P. 10.

Seismic waves

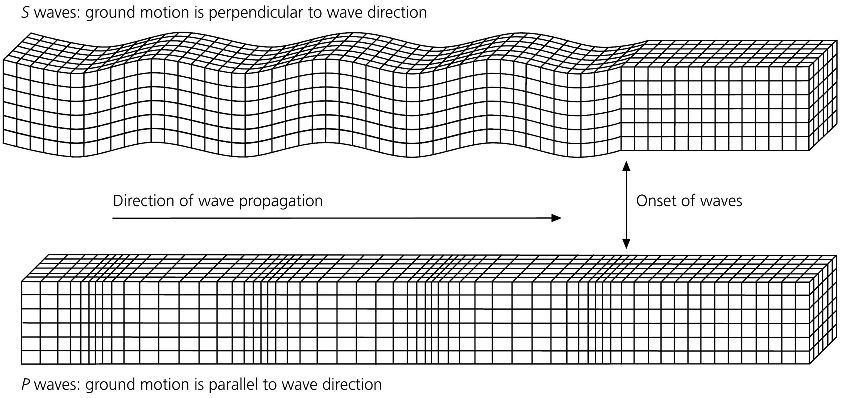
http://en.wikipedia.org/wiki/Earthquake_waves [2012-10-23]

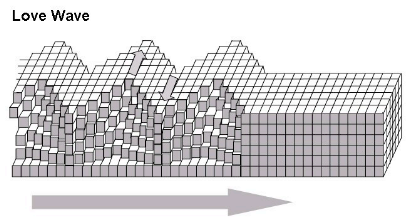
Seismologists distinguish four main types of waves. At the hypocenter, where the earthquake actually takes place, compression waves and shear waves are created by quick movements of rock along a fracture plane. When these two kinds of waves reach the surface of the Earth they cannot continue their way and their energy has to be transformed into other kinds of waves. So the body waves (P- and S-waves), which travel in the interior of the Earth, become surface waves (R- and L-waves):

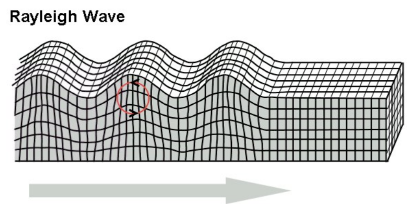
Body waves	Corresponding surface waves
Primary waves (P-waves) are compressional waves that are longitudinal in nature. P waves are pressure waves that travel faster than other waves through the Earth to arrive at seismograph stations first hence the name "Primary". These waves can travel through any type of material, including fluids, and can travel at nearly twice the speed of S waves. Typical speeds are 1450 m/s in water and about 5000 m/s in granite.	**Rayleigh waves**, also called ground roll, are surface waves that travel as ripples with motions that are similar to those of waves on the surface of water (note, however, that the associated particle motion at shallow depths is retrograde, and that the restoring force in Rayleigh and in other seismic waves is elastic, not gravitational as for water waves). The existence of these waves was predicted by John William Strutt, Lord Rayleigh, in 1885. They are slower than body waves, roughly 90% of the velocity of S waves for typical homogeneous elastic media.
Secondary waves (S-waves) are shear waves that are transverse in nature. These waves arrive at seismograph stations after the faster moving P waves during an earthquake. S waves can travel only through solids, as fluids (liquids and gases) do not support shear stresses. Since shear waves cannot pass through liquids, this phenomenon was original evidence for the now well-established observation that the Earth has a liquid outer core. S waves are slower than P waves, and speeds are typically around 60% of that of P waves in any given material.	**Love waves** (L-waves) are analogous to water waves and travel along the Earth's surface and are slower than body waves. They are named after A.E.H. Love, a British mathematician who created a mathematical model of the waves in 1911. Because of their low frequency, long duration, and large amplitude, they can be the most destructive type of seismic wave.

In seismology or geophysics the refraction or reflection of seismic waves is used for research into the structure of the Earth's interior, and man-made vibrations are often generated to investigate shallow, subsurface structures.

Body waves	Corresponding surface waves







Usefulness of P and S waves in locating an event

In the case of earthquakes that have occurred at global distances, four or more geographically diverse observing stations recording P-wave arrivals compute time and location for the event. In the case of local or nearby earthquakes, the difference in the arrival times of the P and S waves can be used to determine the distance to the event. A quick way to determine the distance from a location to the origin of a seismic wave less than 200 km away is to take the difference in arrival time of the P wave and the S wave in seconds and multiply by 8 kilometers per second.

Magnitude and intensity

The severity of an earthquake is described by both magnitude and intensity. These two frequently confused terms refer to different, but related, observations. Magnitude, usually expressed as an Arabic numeral characterizes the size of an earthquake by measuring indirectly the energy released. By contrast, intensity indicates the local effects and potential for damage produced by an earthquake on the Earth's surface as it affects humans, animals, structures, and natural objects such as bodies of water. Intensities are usually expressed in Roman numerals, and represent the severity of the shaking resulting from an earthquake. Ideally, any given earthquake can be described by only one magnitude, but many intensities since the earthquake effects vary with circumstances such as distance from the epicenter and local soil conditions. http://en.wikipedia.org/wiki/Seismic_scale [2012-10-23]

EMS-98 scale http://en.wikipedia.org/wiki/European_Macroseismic_Scale [2012-10-23]

The European Macroseismic Scale (EMS) is the basis for evaluation of seismic intensity in European countries and is also used in a number of countries outside Europe. Issued in 1998 the scale is referred to as EMS-98. Unlike the earthquake magnitude scales which express the seismic energy released by an earthquake, EMS-98 intensity denotes how strongly an earthquake affects a specific place. The European Macroseismic Scale has 12 divisions, as follows:

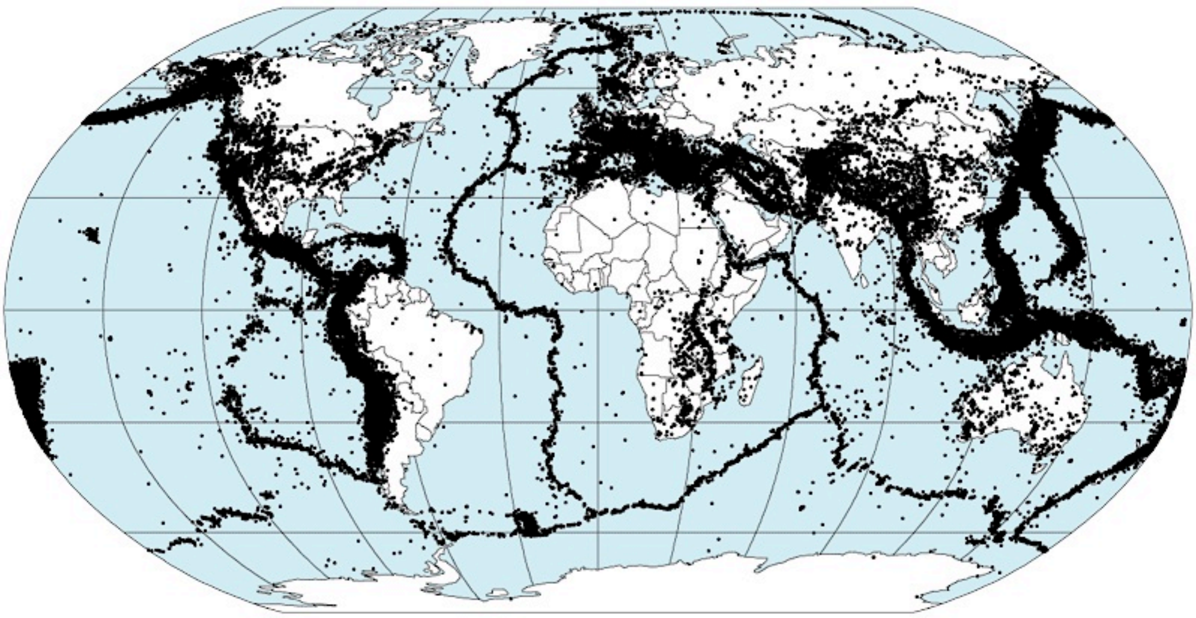
Short form

I. Not felt	Not felt, even under the most favourable circumstances.
II. Scarcely felt	Vibration is felt only by individual people at rest in houses, especially on upper floors of buildings.
III. Weak	The vibration is weak and is felt indoors by a few people. People at rest feel a swaying or light trembling.
IV. Largely observed	The earthquake is felt indoors by many people, outdoors by very few. A few people are awakened. The level of vibration is not frightening. Windows, doors and dishes rattle. Hanging objects swing.
V. Strong	The earthquake is felt indoors by most, outdoors by few. Many sleeping people awake. A few run outdoors. Buildings tremble throughout. Hanging objects swing considerably. China and glasses clatter together. The vibration is strong. Topheavy objects topple over. Doors and windows swing open or shut.
VI. Slightly damaging	Felt by most indoors and by many outdoors. Many people in buildings are frightened and run outdoors. Small objects fall. Slight damage to many ordinary buildings; for example, fine cracks in plaster and small pieces of plaster fall.
VII. Damaging	Most people are frightened and run outdoors. Furniture is shifted and objects fall from shelves in large numbers. Many ordinary buildings suffer moderate damage: small cracks in walls; partial collapse of chimneys.
VIII. Heavily damaging	Furniture may be overturned. Many ordinary buildings suffer damage: chimneys fall; large cracks appear in walls and a few buildings may partially collapse.
IX. Destructive	Monuments and columns fall or are twisted. Many ordinary buildings partially collapse and a few collapse completely.
X. Very destructive	Many ordinary buildings collapse.
XI. Devastating	Most ordinary buildings collapse.
XII. Completely devastating	Practically all structures above and below ground are heavily damaged or destroyed.

With respect to the full version the given external link should be used.

