1. HOW ARE VOLCANIC CALDERAS FORMED?

On some volcanic peaks, we find large craters that did not originate by an asteroid crashing into the Earth, but through volcanic activity. As a rule, they are several kilometres wide and hundreds of metres deep. Scientifically they are known as volcanic calderas. Calderas are formed during the phase of volcanic eruption or after it when the peak of the volcano sinks into the partially emptied magma chamber.

Whereas observing the formation of calderas in nature is extremely dangerous, you can clearly demonstrate their formation in the classroom by a simple experiment using a layer of flour and a balloon.

Supplies:

- box with hard edges (e.g. cardboard) with the minimum dimensions of 40 × 40 × 30 cm
- plastic tube with a diameter of ~5 mm and a length of approx. 1 m
- balloon
- tape
- fine flour

Purchase costs for experiment supplies approx. €10

Construction directions:

Attach the balloon using tape to one end of the plastic tube. Make sure that the tube is firmly attached, and that there are no air leaks. To seal the joint of the tube and the balloon, use a rubber band, a zip tie, tape, or a wire.

Make a hole the size of the tube's diameter in the middle of the lower part of the box. Then thread the tube through the hole so that the end with the balloon remains at the bottom of the box.

It is desirable to tape around the edges of the hole around the tube so that the flour does not fall through the box. After, pour the fine flour into the box to approximately 3 cm under the box edge. While pouring, adjust the balloon's position so that it does not lie on the bottom of the box, but also be careful that it is not near the surface of the flour. For a more compacted material, shake the box. The flour will "settle" and solidify.

Course of the experiment:

Blow air into the balloon through the end of the tube. The balloon will increase in size and press on the surrounding flour. Since the walls of the box surround it, the only possible direction in which the flour can go is up. The flour is pressed up, so the surface bulges and cracks. The blocks of flour move along these cracks. With the next blow, the balloon has reached its maximum size (sometimes, you can see its top, so be careful, it can pop). Afterwards, allow the air to be released through the tube, and the balloon will deflate thanks to the weight of the flour. During this process, the arched area drops, and the flour sinks into the space that was until then occupied by the inflated balloon. The sinking of material is most marked above the balloon, where a distinct crater is formed – a volcanic caldera.

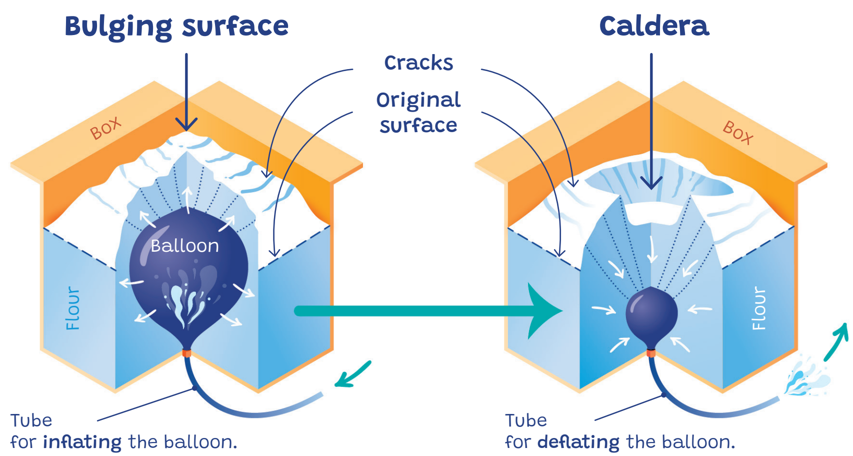


Image 2
Illustrative sketch of the experiment.
The balloon connected to the tube should be covered by flour from the start. When inflated, the balloon increases in volume, thanks to which it applies pressure to the flour (white arrows). Cracks are formed in the flour (dotted lines), along which movement occurs. When the airflow to the balloon is stopped and we unplug the tube, the flour's weight deflates the balloon, causing the flour to collapse.

Image 1
Aerial view of the peak of Mount Aniakchak composite volcano, on whose peak we find an expansive volcanic caldera. Alaska, USA. Author: M. Williams, National Park Service, licence: Public Domain

What to see:

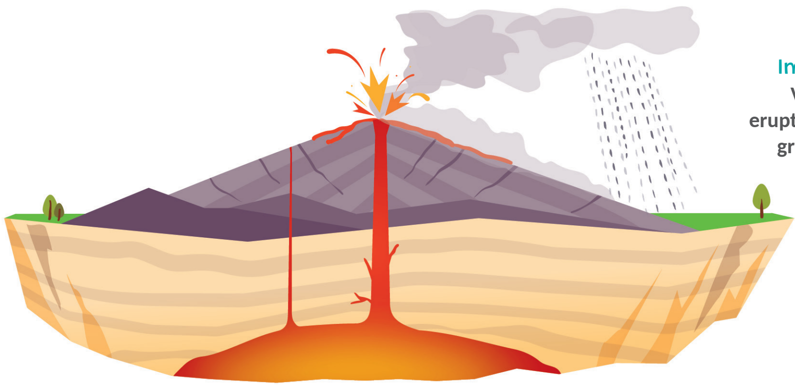
Inflating the balloon simulates the process of magma accumulation in the magma chamber. As a rule in nature, the accumulation of magma leads to the bulging of overlying rock, which can be used in combination with GPS stations to forecast volcanic eruptions. We can show this by placing building blocks on the surface of the flour and observe the movement of the blocks toward each other. The rising of the surface is accompanied by numerous weak earthquakes and the creation of faults, which again can be measured, this time using seismic stations.

Where can we find calderas?

A prime example of a caldera created through this process is found near Naples, namely the nine-kilometre-wide crate *Campi Flegrei*, or the similarly large crater in Oregon known as *Crater Lake*. Calderas are also found on other planets, such as Mars. We can also find a severalfold larger caldera on the peak of the highest mountain of the solar system, Olympus Mons.

Sources:
Experiment design taken from the USGS website (http://gallery.usgs.gov/videos/333).

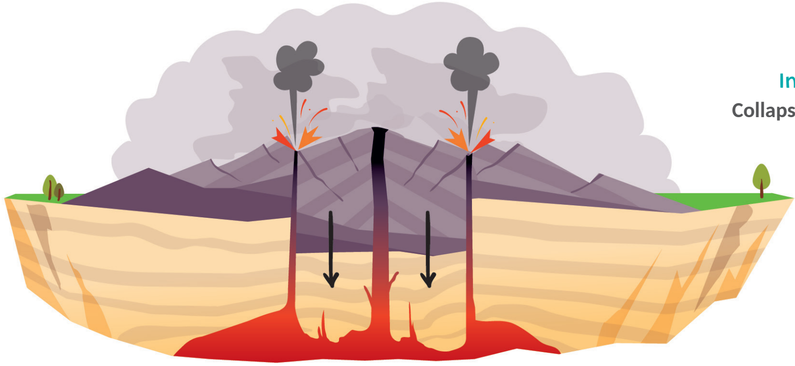
a. After the magma chamber is filled, a volcanic eruption often occurs when the magma is pushed to the surface. Once this happens, the magma is now called lava. It can create lava flows, spilling across the surroundings. If there are enough volcanic gases in the magma, however, it can tear apart into small pieces.



Img. 3a
Volcanic eruption and growth of volcano

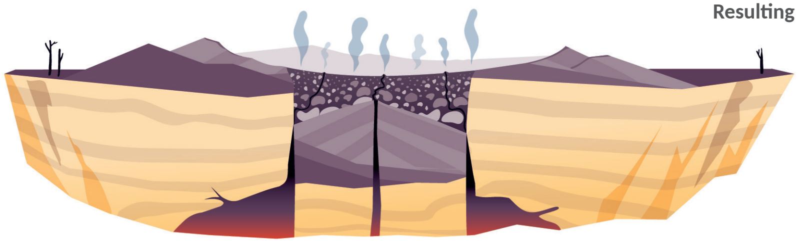
b. The effusing magma gradually empties the magma chamber. This causes the pressure that the magma exerts on the surrounding rock layers to drop. Since gravity affects these layers, they, in turn, push on the magma chamber. If their pressure gains the upper hand, they can sink into the partially emptied magma chamber. In the experiment, this part is represented by the deflating balloon, the collapsing flour, and the formation of a crater.

During the collapse, more magma is pushed up to the surface, which creates **pyroclastic clouds**. These can reach heights of several dozens of kilometres and spread over a large part of the planet along the Gulf Stream. If this happens, it can significantly affect the global climate by blocking sun rays (cooling, bad harvests), but can also affect air traffic.



Img. 3b
Collapse of the volcano

c. This collapse results in the formation of volcanic calderas.



Img. 3c
Resulting caldera

TIP: The experiment can be documented using a smartphone, and you can then create a 3D model from the series of photographs.

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See complementary materials to the experiment
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2. WHY DO SOME VOLCANOS ERUPT BUT ONLY LAVA FLOWS FROM OTHERS?

Image 1
Photo collage of two types of volcanic activity.
Author, image on right: Peter Hartree, lic.: CC BY-SA 3.0, license left image: Public Domain

Volcanic activity manifests in two main ways. Whereas primarily lava flows from some volcanoes, others erupt. During volcanic eruptions, the rising magma tears into variously sized pieces that are then spewed out into the surroundings, either in the form of volcanic bombs or volcanic dust and ash.

When only lava flows from the volcano, we label this type of volcanic activity as effusive. If the tearing of magma occurs, we use the term explosive. The typical eruptions of a given volcano depend on the number of volcanic gases that are dissolved in the magma. And to a lesser degree, also on the magma's ability to flow (so-called viscosity), which influences the speed at which volcanic gases can leak from the magma.

Since it is problematic to actually produce magma under classroom conditions (however, it would be possible by using a special furnace for smelting rocks), we need to try an experiment instead. It suitably illustrates how gases that are dissolved in liquid can suddenly escape and cause it to tear into pieces.

Supplies:

- bottle of carbonated soda or water (a least 1.5 litres)
- package of menthol Mentos candies (careful, some fruity flavours do not work well...) or a fistful of sand
- funnels for adding the Mentos or the sand
- protective eye wear
- tray (if carrying out the experiment indoors)

Purchase costs for experiment supplies approx. €3

Construction directions:

Place a bottle of carbonated soda into open space, ideally outside to prevent damaging the surrounding furniture, walls, or ceiling by the spraying liquid. Prepare several candies (or eventually a fistful of sand) and place them into a paper tube or funnel that allows them to be quickly thrown into the bottle. It is important to throw all candies into the bottle at once, since the rapid degassing of the beverage is fundamental for the clear demonstration of the experiment.

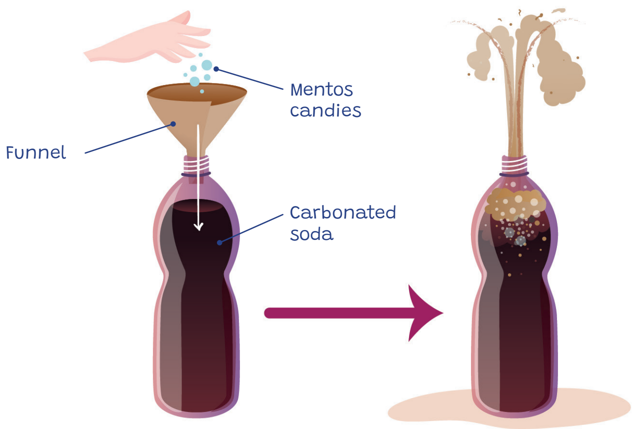

Image 2
Illustrative sketch of experiment

Course of the experiment:

Once the candies fall into the bottle, the carbon dioxide dissolved in the liquid is immediately and abruptly released. This process is accompanied by an extremely foamy jet of liquid squirting from the bottle at heights of several dozens of centimetres. The formation of bubbles is not caused by a chemical reaction, but because the surfaces of the candies have microscopic pores. The pores enable the release of gases from the liquid, causing the opportunity for gas bubbles to form (nucleation). The expanding bubbles of carbon dioxide cause an abrupt increase in the pressure inside the bottle, leading to the rapid pushing of the liquid out of the bottle. Similarly, leaking volcanic gases can accelerate the rise of magma to the surface. While the soda spews out, it is torn into variously-sized drops that are sprayed into the surroundings. Magma is torn for the same reason during a volcanic eruption. The expanding bubbles of volcanic gases can disrupt the integrity of the magma.

You can repeat the experiment using a fistful of sand, which shows that the degassing is not a result of a chemical reaction but of the nucleation of gas on the protrusions of the sharp-edged particles.

What to see:

The eruption of the bottle of soda shows the **explosive phase** of magma degassing, when the gas in magma suddenly expands and causes such pressure that a volcanic eruption can occur. This model shows the fundamental role that volcanic gases play in volcanic eruptions.

Just like carbonated soda, magma contains dissolved gases that can be rapidly released from the magma. The most common volcanic gases dissolved in magma are **water vapour**, **carbon dioxide**, and **sulphur dioxide**.

Whereas in the experiment, the release of gases is caused by the addition of candies (or sand) with many nucleation points, in nature, magma degasses from other causes. Usually, it is a decrease in the **lithostatic pressure**.

Fun fact

All of the aforementioned gases have a profound effect on the global climate. Whereas water vapour and carbon dioxide are important greenhouse gases contributing to the greenhouse effect, sulphur dioxide can both heat and cool the atmosphere, depending on how high up in the atmosphere it reaches (heats when it is in the troposphere, cools when in the stratosphere).

Thus, in the long run, volcanoes can recycle greenhouse gases through the degassing of magma, removing them from the atmosphere through geological processes and stored in rock.

a. As magma nears the surface, an increasingly smaller amount of rock weighs it down. In a certain moment, the lithostatic pressure of the overlying rock falls to such a degree that the dissolved gas can be **liberated from the magma and commence to form bubbles**. During the rising that follows, the pressure drops even more, causing the bubbles to increase in volume. Their growth is also accelerated by their joining with other bubbles while rising to the surface.

b. Close to the surface, the volume of the bubbles grows to such a degree that gas makes up most of the volume of the magma. When these bubbles are then outside of the inlet, they expand into the surrounding air, all the while tearing up the molten lava into pieces through the process of **fragmentation**. These are spewed out along with the volcanic gases into the surroundings.

c. We designate the pieces according to their size either as **volcanic bombs** (larger than 64 millimeters), **cinder** (from 2 mm to 64 mm) or as **volcanic ash** (smaller than 2 millimeters).

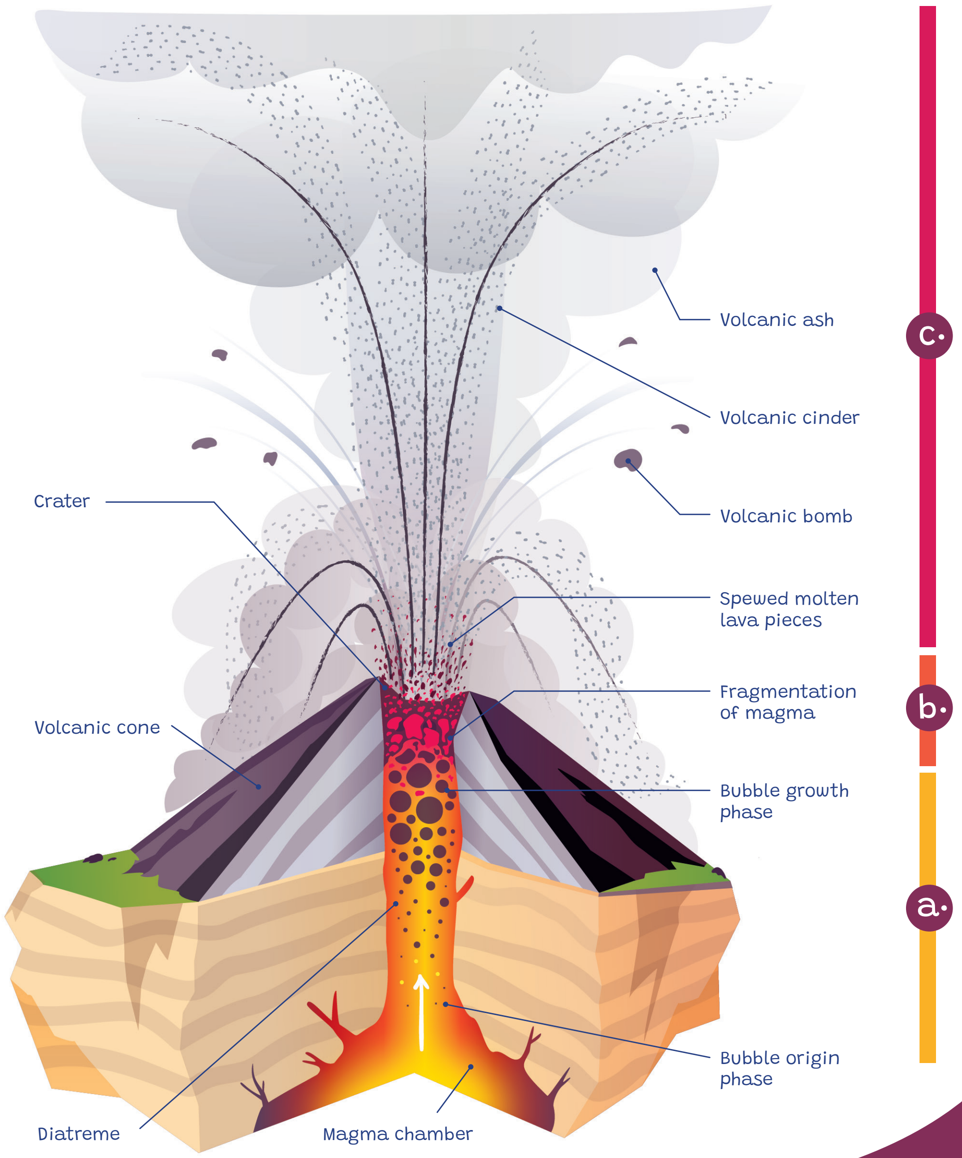

Image 3
Idealized cross-section of a volcano showing the magma tearing process (fragmentation). Magma contains dissolved volcanic gases that can be liberated from the magma by a drop in the lithostatic pressure, then grow, eventually tearing the magma into small pieces.

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See complementary materials to the experiment
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3. HOW DOES MAGMA RISE THROUGH THE EARTH'S CRUST?

