Clarification of the Processes that Shape Earth - Modified Benchmark

Modified Benchmark: The outer portion of Earth—including both the continents and the seafloor beneath the oceans—consists of huge plates of solid rock. The plates move very slowly (a few centimeters per year). Plate movement causes abutting plates to interact with one another. Interactions between plates result in events and features that are observable on Earth's surface (e.g., earthquakes, volcanoes and mountain ranges); these typically occur along boundaries between plates.

† **Denotes sub-ideas considered part of the student domain.**

Sub Idea	Sub-Ideas within the Benchmark	Related Prior Conceptions
A†	1. The solid outer portion of Earth consists of separate plates of almost entirely solid rock. 1.1. Plates abut other plates on all sides. There are no visible gaps between plates that are adjacent to each other. 1.2. The upper portions of some of Earth's plates contain the continents and the seafloor beneath the oceans. 1.3. Some plates do not include continental material but only the seafloor beneath the oceans, or portions of the seafloor beneath the oceans. 1.4. There are roughly 20 *major* plates. Major plates are larger than continents; each one can be thousands of kilometers across. Plates average 100 km thick.	▪ The use of the word "plates" may create an image of "stacked plates" in a kitchen cabinet. ▪ The plates are under the oceans, but do not include the continents. ▪ Continents have no relationship to the plates. ▪ A continent is a plate, or plates are the same shape as the continents. ▪ The plates are somehow "down there" – not really related to Earth's surface.
B	Earth's plates (the lithosphere or lithospheric plate) are cold (relative to deeper portions of Earth), strong and brittle and average about 100 kilometers in thickness. Beneath the lithosphere is a layer of Earth (the asthenosphere) which is hot, weak and plastic and extends from the base of the lithosphere to a depth of about 350 kilometers.	
C†	2. The plates that make up Earth's surface are not static, but are quite dynamic. 2.1. All of Earth's plates move very slowly (a few centimeters per year). 2.1.1. Since the continents are a part of the plates, they move only as the plate moves. 2.2. A plate's size and/or shape can be changed over time. 2.2.1. An individual plate (and its continent if present) may split apart into two separate plates (and two separate continents) by forces from within Earth (South America and Africa	▪ Continents move by somehow floating across oceans. ▪ The continents float around on something – molten rock or water – like very large ships. ▪ All plates move in the same direction and at the same speed. ▪ Plate motion cannot be measured because it is so slow. ▪ If plates are moving apart two centimeters per year, that distance is so insignificant that it could never be noticed. ▪ Since the supercontinent Pangaea split up ~200 million years ago, the continents have remained in essentially the same positions.

	were once part of the same plate, but were split apart [splitting is the explanation for the matching coastlines]); two plates with continents on each are sometimes pushed together and fused to form a larger plate (and larger continent). (India and Asia were at one time on separate plates but were fused together.) 2.3. The speed or direction of plate motion can change over time.	▪ Earthquakes caused Pangaea to break apart. ▪ The fact that the east coast of South America and west coast of Africa have shapes that would fit together like a jigsaw puzzle is just a coincidence. ▪ Continents (and plates) can never join together. ▪ Continents (and plates) cannot split and become smaller. ▪ It is impossible for the continents to have been parts of one large continent in the past. ▪ Plates are the same size and shape now as they've always been. ▪ When plates move toward one another, they fill a gap that once existed between the two plates. ▪ When plates move away from one another, a space between the two is created.
D	Plate motions are driven by a combination of Earth's heat and gravitational forces. The consensus among geologists is that "slab pull," the sinking of oceanic plates at subduction zones (because that rock is old and relatively cold (dense)) is the primary driving force behind plate tectonics. Ridge push (the pushing forces exerted by elevated and relatively hot rock at mid-ocean ridges) is minor as is the traction along the bottoms of plates due to convection in the mantle.	
E	Since the supercontinent Pangaea split up about 200 million years ago, the shapes of continents have been somewhat modified by erosion, sea level changes, mountain-building, etc.; this is why the present-day "fit" of the continents is less than perfect.	
F†	3. Plate motion causes abutting plates to interact with one another along their boundaries resulting in observable geologic features and events. 3.1. Prominent and distinctive *features* on Earth's surface include volcanoes, mountain ranges (volcanic & non-volcanic), deep ocean trenches, and mid-ocean ridges. 3.2. *Events* are significant occurrences or happenings at a given place and time, such as earthquakes, volcanic eruptions, and mountain building. 3.3. These geological features and events are most common at, or close to, the boundaries between two plates. 3.3.1. Volcanoes, mountain ranges, and earthquakes can also occur in areas that are not near plate boundaries. (The specific events and features that result from the different types of plate interactions are detailed in Table 1.)	▪ The plates move, but they have no effect on one another. ▪ There is no way to determine the location of boundaries between plates. ▪ The plates move so slowly that their interactions are insignificant. ▪ Erosion is the only process that alters the appearance of Earth. ▪ All changes to Earth's surface occur suddenly and rapidly. ▪ All events that affect Earth are gradual or slow. ▪ All Earth processes operate at the same rate (on the same time-scale.) ▪ All changes to Earth occur so slowly that they cannot be detected during a human lifetime. ▪ Earthquakes, volcanoes, and mountain formation usually occur in the same general areas, but there is no explanation for this. ▪ Volcanoes and earthquakes always occur at or near plate boundaries. They cannot occur in the interior of plates. ▪ When two plates come together, mountains always form. ▪ Earthquakes are caused by plates crashing into each other. The