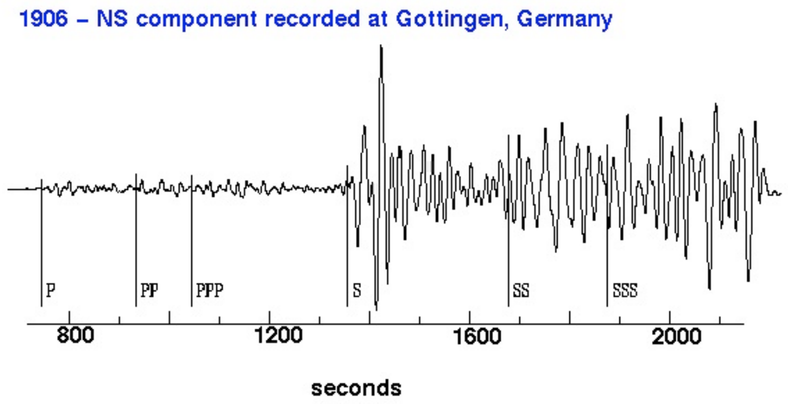
Epicenters of 358,214 earthquakes from 1963 - 1998 http://en.wikipedia.org/wiki/File:Quake_epicenters_1963-98.png [2012-10-23]

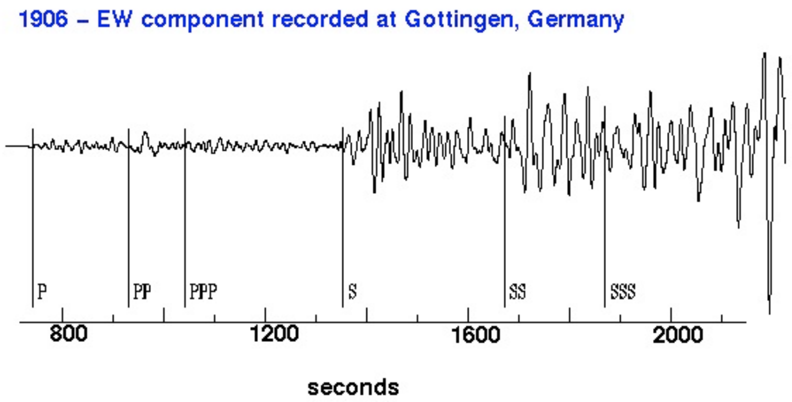
Note the strong coincidence with plate boundaries. Most events occur at depths shallower than about 40 km, but some occur as deep as 700 km.



1906 San Francisco Earthquake - Shaking at Gottingen, Germany

Here is what the shaking looked like in Gottingen, Germany, 9100 kilometers away:





P (the direct, compressional wave) travels fastest and marks the first arrival of waves from the earthquake. S marks the arrival of the slower S or shear wave. P waves generally do not cause as much shaking as some of the larger, later arriving shear waves. The lines PP, PPP, SS and SSS indicate the arrivals of waves which have bounced once or twice off the surface of the Earth in travelling to the seismograph. The actual maximum amplitude of the shaking at the Gottingen observatory during the time of the record shown was less than 1 mm or about 0.04 inches, until the surface waves arrived when the instrument went off scale. (Surface waves, not surprisingly, travel along the Earth's surface, rather than through it as do P and S waves.)

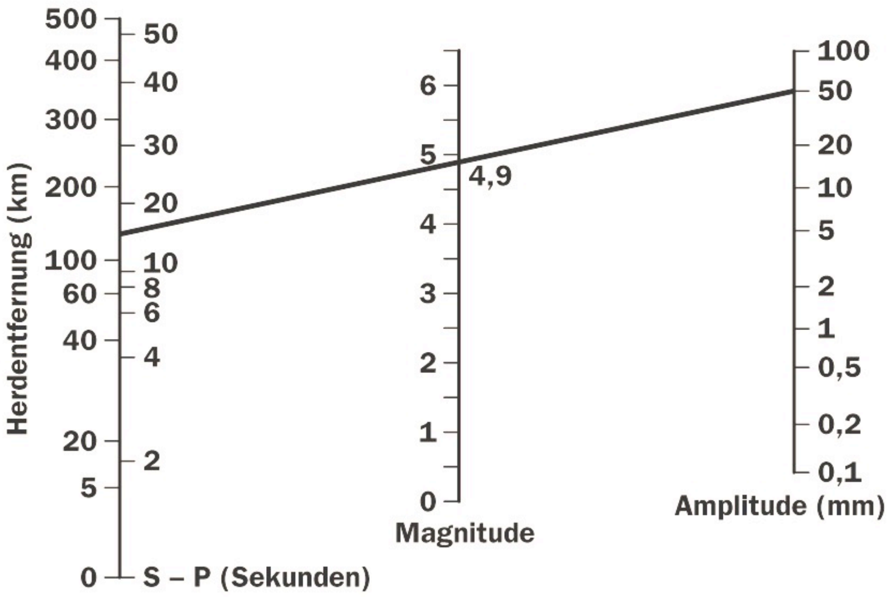
NS = north-south

EW = east-west

http://earthquake.usgs.gov/regional/nca/1906/18april/got_seismogram.php [2012-10-23]

Scheme for calculating the magnitude on the Richter scale

Read in a seismograph the difference of arrival time between the P- and the S-waves and the amplitude of the S-waves and take the corresponding points in the left and the right scales of the scheme below. The line between those two points will show you the magnitude of the event according to the Richter scale.



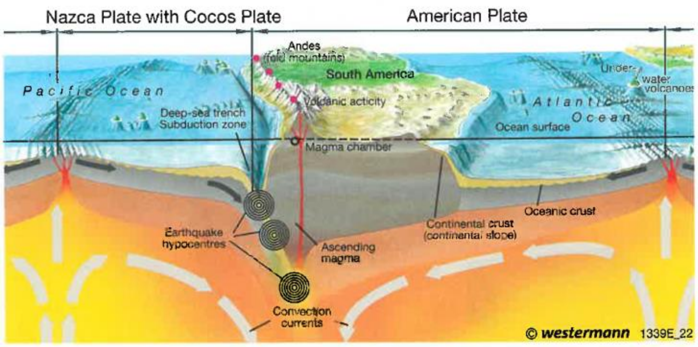
Earthquake exercises

1) What kind of processes may cause earthquakes?
2) What happens in detail at the focus of a tectonic earthquake?
3) What kinds of seismic waves are important, and what are their important properties?
4) You get seismograms from several observation stations. How could you calculate the location of the focus and the epicentre?
5) How does a seismometer function, what is needed?
6) What is the difference between the Richter-scale and the EMS-scale? What is this good for?
7) Say our seismometer 60 km away from Basel records an earthquake, which happened there. We measure a maximum amplitude of 20 mm. What was the magnitude?
8) We observe P- and S-waves arriving at an interval of 20 seconds. What is the distance to the focus?
9) Is there a correlation between the kind of plate boundary and the seismic intensity? Compare the map in the handout with Fig. 1.8 (handout plate tectonics).
10) Do you presume a correlation between the depth of the focus and the kind of plate boundary? Why?

Susceptibility to earthquakes – Chile and Haiti

"Earthquakes by themselves do not kill anybody. And they also do not cause any damage when there is nothing there to be destroyed," concluded an American geophysicist after the major earthquake in Chile in 2010. But what factors are responsible for turning a natural event into a disaster? This question can be answered by comparing two countries, Haiti and Chile, which both suffered massive earthquakes within a short period in 2010.

1. Locate Chile and give reasons for its earthquake risk (M1).
2. Compare the earthquake events, their effects, and the respective political, economic and social situations in the two countries (M2/ M4).

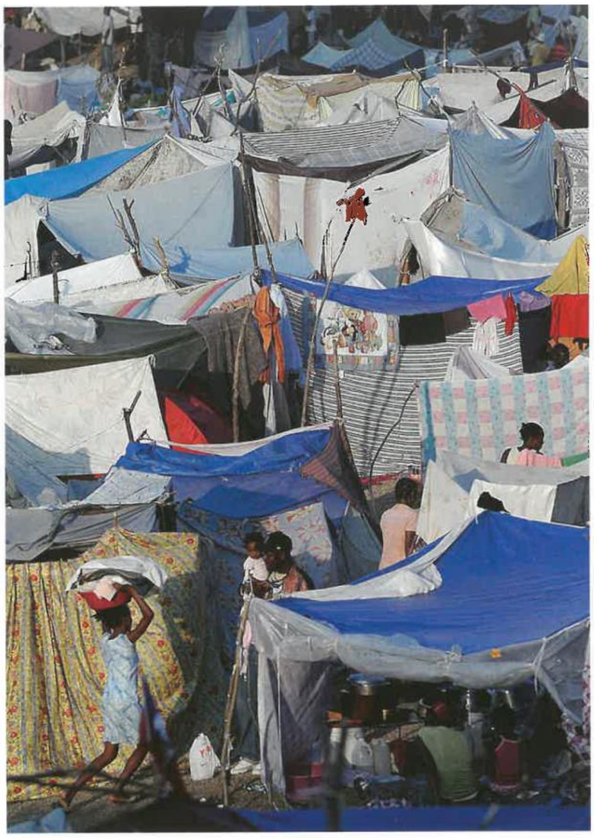


M1 Geological situation of Chile

	Chile	Haiti
Strength of earthquake on the moment magnitude scale	8.8	7.0
Number of deaths	700	220,000
Estimated material damage	30 bill. $	8 bill. $
Population	17 mill.	10 mill.
Gross National Product (adjusted for purchasing power)	243 bill. $	11.5 bill. $
GNP per capita (adjusted for purchasing power)	14,311 $	1,151 $
Public health spending (per capita)	863 $	58 $
Corruption Index: Position in country ranking (Position 1 = least corrupt)	21	146

Source: Bündnis Entwicklung Hilft, 2012

M2 Comparison of earthquake regions



M3 Temporary tent camp for victims of the earthquake disaster in Haiti

The earthquake in Chile was significantly stronger than that in Haiti, yet it was in the small Caribbean country that considerably more people lost their lives. How come?
The answer is very simple: Chile is far better prepared for such disasters. Latin America's most prosperous country has strict building regulations, which are also generally adhered to. And there was also a disaster plan in existence, which was put into operation immediately after the severe earthquake. In Haiti, no such plan exists. It is not the strength of an earthquake that causes buildings to collapse, but above all their building structure. In the past years, and particularly in the public housing sector, many houses have been built in accordance with strict earthquake safety provisions. Thus the poorer districts in particular were spared from massive destruction – in stark contrast to Haiti.
In Chile, not only the architects and building owners but also the public authorities including the rescue services are prepared for earthquakes. In May 1960, the Andean country suffered what was then the strongest earthquake ever recorded anywhere in the world, and the February 2010 quake was its third with a magnitude above 8.8. In Haiti, on the other hand, the last comparably severe quake was 250 years ago. And finally, Chile is rich enough to enable the population affected by the earthquake to provide for themselves. Haiti, by contrast, will be dependent on international aid supplies for months, if not years. Its notoriously poor infrastructure and governance are responsible for this.
Based on: F. Bajak, Associated Press, 28.2.2010

M4 Two earthquakes with differing consequences

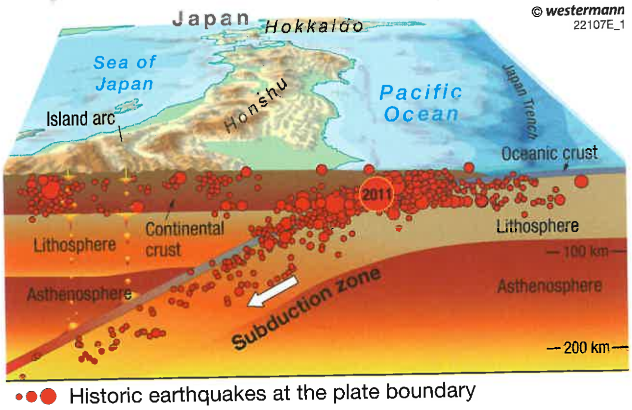
Source: Latz, Wolfgang (Ed.): Diercke Praxis, Activity Book – advanced level. Westermann, Braunschweig, 2015.