For volcanic activity to occur, magma must reach the Earth's surface. This, however, is prevented by the solid casing of the Earth formed by the Earth's crust. The solid and relatively cool rocks create a layer that magma cannot easily get through, and magma must literally push its way through by opening cracks, through which it can then rise to the surface. Since, however, this process occurs several kilometres below the surface, it is not possible to observe or analyse it directly. Luckily, we can easily demonstrate the rise of magma through the solid rock using a simple experiment with gelatine and melted chocolate.

Supplies:

- bowl/container with dimensions of at least 30 × 20 cm
- several packets of gelatine (enough to fill container)
- 1 chocolate bar
- milk
- water
- hot plate
- syringe (larger size, 50 ml or more)
- tube

Purchase costs for experiment supplies approx. €5

Image **1**
Dike (vertical) intersecting the horizontal layers of sedimentary rock in Makhtesh Ramon, Izrael. Author: Andrew Shiva, Wikipedia, license: CC BY-SA 4.0

Construction directions:

First, you need to prepare the gelatine according to the package directions and pour it into the prepared container. The more gelatine you prepare, the thicker the layer you make, and the experiment will be more illustrative. Once the container is full, place it into the fridge until the gelatine properly sets (overnight usually suffices).

The next day, melt the chocolate in a water bath and mix it with some milk. The aim is to create a mixture that easily runs and will be easily taken in by the syringe.

There are two ways of carrying out the experiment. Either carefully tip out the gelatine onto a pad that has a hole drilled into its middle that will allow the injection of chocolate into the gelatine from the bottom. Or, use a see-through plastic container into which a hole has been drilled into the centre and then covered by adhesive tape from the outside prior to pouring the gelatine in.

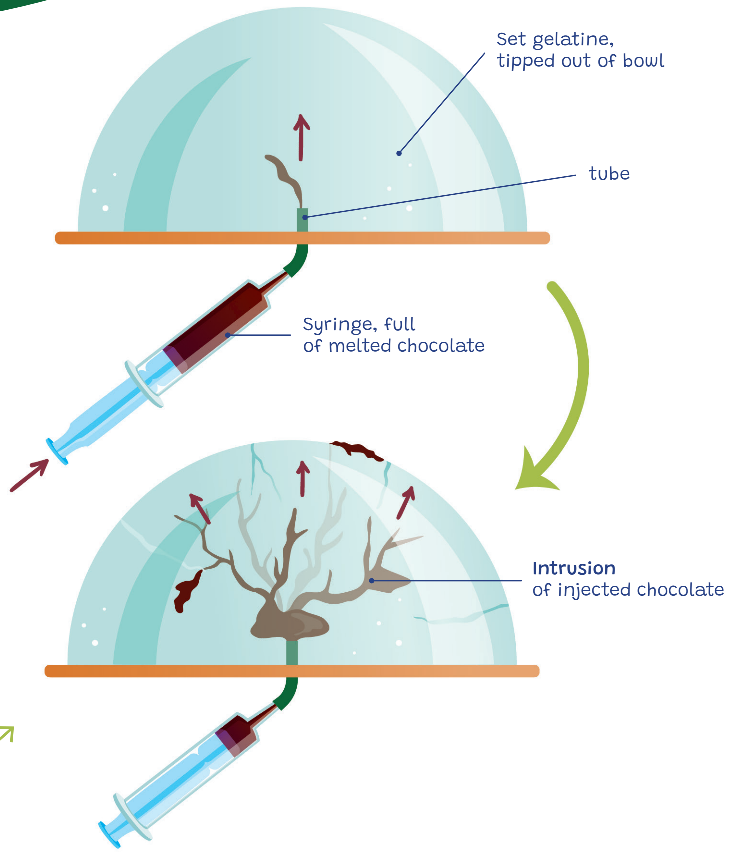


Image **2**
Illustrative sketch of experiment

Course of the experiment:

When the gelatine is ready and the chocolate is in the syringe, attach the plastic tube to the bevel of the syringe. Then, insert the tube into the gelatine from below, ideally so that it is at least 0.5 cm deep, but easily a bit more. This decreases the possibility of the chocolate leaking around the tube (it is ideal to seal the space between the tube and the container with something...).

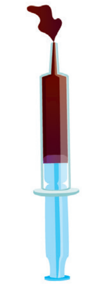
Then, slowly push the plunger of the syringe, pushing the chocolate out into the gelatine.

What to see:

When we push the chocolate into the gelatine, observe how the "magma" (chocolate) behaves when it pushes through the "Earth's crust" (gelatine). Whereas the gelatine represents the solid yet elastic layer of the Earth's crust, the chocolate is liquid magma that is trying to get to the surface.

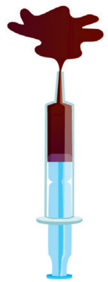
TIP 1: You can **repeat the experiment and mix the chocolate solution with less milk**, creating a higher viscosity. Since such a mixture will run with greater difficulty, the appearance of the open cracks inside the gelatine will also change. The chocolate magma with a greater viscosity moves at a slower pace and creates greater pressure under the surface, which can lead to a more significant jet of chocolate if the crack with the chocolate reaches the surface of the gelatine. On the contrary, runnier magma rises more easily to the surface, leading to calmer "eruptions" with lava flow.

TIP 2: In nature, the movement of magma is complicated by the different characteristics of the rocks that the magma rises through. This can be demonstrated by changing the firmness of the gelatine by adding/reducing the amount of water compared to the amount given in the instructions and by creating **two and more gelatine layers in the container**. In such cases, one can observe how the chocolate magma will behave upon the contact between two different layers. Thus, not only vertical dikes are created in the experiment, but also horizontal dikes, known in geology as sills.



When applying **a small amount**, the chocolate can push through the gelatine slowly and creates formations similar to magma dikes that in reality fill out the cracks and fissures in rocks. If we only push out a small amount of chocolate, the crack need not open all the way to the surface. In such cases, magma formations originate under the surfaces, which we call intrusions.

In nature, magma rather often cannot reach the surface, so it then cools under the surface without demonstrating volcanic activity.



If we push **a larger amount** of chocolate, we can observe that the gelatine begins to deform and eventually cracks. This simulates a volcanic eruption that precedes the cracking of the Earth's crust. Then, the chocolate spills out over the gelatine surface, which shows how lava pours out onto the Earth's surface and the type of eruption known scientifically as fissure vents.

While the chocolate rises through the gelatine, it is possible to observe how small fissures are created, into which the chocolate then flows. Often, unusual lobe formations originate at the edges of the fissures filled with the chocolate, which demonstrates how the tension from the intrusion weakens the gelatine.

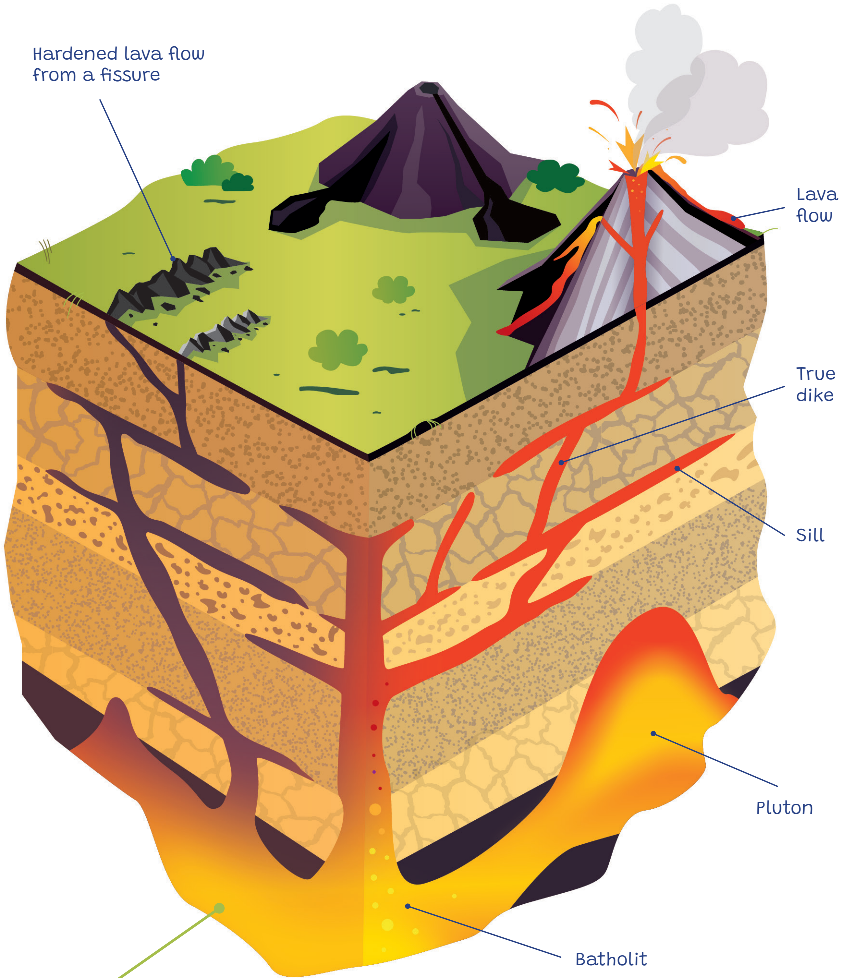


Image 3
Idealised cross-section of the Earth's crust showing magma rising from the depths towards the surface through dikes Batholith

See complementary materials to the experiment
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4. HOW DOES THE EARTH TRANSFER HEAT FROM ITS CORE TO ITS SURFACE?

Just as a hot drink cools in a mug, so the Earth transfers its inner heat to the surrounding cosmic space. Whereas the Earth's surface radiates heat into its surroundings, so does the core of the planet transfer its heat primarily through conduction and convection. Each of these types of heat transfer predominates in different areas of the Earth depending on the characteristics of the Earth's layers and each has a different efficiency.

Conduction primarily occurs in the inner core and in the Earth's crust since these are in a solid state. In this way, heat is transferred between the individual atoms making up the solid material. On the contrary, convection requires the movement of mass. It usually occurs in a liquid or gaseous environment. Since the Earth's mantle and the outer core is partially composed of molten, plastic material that is soft enough to slowly flow in the long-term, convection also occurs in these "solid" layers. In general, however, we can say that due to the contrast in density, the warmer material rises whereas the cooler material drops to the depths.

Convection (flowing) is a faster and more effective method of heat transfer than conduction. It is estimated that material in the Earth's mantle flows at a rate of 20mm per year and is responsible for the transfer of 80 to 90 % of all heat. The demonstration allows us to observe convection flow as an analogy to the heat transfer in the Earth's mantle and outer core (Img. 2).

Supplies:

- ovenproof glass container
- candle
- vegetable oil
- motor oil
- ground fine-grain material (e.g. cocoa)
- two wooden blocks to put under the ovenproof glass

Purchase costs for experiment supplies approx. €10

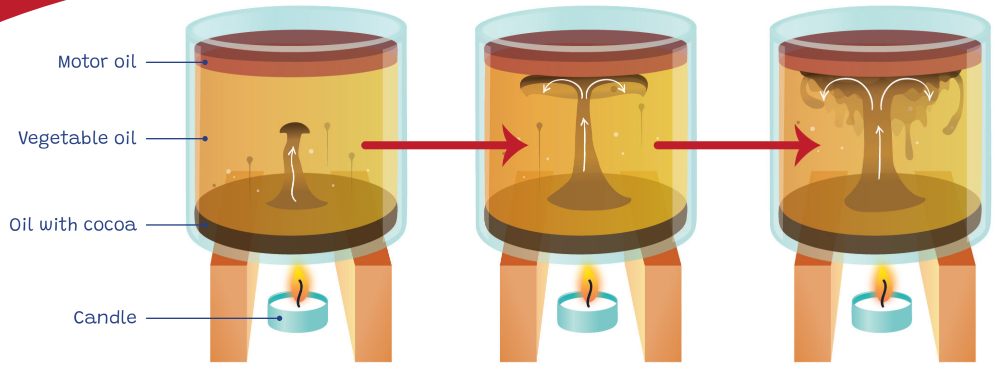

Image 1
Artistic rendition of convection in the Erath's inner layers.
Molten material rises from the core towards to the Earth's crust, under which it cools again and then drops back to the depths.

Image 2
Sequence demonstrating course of experiment.
At first, the layer of oil with the cocoa rolls around on the bottom of the container. After warming up, a lobe forms that rises upward. Notice the wide "head of the lobe". Upon reaching the motor oil, the warm oil dyed by the cocoa cools and again drops down.

Construction directions:

Place the cooking pot on the blocks and place the candle underneath it. The candle flame should touch its bottom. Put approximately one to two teaspoons of a fine-grain material on the bottom (e.g. cocoa). Then slowly pour vegetable oil into the container. Mix the cocoa powder with the vegetable oil. Then add more vegetable oil, ideally by the spoonful so that it does not mix with the coloured layer of oil. Ideally, one should have a thickness of at least 10 centimetres. Finally, pour in the motor oil with a lesser viscosity (try out first on a small sample). This creates an upper layer, forming an obstacle for the rising convection.

Course of the experiment:

The lit candle warms the vegetable oil with the cocoa powder. The warm oil is less thick than the cooler oil surrounding it. The warm oil thus rises upwards and transfers heat to the cooler surroundings, which is gradually cooled. Since the layer of motor oil, which has a different viscosity, is near the surface, it functions as an impermeable layer and the warm oil cannot get through it. The rising flow thus cannot reach the surface and stops at this barrier between the layers of different viscosity, and then it begins to spread horizontally. This accelerates its cooling, causing its viscosity to increase. The oil with the cocoa then becomes heavier and commences to drop to the bottom of the container. This closes the cycle and begins it again.

What to see:

The experiment first shows how the layer with the cocoa heats up and bulges in some places. When enough material is warmed, a narrow body with a hat-like structure on top is formed, the so-called plume. We expect that mantle plumes, which rise from the heated core – the mantle – to the Earth's surface look like this.

When the rising material reaches the transition between the viscosity of the two oil types, it cannot penetrate this barrier. Therefore, the material begins to spread horizontally, cooling it and again increasing its viscosity, then dropping back down to the bottom of the container.

Interesting fact

In 1971, American **geophysicist William Jason Morgan** came up with the concept of mantle plumes to explain volcanic archipelagos (i.e., the Hawaiian Islands). Since then, a wide range of plumes of all shapes and sizes have been documented using seismic tomography. Some probably reach all the way to the Earth's surface, some only to the lower mantle.

Where can we find examples?

The Hawaiian Islands and the belt of underwater mountains stretching from them to Kamchatka, the Canary Islands, Yellowstone, but also the mid-ocean ridges in the Atlantic, the Pacific, and the Indian oceans.

In nature, the rising material can behave similarly. Specifically, to spread **out under the lithosphere** formed by tectonic plates, to cool, and to drop.

In contrast to the experiment, it can cause the **massive melting of rocks in the upper mantle**, thus creating magma that can penetrate the lithosphere and cause extensive volcanic activity.

In such cases, **hotspots** form *(see experiment No. 5)*, or if the heat transfer in the mantle does not occur locally, but in a generalised manner, then so-called fissure fields form on the surface.

In them, the lithospheric crust divides, forming a new crust. One type of rift boundary is mid-ocean ridges *(see ensuing experiment)*, where new ocean crusts are formed.

Convection is a significant process that enables the transfer of heat from the depths of the planet to its surface.

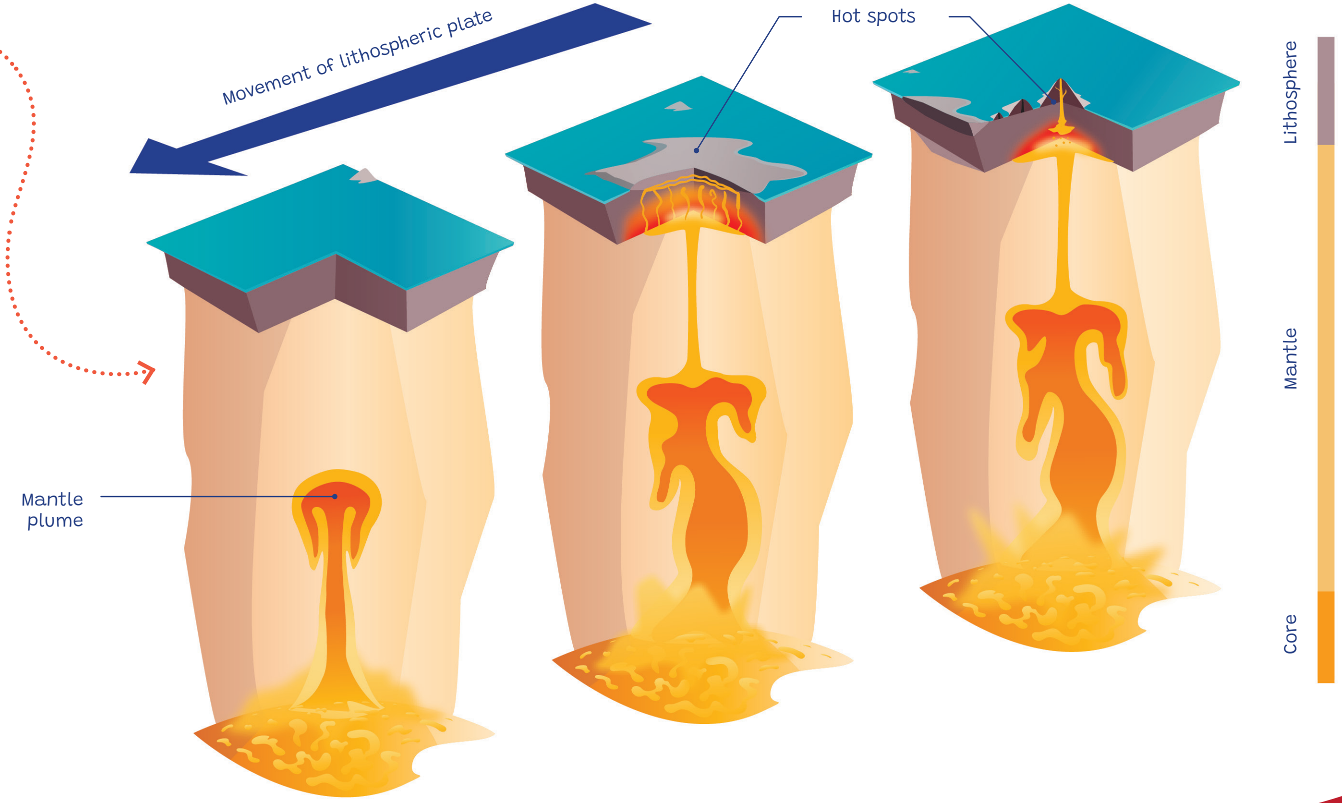

Image 3
Three schematic cross-sections show the Earth's mantle, through which the mantle plume rises

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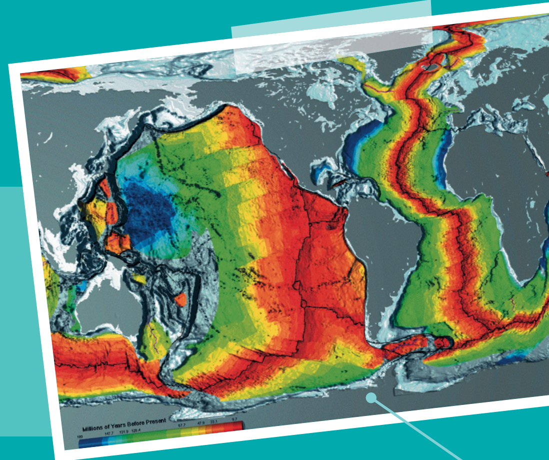
5. WHY DOES THE SEAFLOOR SPREAD?

