Student Worksheet: What drives plate tectonics?

POSSIBLE DRIVING MECHANISMS FOR PLATE MOTION

Mantle convection: Convection is driven by heat from the core and involves either the whole mantle or convections cells within the plastic asthenosphere. The upwelling in the convection cells occurs under the Earth's divergent plate boundaries, and cooler material sinks at the convergent boundaries. The lithosphere plates are dragged along by the horizontal flow of the asthenosphere like a conveyor belt.

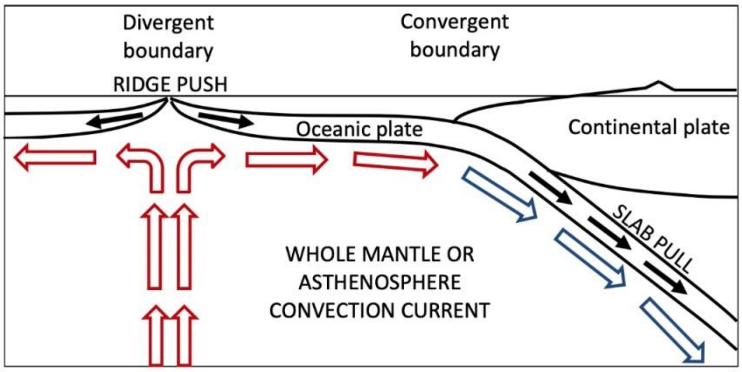


Diagram showing mantle convection, ridge push and slab pull mechanisms

Ridge push: Hot buoyant mantle lifts and pushes the plates apart at mid-ocean ridges where magma solidifies to form new oceanic lithosphere. Gravity pulls the oceanic plates downhill from the ridges towards the deep ocean trenches (or downhill from uplifted continental rift zones like the East African Rift).

Slab pull: Relatively cool and dense oceanic plates (slabs) have negative buoyancy after subducting at ocean trenches and sink into the ductile, less dense asthenosphere, pulling the rest of the tectonic plate along behind it.

Empirical tests (based on observations only) to determine the dominant driving mechanism:

Mantle convection: plate speed should not be related to plate boundary types, and plate speeds should be similar either side of divergent boundaries if convection is symmetric (as presented in Figure 1).

Ridge push: plate speed should be related to the percentage of its boundary that is divergent.

Slab pull: plate speed should be related to the percentage of its boundary subducting under another plate.

Table 1: The relationship between % of a plate boundary subducting or divergent and its speed.

TECTONIC PLATE	AREA (km^2)*	Boundary (km)	Boundary subducting (km)	**% subducting**	Boundary divergent (km)	**% divergent**	**Average speed cm/yr**	Direction
Pacific	103,300,000	46,456	16,311	**35.1**	15,110	**32.5**	**7.5**	WNW
North American	75,900,000	33,670	810	**2.4**	11,740	**34.9**	**1.5**	NW–-SW
Eurasian	67,800,000	44,150	1,990	**4.5**	10,630	**24.1**	**2.9**	NE–SW
African	61,300,000	40,560	1,960	**4.8**	20,790	**51.3**	**2.7**	NE
Antarctic	60,900,000	39,600	2,170	**5.5**	20,540	**51.9**	**1.0**	S–N
Australian	47,000,000	36,365	7,310	**20.1**	14,490	**39.8**	**6.5**	NNE
South American	43,600,000	33,380	1,890	**5.7**	8,660	**25.9**	**1.3**	N
Somali	16,700,000	20,410	0	**0.0**	11,820	**57.9**	**2.9**	NE
Nazca	15,600,000	19,300	6,500	**33.7**	7,480	**38.8**	**6.7**	E
Indian	11,900,000	17,010	1,490	**8.8**	3,530	**20.8**	**5.4**	NE
Philippine	5,500,000	11,260	4,300	**38.2**	2,223	**19.7**	**6.8**	WNW
Arabian	5,000,000	10,530	730	**6.9**	3,350	**31.8**	**4.3**	NE
Caribbean	3,300,000	9,070	0	**0.0**	130	**1.4**	**2.1**	NE
Cocos	2,900,000	7,920	2,790	**35.2**	3,980	**50.3**	**8.9**	NNE

