Background information 3:

How do tidal forces affect the Earth and the Moon? Then, now and in the future. Why is the Moon so important for (human) life on Earth?

Today, the Moon is approx. 380,000 km away from the Earth on average and it always faces the Earth on the same side. However, this was not always the case. The protoplanet Theia was responsible for the formation of the Moon around 4.5 billion years ago, which was already discussed in teaching material 1 for this series. The Moon was formed at a distance of around 40,000 - 45,000 km from the Earth, at a time when extremely high temperatures prevailed. The formation of the Earth's moon, and in particular its size and mass, is very atypical for the mass of the Earth. No other planet in our solar system has such a large natural satellite in proportion to its own mass.

Due to the fact that the Moon has approx. 1/80 of the Earth's mass and is "only" 380,000 km away from the Earth on average, strong gravitational forces act between the two celestial bodies. Although the Earth-Moon system was only in its early stages, the difference in mass quickly forced the Moon into a synchronized orbit, which means that today we can only see the Moon from one side from Earth. The tidal forces therefore act differently on the Earth due to the different position of the Moon compared to the Moon itself, where they always act at a similar position, as the Earth is always at a similar position on the synchronized orbit from the Moon.

The tides on Earth are probably the best-known consequence of the gravitational system Earth-Moon(-Sun). Despite the smaller size and much smaller mass of the Moon, it has an effect on the Earth's tides. The Sun also has gravitational effects on the Earth, but these are three times weaker than those of the Moon due to its great distance from the Earth.

Particularly strong (spring tides) and particularly weak tides (neap tides) occur on Earth due to the influence of the Sun in combination with the Moon. The strength of the tides varies depending on the position of the Earth, Moon and Sun. For example, the celestial bodies are either positioned in such a way that the gravitational forces add up (spring tide) when the Sun, Moon and Earth are on a straight line, as is the case with a full moon and new moon, or the forces act in opposite directions (neap tide). The tidal effect is then particularly weak. The Moon causes the majority of the tides on Earth. The relevant movement of the Earth and Moon is shown in the following figure (see Fig. 1). The centers of

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the Earth and the Moon revolve around a common center of gravity, the so-called barycenter, which lies within the Earth.

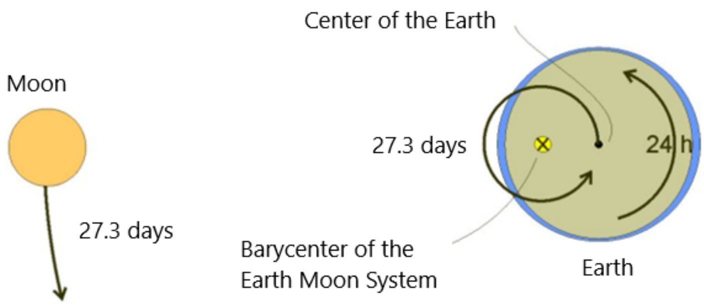

Figure 1: Earth Moon system

At the same time, the Earth rotates on its own axis every day. In this system, the tide is equally high on the side of the Earth facing the Moon and the side facing away from the Moon. The reason for this is the gravitational force that the Moon exerts on the Earth. The difference between the centrifugal forces and the gravitational forces directed towards the Moon result in the tidal forces (see Fig. 2).