At the beginning of the 20th century, German scientist Alfred Wegener noticed that fossils of the same flora and fauna species are found in both West Africa and parts of South America. How could they have crossed the thousands of kilometres of the Atlantic? He developed the idea of the movement of the Earth's surface as an explanation, but it took more than half a century before the spreading of the seafloor was confirmed. Three discoveries greatly contributed to this. The work of Marie Tharp, who discovered extensive mountain ranges on the seafloor, the so-called mid-ocean ridges; the discovery of the magnetic zones of seafloor rocks (Img. 1), **and determining the age of the seafloor** (Img. 2).



Supplies:

- posterboard or cardboard box
- scissors
- piece of paper, sized A3
- variously coloured markers (thick)

Purchase costs for experiment supplies approx. €2

Research on magnetic zones has shown that repeating patterns in the magnetic orientation of rocks in the form of parallel stretches spreading to both sides from the mid-ocean ridges are normal or reversed detections of magnetic fields. Therefore, it proves the pole reversal of geomagnetic poles.

In contrast, the dating of the rock that forms the seafloor has proven that we find the youngest rocks near the mid-ocean ridges, and the oldest are found at the edges of continents (Img. 2). **This has unequivocally proven that new ocean crusts are formed around the mid-ocean ridges!**

This experiment easily illustrates and explains the spreading of the seafloor, the formation of magnetic zones in rocks, and why the ages of rocks are greater the farther we are from the mid-ocean ridges.

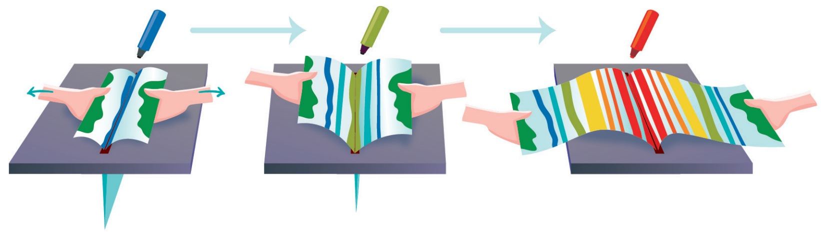


Image **3**
The image illustrates pulling out the paper from the slit in the paperboard and the colouring of the strips of magnetic rock banding

Construction directions:

Cut a several-millimetre-wide, 10cm – long slit into the paperboard. Cut a strip from the A3 paper lengthwise with a slightly smaller width than the slit. Fold the strip and insert the strip crease-first into the cut-out slit so that only its edges are seen. For greater illustration, you can draw the outlines of the continents on the edges that are sticking out.

Course of the experiment:

The demonstrator takes the edges of the paper and slowly pulls the folded paper out away from them. The assistant uses alternate markers to draw thick lines in the place of the slit until almost all the paper has been pulled out.

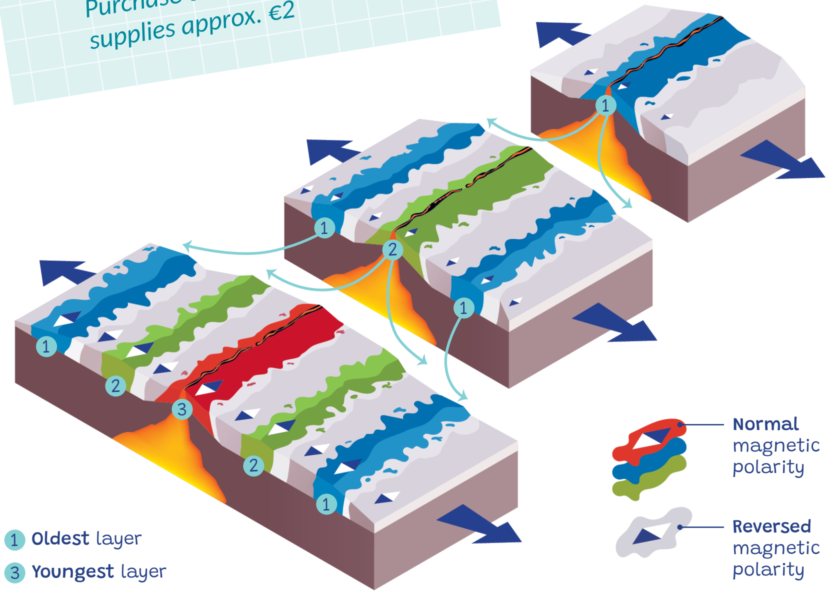


Image **1**
Model of rock magnetic zones.
New ocean crusts originate at the mid-ocean ridge, pushing the older crust to the side.
Rocks have records of the magnetic polarity at the time they petrified.

Image **2**
Age of ocean crust on Earth. The youngest crust is found around the mid-ocean ridges, the oldest near the continents.

What to see:

During the demonstration, observe the formation of new ocean crusts (the protruding strip of paper) at the mid-ocean ranges (the slit). That is, in the place where the rising magma creates new rock. Since the magma contains mineral grains, so-called ferromagnetic particles that can react to magnetic fields, their internal magnetisation is twisted in one direction. The particles are thus polarised. Each differently coloured line of marker corresponds with one direction of the particle's magnetic moment spin according to the current orientation of the Earth's magnetic field. Their existence on the seafloor is proven by changes in the Earths's magnetic fields and its geomagnetic reversal. When a map of the magnetic fields of the seafloor is then made, we can observe the magnetic zonality of rocks just as we see the coloured lines on the strips of paper.

As more magma pushes to the surface of the mid-ocean ridge, new rocks form that push the older rocks aside. The expanding strip clearly shows that the piece of paper that we are pulling is the one we pulled out of the paperboard first. The new paper emerges from the slit and gradually moves farther away from it. This is similar to the ocean crust that forms around the ridge. The newly formed ocean crust pushes the older and helps to push it farther from the ridge. This explains why the oldest ocean crust is found at the edges of continents and on the contrary, the youngest is around the mid-ocean ridges (Img. 2).

The discovery of the expansion of the seafloor contributed to the origin of **plate tectonics**. This key geological theory states that the Earth's surface is cracked into lithospheric plates capable of movement. Thanks to their movement, mountains ranges form, continents are shaped, and oceans are closed off or established. But they also determine most of the volcanic activity and earthquakes on Earth.

Since the Earth is round and space is limited on it, during its movement, the ocean crust crashes into the continental crust, which has a lower mass than the ocean crust. This means that the ocean crust slides under the continental crust, a process known as **subduction**, later to be melted in the depths.

Today we believe that the immersion of the subducted plate due to a greater mass is the **main motor of the movement of ocean plates**.

Thanks to this burying of the old ocean crusts in the areas of subduction and its extinction, we cannot see ocean crust that is older than approx. 200 million years. The older ocean crust slides under the surface, where it is remelted. Large portions of the Earth are thus recycled in the long-term, where rocks containing water and carbon are pushed into the depths of Earth. That is, gases that are then released back to the surface through volcanic activity.

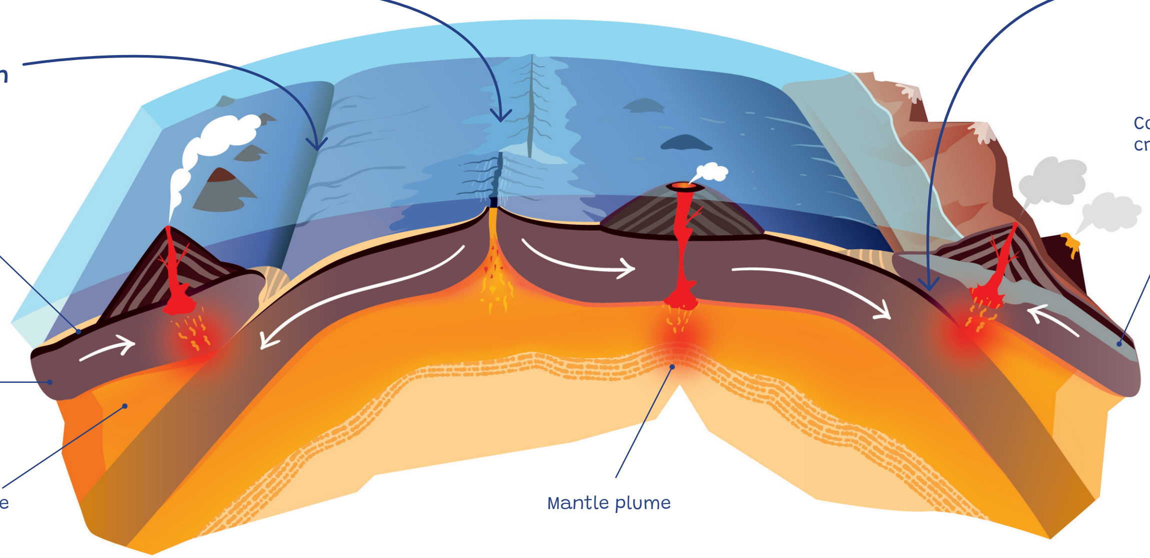


Image 4
Cross-section of lithosphere showing the life cycle of the ocean crus

TIP: **Download the template for making a 3-D model of subduction and of a volcano:**
https://www.ig.cas.cz/pro-verejnost/edukativni-materialy/

See complementary materials to the experiment
www.ig.cas.cz/en/experiments

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6. WHY DO SOME VOLCANIC CENTRES MIGRATE?

Supplies:
- candle
- matches
- piece of paper

Provision costs for experiment supplies approx. €0.5

When looking at a map of the seafloor in the Pacific you can notice an underwater mountain range spreading from Hawaii all the way to Kamchatka. When using radiometric dating to determine the age of the rocks, we discover that the youngest rocks make up the active volcano of Hawaii island, whereas the oldest underwater mountains are found near Kamchatka (Img. 1).

This underwater range proves the existence of a hotspot.

This term describes any part of the Earth's surface that has an abnormally high heat flow. This is a surface manifestation of the mantle plume (see next experiment), that is, areas of the Earth's mantle where warmer material slowly rises. Even though the precise way mantle plumes form is unknown (several theories exist), most scientists believe that they form at the boundary between the Earth's core and mantle.

When looking at a map of the seafloor, it seems that mantle plumes must migrate in the depths of the Earth. However, this movement is ostensible. In reality, it is the Earth's crust above the mantle plumes that moves through the lithospheric plates. And this ostensible movement can be easily explained in the following demonstration (Img. 2).

Construction directions:

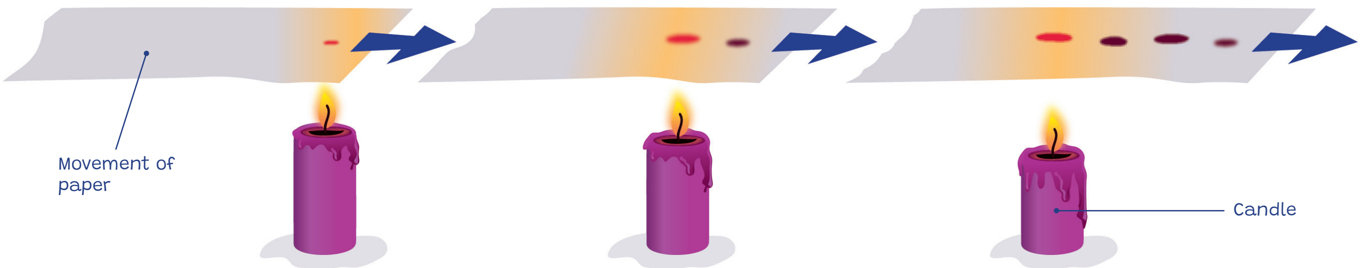
Place the candle on the table and light it. Take the piece of paper and slowly move it over the flame. **Be careful that the paper does not catch fire during the demonstration!**

Course of the experiment:

The flame warms the paper, gradually darkening. The browned part gradually moves thanks to the movement of the paper. A band of darker spots forms on the paper, demonstrating the movement of lithospheric plates above the mantle flame represented by the candle.

Image 1
Age of islands on Pacific Ocean floor according to Raymond et al., 2000.
Author: National Geophysical Data Center / USGS, license: Public Domain

Image 2
The flame heats the paper, which then changes colour. A band of spots forms on the paper, moving away from the source of heat.



TIP: If you have a **thermal camera** available, do not hesitate to use it in the demonstration.

What to see:

The demonstration clearly shows that the movement of centres of volcanic activity (the dark areas on the paper) is not caused by the movement of the mantle plume (candle), but of the lithospheric plate (paper).

Although in nature the movement of lithospheric plates is markedly slow – on average the plates move at a speed of several centimetres per year –, because the movement takes place in geological time that usually deals with tens to hundreds of millions of years, a volcano can significantly move away from the source of magma (Img. 3).

Interesting fact

The concept of the existence of hotspots was first described in 1963 by Canadian **geophysicist J. Tuzo Wilson** on the example of the Hawaiian Islands. Since then, the theory has spread throughout the scientific community. However, scientists have yet to reach a consensus on the number of mantle plumes that are detected as hotspots on the Earth's surface. Their number is given from 20 to up to several hundred. This ambiguity stems from the fact that the current methods of geophysics cannot unequivocally confirm what is found under the hotspots.

Hotspots are typical with their massive volcanic activity caused by a high heat flow and the related melting of rocks on the upper mantle and the lower crust. Primarily lava of a low viscosity is formed, which flows easily. Thus, it could easily melt and create tens to hundreds of kilometres -wide volcanoes with gentle slopes. We call these shield volcanoes because from afar, they look like the shields of ancient warriors.

When this happens, a **volcano becomes extinct**, and if they are in the ocean, they become eroded by waves. This leads to their lowering, until the part that protruded above the water can completely disappear. On the other hand, near the part of the seafloor that moved above the mantle plume, magma searches for new paths to the surface and **forms new volcanoes**. Volcanic activity first takes places on the seafloor, but if there is enough magma, in time, the underwater volcano can grow and reach above the surface of water, and an **island is formed**.

If the lithospheric plates were not to occur, lava would pile up in one place, creating enormously high volcanoes. And that is why the almost-22km-high volcano, Olympus Mons, could originate on Mars. The lithosphere does not move there.

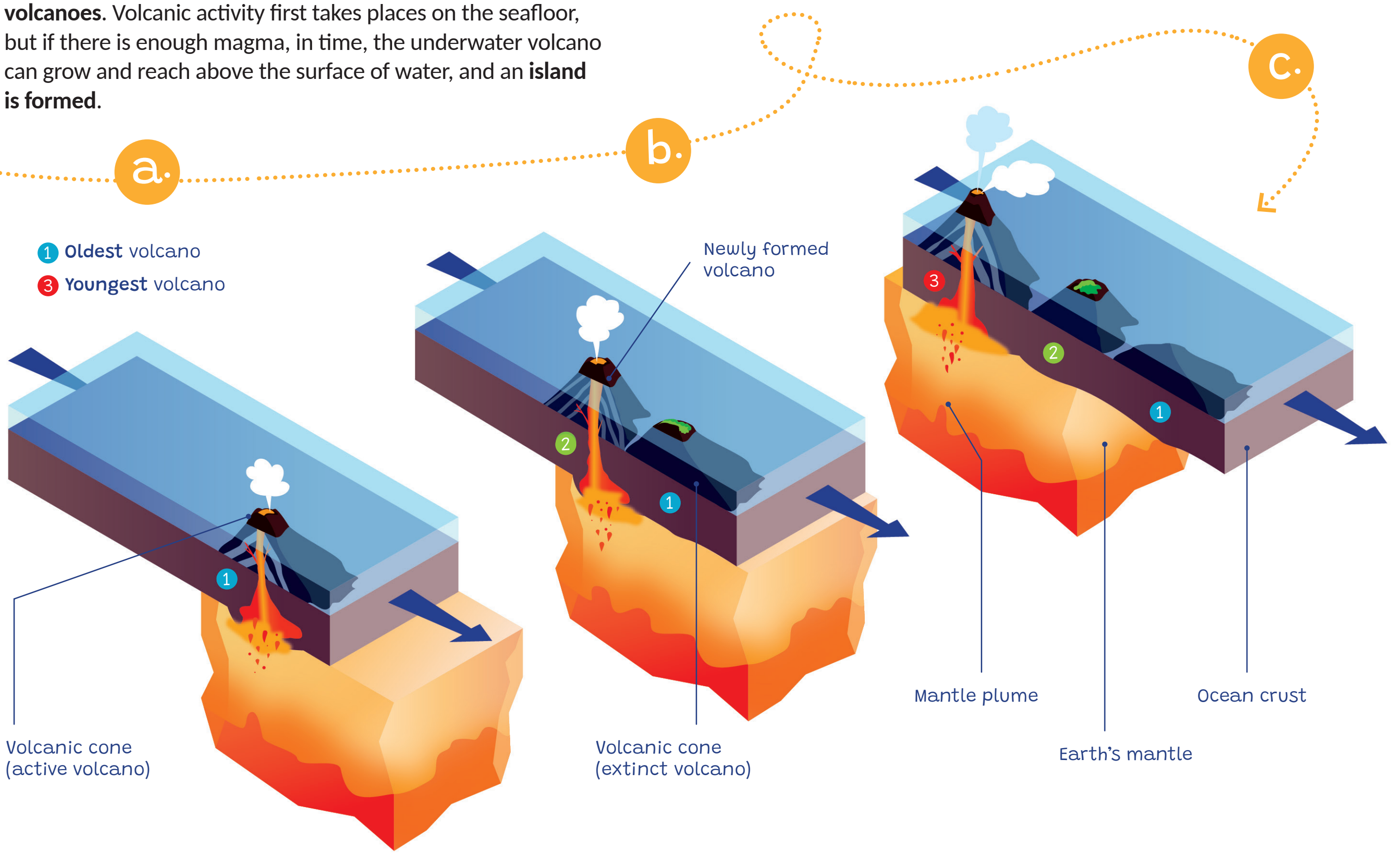


Image 3

The diagram shows an idealised cross-section of the lithosphere with magma rising to the surface through the Earth's mantle. When the magma reaches the surface, a volcanic cone begins to form. The lithosphere created by the lithospheric plates moves in time (marked by the arrow). The volcano thereby moves away from its source of magma that remains under the surface. Thus, a new volcano is formed.

