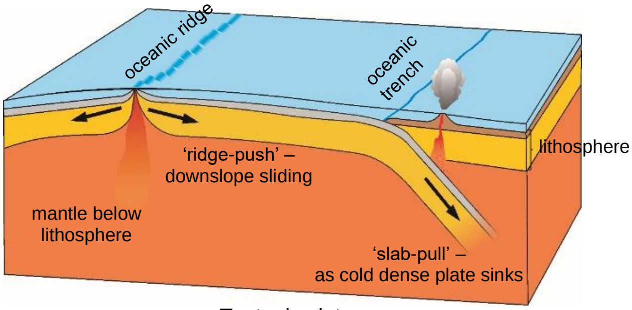
What do the top and bottom of a tectonic plate look like?
Questions to test understanding of plate tectonic processes

Ask your class '*What do the top and bottom of a tectonic plate look like?*' to test their understanding of plate tectonic processes.

The answer to the 'top of a plate' question is fairly simple but is important, since educational research has shown that many college students have little idea of where plates are found. When asked to draw them onto a cross section of the Earth, many drew plates that were deep below the surface. The answer to the 'bottom of a plate' question is more complex, and is being actively researched today.



Tectonic plates –
showing some of the mechanisms that move plates.

The top of a tectonic plate
As you read this, you are sitting on the top of a tectonic plate, since the top of a plate is the Earth's surface, which is the top of the rigid outer zone of the Earth, called the lithosphere.

You could argue with your class whether the top of the plate is the ground surface outside the window or the top of the building in which you are sitting, but this is just fine detail, since the answers have differences of metres whilst tectonic plates are tens of kilometres thick. In marine areas, the top of the plate is the seabed, since the rigid lithosphere does not include the fluid oceans or atmosphere.

The bottom of a tectonic plate
The bottom of a tectonic plate is the boundary between the lithosphere above and the asthenosphere below. The lithosphere is formed of the Earth's crust and upper mantle; it is solid and rigid and averages around 100km in thickness beneath oceans and is c200km thick under continents. Meanwhile, the asthenosphere (from Greek, *asthenḗs* 'weak' and 'sphere') is the weaker zone in the mantle beneath the lithosphere which, although almost entirely solid, can flow over geological time. The boundary between them is called the lithosphere-asthenosphere boundary or LAB.

The LAB is usually taken approximately as the 1300ºC isotherm. As you go deeper into the Earth and it becomes steadily hotter, this isotherm is the place where a temperature of 1300ºC is first reached. However, this information does not help us much in this discussion, as we cannot 'see' a temperature of 1300ºC. We need to think about, what actually happens at or near that point to understand the meaning of this boundary. This thinking suggests the following.
- We will never be able to drill to this depth, and so will never be able to 'see' the boundary.
- The best evidence for the details of the boundary are likely to come from seismic (earthquake shock wave) research.
- The character of the boundary is likely to be different in different parts of the Earth.
- In some parts of the Earth at least, it is more likely to be a zone rather than a distinct line or plane.
- The lithosphere is rigid rock made of minerals; since it is rigid and so generally unable to flow, minerals are likely to be undeformed (the exception is the flow that has occurred where parts of the lithosphere have had mountain-building episodes, when minerals and rocks do become deformed and metamorphosed); however in the asthenosphere, which can flow, minerals are likely to be deformed, and streaked out in the directions of flow. These differences should be visible, at least under the microscope.

More evidence comes from New Zealand in a research paper published in 2015 and summarised in the New Zealand Herald newspaper at: https://www.nzherald.co.nz/nz/news/article.cfm?c_id=1&objectid=11397050. There geoscientists carried out seismological studies by exploding dynamite to produce shock waves beneath the North Island mainland. They discovered that the lithosphere there is 73±1 km thick and that beneath the lithosphere, in the upper asthenosphere, there is a zone 8-12 km thick where seismic wave velocity drops. They suggest that this is a layered zone that may contain up to 2% of molten rock, or liquids such as water, or both [as films around grains, not in magma chambers]. This is described in the newspaper article as 'a weak slippery base' which allows plates to slide on top 'a bit like a ski sliding on snow', so that 'plates can be pushed and pulled around without strong resistance from the base'.

The type of research carried out in New Zealand can only be done on land (they write that dynamite explosions would kill fish at sea) and so much more seismic work, of different types, will be needed across the world to discover if the New Zealand example is typical or not.