Data Sources:

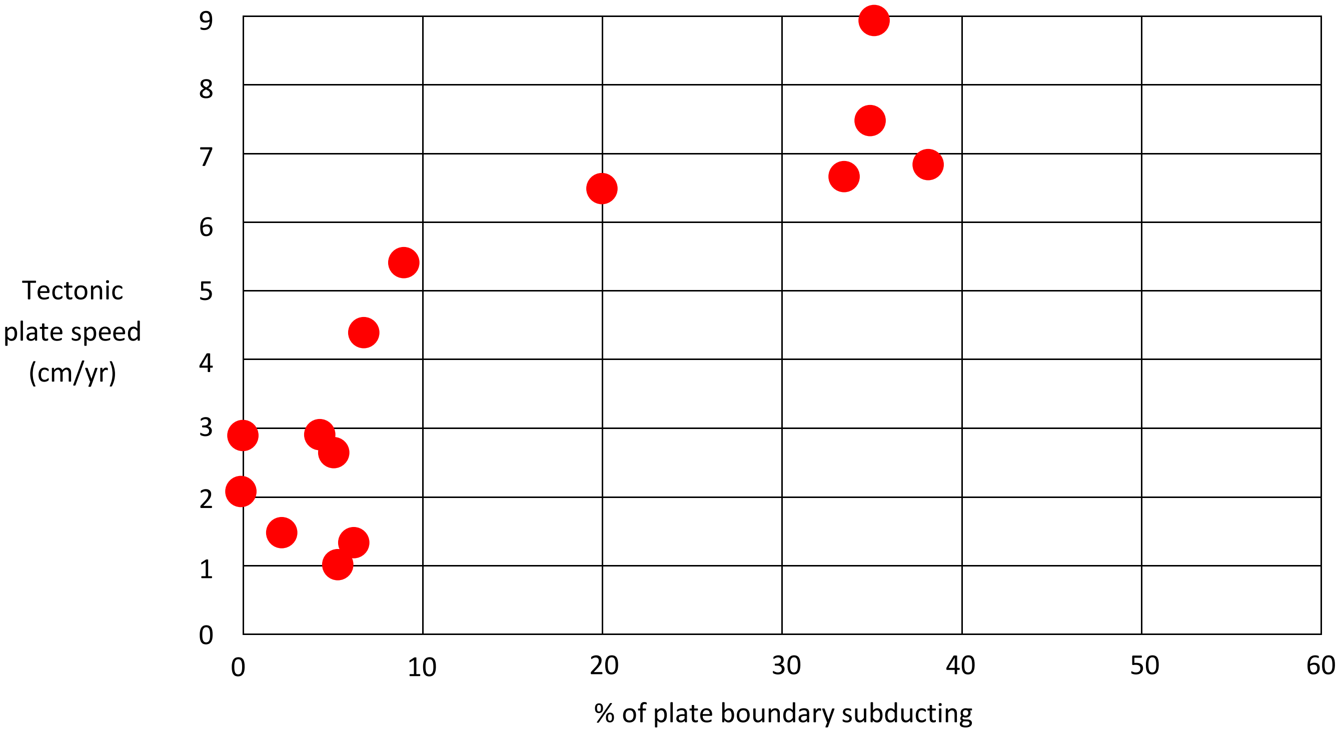
Plate names and areas from https://www.thoughtco.com/sizes-of-tectonic-or-lithospheric-plates-4090143 Accessed 12/07/17

*Plate boundaries, % subducting and % divergent were measured on **Google Earth** using plate boundaries defined by the USGS*