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See complementary materials to the experiment

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7. WHY ARE MOUNTAINS FOLDED?

The formation of mountain ranges is one of the most important and interesting processes that take place on Earth. This activity is given by the movement of lithospheric plates and is associated with extensive volcanic, magmatic, and seismic activity, but also with the formation of rivers and valleys. Since these processes occur at a speed of several centimetres per year, it is difficult to directly observe them. Luckily, it is possible to apply analogous models where the rock is replaced by suitable materials, and which are then deformed in the laboratory. One such experiment can be also prepared at school, showing why and how mountains fold.

Supplies:

- box with clear side (e.g. an aquarium or two glass panels)
- panel to fill out the space between the sides of the box
- yoghurt container
- ruler
- mobile with tripod
- coloured sand (more variants of grain possible)
- modelling clay or silicone paste

Purchase costs for experiment supplies approx. €20

Construction directions:

You need a long and narrow box that has clear sides. Insert a panel on one side of the box, which will function as a piston. This should be placed away from the front of the box so that you can place your hand or guide rod inside and push the piston (a better, but more complicated way is to attach a rod with a screw to the panel and a nut to the wall of the box, creating a handpress system). After preparing the box, you need to create a base from the variously coloured layers of sand (the sand can be easily coloured using marker dye), representing various layers of rock that will then be pressed. The layers can be 1 cm thick, but the thinner the layers are, the more beautiful and clear the experiment is. Choose the overall thickness of the model according to the length of the box. For example, for a 50 cm length and a 30 cm box height, choose a 5-10 cm thickness for the model, i.e., 5-10 sand layers one centimetre thick. To pour, it is desirable to use a cup with perforated holes in the bottom. Try to make the poured-out layers flat, flattening them out with a ruler.

This demonstration can be carried out in several modifications. It is possible to use different-grain sand or various powders to create each of the layers (e.g. switching layers of sand and fine-grain flour) or alternate the layers irregularly. At the same time, you can form the base layer, upon which the other layers are poured on, out of modelling clay or silicone paste. This layer should be 0.5 – 1 cm thick. In this case, it is appropriate to use rubber to seal under the piston.

Course of the experiment:

When the experiment is ready, begin pushing on the piston against the sand, which simulates the movement of lithospheric plates against the other and the related pressure that the plates exert during their movement.

Image 1
Example of faults and folds, Senhora do Salto, Porto, Portugal.
Author: Nuno Correia, license: CC BY 3.0

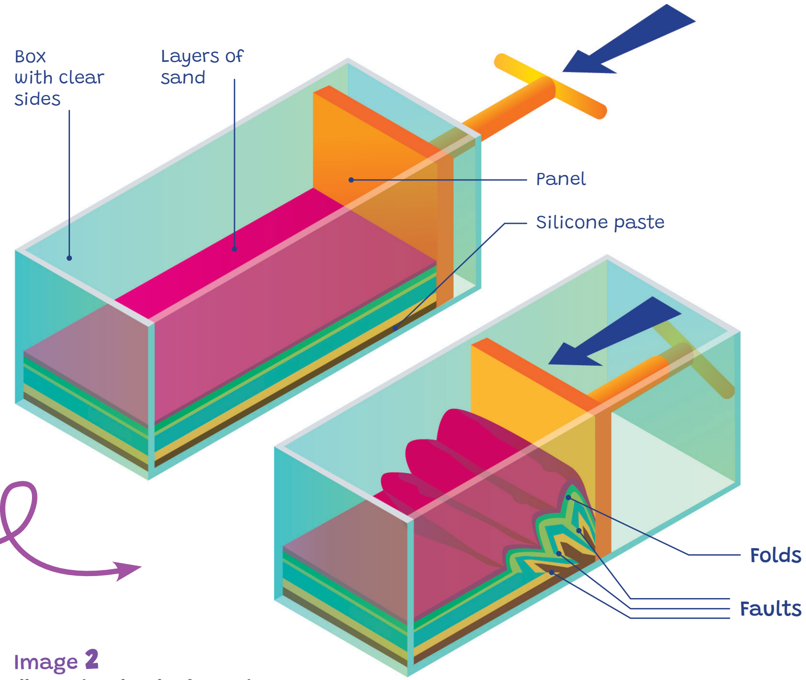

Image 2
Illustrative sketch of experiment

What to see:

As the piston moves, the layers of sand are deformed and folded into a peculiar bulging formation in which we can see a **series of faults**, but where the material is also piled up. Scientifically, such formations are known as an **accretionary wedge**, and in nature we find them on the edges of subducting lithospheric plates. Accretionary wedges are signs of piled up primarily sedimentary rock "scraped" from the surface of the subducted lithospheric plate. When surveying it, it looks like they are made of ostensibly illogically mixed layers of rock.

In case that we have put the silicone paste or modelling clay on the bottom of the model, i.e., material that deforms in a plastic and not brittle manner, this layer is **folded** rather than forming a series of faults and the plastic material moves closer to the surface.

TIP:

It is desirable to record the course of the experiment in a time-lapse video, where the shifting of each layer and movement of material is nicely apparent. At the same time, you can measure the distance between the originating faults and the panel or their orientation using a ruler.

These two processes are a simplified model of the orogenic process, where the pressure caused by the movement of tectonic plates creates the base of a future mountain range – with growing pressure and plate movement, the layers in the **accretionary wedge** fold up, pile up, and are pushed upwards to the surface. This is how mountain ranges are gradually formed, the result not only of the long-term accumulation and deformation of materials in the accretionary wedge, but also of the effects of orogenic forces that form the high and complex mountain ranges through the process called **orogenesis**. In nature, this process takes millions of years and consists not only of the movement of plates, but also of the complex reactions between the Earth's crust and mantle.

The experiment also clearly shows the **difference between brittle and plastic material behaviour**. This allows you to grasp how various structures form based on their bedrock. If the base is a plastic layer, such as silicone paste, folds without the presence of faults occur, which is like the processes that truly occur in the Earth's crust if there is a layer of more malleable rock. This experiment therefore not only provides a visual of how mountains are formed, but also helps you understand the different behaviour of layers and the effects of various materials, which is key for the complex study of tectonics and the geology of orogenesis.

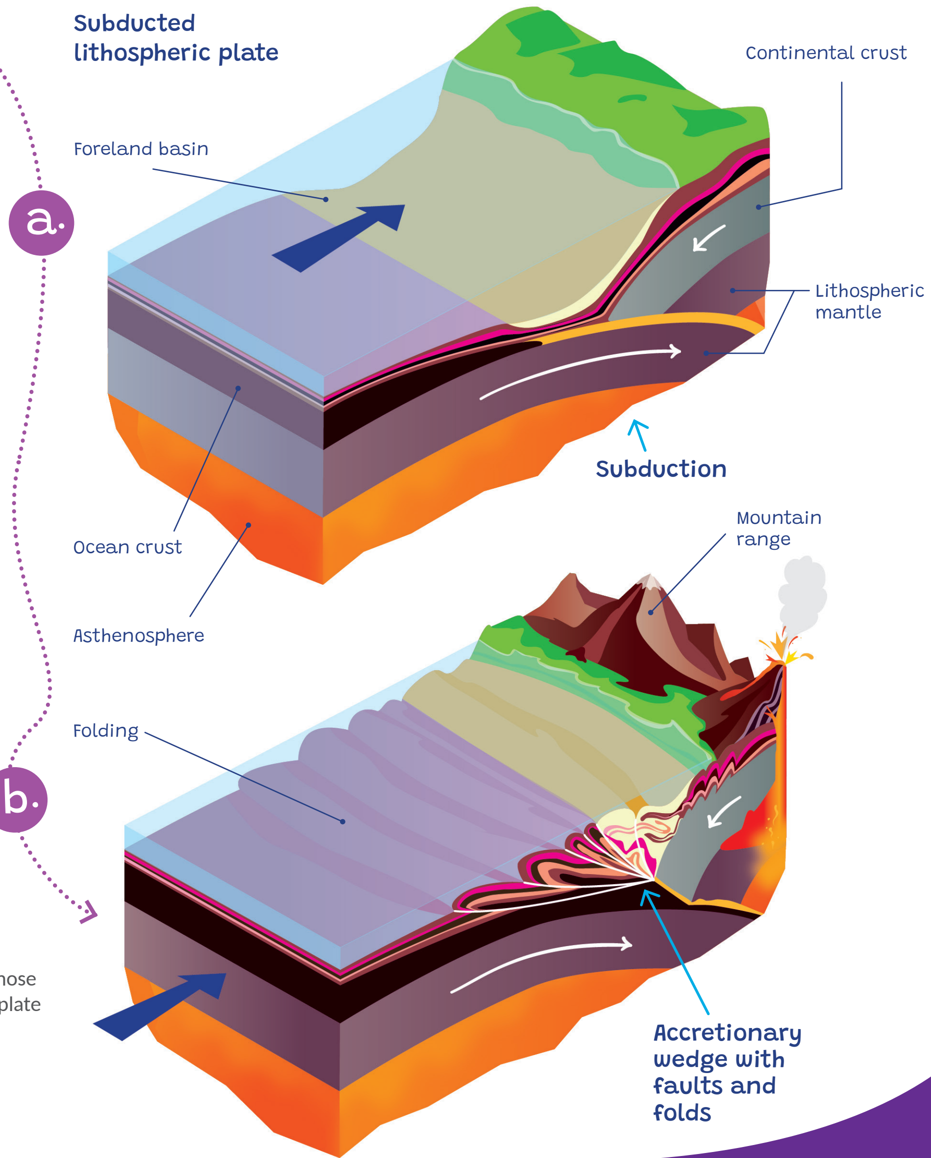

Image 3
Schematic sketch of formation of accretionary wedge in those places where the ocean plate slides under the continental plate and during which the upper rock layers are compressed

TIP2: **Download the template for making a 3-D paper model of subduction and a volcano:** https://www.ig.cas.cz/pro-verejnost/edukativni-materialy/

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See complementary materials to the experiment
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8. HOW ARE RIFT VALLEYS FORMED?

Trench depressions, also known as rifts, are geological formations that result on the Earth's surface thanks to the movement of tectonic plates. These formations are created in those places where two lithospheric plates move away from each other, or eventually in those places where a continental plate breaks in two. These areas are labelled as divergent boundaries and form due to rising flows in the Earth's mantle (Img. 3). As a rule, the process of their formation is accompanied by magma flows that reach the surface, creating new Earth crust. Since the processes of lithospheric plate movement are in terms of a human lifetime very slow, we cannot directly observe the formation of trench depressions. The process can be illustrated through a simple experiment that shows the spreading of lithospheric plates and the formation of rift depressions.

Image 1
Satellite shot of part of the Great Rift Valley in Africa.
Author of image: ESA, license: CC BY-SA 3.0 IGO

Supplies:

- strip of rubber or neoprene (at least 20 × 40 cm, but can be larger)
- paper box
- flour and coloured sand
- trowel or yoghurt container with drilled holes

Purchase costs for experiment supplies approx. €15

Construction directions:

Cut a slit on two opposite sides of the paper box just above the bottom so that a band of rubber or neoprene can be pulled through with a tight fit. The width of the band/neoprene should be just as wide as the box (therefore, a shoe box is suitable for use). Then pull the piece of rubber/neoprene through the slots so that its ends stick out of the box.

Put layers of the coloured sand or flour onto the rubber/neoprene pad. Or you can alternate layers of flour and coloured sand. You should have at least three variously coloured layers. The thickness of each layer depends on the length of the rubber/neoprene pad, but for pads with a length of approximately 40 centimetres it is desirable to make layers with a thickness of 4 centimetres. Try to make each layer flat.

It is important that the poured layers do not end up near the walls of the box that have the slits with the rubber/neoprene in it. It is necessary that the material has room to move when spreading the rubber/neoprene.

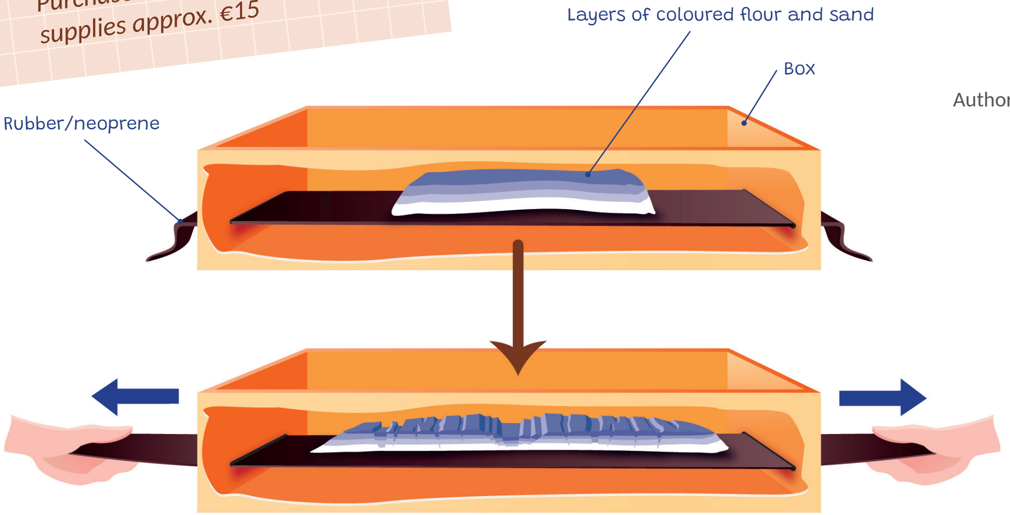

Image 2
Illustrative sketch of experiment

Course of the experiment:

After you create the layers, grab the ends of the rubber/neoprene pad and slowly spread open the pad away from you. Be sure that the speed of the spreading is constant and that no shocks that would ruin the formations that are originating on the surface of the poured layers.

TIP:

It is desirable to document the course of the experiment on a time-lapse video, where the movement of each layer and the movement of material are nicely apparent. You can also measure the distance of the forming rifts from the panel and their orientation using a ruler.

What to see:

As you pull the ends of the rubber/neoprene pad away from you, observe the surface of the poured layers, where the rifts are originating, between which a central depression is forming. If the layers are made from variously coloured sands/materials, you can observe the formation of uncovered lower layers thanks to the revealed colours.

The successful course of the experiment depends on the firmness of the pad and the method of spreading. It is necessary that the pad can be spread considerably and thus the poured material can be sufficiently moved and the described formations can form. Also, it is more appropriate to use flour than sand, because it is more compact and thus the origin of trench depressions is better observed.

Interesting fact

Trench depressions play a significant role in the geological cycle because they function as places for the formation of new ocean crust, which contributes to the renewal and change of the Earth's surface. Diverse geological formations, such as lava landforms, hot springs, and geothermal fields, which can serve as a significant energy source form in the rift regions.

Weak earthquakes often occur in the surroundings of trench depressions, since the thinning and taut Earth's crust reacts to the forces acting on it due to the spreading of plates.

In nature, we can encounter such trenches **anywhere that the Earth's crust is spreading**. When the plates move apart, the Earth's crust becomes thinner and sinks, whereas magma rises through the Earth's mantle, often filling the originating rifts and through which it reaches the surface. If it reaches the surface, volcanic activity occurs. The magma that flows along the surface, but also the solidification in the rifts under the surface creates new parts of the Earth's crust. This movement of plates is usually slow, occurring at a speed of several centimetres per year, but its impact is fundamental, because deep valleys are formed that can gradually become ocean basins or other types of rift structures.

Where are depressions found?

Currently, the Earth's crust is thinning e.g. in Africa around the Great Rift Valley. **Before**, it also occurred here around the Eger Graben, found in North-east Bohemia around the Ohře River.

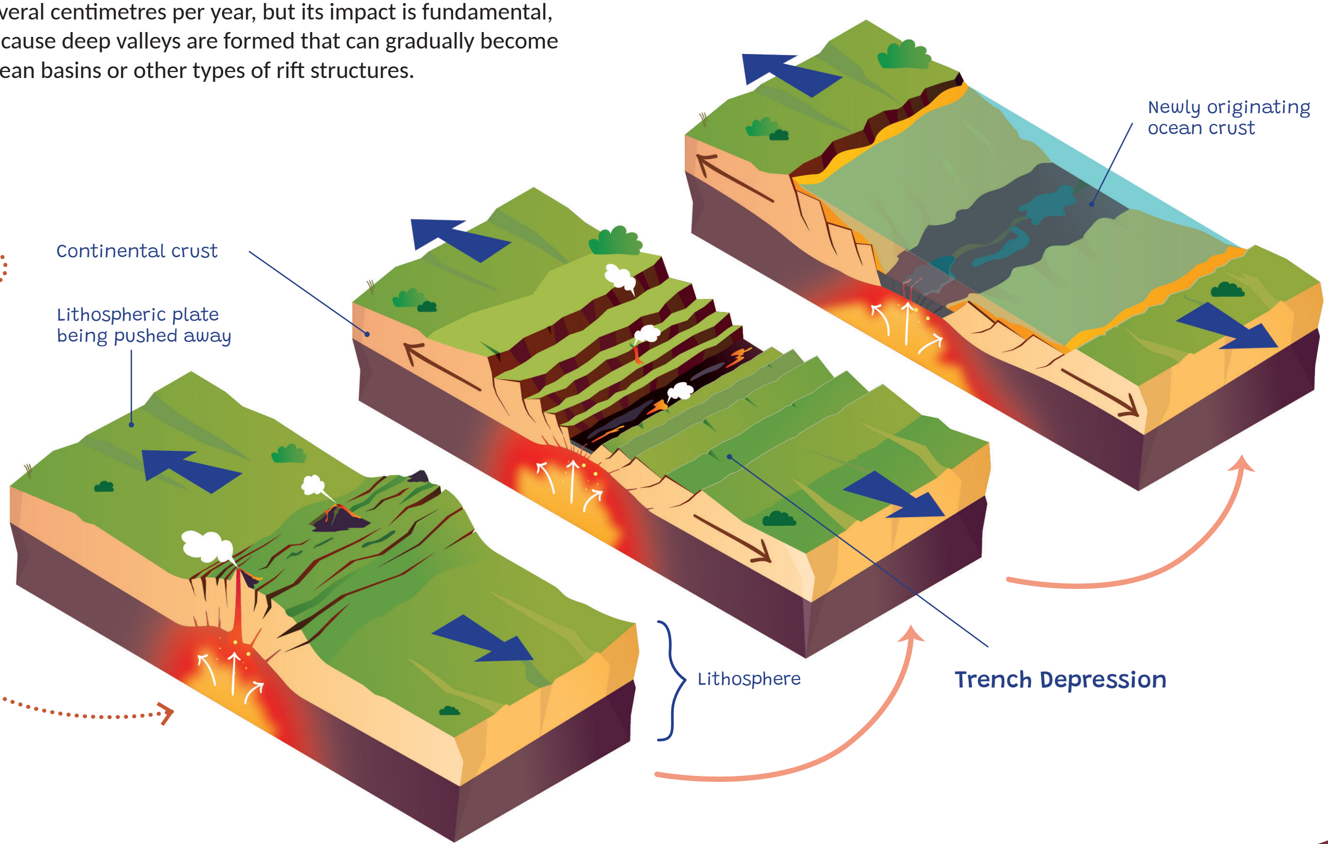

Image 3

Demonstration of formation of mid-ocean ridge above the Earth's mantle.