If the New Zealand example is typical, it would show that there is a 'decoupling channel' beneath the lithosphere which allows it to slide easily on the asthenosphere beneath.

The back up

Title: What do the top and bottom of a tectonic plate look like?

Subtitle: Questions to test understanding of plate tectonic processes.

Topic: A deep question discussion on the properties of tectonic plates.

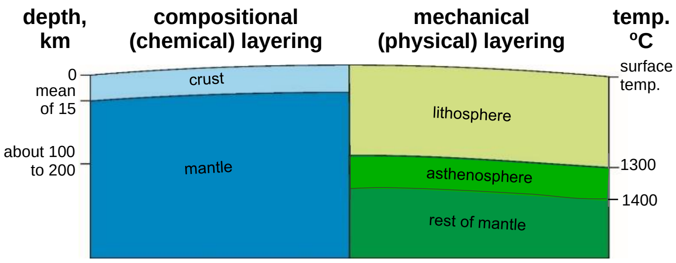
Age range of pupils: 16 years upwards

Time needed to complete activity: 10 minutes

Pupil learning outcomes: Pupils can:
- describe a tectonic plate and its characteristics;
- explain that the top of a plate is the Earth's surface or seabed;
- explain and discuss the evidence we have for the characteristics of the base of a plate.

Context:
When asked to draw tectonic plates on cross sectional diagrams, many college students have drawn plates deep beneath the surface, thus showing a lack of understanding of plate processes. This deep question discussion tests understanding not only of the tops of plates but also of the lithosphere-asthenosphere boundary (LAB) at the bases of plates, currently the focus of much geoscientific research across the world.

Some students confuse the base of the lithosphere with the base of the crust. The crust/mantle boundary is a change in chemical composition, whereas the much deeper boundary at the base of the lithosphere is between the rigid lithosphere and the less rigid asthenosphere, as shown below.



The LAB is much deeper under continental areas than under oceanic regions. It is around 100km deep beneath oceans but about 200km deep under continents, as shown by mapping the depths at which seismic surface waves have different velocities due to the alignment of minerals; LAB depths can be variable and complex in some regions.

Understanding of the 'top of a plate' can be developed using the '*Plate-riding'* Earthlearningidea at: https://www.earthlearningidea.com/PDF/87_Plate_riding.pdf

Following up the activity:
Ask what the edge of a plate at a transform fault/conservative margin might look like. The evidence suggests that this would be a strike-slip fault zone, likely to be formed of several faults, and that many of the fault surfaces would carry slickensides indicating horizontal movement. Some areas of the fault zone might be more chaotic.

Describing what a tectonic plate might look like at divergent and convergent margins might be much more difficult, and controversial!

Underlying principles:
- Tectonic plates are made of lithosphere; lithosphere comprises the Earth's crust and the top of the mantle; it is solid and rigid.
- Beneath the lithosphere is the asthenosphere, which, although almost entirely solid, is able to flow plastically (in a ductile manner) over geological time.
- The character of the Lithosphere-Asthenosphere Boundary (LAB) is an area of active geoscientific research.

Thinking skill development:
Pupils need to construct a model of a tectonic plate in their minds before bridging this model to a 'real world' scenario by discussing the characteristics of its top and bottom. Such discussion is likely to involve different views, and so cognitive conflict, as well as discussions about how their thinking developed (metacognition).

Resource list:
- none

Useful links:
The source of the New Zealand Herald newspaper article is given above. The original academic paper is: Stern, T., Henrys, S. A., Okaya, D., Louie, J. N., Savage, M. K., Lamb, S., Sato, H., Sutherland, R. & Iwasaki, T. (2015) A seismic reflection image for the base of a tectonic plate**.** *Nature,* 518, 85–88.

More information on the lithosphere-asthenosphere boundary can be found at: https://en.wikipedia.org/wiki/Asthenosphere and https://en.wikipedia.org/wiki/Lithosphere%E2%80%93asthenosphere_boundary, but be wary; our understanding of the LAB is changing as ideas and evidence evolve.

See a list of all the Earthlearningideas related to plate tectonics at: https://www.earthlearningidea.com/home/Teaching_strategies.html#platetectonics

Source: Chris King of the Earthlearningidea Team, with thanks to Duncan Hawley for information about the New Zealand research. Thanks also to Ian Stimpson and Phil Heron for valuable comments on earlier drafts of this Earthlearningidea.