Earthquakes – moving facts

Tsunamis – a threat to the coasts also in Japan

On 11 March 2011, a severe earthquake of magnitude 9.0 occurred off the east coast of Japan. The epicentre was 129 km east of the port city of Sendai. After the main quake at 14:46 hrs local time, more than 30 aftershocks with magnitudes of at least 6.0 were recorded in the following 48 hours. A tsunami warning was issued for all the coastal districts of the Pacific region. Tsunamis (jap. "harbour wave") occur due to movements on the sea floor which cause water to be displaced. They are triggered e.g. by seaquakes, plate tectonic shifts in the sea floor or major rock and ice falls. Shortly after the first quake, a tidal wave up to ten metres high devastated 500 km of the Pacific coastline. In narrow, deep bays the wave ascended as far as 40 m up the hillsides. In the flat plain near Sendai, the water masses penetrated five kilometres into the interior of the country. In the Fukushima nuclear power station, the tsunami resulted in explosions in the reactors which were no longer controllable, and ultimately led to a meltdown. A large number of inhabitants had to be evacuated from the surrounding areas (see also p.89, M4).
There are certainly very few other countries where such a potential for natural risks exists as in Japan. But there is also no other country in the world that is so well prepared against events such as earthquakes. So how does Japan protect itself? How do tsunamis arise? And what were the consequences of the 2011 earthquake?

1. Explain how tsunamis arise (M1).
2. Give reasons for the earthquake risk in Japan (M2, atlas).
3. A Give a tabular overview of the consequences of the Tohoku earthquake (M3 – M6, p. 86).
   B Using the data from M3, compare the consequences of natural disasters in Japan, Haiti and Chile (M2, p.94).
4. The balance sheet of the earthquake would have been even worse if decisive strategies and forms of behaviour had not contributed to minimising the earthquake damage. Explain (M6).
5. Locate regions of the Earth that are especially endangered by tsunamis (atlas).



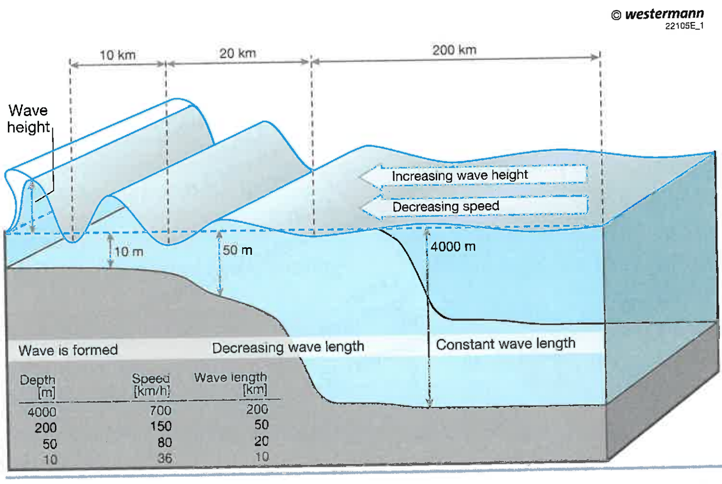
M2 Japan, geological situation

Consequences of the earthquake

The earthquake mainly affected the Pacific coastal strip in the Tohoku region: c. 16,000 dead and nearly 3,000 missing, some 130,000 buildings completely destroyed, infinite personal suffering, incalculable damage to property.
The media's focus on the massive wall of water sweeping inland left the impression that large parts of Japan were destroyed. But "only" some 400 km² along the east coast was directly devastated by the tsunami, i.e. 0.1% of the country's land area; the destruction was disastrous locally but was not spread over a wide area. That the primary impact did not result in any particularly large-scale damage in the 130 km distant city of Sendai, with over a million inhabitants and the centre of the Tohoku region, borders on a miracle. Japan's core economic regions were spared.
The damages are put at around 150 to 250 billion US dollars out of a GDP of 5,459 billion US dollars. But this calculation is only valid if the damages caused by the nuclear accident at Fukushima are left out of the account. Japan can cope with the economic consequences of the earthquake and tsunami, but the consequences of the reactor disaster remain uncertain.
Based on: W. Flüchter: Das Erdbeben in Japan 2011, GR 12/2011

M3 Balance sheet of the Tohoku earthquake

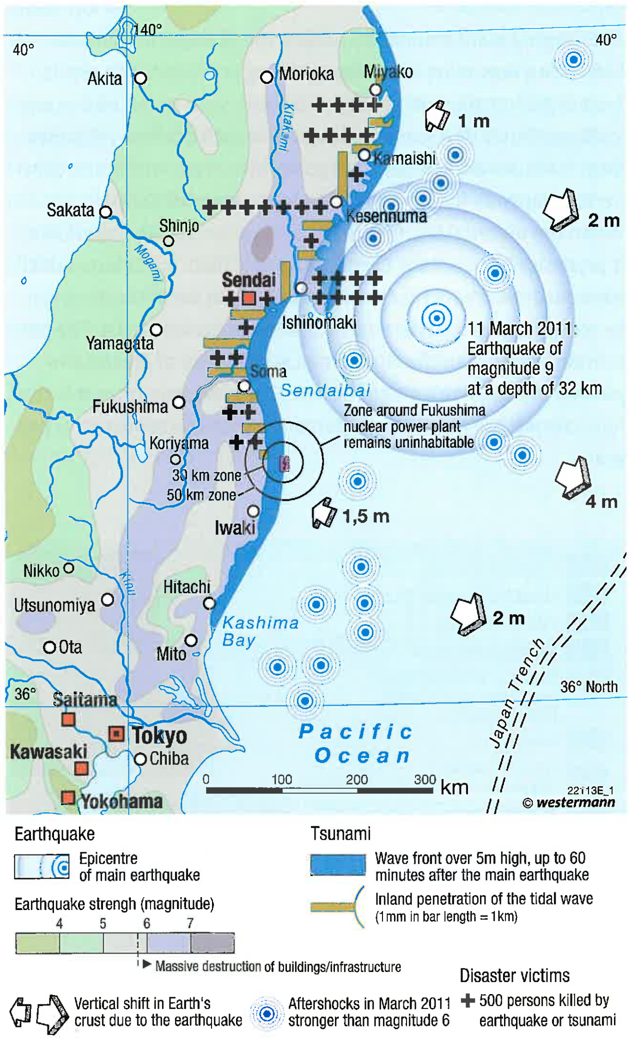
Tsunami



A tsunami spreads out in all directions from its point of origin at a speed that depends on the depth of the water. The wave is often very long, but on the open ocean it may not be very high.
In contrast to a "normal" wave which is triggered by the wind and thus only affects the topmost layer of water, a tsunami affects the entire column of water from the sea floor to the surface.
Due to the great length of the wave, it is not noticeable on the open sea. Only when it reaches the coast is the front of the wave slowed down while a gigantic mass of water is pushing from behind at high speed. As a result, the wave piles up and can sometimes reach a height of many tens of metres when it runs out onto the coast.
Based on: R. Glawion u. a.: Physische Geographie, 2012

M1 Formation of a severe tsunami

M4 Water masses at Miyako in Japan from a tsunami caused by the earthquake on 11.3.2011



M5 Tohoku earthquake off Japan on 11.3.2011

Seismic early warning

- **Earthquake:** It is currently impossible to reliably predict the timing and location of earthquakes. But in the event of an earthquake, an efficient early-warning system comes into play. This is based on the differing speeds of the P-waves and S-waves. The first signals of the P-wave mean an early-warning potential of 40 seconds in the case of the metropolis of Tokyo, 370 km from the hypocentre, or 14 seconds in the case of the 130 km distant Sendai: valuable time. Express trains could be halted automatically, flood gates opened, bridges closed off. In spite of the permanent danger of earthquakes, the Shinkansen high-speed train has not suffered one single fatal accident.
- **Tsunami:** The fact that tsunami waves move much more slowly that seismic waves makes it possible to obtain adequate early warning with the aid of a close-knit network of seismic sensors, gauges and buoys. According to reports, the tsunami took 10 to 30 minutes to reach the nearest affected coastal region – valuable time for saving human life. Tens of thousands took advantage of this opportunity.
- **Earthquake-resistant and earthquake-flexible building technology:** In terms of building technology, Japan with its internationally first-class vibration monitoring and insulation technology represents the model for cities with a similar degree of vulnerability, e.g. San Francisco and Istanbul. But even this exemplary country still needs to do a great deal to make its great mass of private wooden housing both more earthquake-resistant and more fire-resistant. In Japan, the secondary effects due to fires are at least as dangerous as the destructive power of the earthquake.
- **Conduct and reaction of the population in an emergency:** In Japan through the ages, people have been accustomed to natural disasters. Respect for the powers of nature is deeply rooted in the consciousness of the population. Disaster prevention exercises are held at least once a year, ritualised on 1 September in memory of the Great Kanto earthquake of 1923.

Based on: W. Flüchter: Das Erdbeben in Japan 2011. GR 12/2011

M6 Disaster precautions

M1 Agriculture next to Mount Merapi (Indonesia)

M3 Retrieving bodies after the 2010 Merapi eruption

Volcanoes – A Curse or a Blessing?

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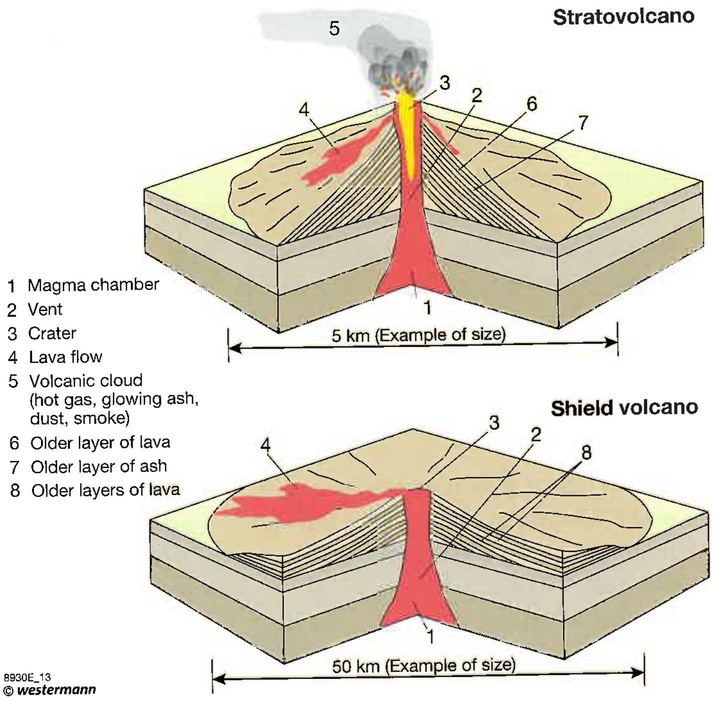
At present, there are more than 600 active volcanoes on Earth, such as Mount Etna on Sicily, and Mount Kilauea on Hawaii. Most of them are found near active plate margins, for example the 'Ring of Fire' around the Pacific Ocean.