Hot currents in the Earth's mantle bulge out part of the crust, the rock material is adjusted and the neighbouring parts of the lithosphere move away from the thinned and soft central parts. As an accompanying phenomenon, graben faults form, creating a central depression lined by eventual magma flowing along the surface.

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9. WHY ARE SOME ROCKS FOLDED?

When observing a pile of rocks, you can easily notice that some shards are made of rocks with large grains, some are fine-grained, and others captivate with their number of small bands and folds. The appearance of a rock structure depends on the way it was formed and what it then experienced.

Supplies:

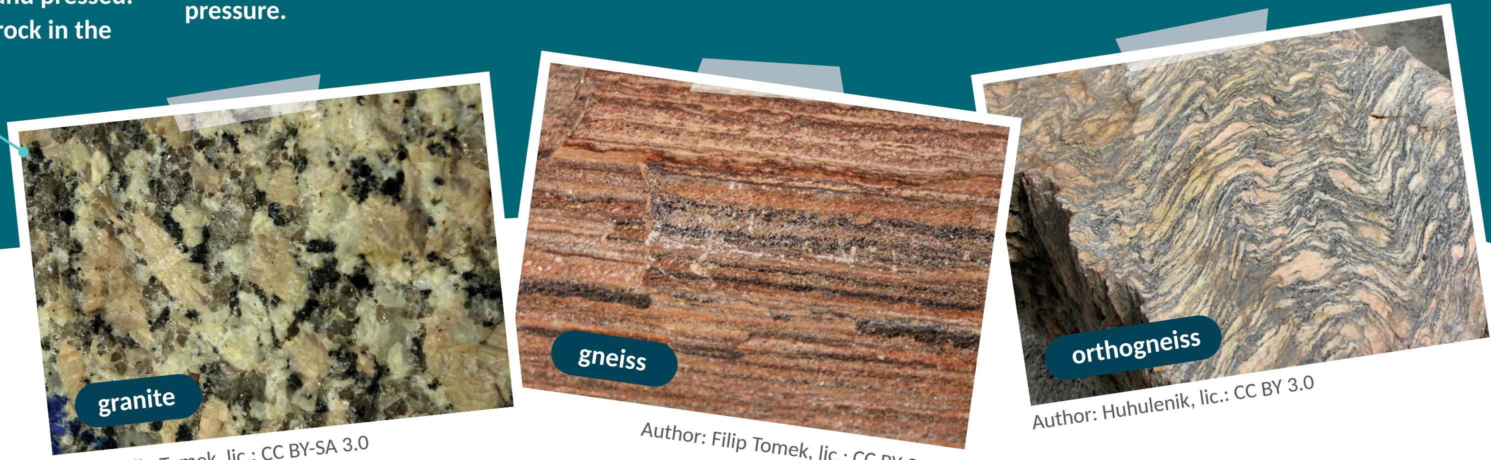
- coloured modelling clay
- knife
- firm pad

Purchase costs for experiment supplies approx. €2

Igneous rocks are formed by the crystallisation of mineral grains from magma. This process often creates regular grains, evenly arranged into multi-coloured mosaics. One of the most known representatives of this group is granite. Except sometimes, under the influence of high temperatures and pressure found in the depths of the Earth, the granite is considerably heated and pressed. Thus, it is transformed and metamorphosed (changed) rock in the form oforthogneiss. This is characteristic by its presence of large, light grains surrounded by dark bands that can be, but need not be, folded.

This simple experiment allows the transformation of rock to be shown and explains their appearance and describes the processes that occur deep in the Earth's crust under high temperature and pressure.

Image 1 **Examples of transformed rock**



Author: Filip Tomek, lic.: CC BY-SA 3.0

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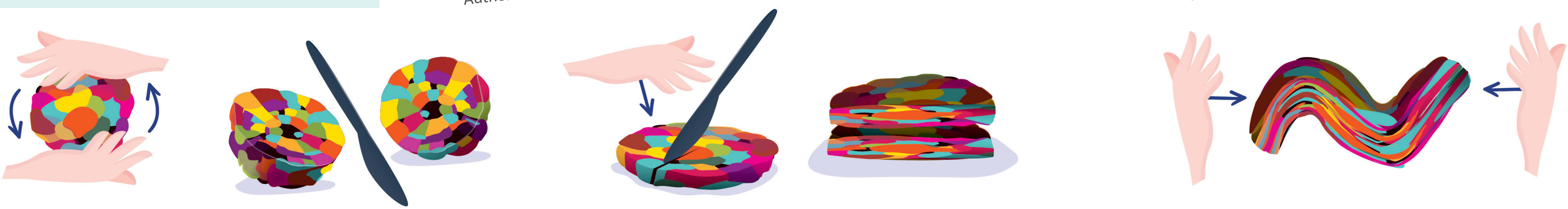
Author: Huhulenik, lic.: CC BY 3.0

Course of the experiment:

Divide the modelling clay into small pieces. We can tear it or cut it, it is okay if the pieces have various shapes and sizes. The pieces of modelling clay will represent separate mineral grains that together form the rock, originating though the crystallisation of magma during its cooling. Then push the small pieces of modelling clay together, as if you were making a snowball.



a. When you then **cut open** the ball, you will see a pattern like that of granite.

b. Then, join the half-spheres back into a ball and **smash it into a pancake**. **Cut this in half**, as well, and in its inner structure, you see the stretched grains, which create a banded structure that we can see in gneiss.

c. If we then push **pancake from the sides**, it is bended and crumpled. Upon cutting open, we see folds like those that form folded orthogneiss.

Image 2
Illustrative sketches of course of experiment

What to see:

With the help of this simple experiment, we have the opportunity of observing and explaining how rocks can be deformed and how such deformations can change their appearance. If rocks are found close to the Earth's surface, they are brittle due to the low temperatures. However, the deeper one gets below the surface, where the temperature is much higher and the rocks are heated, they will display plastic behaviour. The temperatures under which rocks become plastic differ according to the contents of the rock. For example, marble can be plastically deformed already at 250 °C, whereas granite not until temperatures of approx. 400 °C.

Rocks heated to their critical temperatures can relatively easily react to pressure and deform. In such cases, the grains of each mineral comprising the rock (in our case the pieces of modelling clay) can change their shape and rearrange themselves. In the experiment, this aspect is demonstrated by the flattening of the variously coloured pieces of modelling clay.

In nature, a distinctive banded pattern in the form of **flow banding** originates, which is created by "little layers" of arranged, flattened mineral grains. In science, this banded rock structure is known as **foliation** and originates when the rocks deep in the Earth's crust are crumpled. Geologists use these layers to determine the manner and direction of the rock deformation and thus better understand what the given rock underwent during its formation and development.

Banded rocks, whether transformed or sedimented, can be folded further. This means that there is significant bending of the bands or existing layers because of tension.

This time, it is necessary that the deformation occurs in the direction along the bands or layers. **The more we push on the bands, the more the folds are closed in.** If we were to not stop crumpling/deforming the rock, we would again achieve banded modelling clay and in nature, rocks that are never to be folded again. Just as in the previous case, here, the folds and their orientation help determine the character and direction of this deformation.

Interesting Fact

The folding of rocks occurs in nature to various degrees. We can see folds that are observable only with the help of a microscope but also folds that form entire mountain slopes or parts of continents. The deformation of rocks and their folding allows the transfer of mass within the Earth from one place to another, from the depths up towards the surface, and vice versa. Also, oftentimes the rocks have already undergone the process of transformation and pressure several times. We can encounter such cases, for example, in the region of the Bohemian Massif.

The description and interpretation of the deformation record in rocks forms one of the foundations of understanding the tectonic processes that led to the formation of mountain ranges or to the disintegration of continents.

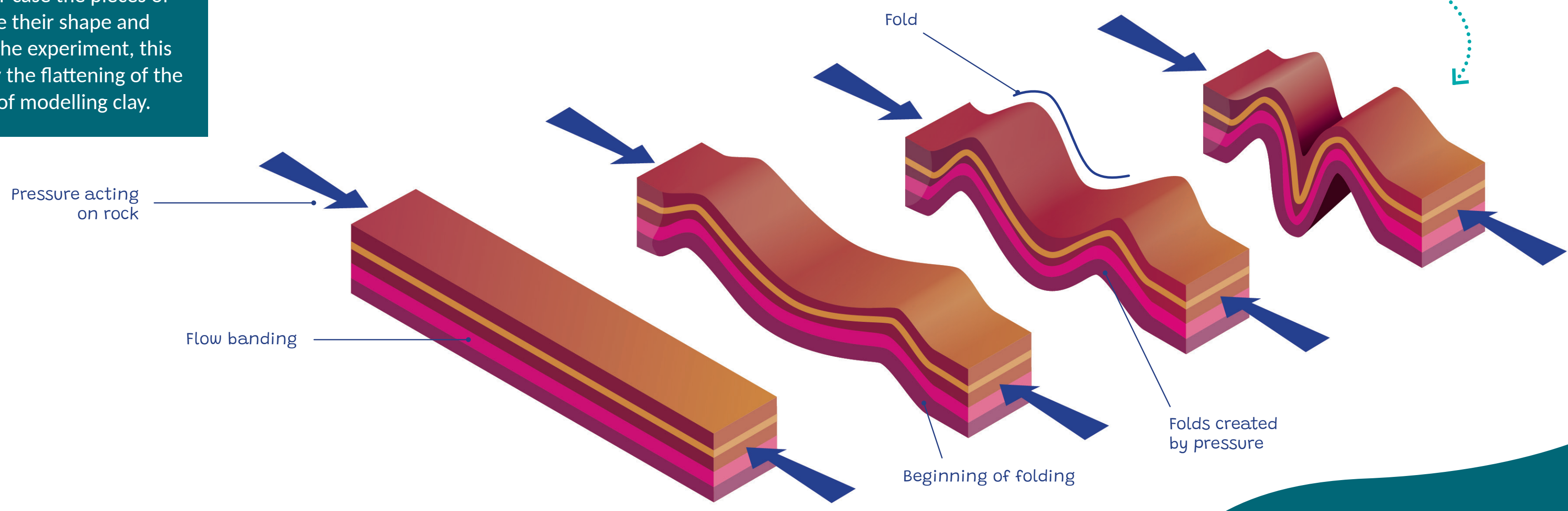


Image 3
Schematic illustration of fold origin caused by the bending of rocks through pressure

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10. WHY DOES THE EARTH BENEATH YOUR FEET LIQUIFY DURING AN EARTHQUAKE?

Imagine that you are standing in the centre of town when suddenly, the ground beneath your feet begins to shake. The surrounding buildings tremble, you hear glass breaking, walls cracking, and people run out of buildings in a panic. Luckily, buildings are constructed according to strict norms, allowing them to withstand even strong earthquakes. Even so, many buildings collapse. When the dust settles, it is evident that their demise was not caused by badly constructed walls, but by neglecting building preparation. Aside from the collapsed buildings, there are also many that have sunk underground or are distinctly leaning. The earth that was supposed to support them suddenly lost its firmness and could not carry their weight.

This destructive phenomenon known as liquefaction causes solid ground to turn to liquid. The process can be easily demonstrated in a simple experiment using sand and water, simulating how soil can become unstable and liquid for a short period of time.

Supplies:

- plastic box (at least 40 × 30 × 20 cm)
- fine sand
- water
- vibrating device (e.g. electric toothbrush, cordless drill or rubber mallet)
- small items (e.g. coins, stones, models of buildings from building sets, etc.)

Purchase costs for experiment supplies approx. €10

Image 1
Collage of photographs showing the effects of ground liquefaction in Niigata.
Source of lower image.: https://ecom-plat.jp/19640616-niigata-eq/, license: CC BY 4.0 License upper image: Public Domain

Construction directions:

Fill the plastic box with sand up to a height of 10 centimetres and use a ruler to flatten the surface. Then, pour water evenly over the sand using a funnel until it is saturated. It is vital that the water seeps all the way to the lower parts and that no dry spots can be found in the sand. At the same time, the surface of water must not be more than the surface of the sand or form "puddles".

Then place several small items on the sand, such as coins, stones, or building blocks. These items represent buildings or other structures. You can build an entire town out of building blocks on the sand and leave small spaces between them.

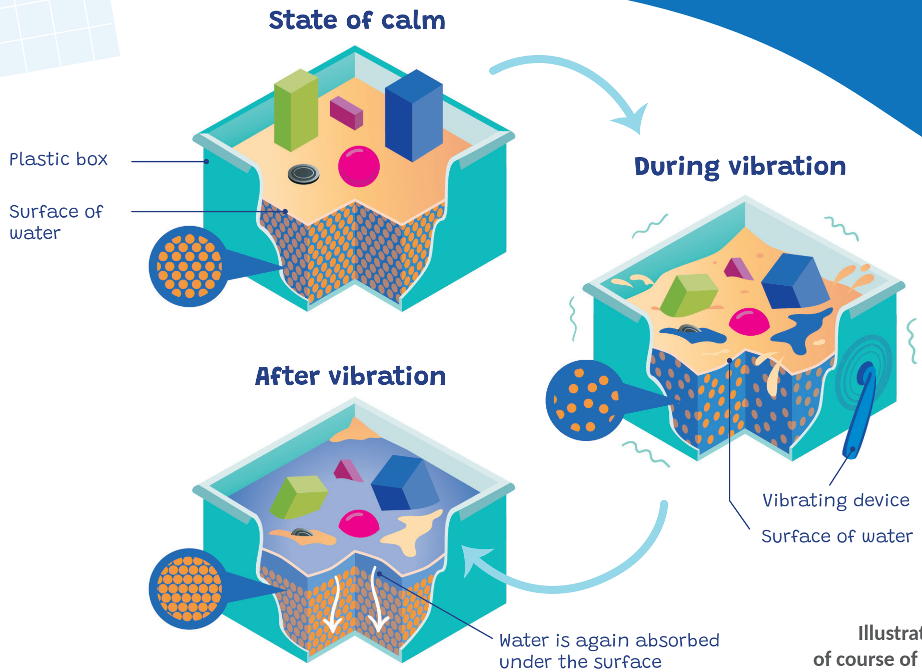

Image 2
Illustrative scheme of course of experiment

Course of the experiment:

After preparing the box, place the vibrating device to the side of the box (or under it) and turn it on. Alternatively, use a rubber mallet and gently tap the sides of the box. The vibrations simulate the passing of seismic waves through the ground. Observe how the solid ground begins to act like a liquid – the items on the surface slowly sink into the sand, some can tip over or fall. Once the vibrations stop, the water again seeps down to the lower layers thanks to gravity, and the sand at the surface regains its firmness. However, the items remain partially sunken or tipped, showing how buildings can be damaged during earthquakes and the resulting liquefaction.

What to see:

Observe how the solid ground begins to behave like a liquid during the vibrations/tapping. The items that are on the layer of sand begin to slowly sink into the sand and some may begin to tip over or even fall. Once the vibrations stop, the water again seeps down into the lower layers of sand thanks to gravity and the sand at the surface regains its firmness. However, the items remain partially sunken or tipped, showing how buildings can be damaged or ruined during earthquakes and the resulting liquefaction.

Liquefaction occurs when the grains of sediment such as sand or gravel are surrounded by small spaces (pores) that are full of water. Under normal circumstances, these grains form a solid net that allows the sediment to act like a solid material. During earthquakes however, seismic waves cause the grains to be pressed and rearranged, disrupting their mutual contact. At the same time, the water pressure in the pores increases to such a strength that it separates the grains and the ground loses it firmness. As a result, the sediment begins to behave as a liquid. One must add, however, that liquefaction can be caused by a whole range of other processes (such as flooding, which increases the pressure in the water pores, or by simply building on unstable bedrock).

This **process can cause extensive damage** to buildings and infrastructure. Buildings can sink down, lean over, or even collapse, whereas the subterranean infrastructure, such as pipelines and water mains, can rise to the surface. This phenomenon can be simulated in the experiment by hiding a ping pong ball in the sand layers – it will rise to the surface thanks to the shaking.

Earthquakes associated with liquefaction a**re not just a thing of a region's past**. This phenomenon can occur any place that has saturated ground, including modern cities. For this reason, great emphasis is placed today on urban planning and construction norms that must consider this risk. Modern technologies allow for the fortification of building foundations or stabilising ground using various methods, such as injecting cement into bedrock or constructing firm pilings, which transfer the weight of buildings to the deeper and more stable layers of rock.

Despite this advance in technology, liquefaction is still **a grave risk**. The catastrophic consequences in those regions where liquefaction has occurred still show how a **key form of prevention is proper construction**.