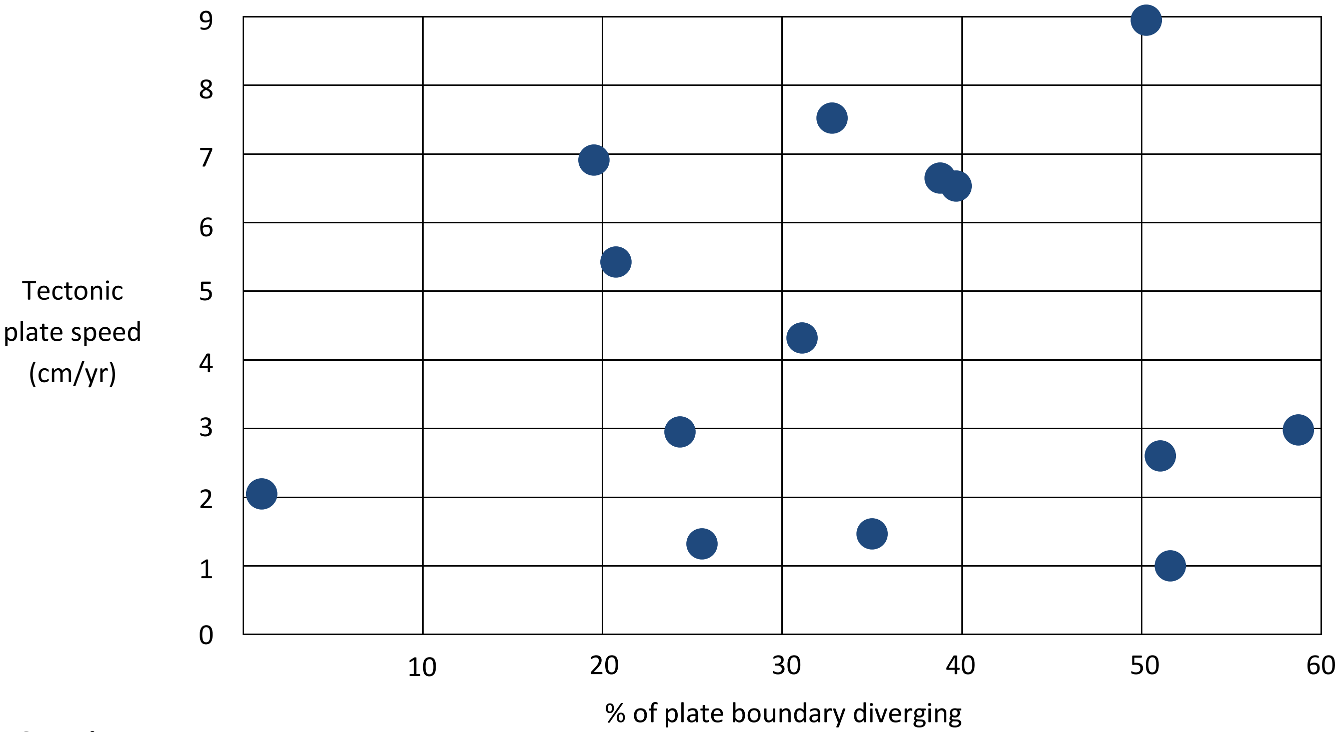
Plate speeds and directions based on average movement of GPS stations within each plate from http://sideshow.jpl.nasa.gov/post/series.html Accessed 26/04/13

Plot the data on the graphs below.

Tectonic plate speed and percentage of boundary subducting



Tectonic plate speed and percentage of boundary diverging



Questions:

1. Based on this data and the empirical tests, what is the dominant driving mechanism for plate motion? Explain your answer by referring to the graphs.

The top graph shows that plate speed is strongly correlated with the percentage of the plate that is subducting under another plate, so the dominant driving mechanism for plate motion must be slab pull. The bottom graph shows that there is no relationship between the percentage of boundary diverging and plate speed, so ridge push is not a dominant mechanism. Also, plates on either side of divergent boundaries have speeds that vary widely, so symmetric mantle convection is not a dominant mechanism.

2. Copy the data from Table 1 into an Excel or similar spreadsheet, and determine the correlation coefficients between: **% subducting** and **average plate speed** 0.89 (strong positive correlation)

% divergent and **average plate speed** 0.06 (no correlation)

Student Worksheet: Density of Lithosphere and Mantle Rocks Experiment

Aim: To determine the role of rock density and buoyancy in tectonic plate motion.