M2 Cross-sections of a stratovolcano and a shield volcano

Different types of volcanoes

There are two basic types that make up most of the Earth's active volcanoes: stratovolcanoes and shield volcanoes (M2). Both their shape and the way they erupt depend on the type of liquid rock in their magma chamber. As soon as this magma reaches the surface it is called lava.

Stratovolcanoes are formed from viscous lava that contains high amounts of gas. This gas is the reason for the explosive eruptions of stratovolcanoes. When magma rises to the surface and is blocked on its way, the pressure increases because gas collects inside the volcano. The explosion leads to lava, rock fragments, ash, and gas being ejected. This mixture can also run down the slope of the mountain as a glowing cloud. The lava cools down fast forming a cone-shaped mountain that is built by alternating layers of rock, lava flow, and ash.

The eruptions of shield volcanoes are less violent than those of stratovolcanoes. They are formed from very hot and highly liquid lava spreading out quickly over large areas. This type of lava contains little gas and pours out of vents or rifts. These comparatively quiet effusions gradually build up mountains with gentle slopes.

Mount Merapi – a dangerous volcano

Mount Merapi is one of most active stratovolcanoes worldwide. In 2010, these eruptions became more severe. Glowing clouds of ash and gas spread around the volcano for more than 15 km. The eruption destroyed 26 villages and killed 324 people. Large numbers of farm animals were killed as well.

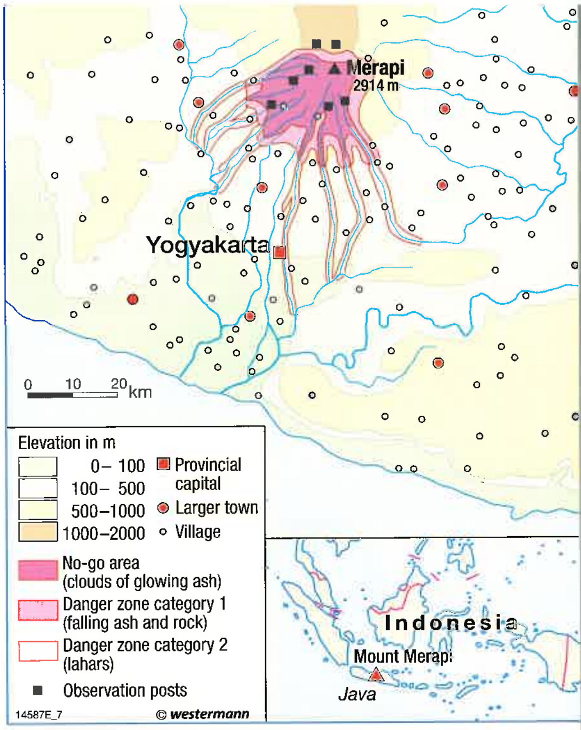
Mr. Arimbawa, you are an expert on volcanoes and live in the region. Are you glad that the catastrophe is over?
'Yes, I am, but there is still the threat of lahars.'
Lahars? Can you explain what that is?
'Lahars are dangerous mudflows that bury everything that's between them and the valley floor. They can occur when eruptions are followed by heavy rain.'

So it is the combination of different hazards that makes the catastrophe?
'Oh yes! The eruptions turn day into night and they continue for quite some time. But they are accompanied by rain that is thick like mud. Drinking water is contaminated and people don't have any electric power for weeks. Often there is no help from the outside because the roads are blocked or destroyed.'

But why, then, do so many people live in this area? It seems to be extremely dangerous!
'Usually, the mountain is good to us. Volcanic soils are rich, fertile and good for farming. When the lava cools, it turns into solid rock, which is rich in valuable materials such as gold, copper, and nickel. We also use the rock as building material for roads and houses. And there is a vast potential source of renewable energy from the hot water springs around volcanoes. And don't forget that many people like the scenery around here. Our landscape attracts lots of tourists each year, so many people find jobs in the tourist industry.'

So you have to live with the risk?
'Actually, we try to minimise it. There are lots of observation posts and we measure tectonic activity in the area. But you're right: in the end, we have to live with it.'

M4 2010 Merapi Eruption – An interview with an eyewitness



M5 Position and zoning of the Merapi area

pp. 194-195 Photographs
pp. 212-213 Presentation

HELPFUL WORDS AND PHRASES
for TASK 2:
- ... are more dangerous / less dangerous / (not) as dangerous as ...
- ... are more dangerous because ...
- Due to the fact that ...
- Compared to... , ... are less dangerous, because...
- In comparison to ...

KEY TERMS
- lahar
- lava
- magma
- shield volcano
- stratovolcano
- vent
- volcano

TASKS

1. Describe the negative effects of volcanic activity.
2. Explain which type of volcano is more dangerous.
3. Explain why so many people still live near active volcanoes.
4. Prepare a short presentation about a recent volcanic eruption.

Source: Hoffmann, R. (Ed.): Diercke Geography, For Bilingual Classes, Volume 1. Westermann, Braunschweig 2015.

Volcanology

The term **volcanology** includes all the processes by which solid, liquid or gaseous materials are forced into the Earth's crust or are ejected onto the surface. Although material in the mantle has a high temperature, it is kept in a semi-solid state because of the great pressure exerted upon it. However, if this pressure is released locally by folding, faulting or other movements at plate boundaries, some of the semi-solid material becomes molten and rises, forcing its way into weaknesses in the crust, or onto the surface, where it cools, crystallises and solidifies.

The molten rock is called **magma** when it is below the surface and **lava** when on the surface. When lava and other materials reach the surface they are called **extrusive**. The resulting landforms vary in size from tiny cones to widespread lava flows. Materials injected into the crust are referred to as **intrusive**. These may later be exposed at the surface by erosion of the overlying rocks. Both extrusive and intrusive materials cooled from magma are known as **igneous rocks**.

Extrusive landforms

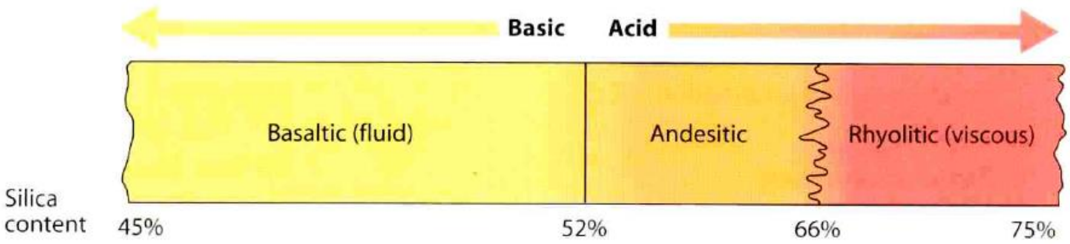
There are several types of extrusive landform whose nature depends on how gaseous and/or viscous the lava is when it reaches the Earth's surface (Figure 1.21).

- Lava produced by the upward movement of material from the mantle is **basaltic** and tends to be located along mid-ocean ridges, over hot spots and alongside rift valleys.
- Lava that results from the process of subduction is described as **andesitic** (after the Andes and occurs as island arcs or at destructive plate boundaries where oceanic crust is being destroyed.
- **Pyroclastic material** (meaning 'fire broken') is material ejected by volcanoes in a fragmented form. Tephra, fragments of different sizes, include ash, lapilli (small stones) and bombs (larger material) which are thrown into the air before falling back to earth. Pyroclastic flows move down the side of a volcano as a fast-moving cloud (Figure 1.46). Subsequent heavy rainfall, e.g. Mount Pinatubo (Case Study 1) or the melting of ice and snow, e.g. Nevado del Ruiz (Case Study 2A) can rework the fragmented pyroclastic material to form mudflows (or lahars).

Source: Waugh, David: Geography – An Integrated Approach. Nelson Thornes Ltd, Cheltenham, 4th edition, 2009.

Figure 1.21

Basic and acid lava



Basaltic or basic lava	Andesitic or acid lava
Has low viscosity, is hot (1200°C) and runny, like warm treacle	Viscous, less hot (800°C), flows more slowly and for shorter distances
Has a lower silica content	Has a higher silica content
Takes a longer time to cool and solidify, so flows considerable distances as rivers of molten rock	Soon cools and solidifies, flowing very short distances
Produces extensive but gently sloping landforms	Produces steep-sided, more localised features
Eruptions are frequent but relatively gentle	Eruptions are less frequent but violent due to the build-up of gases
Lava and steam ejected	Ash, rocks, gases, steam and lava ejected
Found at constructive plate margins where magma rises from the mantle, e.g. fissures along the Mid-Atlantic Ridge (Heimaey); over hot spots (Mauna Loa, Hawaii)	Found at destructive margins where oceanic crust is destroyed (subducted), melts and rises, e.g. subduction zones (Mount St Helens); as island arcs (Mt Pelée, Martinique)

Exercises

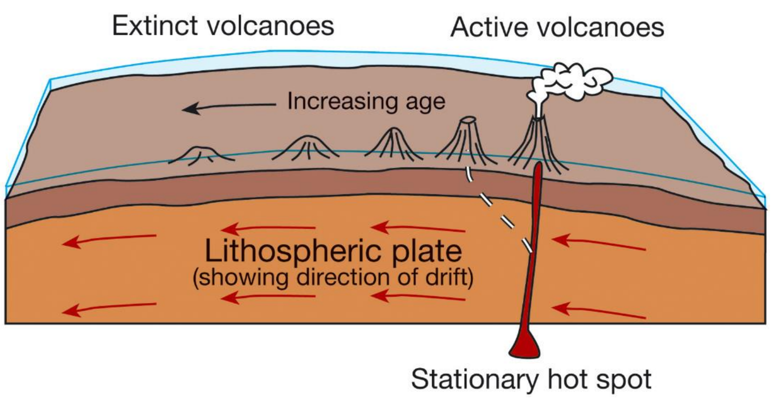
1) *What are the typical relations in volcanism? Fill out the following table:*