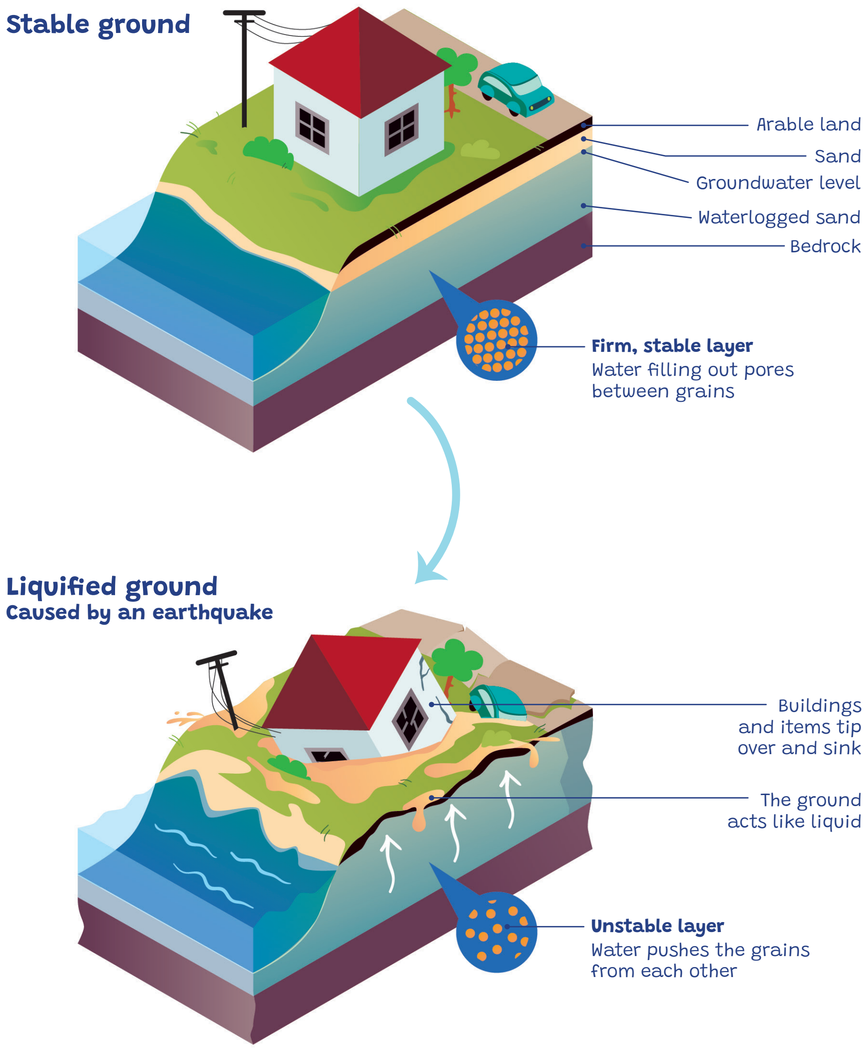

Image 3
Schematic sketch of liquefaction process

Where has this occurred?

In nature, liquefaction occurs primarily in areas where the ground is saturated with water. As shown by the earthquake in Niigata, Japan in 1964, liquefaction can have catastrophic results. Strong tremors caused the liquefaction of unstable bedrock underlaying a large part of the city, leading to the destruction and damage of thousands of buildings. Similar consequences were also felt after the earthquake in Christchurch, New Zealand in 2011.

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Produced by the Institute of Geophysics of the Czech Academy of Sciences in 2024 as part of the project Space for Humanity. Text: Petr Brož / Illustrations and graphics: Lucie Škodová

See complementary materials to the experiment
www.ig.cas.cz/en/experiments

11. HOW DO EARTHQUAKES ORIGINATE?

Earthquakes are some of the most destructive natural phenomena that cause distinct changes to the Earth's surface. The strongest of them originate because of suddenly released energy in the Earth's crust that then spreads out into the surroundings in the form of seismic waves.

For a strong earthquake to occur, it is necessary that a huge amount of energy accumulates. Areas where such amounts of energy can easily accumulate are most often associated with the movement of the lithospheric plates that form the Earth's surface. Specifically with those places where the lithospheric plates move against each other or their edges grind against each other, causing friction.

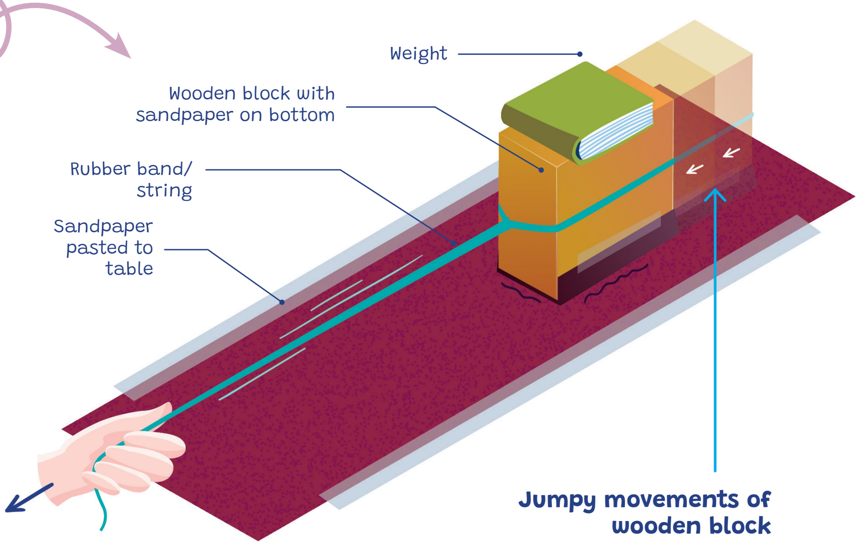
Supplies:

- wooden block
- two pieces of sandpaper (one pasted on the bottom of the block and the other on the pad)
- rubber band or string
- ruler for measuring distance
- weight (e.g. book)

Purchase costs for experiment supplies approx. €4

Earthquakes occur most often at the boundaries of two lithospheric plates, where the greatest number of faults is found. Although the movement of lithospheric plates is not in any way staggering – it is approximately just as fast as the rate at which our nails grow, that is, several centimetres per year, this process occurs within geological time. This means that energy in the form of tension can accumulate in proximity of the lithospheric boundary in the long-term and after reaching a critical level of tension, it can be suddenly released if the resistance is overcome. Thanks to this, parts of the lithospheric plates can rapidly move by up by several metres near the faults. The following experiment allows us to easily illustrate this process of accumulation and sudden release of tension.

Image **2**
Illustrative sketch of experiment



Construction directions:

Use cardboard to attach the large strip of sandpaper to a flat surface (e.g. a table) so that it will not move. This sandpaper represents the surface of the fault, along which the wooden block representing the other lithospheric plate will "slide". Then prepare the wooden block by pasting the other piece of sandpaper on its bottom. This simulates the rough surface of the lithospheric plate that grinds against the surface when moving. Attach a rubber band or string to one end of the wooden block. Then place the block on the surface so that both sandpapers touch each other.

Course of the experiment:

After preparing the experiment, carefully pull the string/ rubber band towards you. The tension of the rubber band represents the tension that is accumulated in the Earth's crust during the movement of lithospheric plates. Even if we gradually increase the pull, the wooden block will not move immediately. The friction between the sandpapers keeps it in place. As we continue to pull the rubber band, the friction between the block and the pad is overcome and the block suddenly moves. **This fast movement simulates** the moment when an **earthquake** occurs. When "breaking loose", the block also significantly moves.

Repeat the experiment several times, each time measuring the distance the block moves during each "earthquake" with a ruler. You can also place a weight on the wooden block (e.g. a book) and compare how the tension necessary for the sudden jump and the distance the block moves changes.

Image **1**
View of collapsed buildings after the 1906 San Francisco earthquake.
Author: NARA, license: Public Domain

What to see:

During the experiment, we observe how energy accumulates until it reaches a critical level that allows it to overcome friction and cause sudden movement. In nature, energy for growth is provided by moving lithospheric plates. As mentioned in the first paragraph, although they move relatively slowly, it is in the long-term. Thanks to their movement, however, friction is caused, and tension is accumulated. Thus, the energy associated with the movement of lithospheric plates can accumulate underground for years, decades, centuries, or even millennia.

Just like in our experiment, earthquakes do not occur constantly, but only when the tension between plates grows sufficiently to overcome the resistance between them.
In general, we can say that **the longer that energy accumulates, the more energy can be suddenly released**. And the stronger the earthquake can then occur. This, however, is not a generally binding rule. It also depends on the speed of the lithospheric plate movement. If the plates move quickly, a smaller period is needed to accumulate the critical amount of tension than when the plates move slowly.

When the energy at the boundary of two lithospheric plates is finally released, it can have marked consequences for the landscape. Parts of the Earth's surface may sink, and if these are on the coastline, they can be then flooded. On the other hand, other areas may rise, increasing the height of existing hills or mountains and lift a part of the seafloor. This often occurs near subduction, that is, in those places where one lithospheric plate slides under another. When sliding under, the overlying plate can bulge because of the accumulating tension, and if released, the overlying plate drops. This phenomenon is often seen in Japan, which is in an area with several subductions.

Moving several metres can also cause the formation of new extensive fissures on the surface, which can distinctly damage the existing infrastructure or even change the flow of watercourses. We often witness this type of earthquake in Turkey on the North Anatolian Fault or in California on the San Andreas Fault.

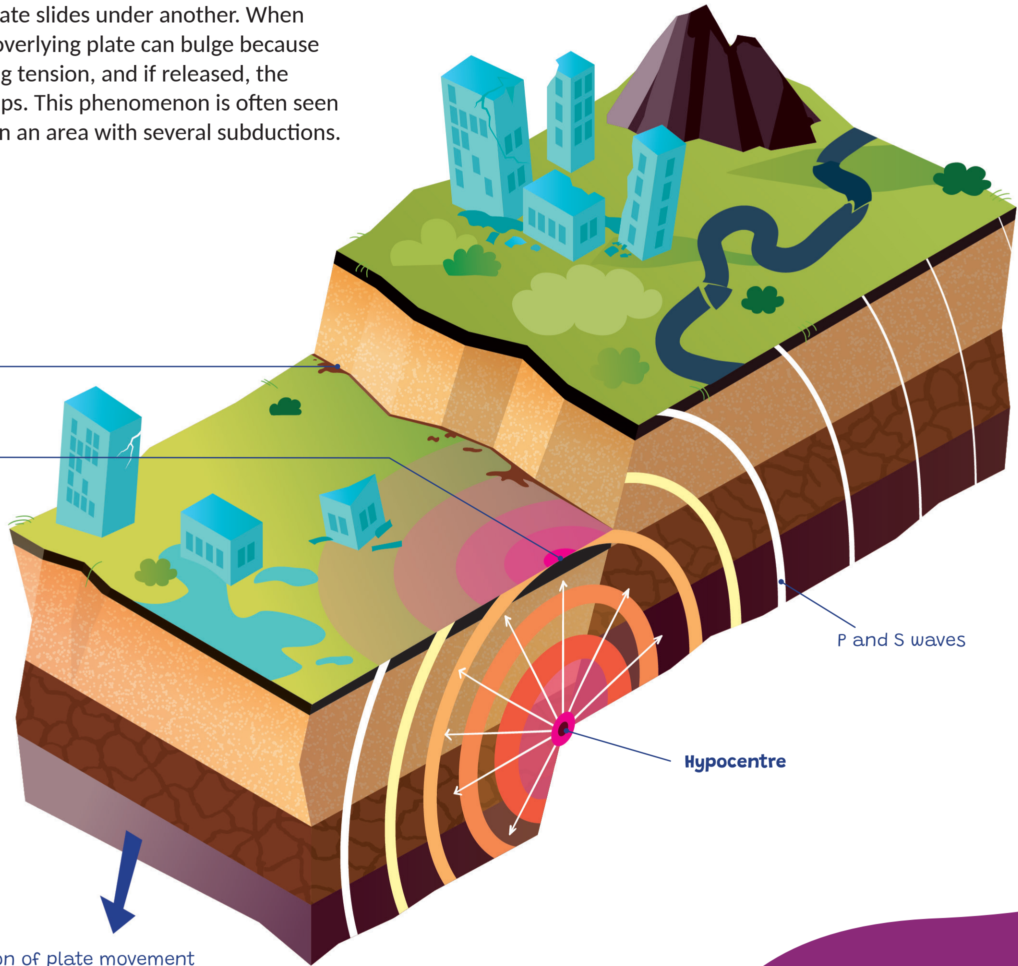


Image 3
Schematic sketch of movement at a fault where a drop occurs. This results in the release of energy that spreads out in the form of seismic waves. The place under the surface where the earthquake occurs is known as the hypocentre, and its projection onto the Earth's surface is labelled by the term epicentre.

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12. A TABLE-TOP RIVER SYSTEM

✓ **Supplies:**

- plastic crate or large cardboard box
- PET bottle
- tube approx. one metre long with a small diameter (0.5 cm)
- fine-grain sand
- pail
- plastic film and tape (in case of using cardboard box)

Purchase costs for experiment supplies approx. €30 (depends on amount of sand used)

Rivers are inseparably associated with the appearance of the landscape, and they form and transform it through the millennia. Running water has enough force to carry away rock material and then deposit it elsewhere, thus forming and deepening riverbeds (Img. 1). **However, it is not easy to observe how the riverbed changes and evolves. More distinct changes only happen gradually. With the help of a simple experiment using running water and fine sand, we can imitate the processes associated with the origin and changes in the appearance of riverbeds even in the classroom. And so better understand the processes linked with the processes associated with the development of the riverbed upstream, its gradual bending and deepening, but also observe the transfer of rock fragments and their placement as alluvium.**

Image **1**
Aerial photo of upper part of Waimakariri River on New Zealand,
where the river is "wild". Author: Greg O'Beirne, license: CC BY-SA 3.0

Construction directions:

Cut out a corner in the crate to make an outlet for water. If using a cardboard box, place a plastic film on the inside up to the edge of the sides after cutting out the hole. Puncture the film where the hole is for the water outlet and tape it to the box.

Place the crate/box on the pad so that the water outlet remains off it. Place a pail under the outlet. It is desirable to wedge something under the crate/box to tip it slightly. Then, we pour sand in up to a height of several centimetres. It is better to use fine-grain sand, which is better carried by the water current.

Try to pour the sand out evenly so that no higher or lower areas form. If they were to do so, the running water would only flow around the bumps and form puddles in the dips. Fill the PET bottle with water and insert the tube through the neck (we can tape it to the neck, so it is sturdier or drill a hole in the bottle top). Siphon water into the tube with your mouth, making the water flow, and place it into the corner opposite the outlet we cut out (and attach using tape). If doing the experiment outside, a garden hose with its stronger current will serve the purpose better.

Course of the experiment:

The running water begins to accumulate on the sand and some of it is absorbed. With increasing amounts, it begins to spill into the surroundings, following the incline of the pad. When flowing, the water carries with it the fine-grain material and searches for the lowest-laying point, which is the outlet. As the water flows, it forms a bed that is continuously deepened by the carrying away of material. At the same time, material is also eroded (carried away) from the sides of the bed in those parts of the stream where the current is strong. Thus, the banks are moved. On the contrary, in some places (where the speed of the water current is slow), the material settles. The whole system thus formed develops over time and continuously changes. New beds form because the older ones either clog or are eroded away.

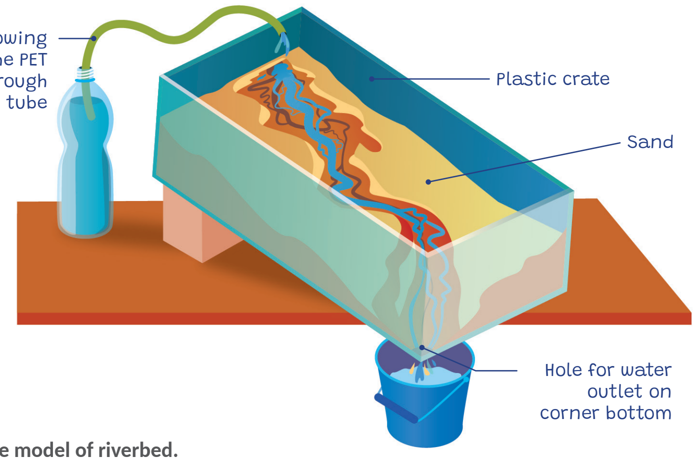


Image **2**
Illustrative model of riverbed.
Water is supplied from the upper right-hand corner and flows out in the lower left-hand corner.

TIP: If the experiment continues for several tens of minutes and we use a smartphone to make a time-lapse video this will be beautifully apparent. In such cases, however, you need to refill the PET bottle with water and return the sand from the pail to the crate.

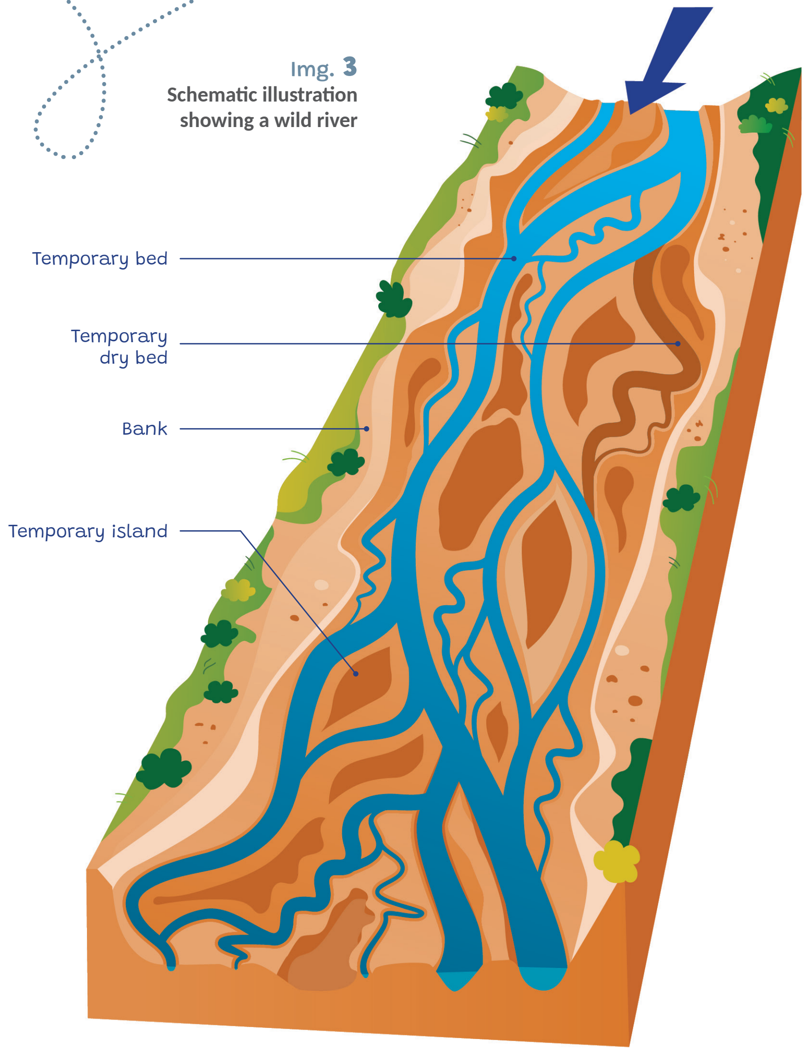
What to see:

We observe **the wild river course** during the experiment. During this process, the water forms branches, i.e., the watercourse is divided into more courses. This not only increases the amount of water that is able to flow through the riverbed (for example during floods), but also lowers the speed and the erodible energy of the stream. This results in the large-grain alluvia to be deposited, most often in bends, creating benches along the banks or in the centre of the river, as well as islands. In nature, the eroded material can have the character of gravel or sand. Gravel is typical for submontane becks, and sand of various grain size is typical for areas downstream.