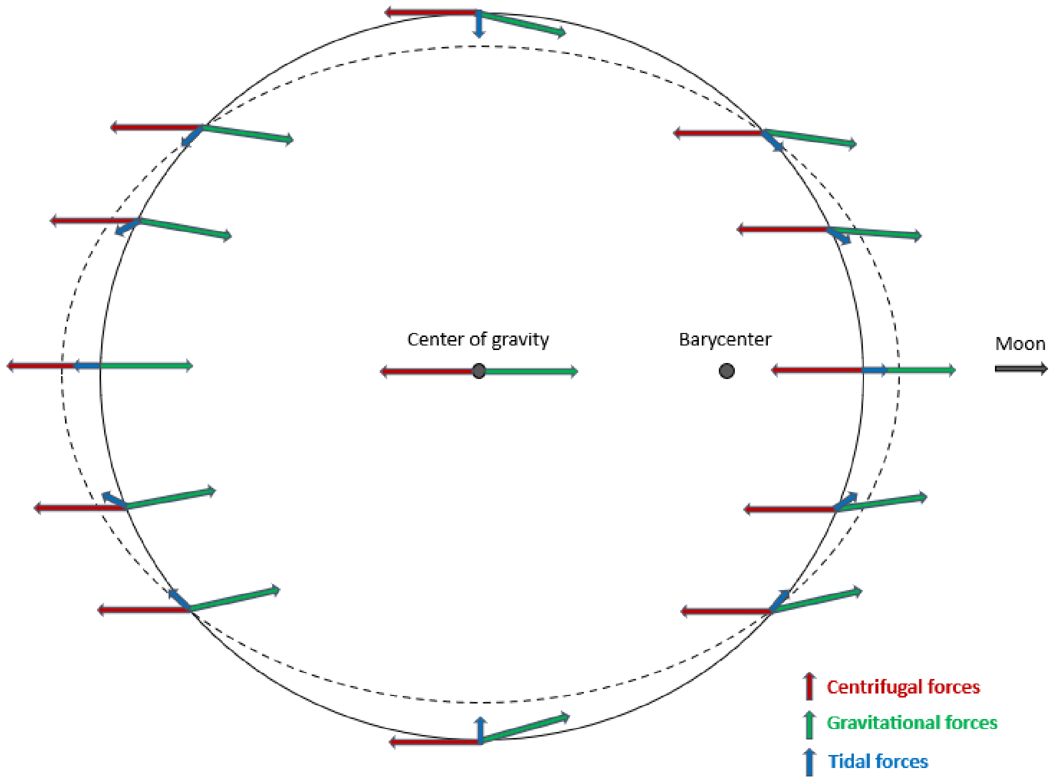

Figure 2: Formation of the tidal forces

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As the Earth rotates on its own axis at the same time, it rotates under the two high and low tides. The Moon's tides have an average period of 12 hours and 25 minutes. While the Earth rotates on its own axis, the Moon also moves a little further in the same direction during its monthly orbit. As a result, the tides caused by the Moon are shifted backwards by around 53 minutes every day. For the tidal effect of the Sun, the corresponding shift is only about 4 minutes.

The explanation presented is model-based and reduced in complexity in order to illustrate the physical processes more simply and clearly. In reality, other variables must also be integrated. For example, the inclination of the Earth's axis, the shape of the coastline, the nature and shape of the seabed, wind and weather or the position of the Moon in relation to the equatorial plane. All have an influence on the height of the tidal range. However, the interaction of the individual factors is so complex that it is still not possible to predict the exact tidal range for a specific time. Therefore, empirical knowledge still plays a role that should not be underestimated.

The Earth's rotation around its common center of gravity is slowed down more and more over the years. Before the Moon was formed, one Earth Day lasted around 6 hours. Now it is 24 hours. Because the Moon's orbit is already synchronized, the tidal forces act on the Moon in such a way that the orbital angular momentum causes the Moon to move further and further away from the Earth, by about 4 cm per year. As the total angular momentum of the Earth Moon system is a constant, the decrease in the Earth's rotational angular momentum is balanced out by the increase in the Moon's orbital angular momentum.

As the masses of the Earth and Moon do not change, the distance must increase as the angular velocities decrease, so that the Moon moves away from the Earth over time. Without the Moon, the Earth would rotate much faster. An Earth Day would then last approx. 9-10 hours. Wind speeds would increase. Only very flat and adapted creatures would survive the changed situation. In addition, the Earth's axis of rotation would be much more unstable and would fluctuate greatly. Potentially, for example, the North Pole would then be at the zenith of the Sun, which would result in drastic changes on Earth in terms of climate, flora and fauna and would make life on Earth practically impossible. In addition, only the Sun would still have an influence on the tidal effect. This would mean that the tides would be weaker, but the faster rotation of the earth would cause storm surges and tsunamis. In addition, there would be less to no light at night, which would also have a decisive influence on the fauna and lead to the extinction of many species. Some animals, for example, spawn in the rhythm of the Moon and tides.

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The impact of Theia and the associated formation of the Moon are responsible for the disproportionately large Earth's core and for the formation of plate tectonics on Earth. It is assumed that without the impact of Theia, no life would have taken place on Earth, as no extremophile organisms (so-called archea) would have developed, predominantly in the extreme habitats that existed at that time.

The Moon is also highly relevant for research into the terrestrial past. On the Earth, which is still very active geologically compared to the Moon, traces of its past evolutionary history have already been largely erased. However, due to its smaller size, the Moon has cooled down almost completely and is therefore hardly geologically active. Accordingly, as part of the former primordial Earth, the Moon offers the opportunity to carry out geological investigations into processes that took place more than three billion years ago.

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