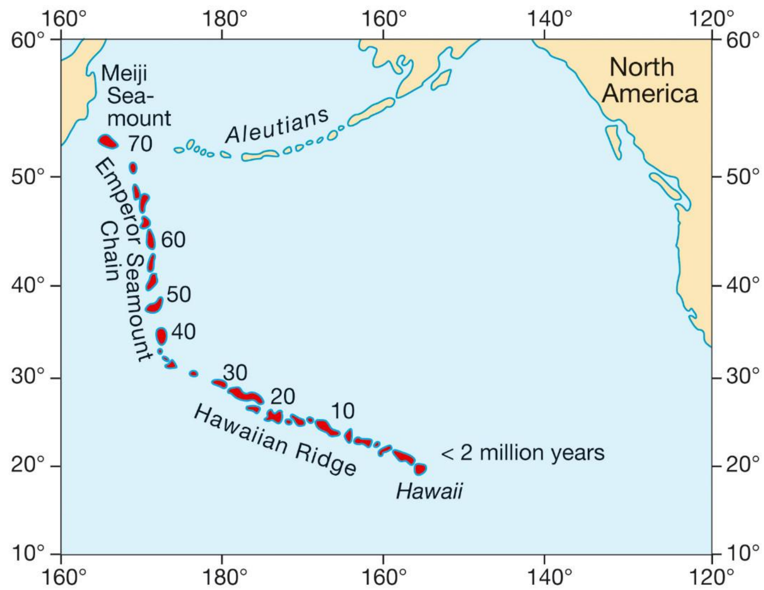
Kind of lava	Tectonic origin	Nature of eruption	Form of volcano

2) *Explain the process of formation of the Hawaii Islands.*

Mauna Loa (Hawaii, USA) is the world's largest volcano, with a volume of roughly 42,500 cubic kilometres, of which 84% lie under water. Above ground, lava flows cover an area of over 5,000 square kilometres. Geologists assume that a stationary **hot spot** has been present beneath the Hawaii island group for some 85 million years, and that it lies in the magma chamber anchored in the sub-lithospheric mantle. This extreme hot sport works much like a welding torch. It exudes basic magma, which burns its way through the Earth's crust and creates volcanoes through effusion. Yet because the oceanic crust wanders over the hot spot, the direct connection to the Earth's interior is continually broken and the flow of lava interrupted. New volcanoes are formed in the aftermath, however, producing an island chain consisting of volcanoes of different ages.

Source: Latz, Wolfgang (Ed.): Diercke Geography, advanced level. Westermann, Braunschweig, 2015.





3) *Explain how far the existence of hot spots can be accepted as proof of continental drift.*

MINERAL

A mineral is a naturally occurring substance that is solid and stable at room temperature. It is a substance in the chemical sense, which means that it is composed of molecules and that it can be represented by a chemical formula. Most minerals are formed in inorganic processes. Geology is interested in minerals because rocks are made of minerals. Many minerals show a geometrically regular atomic structure – they form crystals. Noncrystalline solids, like glass or gel, are called amorphous (amorph, formlos). Nowadays close to 5000 minerals are known, but only about 30 are really important for geologists. The crust of the Earth and by consequence the mass of minerals is mainly composed of only eight elements: O, Si, Al, Fe, Mg, Ca, K, and Na. While every mineral may theoretically represent a sort of rock, in nature most rocks are composed of a mixture or several minerals.

THE FORMATION OF ROCKS AND MINERALS AS A GATE TO THE HISTORY OF THE EARTH

When we look at nature as a product of processes, whatever we understand, it will tell us stories about the past and about relations of phenomena. That's the natural science approach to the world. If we understand the processes of the rock cycle, the rocks that we find at some location will tell us many secrets about the geological history of that place. If we find coal, for instance, there must have been rich vegetation. If we find rounded pebbles, there must have been a river. If we find pumice, there was a volcano nearby. If there is salt, the place was once covered by a sea. These are just the most obvious examples.

However, if we look closer at rocks and their mineral composition, we may draw many more interesting conclusions. But to do this, we have to acquire two geological key competences: first, we have to be able to identify rocks, second, we have to understand the processes that create them.

THE ROCK CYCLE

Rocks are linked by the rock cycle. Rocks seem permanent and unchanging. In fact they are changing slowly all the time.

There are three different types of rocks building the lithosphere:

- **igneous** rocks
- **sedimentary** rocks
- **metamorphic** rocks

However, each rock type forms from the remains of a previously existing rock as each rock is melted and cooled, weathered or compressed into a new type of rock. There is no beginning and no end to this rock cycle. It just goes round and round as rocks, sediment and magma moves around the Earth's lithosphere. Some rocks have been round the cycle several times during the Earth's history of 4500 million years.

Processes at the Earth's surface

Igneous Processes

When magma reaches the surface either **lava flows** or **pyroclasts** (= explosive magma: solid fragments) are produced. The lava and pyroclasts cool down at the surface, **extrusive igneous rocks** are formed. The lava becomes solid rock during the process of cooling down when crystals of minerals form. This is called **crystallisation**.

Sedimentary Processes

As soon as a rock is exposed to the Earth's atmosphere and water the processes of **weathering** begin. The rocks are broken down by physical, chemical and biological processes in situ (= where they are). In parallel the fragments and soluble compounds are removed by **erosion**. The rock fragments and soluble compounds are transported from one place to another by gravity, running water, ice, wind and the sea. During their transport the fragments are reduced further in size by collisions. Sooner or later the transport agents lose energy and the fragments and soluble compounds are **deposited** again at another place.

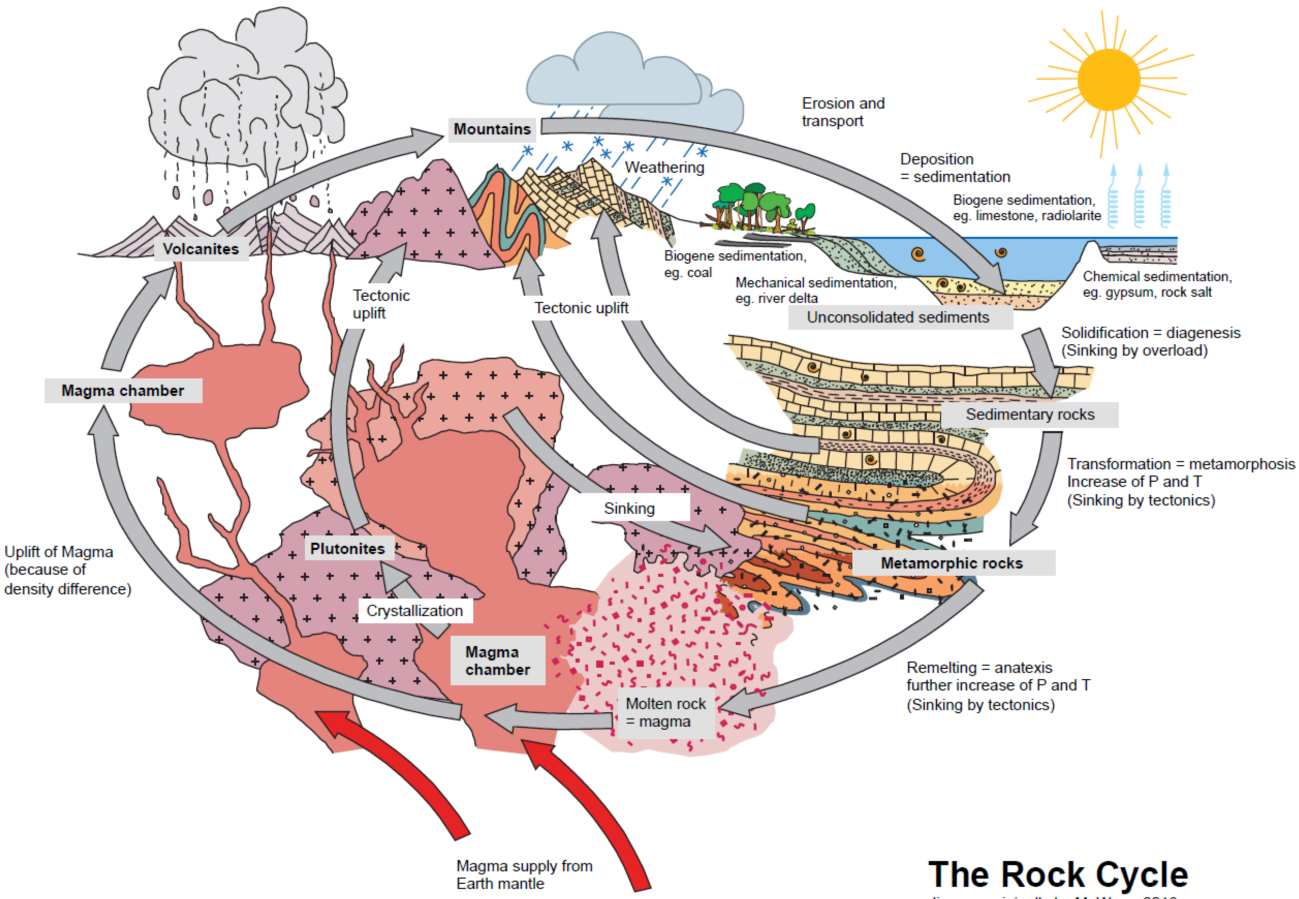
Processes below the Earth’s surface

Sedimentary Processes

Oceans and lakes are the most common places for deposition. **Burial** occurs as sediment is covered by more and more layers of sediment deposited on top: the deeper sediments are buried the more compact they become as the grains move into closer contact, due to the rising pressure of the sediment above them circulating water between the grains of a sediment deposits minerals in the spaces between the grains the growth of minerals in pore spaces and the compaction of grains result in the formation of sedimentary rocks. The changes that occur in buried sediments because of the increase of pressure and temperature while they move to greater depths inside the Earth are part of the process of **diagenesis**.

Metamorphic Processes

(Greek: meta = change; morphe = form)
Metamorphism changes parent rock (= original rock) into a **new type of rock** by the effects of **heat** and/or **pressure**.



The Rock Cycle
diagram originally by M. Wyss, 2013

IGNEOUS ROCKS

Igneous rocks are formed by the **solidification of magma**, a silicate liquid generated by partial melting of the upper mantle or the lower crust. Different environments of formation, and the cooling rates associated with these, create very different textures and define the two major groupings within igneous rocks:

Volcanic (or extrusive) rocks

Volcanic rocks form when magma rises to the surface and erupts, either as lava or pyroclastic material. The rate of cooling of the magma is rapid, and crystal growth is inhibited by this. Volcanic rocks are characteristically fine-grained.

Plutonic (or intrusive) rocks

Plutonic rocks form when magma cools down within the Earth's crust. The rate of cooling of the magma is slow, allowing large crystals to grow. Plutonic rocks are characteristically coarse-grained.