Issues

This model does not allow us to precisely copy the origin and the course of the entire river system, since we have problems with scaling here. The current that runs through the model is too slow, and is thus too weak, to carry away the massive grains of quartz sand for a further distance, and thanks to the slow speed, the grains themselves merely roll along the river bottom, which prevents us from making those formations that are typical for central and lower parts of the stream (e.g. meanders). In such cases, you need to choose different material that is not as thick, and thus not as heavy (for example, ground plastic).

Img. 3
Schematic illustration showing a wild river



Temporary island

This experiment allows for many adjustments that can variously manifest on the formations that originate. We can regulate the amount of water that flows into the crate by adjusting the flow rate. The more water that flows into the system means the more sediment that is carried away. We can also adjust the incline of the box, changing the speed of the water current. In general, we can say that the higher the incline, the higher the speed of the water flow. The bed then straightens out and more material is carried away.

Where can we see examples?

In our country, wild currents formed primarily in the cold periods of the Pleistocene (the era beginning 2.58 million years ago and ending 11,700 years ago), when the higher intensity of the bedrock's natural weathering led to the clogging of valleys with thick layers of sediment. However, under today's conditions of cultivated landscapes, such watercourses are rare in the Czech Republic. Despite this, we can still see them in the upper and central parts of the rivers under the Beskids, such as Morávka, Ostravice, Lomná, Olše, Rožnovská Bečva, as well as on their tributaries, where gravel-like material is deposited.

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13. HOW IS IT POSSIBLE FOR LARGE HAILSTONES TO FORM IN CLOUDS?

Supplies:

- a high-powered hairdryer (not every model can form a sufficiently strong air flow)
- a ping-pong ball

Purchase costs for experiment supplies approx. €1 *(without hairdryer)*

Even though it is not evident at first glance, a large cloud carrying a summer thunderstorm, a rain shower, or a hailstorm can weigh even around one million tonnes. And that is considering only water and ice, not the air itself! Thus, such a cloud has a weight comparable to the sum of the entire population of the Czech Republic.

A storm cloud forms thanks to a strong updraft of air, which can hold not only tiny droplets and ice crystals, but also much larger particles – such as hailstones, which are sometimes larger than a golf ball. How is it possible, then, that hailstones can grow to such large sizes and not fall from the cloud? The hail remains airborne thanks to the air stream. The strong updraft continuously pushes the droplets higher while simultaneously preventing the hail from falling. Thus, the hailstones can form new layers from the new drops of water that freeze on them, thereby increasing in size.

Image **1**
To date, the largest hailstone in the world ever found had the considerable radius of 20 cm and a circumference of 47.3 cm. It fell to the ground in South Dakota (USA) in 2010. Author: NWS Aberdeen, SD, license: Public Domain

Construction directions:

This is a quite simple experiment that very clearly demonstrates the phenomenon in question. All you need to do is to take a ping-pong ball and place it above the nozzle of the hairdryer pointing upwards. And then also, to be at least a little patient and to gain experience.

Course of the experiment:

After turning on the hairdryer and aiming its nozzle upwards, we create a stream of air that simulates a cloud updraft. This suspends not only the cloud droplets in the air, but also the larger particles of precipitation, including hailstones. By placing the ping-pong ball into the air stream of the hair dryer, we simulate the suspension of hail in the cloud. The hailstone is suspended by the updraft but notice that it does not remain in one place. Thanks to the turbulence of the air, its position shifts slightly, which in nature causes the hailstone to move into areas with different conditions. Thanks to this, the hailstone grows in many ways throughout its journey; different layers of ice are formed. When you turn off the hairdryer or shift the air stream to the side, the ping-pong ball commences to fall to the ground. Just like a hailstone that finds itself outside of the strong draft.

Image **2**
Illustration of the experiment

What to see:

Hailstones form in massive storm clouds that look like gigantic towers or castles in the sky. We call such clouds *cumulonimbus* – and these are the clouds that can bring not only rain showers and hailstorms, but also thunderstorms and lightning, strong winds, or even tornados. At the same time, they rank among the most beautiful phenomena we can see in the sky – not only with their shapes, but also in the way that rainbows form on their droplets.

The inside of such a cloud is formed by **strong updrafts**, which can reach a speed of over **50 metres per second**, i.e., more than **180 kilometres per hour**! It is these updrafts that can suspend the heavy icy hailstones within the cloud, allowing them to grow to increasingly larger dimensions. A hailstone in a cloud behaves similarly to the ping-pong ball caught in the airstream of the hairdryer – it floats, and the rising winds continuously bring more and more **icy water droplets** to it, which freeze to its surface.

Hailstones are formed in an atmosphere where the air temperature fluctuates between **0 °C and –20 °C**. Water droplets in clouds may remain liquid even up to temperatures of **–40 °C**, but once they touch the cold hailstone, they immediately freeze and form a layer of **opaque ice** full of tiny bubbles. Because water freezes quickly, we refer to this process as **dry growth** of hailstone.

Interesting phenomena appear as the hailstone continues to grow. The freezing droplets release **latent heat**, which can slightly warm the hailstone's surface. The newly falling drops thus first melt, fill in the small fissures in the hailstone, and only then do they freeze – this time into **transparent ice** without bubbles. Water on hail does not freeze immediately, which is why we refer to this phase as **wet growth** of hailstone.

Thanks to the alternation of these layers, beautiful **stripes of transparent and milky-white ice** form inside of the hailstone.

So, the next time you have the chance to observe a hailstone up close, look at its inner structure – you will see that true natural beauty can be hidden even inside an ordinary piece of ice.

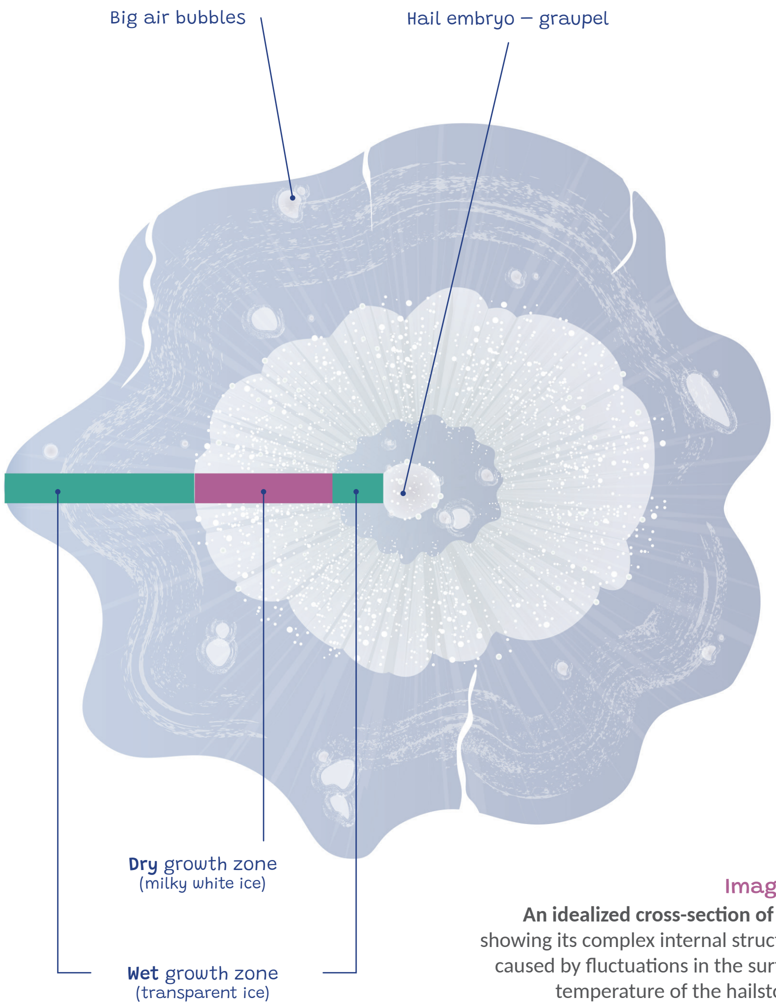

Image 3
An idealized cross-section of hail showing its complex internal structure caused by fluctuations in the surface temperature of the hailstone.

Interesting fact

Hailstorms are a phenomenon that is observed and measured with great difficulty. In the event that the hailstones do not cause extensive damage or do not fall directly on the meteorological station, we often do not even know of their existence. So, if you ever see extremely large hailstones, try to **take a picture of them** – ideally so that you can estimate their size on the photograph. **A coin, a ruler, or a matchbox** placed next to the picture could help, for example. You can then send the photo by e-mail or through **social media to the Czech Hydrometeorological Institute, the Institute of Atmosphere Physics of the Czech Academy of Sciences**, or upload it to the webpage **ESWD.eu**, the European Severe Weather Database. Your observations can help scientists better understand the occurrence and intensity of hailstorms.

TIP: **If you wish to create your own hailstones, you can download the 3D model on the website https://sketchfab.com/joshua-wx/models and have students print out their own huge hailstone.**

See complementary materials to the experiment
www.ig.cas.cz/en/experiments

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Text: Kateřina Skripniková, Petr Brož / Illustrations and graphics: Lucie Škodová

14. WHY DO RAINBOWS FORM?

Rainbows are some of the most beautiful weather phenomena. Every one of us has surely already seen one – a rainbow appears when it is raining but at the same time, the Sun is shining. At first glance, it seems that the rainbow is painted on the sky or on the clouds, but in reality, this is an optical illusion that occurs in our eyes thanks to the way that light is refracted, dispersed, and reflected on the raindrops. To observe a rainbow, three conditions must be met: we must be looking at rain, the Sun must be shining from behind our backs, and its height above the horizon must not be more than approximately 40°. That is why we most often see rainbows in the morning or in the evening, when the Sun is low – and that is also when they are at their most enchanting. But you can easily create a rainbow of your own!

Image 1
Primary rainbow with a hint of its secondary bow.
Author: Eric Rolph,

Supplies:

- a mirror
- a bowl for water
- water
- a pocket torch

Purchase costs for experiment supplies €0 (all the materials used are commonly available at home or at school)

Construction directions:

A baking dish, ideally rectangular, is great for the experiment – a small mirror is easily leaned against its sides. Place the small mirror askew to the side of the dish and fill the dish up to the edges with water. Then take a torch or a stronger hand-held lamp and aim the light from the opposite side of the dish so that the light goes through the water and hits the mirror.

It is important to have the light as close as possible to the water's surface and to slightly tilt the light, so that the rays hit the mirror at a slant. After trying for a while, a beautiful rainbow should appear on the wall behind the lamp. If you are not successful at first, do not give up – try changing the angle of the tilt of the mirror or of the lamp. Just a minor change is needed, and the colours of the rainbow appear on the wall.

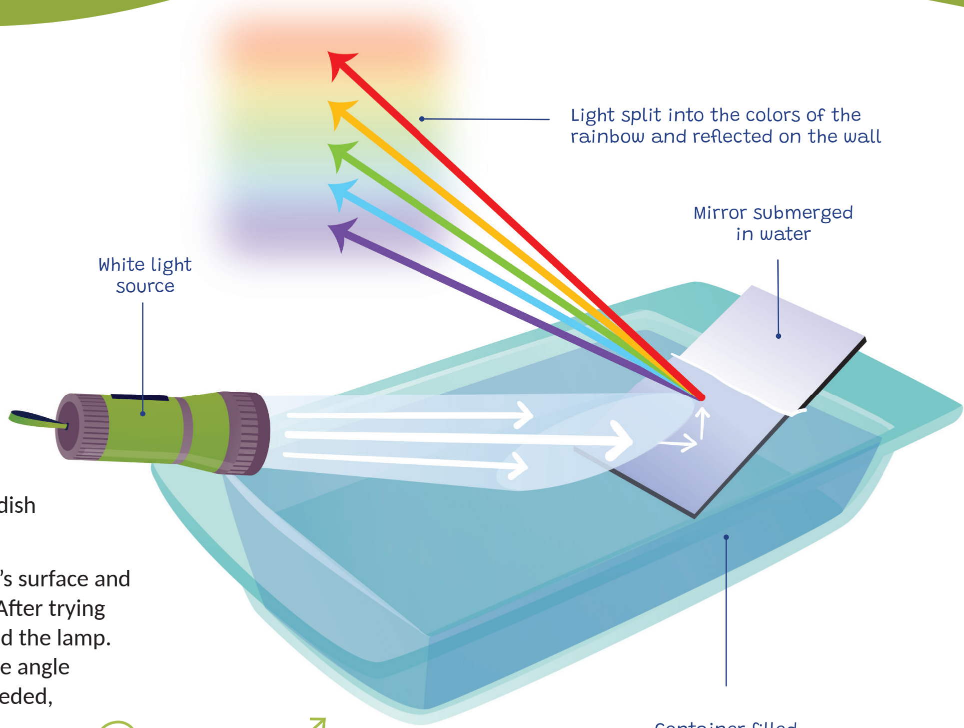

Image 2
Illustrative sketch of experiment

Course of the experiment:

After hitting the surface, the white light of the lamp is partially reflected and **partially refracted under the water**. Each colour, however, has a different **wavelength**, and so it is refracted under a slightly **different angle**. Rays of diverse colours then hit the mirror and are **reflected** through the water and reach the wall or screen. The water in the bowl, representing raindrops, sends the colourful image of a rainbow to the screen or wall, just as it is sent to our eyes in nature.

What to see:

Rainbows are some of the most beautiful optical phenomena to be seen in the sky – usually during a summer afternoon after a rain shower. You see, the raindrops act somewhat like tiny prisms, which disperse the white sunlight into separate colours and reflect them into our eyes at a precisely given angle. A rainbow thus does not form in a certain place in the sky, but at the moment the variously coloured light rays reflected by the billions of raindrops hit our eyes.

However, a rainbow cannot always be observed. At **noon** in the summertime, when the Sun is high, we will not see a rainbow in the Czech Republic, at all. The best conditions occur in the **afternoon**, when **the Sun is shining behind our backs** and **is lower than 40° above the horizon**. The lower the Sun, the higher up the rainbow is – just before sundown, we can even see **an entire arc**. From planes, mountains, or from a hot-air balloon, you can even see **a circular rainbow** if you are lucky, since this is a rare, yet exceptionally beautiful sight.

Sometimes, a secondary rainbow appears above the primary rainbow. This is formed when the **rays inside of the raindrops are reflected twice**, so only part of the original energy – about **43%** of the primary arc – hits our eyes.

However, we can also observe other colourful phenomena in the sky in the form of colourful stripes and circles that can be easily mistaken for rainbows. Haloes form on **ice crystals** in the thin, high clouds, and can be seen **around the Sun**, not opposite of it. Similarly, coronas – delicate, coloured rings around the Sun, the Moon, or lamps – form from the tiny droplets **in fog** or clouds. And although these phenomena look like rainbows, they are created in a completely different manner.

Interesting fact

A rainbow is formed by **polarised light**, and so you can try to either **“erase” it from the sky** or, on the other hand, **emphasise its colours** using **a polarising filter**. Such filters are used in photography and are also usually found in **sunglasses** – you can recognise them by the “*polarised*” label. Try looking at the rainbow through the sunglasses while **slowly turning them around**. When the rainbow disappears, you have proof that it is not drawn onto the rain, and when the rainbow gets stronger, you can see more repeating bands on the inside of the primary rainbow, usually in violet and green hues. These form through the diffraction of light and are a manifestation of the wave nature of light.

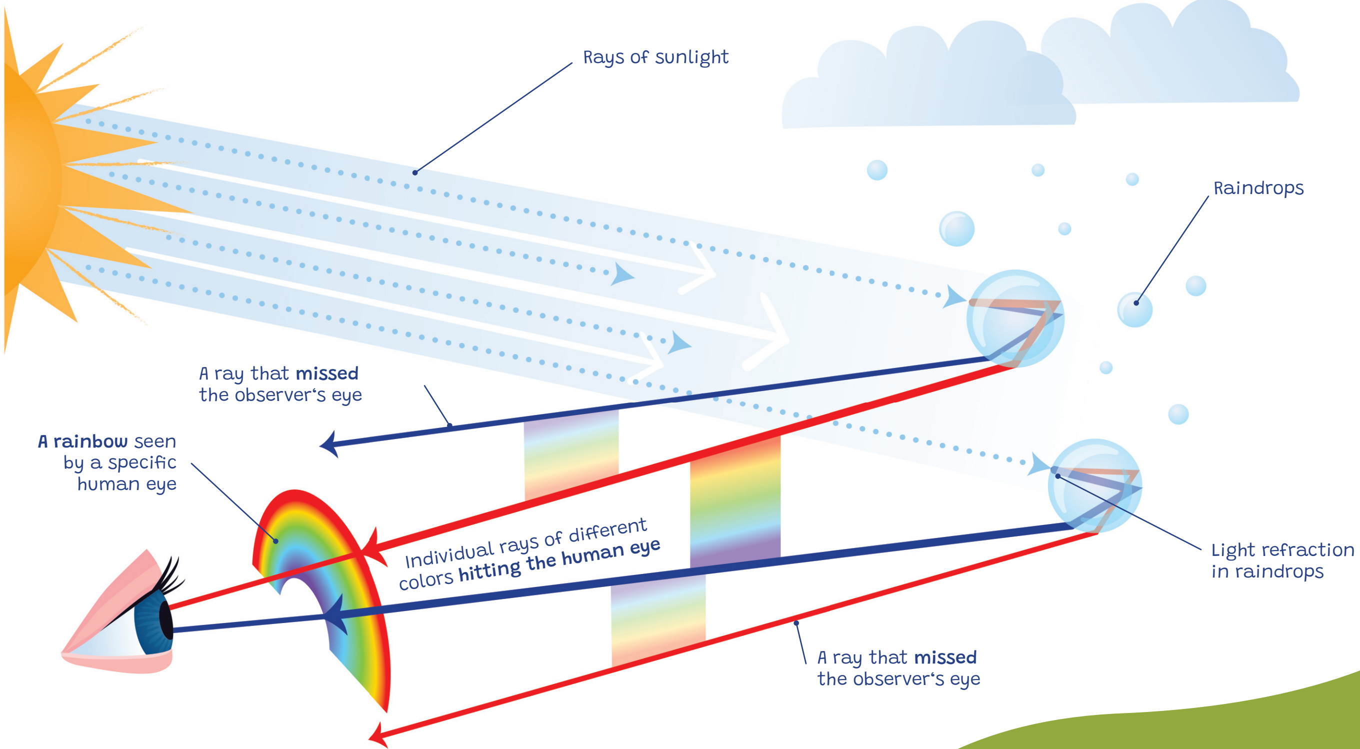

Image **3**

Schematic image of rainbow formation.
Each drop sends all the colors of the spectrum toward the observer, and only one from each drop hits our eye.