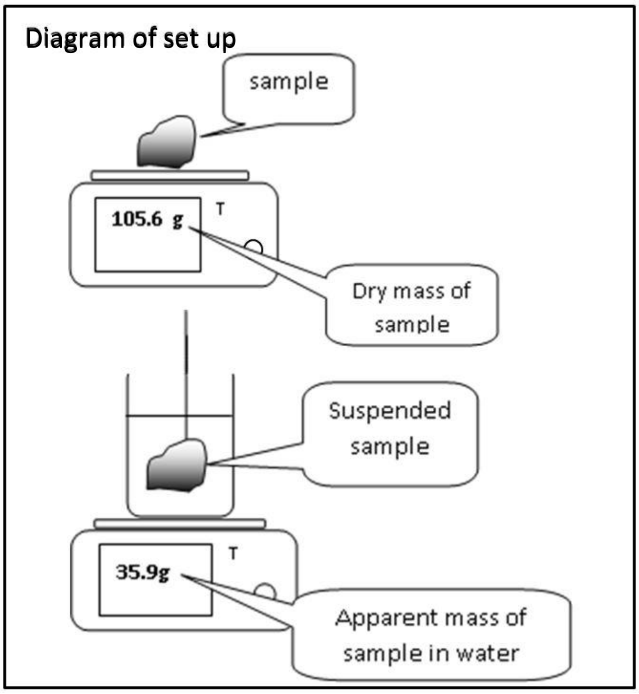
Materials: Rock samples (basalt, gabbro, blueschist, eclogite, andesite, granite, peridotite, serpentinite), scales (+/- 0.1 g), cotton thread, 500 mL beaker or plastic container, tap water, retort stand, boss head, clamp

Method:

1. A dry rock sample was placed on the scales and the mass recorded.
2. A length of cotton was securely tied to the rock.
3. The retort stand, boss head and clamp were set up so that the rock sample could be suspended from the clamp.
4. A half-full beaker of water was placed on the scales and the scales were zeroed.
5. The rock was suspended and wholly immersed in the water and the mass recorded (this mass will be equal to the volume of the displaced water in cm^3 because the density of fresh water = 1 g/cm^3).
6. The density was calculated using the formula:

Density (in g/cm^3) = $\frac{\textbf{mass}}{\textbf{volume}} = \frac{\textbf{dry mass in air (g)}}{\textbf{volume of rock (cm}^3\textbf{)}}$

7. The rock densities were plotted on the cross-section of a subduction zone (following page).



Results: **(TYPICAL)**

Rock type	Location	Dry mass in air (g)	Mass in water (g) = volume (cm^3)	Density (g/cm^3)
basalt	oceanic crust (upper 0.5 km)	**188.0**	**64.5**	**2.91**
gabbro	oceanic crust (0.5-10 km)	**105.6**	**35.9**	**2.94**
blueschist	subducting oceanic crust	**182.1**	**59.1**	**3.08**
eclogite	subducting oceanic crust	**185.9**	**54.1**	**3.44**
andesite	continental crust (volcanic arc)	**117.1**	**43.0**	**2.72**
granite	continental crust	**154.3**	**58.0**	**2.66**
peridotite	upper mantle (lithosphere + asthenosphere)	**310.9**	**95.6**	**3.25**
serpentinite	hydrated mantle	**102.8**	**39.2**	**2.62**