Granite (Granit)	High content of feldspar (milky), medium content of quartz (grayish, slightly transparent). Often some biotite is easy to identify (black). Usually rather bright appearance. Granite alludes to orogenic processes (formation of mountain ranges). It does not occur at mid-oceanic ridges.
Gabbro (Gabbro)	Dark appearance. Often found along mid-ocean ridges or in ancient mountains composed of compressed and uplifted oceanic crust. Gabbro is the plutonic equivalent of basalt.
Basalt (Basalt)	Dark, fine-grained volcanite (crystals usually barely visible). Their mineralogical composition corresponds with gabbro. Basalt typically emerges at diverging plate boundaries, but also at other locations where magma is not far away from the surface, so that certain minerals did not have enough time to crystallize. Basalts are thin fluids (low viscosity) and often form effusive volcanoes (shield volcanoes). As a result of tensions during their cooling of the lava they often break into hexagonal pillars, which, forming walls, may look like organ pipes.
Obsidian (Obsidian)	Glassy frozen magma. This is only possible if the lava did not release gases during the eruption. The rock breaks shell-like with sharp edges. In the stone age obsidian was often used for tools and traded over long distances.
Pumice (Bimsstein)	Pumice is characterized by closed bubbles. It is so to speak frozen lava foam. Consequently, it has a low density. Usually it is a bright rock that occurs at explosive volcanoes.
Quartz porphyry (Quarzporphyr)	Volcanite, hemicrystalline rock with inclusions of quartz and alkali feldspar.

SEDIMENTARY ROCKS

Sedimentary rocks are the product of weathering and erosion of existing rocks. Eroded material accumulates as sediment, either in the sea or on land, and is then buried, compacted and cemented to produce sedimentary rock, a process known as diagenesis.

Mechanical and chemical weathering disintegrate or dissolve rocks respectively. While mechanical weathering only affects the physical structure of the rock, chemical weathering changes its mineralogic composition and creates new minerals. While mechanical and chemical sediments are related to their specific forms of weathering, biogene sediments are made of remnants of living beings.

As in the case of igneous rock also the kind of minerals and the mechanical structures of the rock in question provide us with information about the conditions of their origin and the processes of their transformation. However, sediments do not only talk about the conditions of the place, where they were found, but also about the place where they were eroded from or the organisms they stem from, and they may also inform us of their transport medium. In many cases layers of sediment also conserve dead plants and animals over many hundred millions of years. These fossils allow us to reconstruct the history of life and climate on the earth.

Mechanical sediments

Wind and water transport the particles or the dissolved substances. The erosion and deposition of particles depends on the size of the particles and their density, as well as on the velocity and the density of the transport medium. As a consequence, mechanical deposition usually shows a differentiation or sorting of the particles. If the velocity of water changes, for instance in the course of seasons, its sediments are composed of layers of rhythmically varying particle sizes. Also seasonally changing wind directions may create sediment layers whose ripples show different directions. But the ice of glaciers does not sort the particles. While the fine particles that were eroded at the bottom of a glacier are transported mainly by the melting water, the coarse particles and all those that dropped once onto the ice, are carried by the ice until it melts at the glacier sides or its tongue, where they form the unsorted material of moraines.

Results of weathering and transport: Sediments

Grains get rounder the longer/further they have been transported. The shape of grains depends on the type of rock or mineral from which they are made rather than on transport.

grain size in mm	sediment name	sedimentary rock
> 2	gravel, pebbles, boulders	breccia (elements unrounded) conglomerate (elements are well-rounded)
1.1 to 2	sand — coarse	sandstone
0.5 to 1.1	sand — medium	
0.1 to 0.5	sand — fine	
0.05 to 0.1	silt	mudstone
< 0.05	clay	clay, shale

Diagenesis: turning sediments to sedimentary rocks

Sandstone is not the same as sand, mud is not the same as shale and organic matter is not the same as hard coal. The processes transforming the sediment sand into sandstone, the sediment mud into shale and organic sediments into hard coal is called diagenesis.

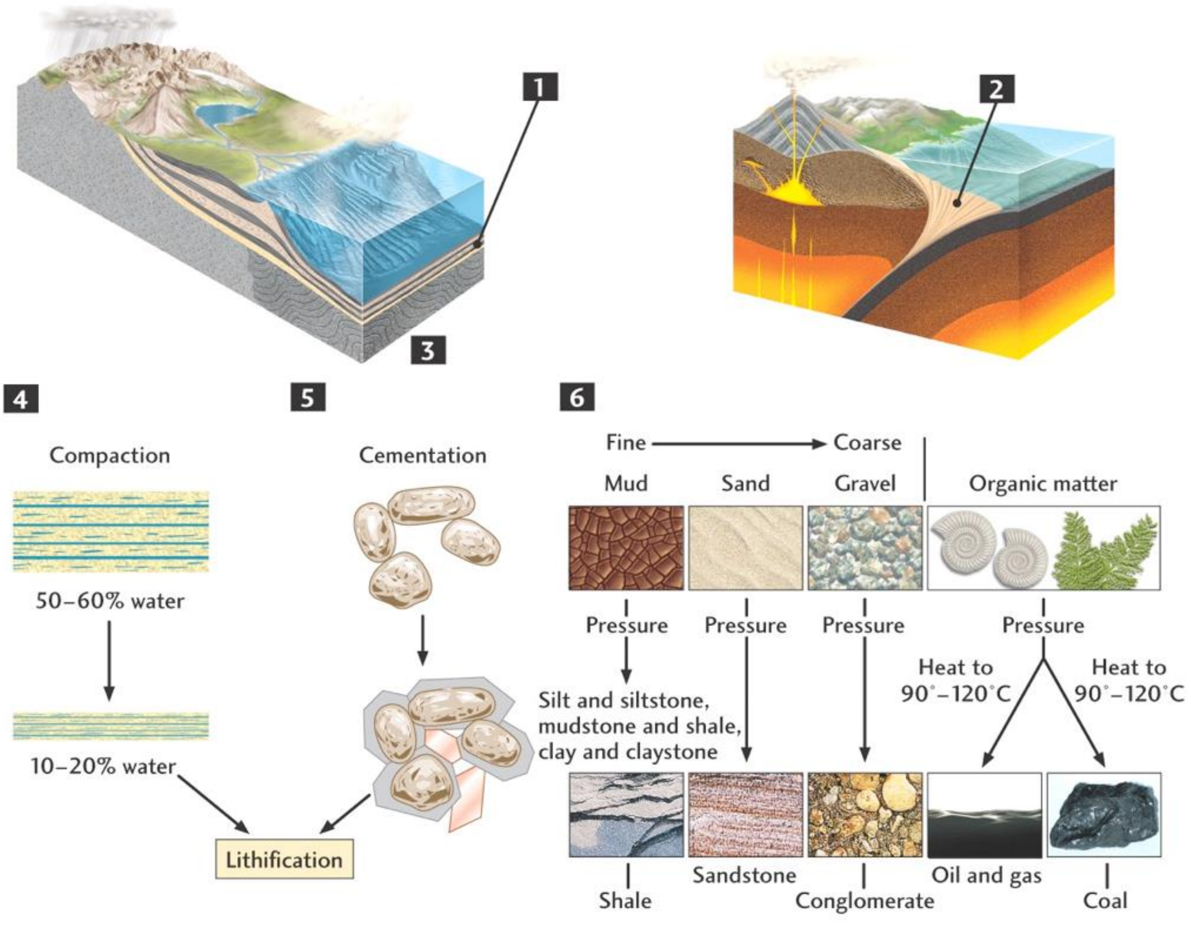
Diagenesis takes place at low temperatures and pressures at or near the Earth’s surface. The main processes involved in diagenesis are compaction and cementation.

Compaction:

As layers of sediment accumulate one on top of another, their mass produces load pressure. This acts vertically and affects the sediments below causing compaction to take place. Grains become more closely packed and this reduces the porosity of the sediment and the amount of water contained within the pores. Mud and clay are mostly affected by compaction turning into mudstone or shale. The original thickness of the mud or clay sediments can be reduced down to 20%. The formation of coal is also based on the process of compaction rather than on cementation.

Cementation:

Sands and many biologically formed types of sediments have greater permeability than muds. Groundwater containing minerals in solution flows through the pore spaces and where the conditions are right the minerals are precipitated forming a cement which binds grains together to form sandstones and limestones. The most common cementing minerals are: quartz, calcite and iron minerals.



source: http://bc.outcrop.org/images/rocks/sedimentary/press4e/figure-08-11.jpg

Five basic classes of mechanical sediments are distinguished:

a) Breccias (Brekzien) consist of coarse, angular (eckig, kantig) debris (Schutt) which is filled with a fine cement (Bindemittel) that holds the particles together. The size and the angular form of the main component indicate that the material was not transported far by water or that it was deposited by ice.

b) Conglomerates (Konglomerate) consist of rounded pebbles, the space between which is also filled by sand or fine cement. Contrary to breccias the rounded shape of the main component indicates a long transportation by water. They are thus river sediments. Conglomerates fill also the central basin between the Alps and the Jura mountains in Switzerland, where they are called "Nagelfluh".

c) Sandstones (Sandsteine) are composed of smaller grains (ca. 8 mm to 0.1 mm), which may be rounded or not and which may have been deposited by water or by wind. Depending on the degree of compaction (diagenesis) they may be crumbly (bröckelig) or hard. Very fine "sands" are called silt.

d) Clay (Ton) is an extremely fine sediment (< 0.002 mm) which consists of a variety of clay-minerals. It is formed either as a very fine sediment from water or wind or then as a chemical sediment (transformation of soils) in warm and humid climates.

e) Marl (Mergel) is a mixture of clay and limestone (Kalk), the latter of which may be a marine-biogene or then a chemical sediment. A typical location for marl would be large river deltas at the coast, where freshwater and seawater mix without considerable currents.

Chemical sediments

If rock material is transported dissolved in water, the deposits are called chemical sediments. Or in simpler words: chemical weathering produces chemical sediments. Usually, substances that were dissolved in water, crystallize and accumulate at certain locations. This mostly takes place when the temperature or the velocity of the water changes or when the concentrations of the dissolved substances increase, for instance when water is evaporating.

On a global scale, clay is one of the most important chemical sediments. It provides the tropical soils their characteristic red color. The evaporation of shallow seas or lakes in the tropics increases the concentration of dissolved minerals which leads to deposits of salt, gypsum and other substances containing Ca (calcium), Na (sodium / natrium) or K (potassium).

Biogene sediments

Biogene sediments are materials that stem from plants or animals. Rivers transport large amounts of calcium bicarbonate (which under normal conditions exists only in dissolved form) into the oceans. Many organisms living in the sea, mostly animals, have the ability to absorb the calcium or silica components, to form shells and skeletons. Most of these organisms are very small but numerous. When they die, in many millions of years their remnants may form layers of limestone several kilometres thick. The younger sediments thus enforce an increasing pressure on the earlier ones, which intensifies their solidification and which eventually may lead to first forms of transformation. This diagenesis transforms the original lime slurry of the ground into hard limestone.