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Text: Petr Zacharov, Petr Brož / Illustrations and graphics: Lucie Škodová

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15. WHY DO CLOUDS FORM?

Every day, we can observe various shapes in the sky created by nature for us. Whether they be thin folds, or sheep clouds, or fluffy masses, towering clouds, or variously thick layers – they are always clouds formed by tiny droplets of water or ice crystals. These particles form when humid air cools down and the water vapour in it begins to condensate into small droplets. This is because a greater amount of it cannot fit into the colder air. You can easily try to form a cloud at home or at school – all you need is a plastic bottle, some water, and a wooden skewer with a match.

Image 1
A cloud – one of the most common and yet most beautiful manifestations of weather.
The lower part of the cloud is formed by water droplets, and the higher layers are formed by ice crystals.
Author: Ervins Strauhmanis, license: Public Domain

Supplies:

- 2 plastic bottles (ideally a 1-litre milk bottle)
- matches
- a wooden skewer
- some water

Purchase costs for experiment supplies approx. €4

Construction directions:

Take the plastic bottle and pour cold water into it. A fifth or fourth of the total volume of the bottle will suffice. If you should wish to repeat the experiment several times in a row, it is handy to have two such bottles prepared.

TIP: The experiment will be more attractive if you have a larger receptacle available – like a ten-litre demijohn. In such an event, it is enough to pour one to two litres into it and then close it off with a cork. However, you must prepare the cork beforehand. Drill a hole through using a drill and paste a bicycle tyre valve into the hole. Ideally cut the tyre valve out of the tyre with some rubber still attached, which you will paste from the bottom side of the cork so that the coil of the valve protrudes out of the demijohn.

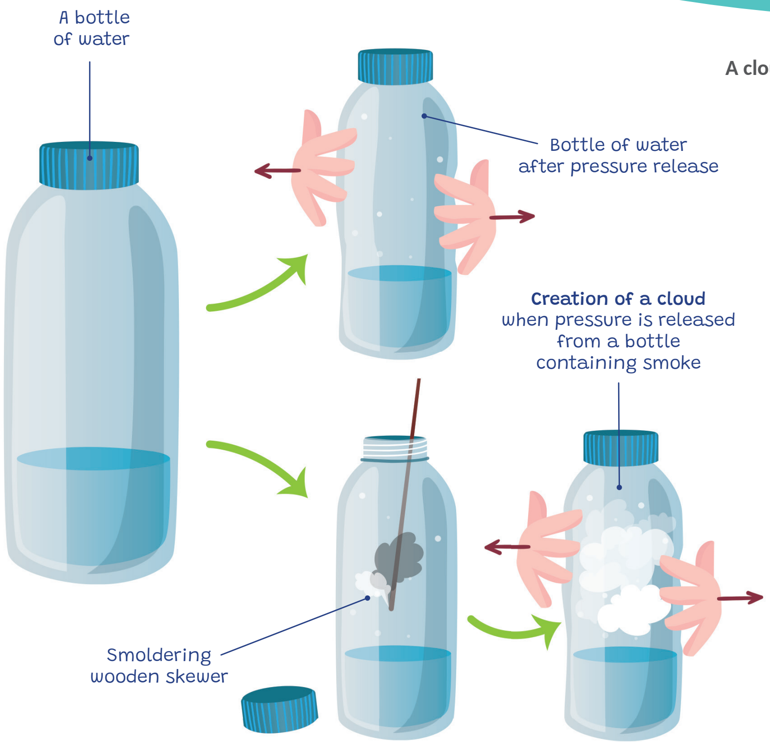

Image 2
Illustrative sketch of experiment preparation and course of experiment

Course of the experiment:

First close the bottle with the top and increase the pressure inside of the bottle by squeezing it with your hands. If you are conducting the experiment in an environment that is not very humid, nothing will happen after releasing the squeeze. This is correct, because we find ourselves far from the conditions needed for the formations of clouds and, as a rule, the air in classrooms is usually dry. We shall then repeat the experiment, but this time we will insert a wooden skewer into the bottle that was ignited prior to its insertion. Let it fume inside of the bottle for several moments prior to removing it. Then, close the bottle and again add pressure to the bottle using your hands. After releasing your hold, you will see that inside of the bottle, water vapour is condensing on the smoke particles. If we want to repeat the experiment several times, it is better to have another bottle with clean air ready, where the droplets do not form, and another bottle, into which we add the smoke particles. To pressurize the demijohn, we use a hand pump – but otherwise the experiment is the same.

What to see:

In nature, clouds and fog form in those places where the air is cooling down. This is simulated in the experiment through the pressurisation of the bottle, where air temperature increases along with the increase in air pressure. Immediately, water at the bottom of the bottle begins to evaporate into the warmer air, forming water vapour. After releasing your hold, the air pressure within the bottle rapidly falls, causing the air temperature to also lower. The water vapour then must condensate on the smoke particles.

In nature, air most often cools down by rising. While rising, the air pressure also changes, just like in our experiment, and so also the air temperature cools down. Air that contains much water vapour becomes saturated with this water vapour during the process of cooling down, so that it is then forced to condensate on tiny condensation nuclei into miniature cloud droplets.

Fog occurs in those places where the air is rapidly cooled from the ground, mainly at night. In the mornings following a clear autumn night, you can observe strips of fog on damp meadows, whereas above fishponds and rivers, you see a continuous blanket. In the dry summer, usually no fog is formed, as the air does not contain enough water vapour.

If the air in the classroom should be rather humid, which can sometimes happen on a rainy day, the droplets in the bottle may form without the addition of the smoke particles. This is not a fault in the experiment, just proof of the fact that the air contains a lot of moisture and a certain amount of natural condensation nuclei.

Interesting fact

For clouds to form, one rule must be met: warm air holds more water than cold air. Therefore, when humid air cools down, the water from it begins to form droplets in a process that we call condensation. These droplets form around the tiny particles of dust, pollen, or salt that float in the air and that are known as condensation nuclei.

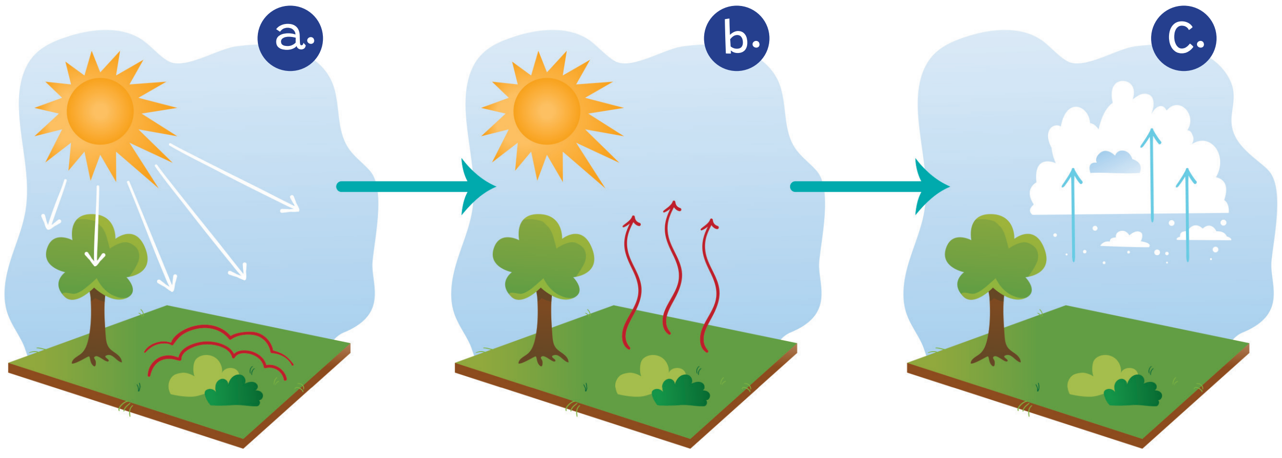

Image 3
The three phases of cloud formation

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Text: Petr Zacharov, Petr Brož / Illustrations and graphics: Lucie Škodová

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16. DO TORNADOS ALWAYS ROTATE IN THE SAME DIRECTION?

Supplies:

- two two-litre plastic soda bottles – the harder the plastic, the better
- water
- two tops from PET bottles (or a 3D printer)

Purchase costs for experiment supplies approx. €0.5

Tornados rank among the most impressive, but also the most dangerous manifestations of weather. They appear suddenly, their force is usually staggering, and they often leave behind considerable damage – sadly, sometimes even taking human lives. Forecasting their formation is exceptionally complex, even in the United States where we can observe their occurrence the most often. Meteorologists can usually just forecast the conditions suitable for their formation, but not the tornados themselves.

Since a tornado is a rotating vortex, it can either rotate clockwise or counterclockwise. Most probably, you have heard that vortices – such as those that form when draining a sink – must rotate counterclockwise in the Northern Hemisphere due to the Earth's rotation. Is this true, however? You can assess this with the help of simple experiment that illustrates the formation of a tornado!

Image 1
Photograph of a strong tornado in Canada in 2007.
Tornados are unpredictable not only by their force, but also in the direction of their rotation.
Author of photograph: Justin1569, license Creative Commons BY SA 3.0

Construction directions:

It is necessary to paste the tops of the PET bottles together using a hot melt glue gun so that their screws are facing opposite directions. Or you can use a 3D printer and print out the doubled bottle top (the instructions are available in the materials accessed by scanning the QR code on the other side of the sheet). In the case of two bottle tops pasted together, it is better to add tape around the seal to prevent any water from leaking through an imperfectly pasted seal or the seal from breaking. Then drill a hole through the pasted-together tops using a wider drill (at least 8 mm) so that water can easily flow from one bottle to another. With the 3D printed top, expect that the tops are not tightly sealed and that a lot of water will be splashed out during the experiment if teflon tape is not used in the screws.

Then fill one bottle with water at room temperature. Screw the bottles together using the double-sided top.

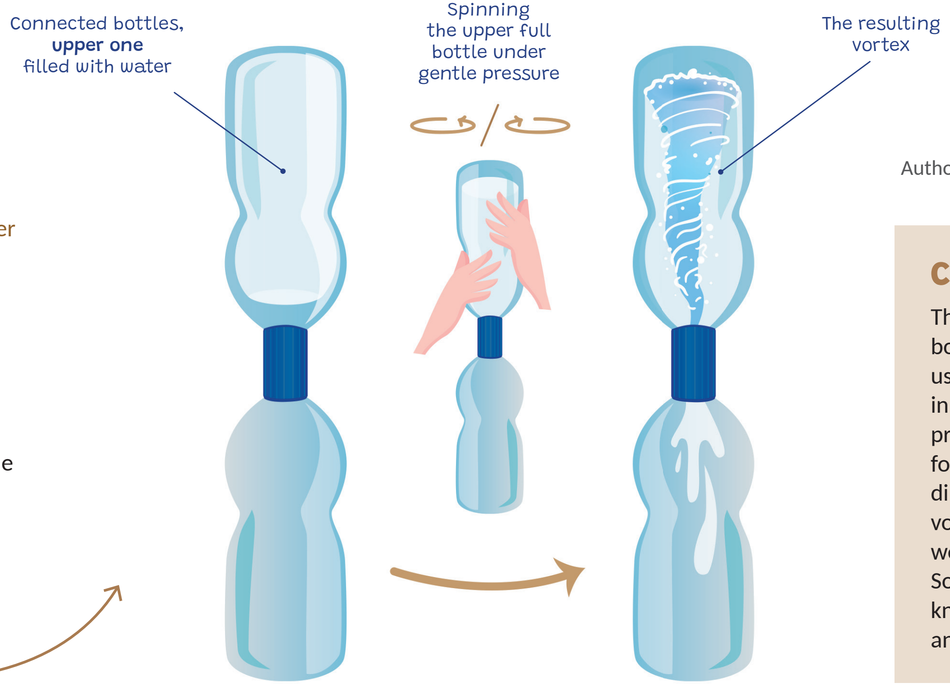


Image 2
Illustrative sketch of experiment

Course of the experiment:

The experiment begins by turning the bottles so that the bottle filled with water is on top. Slightly squeeze it, and using circular movements, we attempt to create a vortex in the water flowing out. Be patient, it needs some practice and sometimes it takes time for the vortex to form. After it forms, try to rotate the bottle in the other direction, again squeezing slightly. You will see that the vortex can be formed gradually in both directions, and we do not even have to alternate the Northern and the Southern Hemispheres. The effect of the Earth's rotation known as the **Coriolis force** is negligible with such small and rapid vortices.

What to see:

The Earth's atmosphere is continuously in movement and full of various vortices – from expansive cyclones with a diameter of hundreds to thousands of kilometres to smaller, yet much stronger hurricanes, to cloud vortices, massive tornados or tiny dust devils that whirl around dust and leaves. Whereas expansive cyclones or hurricanes do always rotate counterclockwise in the Northern Hemisphere due to the Earth's rotation (and clockwise in the Southern Hemisphere), for smaller vortices such as tornados or the vortex of bathtub drains, this law does not apply, even though it is often purported.

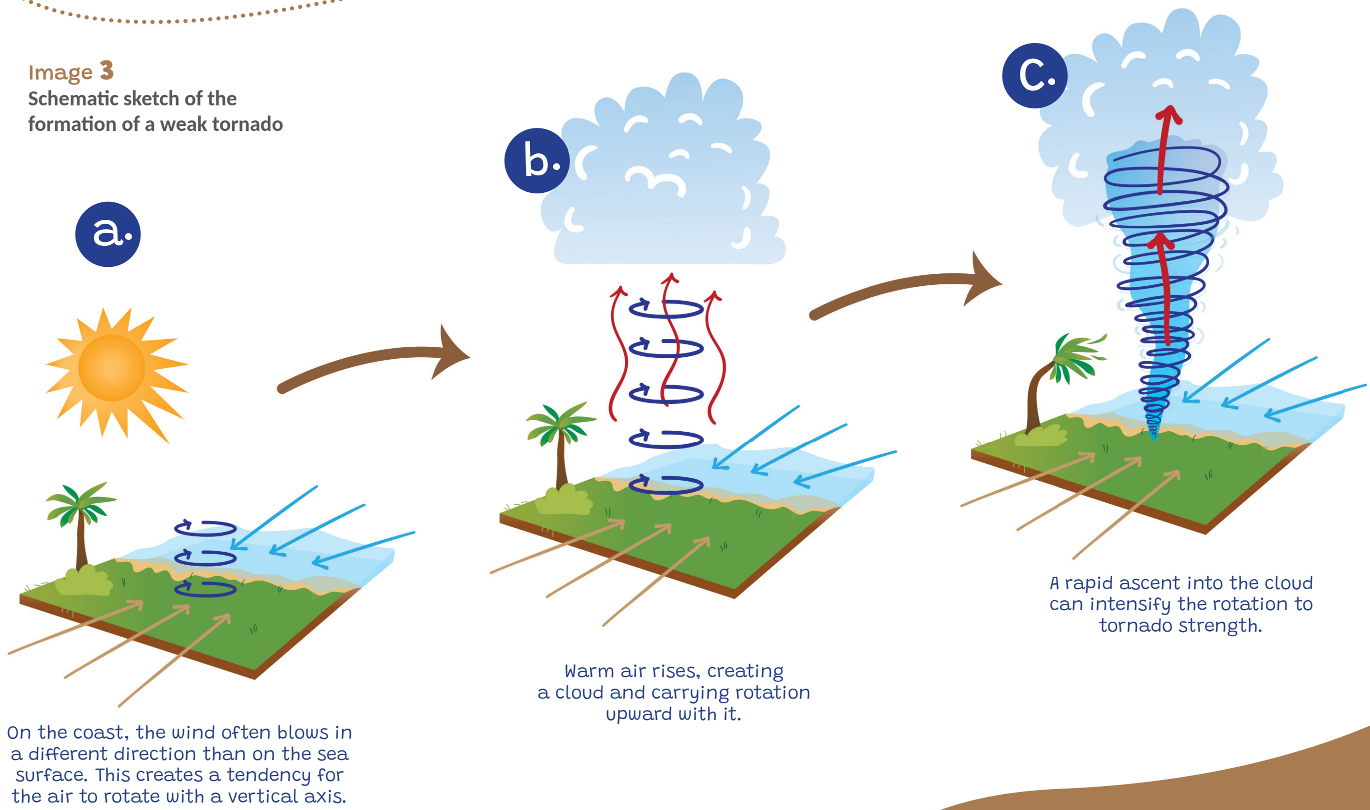
With the help of a simple experiment, we can easily assess that an external force – like that of our hands - influences the direction of the vortex's rotation in the bottle much more than the effect of the Earth's rotation itself. A tiny movement is enough to suddenly "turn around" the rotation into the opposite direction. Similarly, with tornados, it depends on how the thunderstorm that generates it formed. And with the vortex in the bathtub, the very shape of the vessel is all it takes to turn around its rotation.

On the other hand, with large pressure systems, such as low-pressure systems (cyclones) or hurricanes, the forces of **the Coriolis Effect** and the pressure differences between the core and their surroundings prevail. These forces unequivocally determine the rotation – and therefore every hurricane that batters the coast of the USA always rotates counterclockwise.

Interesting fact

If you are ever on a trip to Africa or in South America near the Equator, do not be bamboozled by street "magicians" who will show you that a vortex in a plastic bucket rotates counterclockwise in the Northern Hemisphere and when taking a few steps into the Southern Hemisphere, it suddenly rotates clockwise. You now know that this is not due to the Earth's rotation, but just the result of dexterous hands that can properly whirl the water.

Image 3
Schematic sketch of the formation of a weak tornado



TIP:

Scan the QR code to watch the video and learn even more about tornadoes.

See complementary materials to the experiment and download the template for the 3D printed bottle top
www.ig.cas.cz/en/experiments

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