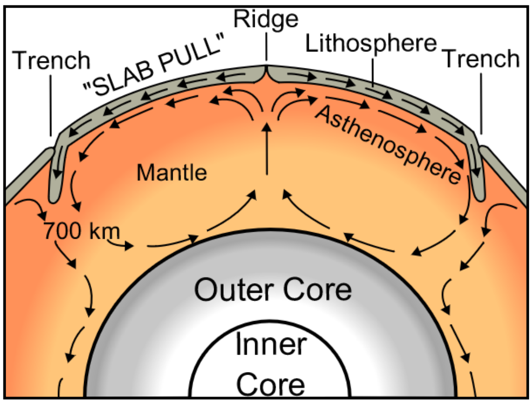
‘All models are wrong’ – but some are really wrong: plate-driving mechanisms
Many textbook diagrams of plate-driving forces have arrows in the wrong places

George Box, a statistician, wrote in 1976 that ‘*All models are wrong, but some are useful’*. The first part of this phrase is used by the inspirational geoscience teacher, Pete Loader, to help his students to understand that all models, whether physical, diagrammatic, computer or mathematical, are simplifications of the ‘real world’ and so are ‘wrong’, or at least, incomplete. This means that the models need to be tested and the assumptions made in producing them must be discussed and understood.

One way in which models can be ‘wrong’ is if we have newer models that explain the evidence more fully, and so are better models. A good example is the models drawn to show the processes that move tectonic plates.

When the ‘plate tectonic revolution’ took place in the 1960/70s, as scientists across the world first understood plate tectonics, the main mechanism for moving the plates was thought to be convection currents in the mantle. This was shown in many diagrams. One of these was published in a booklet by the US Geological Survey in 1994, copyright free for use in education, and so has been used for drawing many textbook diagrams ever since.



The model of plate-driving mechanisms produced by the USGS in 1994 in their ‘*This Dynamic Earth’* booklet. Although the term ‘slab pull’ appears in the diagram, it is not explained there – only in the nearby text.

The diagram was accompanied by another diagram showing how convection currents flow in a beaker.

Beaker convection from ‘*This Dynamic Earth’* booklet by Kious, W.J. and Tilling, R.I. (1994), USGS, p54.

These two diagrams indicate that the main driving force for plate movement is convection currents in the mantle. They also reinforce a common misconception, that the mantle is liquid because it can flow.

Until the 1990s, the main plate-driving force had been thought to be mantle convection, but the views of geoscientists were changing as the USGS booklet was being written, to show that two other forces were also being considered:

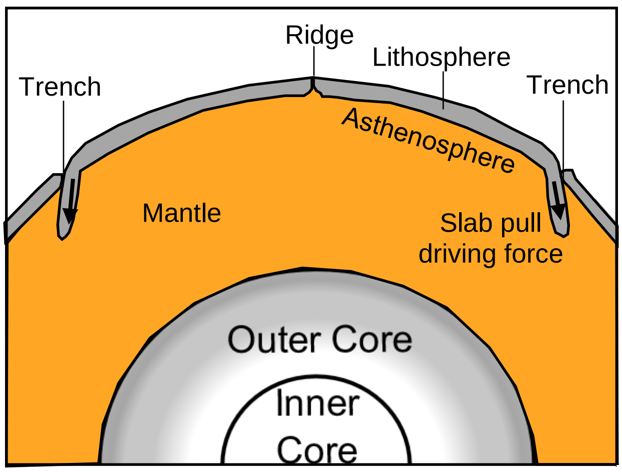
Slab pull – where plates become pulled down into the mantle (subducted) because the subducted parts are more dense than the mantle material below, and so sink down – pulling the rest of the plate behind them; this is called the slab-pull mechanism.

Ridge push – when new plates are formed at divergent plate margins in the oceans, the new plate material is hot, and less dense that the surrounding area and so it rises to form oceanic ridges. The newly-formed plates slide sideways off these high areas, pushing the plate in front of them – called the ridge-push mechanism.

Most recent evidence shows that:
- slab pull is the main plate-driving mechanism;
- ridge push can have an effect where slab pull is not the main plate driver;
- there is little or no evidence that convection currents in the mantle move plates (apart maybe from some very small plates in unusual circumstances).

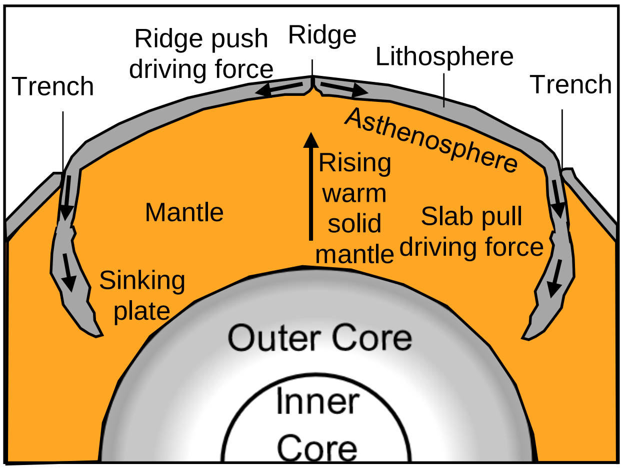
This means that the original USGS diagrams, and many diagrams drawn since then, are ‘really wrong’ in showing that convection currents in the mantle are the main driving force for plates.