Because cold water under high pressure is able to dissolve more carbon dioxide, at roughly 3500 m below sea level the mineral calcite is dissolved again. Below this calcite compensation depth (CCD) no limestone is sedimented, but only silica (Silikate) components, e.g. as radiolarite (Radiolarit). In the zone of transition also siliceus limestone (Kieselkalk) is deposited. As a consequence of diagenesis, within limestone a concentration of silica may take place, forming chunks of flint (Feuerstein).

If oxygen lacks, the organic deposits of plants or animals are not fully biologically decomposed, and may eventually become coal, oil or gas. While coal is mainly compressed organic material (mainly from land plants) in various degrees of compaction, oil and gas are stem from plankton (Plankton; mostly invisibly small animals of the sea) which was in the course of diagenesis disintegrated into components of various density and viscosity. These liquids and gases possess a low density and may travel upwards through layers of sediments until the reach an umbrella-like impermeable layer which traps them. In the porous sediment below, they reach high concentrations, which is favourable for their exploitation. Diagenesis drives also the transformation of lignite (brown coal) into bituminous coal (stone coal) and finally into anthracite (Anthrazit).

METAMORPHIC ROCKS

Metamorphic rocks begin as either igneous, sedimentary, or pre-existing metamorphic rocks and undergo a major change: **metamorphosis**. The change is caused by **high levels** of **heat** and **pressure within** the **earth's crust**.

However, there is **no melting** involved in the process of metamorphism. Thus, the chemical composition of the rocks stays the same before and after metamorphism (= isochemical process).

High levels of heat and pressure make either new minerals grow or force the minerals to align themselves in a new way, therefore the mineral grid changes and the rocks show clear **schistosity** (= Schieferung).

During the isochemical process of metamorphism, the rock undergoes the very slow process of solid-state recrystallisation without melting caused by either heat or pressure, or both heat and pressure. Different temperatures and different levels of pressure cause new minerals to grow, however, still showing the same chemical composition.

The lower temperature limit for metamorphism is between 150 and 200°C. Below these temperatures changes are part of **diagenesis**. The upper temperature limit is where melting occurs: around 800°C.

The process of metamorphism may result in:

- destruction of fossils, sedimentary structures
- hardening of the rock
- change in colour
- (new) alignment of minerals
- growth of new metamorphic minerals, e.g. garnet.

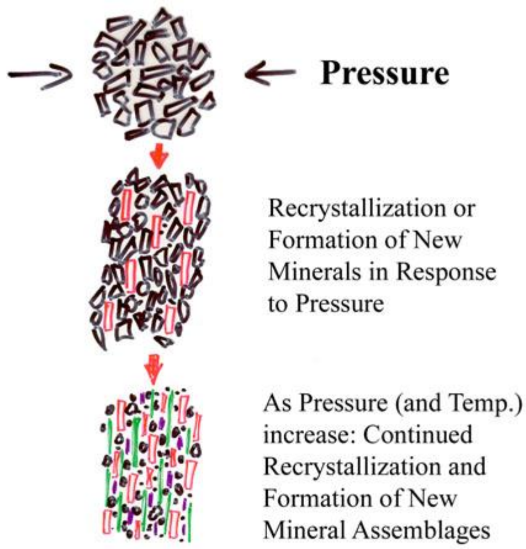


Figure 1: Mineral growth under stress

Regional metamorphosis designates cases of large scale transformation of rock, usually through tectonic processes (e.g. at a subduction zone). The transformation happens under both, high pressure and high temperatures. Particularly at converging plate boundaries materials may be pressed several dozen kilometres into the ground, way beyond the usual lower boundary of the crust. At such depths, in the upper asthenosphere, materials are ductile but not yet liquid and they are mechanically transformed according to the powers that the plates exert onto each other. The igneous rock granite, for instance, may be transformed into gneiss, which still shows minerals of the same kind. But the shapes of the crystals point now into the same direction, which provides the rock with a layered look. Furthermore, under high temperatures and pressures also their minerals may transform and new minerals may emerge. Interestingly enough, these chemical alterations happen in the solid state, but over long periods of time.

Besides orogenic processes also the rather small contact zones to magma chambers and volcanic vents provide conditions, where metamorphosis may happen. Here the temperature is extraordinarily high relative to the depth and the corresponding pressure. In **contact metamorphosis** mineralogic transformations prevail over mechanical ones. Finally, also the extreme conditions created by impacts of larger meteorites may create metamorphic rocks.

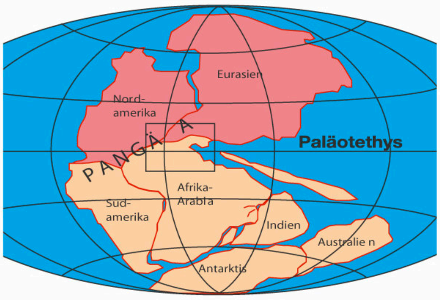
What can we read from metamorphic rocks? First, the forces and the movements of tectonic processes imprint themselves onto the material. Many metamorphic rocks show a directionality of their crystals or even a clearly layered structure. Thus, they indicate the direction of forces and plate movements. Second, for the formation of many minerals specific combinations of temperature and pressure have been identified. Therefore, the appearance of certain minerals allows a rough estimation of the depths at which the rock in question was transformed and the sequence of its transformations. Third, in spite of the transformations, also metamorphic rocks indicate their igneous or sedimentary origin, since many metamorphic minerals have their specific predecessors. Taken together, these three components make metamorphic rocks very informative witnesses of large scale tectonic processes. Their interpretation is a very skillful task, though.

Geology of Switzerland

ZiW, 2012-11-13

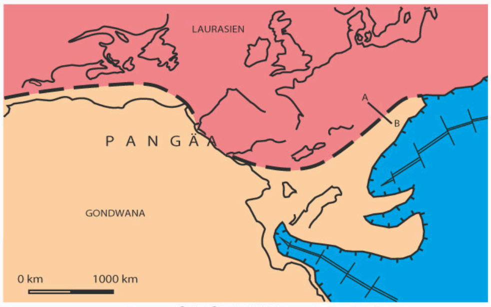
Global drift of the continents

Plate movements in the area of the contemporary Alps

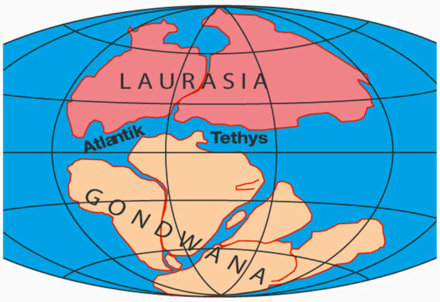


About 250 million years ago

The supercontinent Pangaea starts to break apart. A new mid-oceanic ridge is built.

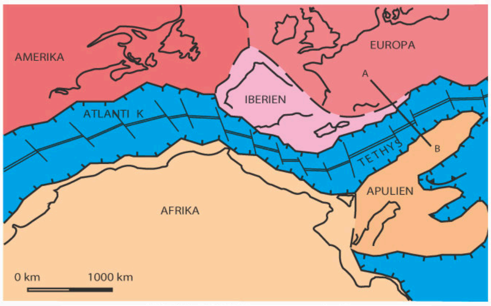


About 250 million years ago

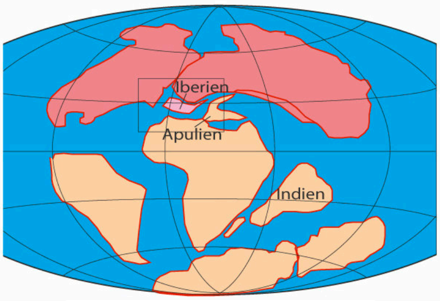


About 160 million years ago

Between Laurasia and Gondwana the Atlantic Ocean and Tethys Sea expand. The Iberian peninsula and the Apulian plate detach themselves from Europe and Africa respectively.

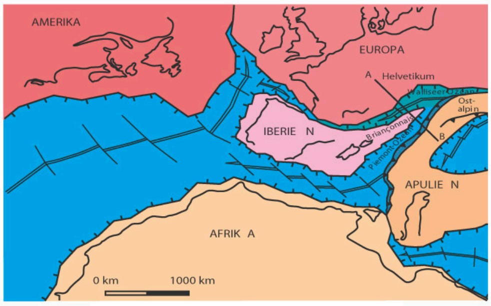


About 160 million years ago

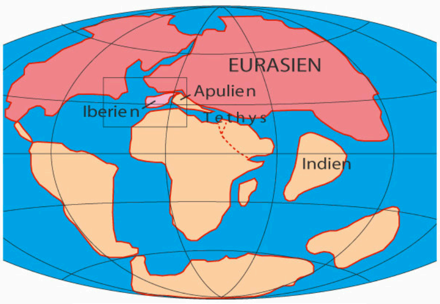


About 100 million years ago

The eastern part of the Iberian peninsula splits the Tethys Sea into two small and shallow branches. The Apulian plate now pushes against the European plate.

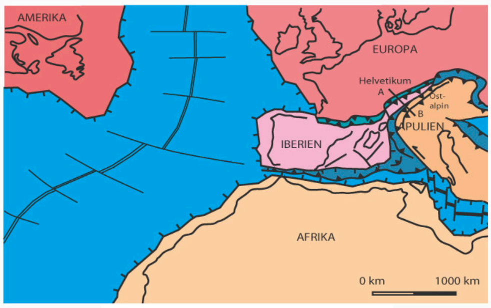


About 100 million years ago

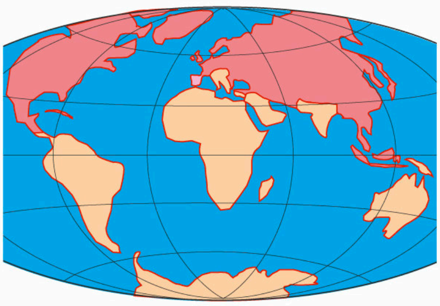


About 55 million years ago

While the two parts of the Tethys are squeezed, the Mediterranean Sea takes shape south of the Apulian plate. All involved plates show faults as a result of the compression. The orogeny of the Alps has begun. Parts of the overlapping plates in the collision zone are scraped off their base.



About 55 million years ago



The ompression forces increase and scraped of layers are folded and build nappes. Eroded material of the early Alps fills basins north and south of the mountain chain. These molasse sediments separate the Helvetic from the Jura, and they are folded as well.