		bigger the crash, the bigger the earthquake. ▪ Mountains form when earthquakes push the ground up.
G	The occurrence of features and/or events at locations distant from plate boundaries are for reasons other than plate interactions (the presence of a hot spot in the mantle has resulted in the formation of the Hawaiian Islands (a series of volcanic islands that are not close to a plate boundary.))	
H†	4. The rock that makes up plates is slowly but steadily being recycled along plate boundaries. 4.1. New rock is added to the edges of plates that are moving away from one another. 4.2. Old rock goes back into Earth's interior in places where one plate goes beneath another plate. (The specifics of what, where, and how rock are being recycled are detailed in Table 2.) 4.3. Although plate material is created in some places and consumed in other places, the overall size of Earth remains unchanged.	▪ All rock on Earth is the same age. ▪ New rock is added to plates primarily from the top when volcanoes spew out molten rock that solidifies into new rock on the surface of the plate. ▪ The subduction of plates means that Earth is becoming smaller. ▪ The continual formation of new rocks that are under the ocean (ocean floor) means that Earth must be getting larger.
I	An oceanic plate is always subducted beneath a plate with a continent along its boundary. Continental plate material is not subducted because of its low density. When two separate continents are pushed together, the continental material is forced upward to form mountain ranges rather than being subducted into Earth's interior.	
J	Old ocean floor rocks return by subduction into Earth's interior. Hence, ocean floor rocks are relatively young. Most continental rocks stay at Earth's surface because of their low density (although sediment eroded from the continents is carried to the oceans and can be subducted along with oceanic lithosphere). Hence, the age of some continental rock is quite old.	

Table 1
Relative Plate Motion/Plate Interactions of Two Abutting Plates

	Plates moving away from one another	Plates Moving Toward One Another		Plates moving alongside one another	Implication
		With no continents or a continent on only 1 of the plates	With continents on both plates		
Events*					The unique combination of features & events provides evidence of certain types of plate interactions in a given area.
Earthquakes**	**X**	**X**	**X**	**X**	
Volcanic eruptions**	**X**	**X**	**[1]**		
Mountain building	**X (volcanic)**	**X (volcanic)**	**X (non-volcanic)**		
Features*					
Volcanoes	**X**	**X**			
Volcanic mountain range (on land or a series of volcanic islands[2])	*****	**X**			
Mid-ocean ridge	**X**				
Non-volcanic mountain range			**X**		
[Rifts/rift valleys]	**X**				
[Deep sea trench]		**X**			
[Faults/Fault lines]	**X**	**X**	**X**	**X**	

[Teacher ideas are in brackets.]

* Events/features not included in these lists are not a direct result of plate interactions.

** Volcanoes and earthquakes are associated with one another (found in the same areas) because they are caused by some types of plate interactions. Earthquakes don't cause volcanoes, and, for the most part, volcanoes don't cause earthquakes. [Earthquakes can indicate volcanic activity. A volcanic eruption (especially violent eruptions) can lead to earthquakes, although not major earthquakes.]

***** A cell that is blank in this table means that this event/feature is not typically found along that type of boundary. A few exceptions exist.

[[1] As two continents are pushed together, some limited amount of molten rock can be formed, but such formation rarely results in volcanoes or volcanic eruptions.]

[[2] Examples are Japan and other island arcs that formed by volcanic activity. The Hawaiian Islands are not an island arc – they are volcanic, but they are not near a plate boundary. Instead, they formed over a hot spot under the Pacific plate.]

Table 2
The Recycling of Plate Material (Rock) Along Plate Boundaries

Recycling	Plates moving away from one another	Plates Moving Toward One Another		Plates moving alongside one another	Implication
		With no continents or a continent on only 1 of the plates	With continents on both plates		
New material (rock) from Earth's interior is added to both plates along their shared boundary (edge).	**X**				Plate material is added to some plates and removed from others → Earth's size remains constant.
Plate material (rock) that is sliding beneath another plate is removed from Earth's surface and becomes part of Earth's interior.		**X**			
Plate material usually is not recycled. Instead, the rock that makes up the continents is pushed together and forced upward to form mountains; the plates may fuse and form a larger plate.			**X**		