BUT slab pull is part of convection, since sinking cold dense material that can flow, can drive convection currents in the solid mantle. The difference between the USGS and similar diagram models, and what geoscientists think today, is that the arrows showing the slab pull driving force near subduction zones should **not** be shown in the mantle, but **only** in the subducting plate. A better drawing looks like this, with arrows in the subducting plates showing the slab-pull effect.



USGS diagram modified to show the slab pull plate driving mechanism.

An even better diagram shows how the slab pull mechanism can continue into the deep mantle as plates continue to subduct (as shown by modern seismic tomography). It also shows the ridge push mechanism, as well as the rising warm solid mantle beneath oceanic ridges and other divergent plate margins; these rising currents are often called mantle plumes.



USGS diagram modified to show flows of solid material.

So, a problem with many textbook diagrams today is that they have the plate-driving mechanism arrows in the wrong places.

The arrows should **not show** circulating convection currents in the general mantle, but **should show** convection-driven flows of solid material where they actually happen.

Use this information to check diagrams of models showing plate-driving mechanisms in textbooks, online in diagrams and animations, and even in museum displays. You might be surprised to see how many are 'really wrong'.

At the same time, check that the model diagrams label the mantle as solid. Seismic data shows that the mantle is entirely solid, except possibly for tiny percentages of molten rock at the top of the asthenosphere and magma chambers beneath divergent plate margins.

The back up

Title: 'All models are wrong' – but some are really wrong: plate-driving mechanisms.

Subtitle: Many textbook diagrams of plate-driving forces have arrows in the wrong places.

Topic: A strategy for teaching that all models are simplifications, and that these can be wrong when superseded by better evidence-based models, as in the case of plate-driving mechanisms.

Age range of pupils: 16 years upwards

Time needed to complete activity: the checking of textbooks and other diagrams/animations can take as long as time allows

Pupil learning outcomes: Pupils can:

- explain that all models are simplifications and so therefore cannot represent reality completely correctly; they are based on a series of assumptions which may or may not be correct and which often lack fine detail;
- explain how the mantle convection plate-driving model was once thought to be correct, but is now thought to be mostly incorrect; it has been superseded by the slab-pull and ridge-push driving mechanisms;
- redraw incorrect diagrams by moving the arrows to show the forces correctly.

Context:
Many diagrams in textbooks, which cannot be reproduced here for copyright issues, show mantle convection to be the main driving force behind the movement of tectonic plates, through arrows showing convection currents throughout the mantle. However, evidence from seismic tomography and from the speed of plate movement related to the area of plates and the length of plate margins, shows that slab-pull and ridge-push mechanisms are more important drivers for most, if not all plates.

Seismic tomography uses seismic earthquake waves to provide pictures of the inner Earth in the same way as C/T scans can provide pictures of the human brain. Areas within the mantle where seismic waves travel more quickly than expected are cooler, allowing this method to pick out the subducting and sinking plates. Where seismic waves travel more slowly than expected, the mantle is warmer, allowing mantle plumes to be outlined.

The original mantle convection idea was first published in a diagram by Arthur Holmes in 1928, long before plate tectonic ideas were accepted. You can see his drawings, which were amazing for the time, by an internet search using 'Arthur Holmes and 'mantle convection' and clicking on 'images'.

Following up the activity:
Try redrawing Holmes' model to show the correct plate-driving mechanisms.

Underlying principles:
- Three main plate-driving mechanisms have been proposed; mantle convection (or mantle drag – flowing mantle carrying the plate above along), slab pull and ridge push (both described above).
- Between the 1970s and the 1990s, mantle convection was thought to be the main plate-driving force and many diagrams of plate-driving models still show this to be the main mechanism.
- With today's understanding that slab pull is the main plate-driving mechanism, these diagrams of plate driving models need to be corrected by removing the mantle convection arrows and replacing them with arrows showing the processes of slab pull, ridge push and rising mantle plumes.

Thinking skill development:
Producing an abstract model to show a process is a construction activity. Criticising the model involves more construction and cognitive conflict. Matching the model to reality involves bridging skills.

Resource list:
- (optional) textbook and other diagrams showing plate-driving mechanisms, some correct and some 'really wrong'

Useful links:
A model of plate movement connected with flows in the solid mantle can be seen at: http://www.en.uni-muenchen.de/news/newsarchiv/2018/bunge_amnh.html – where colder areas are shown in blue and warmer areas in red.
Try the 'What drives the plates' Earthlearningidea: https://www.earthlearningidea.com/PDF/217_Slab_pull.pdf to reinforce the idea that slab pull is the main plate-driving mechanism.

Source: Chris King of the Earthlearningidea Team.