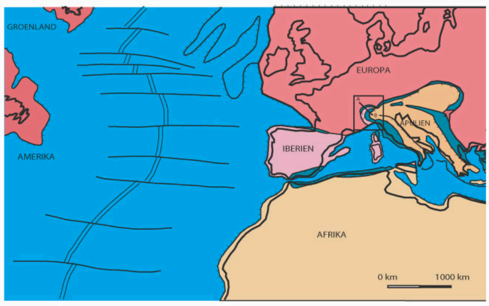
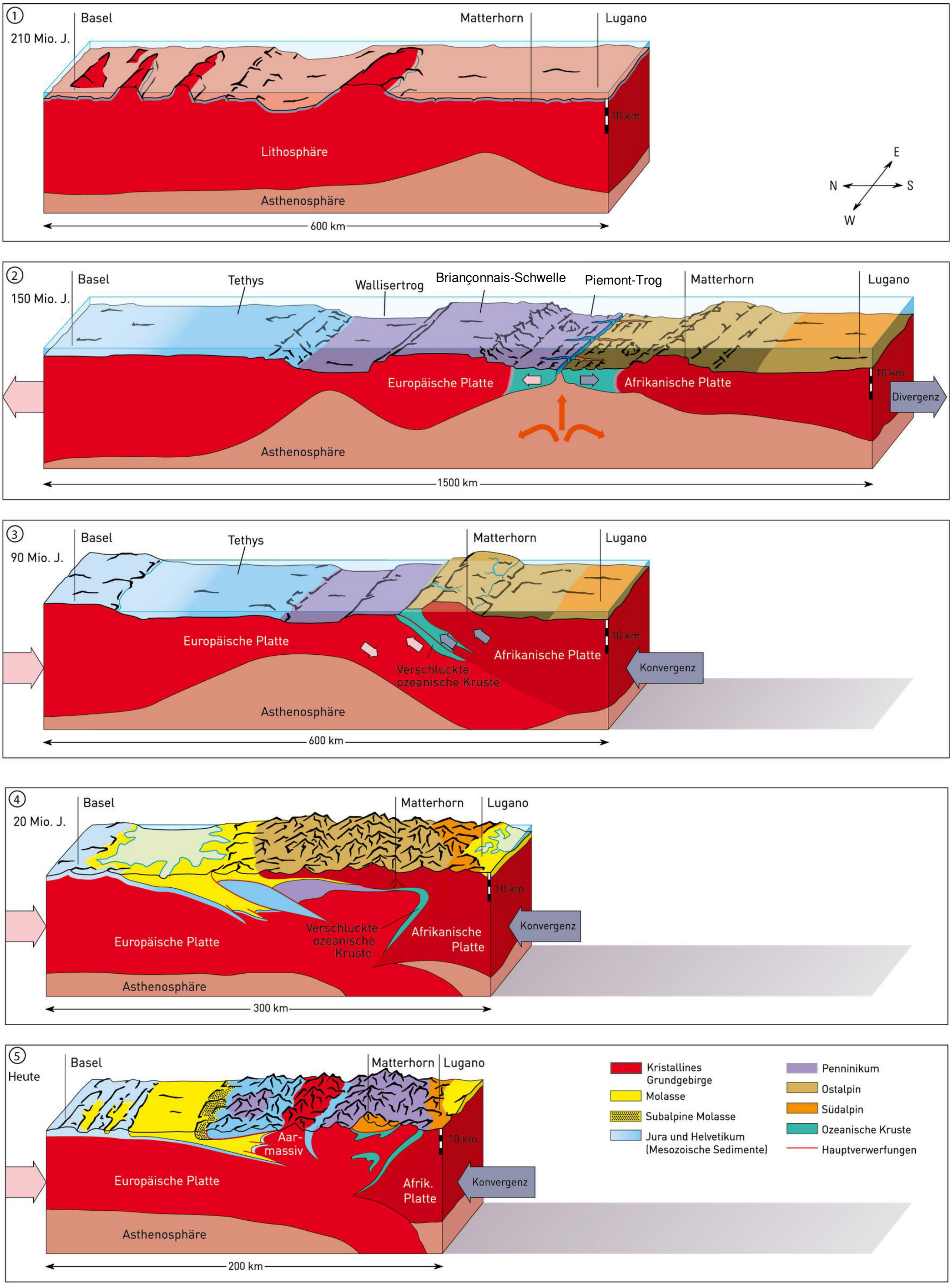


Fig. 1: Plate tectonic history.

Formation of the Alps



Orogeny and geology of the Alps

The formation of the Alps (the Alpine orogeny) was an episodic process that began about 300 million years ago. Then the Pangaean supercontinent consisted of a single tectonic plate, but it began to break apart broke separate plates and the Tethys sea developed between Laurasia and Gondwana during the Jurassic Period (ca. 200 - 160 million years ago). The Tethys was later squeezed between colliding plates causing the formation of mountain ranges called the Alpide belt, from Gibraltar through the Himalayas to Indonesia—a process that began some 70 million years ago and continues into the present. The formation of the Alps was a segment of this orogenic process, caused by the collision between the African and the Eurasian plates.

Under extreme compressive stresses and pressure, marine sedimentary rocks were uplifted, creating characteristic recumbent folds, or nappes, and thrust faults. As the rising peaks underwent erosion, a layer of marine flysch sediments was deposited in the foreland basin, and the sediments became involved in younger nappes (folds) as the orogeny progressed. Coarse sediments from the continual uplift and erosion were later deposited in foreland areas as molasse. The molasse regions in Switzerland and Bavaria were well-developed and saw further upthrusting of flysch. A late-stage of orogeny (starting 5 million years ago) caused the development of the Jura Mountains.

In simple terms the structure of the Alps consists of layers of rock of European, African and oceanic (Tethyan) origin. The bottom nappe structure is of continental European origin, above which are stacked marine sediment nappes, topped off by nappes derived from the African plate. The Matterhorn is an example of the ongoing orogeny and shows evidence of great folding. The tip of the mountain consists of gneisses from the African plate; the base of the peak, below the glaciated area, consists of European basement rock. The sequence of Tethyan marine sediments and their oceanic basement is sandwiched between these rocks derived from the African and European plates.

Source: Wikipedia, entry on Alps, http://en.wikipedia.org/wiki/Alps [2012-10-29], edited by W. Zierhofer

Vocabulary:

clay = Ton, fine sediment, typically from lakes

coarse = grob

dolomite = Dolomit, “lime” with high content of magnesium

flysch = Flysch, various river-sediments from the Alps

gneiss = Gneiss, metamorphic rock, shows faint layers

lime = Kalk, marine sediment (calcium carbonate)

marl = Mergel, mixture of clay and lime, typically from deltas in the sea

molasse = Molasse,

nappes = Decken

orogeny = Orogenese (Gebirgsbildung)

recumbent = liegend

sandstone = Sandstein, river-sediment, chemical composition usually like granite

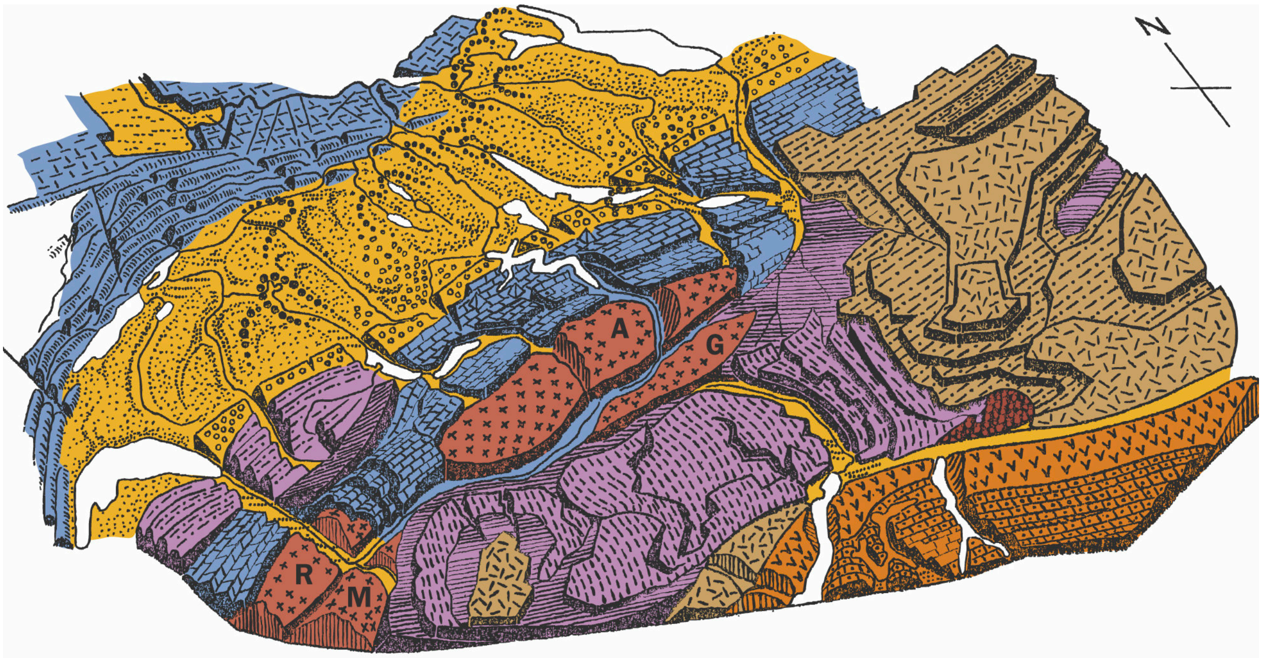
schist, shale, slate = Schiefer, either finely layered sediment (clay) or metamorphic rock

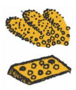
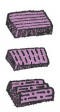
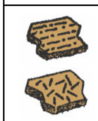
sediment = Sediment, Ablagerung

thrusting = überschieben

thrust faults = Überschiebungen

Tectonic units of the Alps (Fig. 3)



Symbol	Tectonic unit	History	Rocks
	Jura *Jura*	European shelf (as Helveticum)	marine sediments: lime, marl
	Molasse *Molasse*	Sediments from the Alps	river-sediments: some on land, some into the sea
	Helvetic *Helvetikum*	European shelf (as Jura)	marine sediments: lime, marl
	Penninic *Penninikum*	European deep-sea area and thresholds	various marine sediments (marl, lime, sandstone), some of which may be metamorphic (gneiss, schist)
	Eastern Alpine *Ostalpin*	African shelf (Apulian plate) and/or basis of African crust	African shelf: marine sediments like lime and dolomite African crust: granite, volcanite, gneiss
	Southern Alpine *Südalpin*	African shelf (Apulian plate) and/or basis of African crust	African shelf: marine sediments like lime and dolomite African crust: granite, volcanite, gneiss
	Central massifs *Zentralmassive*	(old) European crust	granite, gneiss
	Post-Alpine intrusion *Nachalpine Intrusion*	magmatic intrusion after the folding	granite