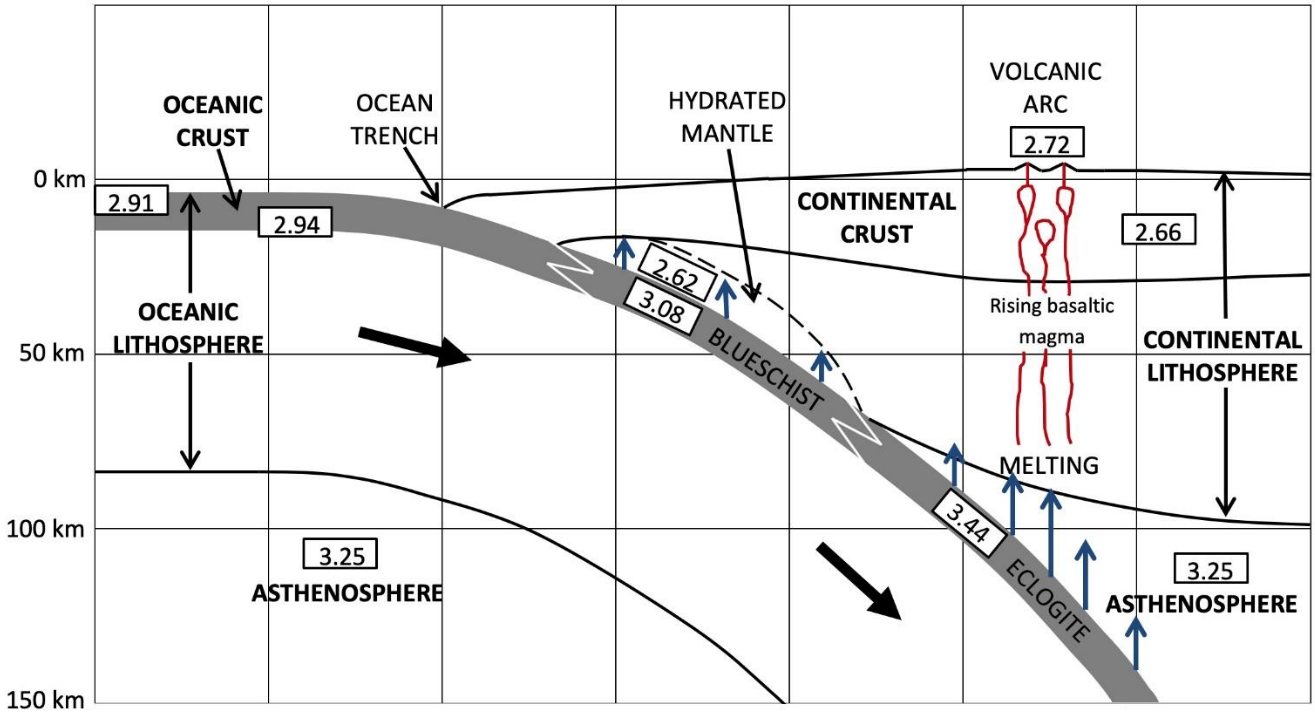


Figure 7: Cross section of a subduction zone with measured rock densities in g/cm³

Questions:

1. Classify the eight rocks in this experiment as:

Volcanic igneous basalt, andesite

Plutonic igneous gabbro, granite, peridotite

Metamorphic blueschist, eclogite, serpentinite

2. Why does continental lithosphere float higher on the asthenosphere that oceanic lithosphere?

Because continental lithosphere is less dense, due to the low density continental crust (2.6-2.8 g/cm³) also being much thicker (30km) than the oceanic crust (2.9-3.0 g/cm³, 7-10km). So continental lithosphere has stronger positive buoyancy than the oceanic lithosphere. (The rigid upper mantle in the lower part of the continental and oceanic lithosphere is similar density.)

3. Explain why the metamorphism of basalt and gabbro to blueschist and then to eclogite is a possible cause for subducted plates being pulled down into the mantle (slab pull).

The metamorphism of basalt and gabbro to blueschist and then to eclogite causes its density to increase from 2.9 g/cm³ to 3.1 g/cm³ and then to 3.4 g/cm³. This causes the descending plate to be denser than the asthenosphere (3.2-3.3 g/cm³), so that it has negative buoyancy. So the subducting plate sinks into the asthenosphere pulling the rest of the plate along with it.

4. The metamorphism of blueschist to eclogite as the oceanic plate descends also releases a large amount of water. This water lowers the melting point of mantle peridotite causing the generation of mafic or basaltic magma (called flux melting). Why are volcanic arc eruptions often immense explosions of ash and pumice?

The lower pressure near the surface causes the water in the magma to become a gas and expand rapidly.

Conclusion:

The metamorphism of oceanic crust to eclogite causes its density to become greater than the peridotite of the asthenosphere, causing the oceanic lithosphere to be negatively buoyant and to pull the whole plate towards the subduction zone and down into the mantle (the slab pull mechanism).