Name: _____ _____
First Name *Last Name*

Name: _____ _____
First Name *Last Name*

School: _____ Team Number: _____
Full School Name, No Abbreviations

DYNAMIC PLANET

TECTONICS

Pembroke Hill Invitational
January 6, 2018

EXAM BOOKLET

INSTRUCTIONS

- By marking your name(s) on the lines above and on your Answer Sheet, **you are agreeing to the Science Olympiad Code of Ethics Students' Pledge**: "[I/We] will compete with integrity, respect, and sportsmanship towards my fellow competitors. [I/We] will display courtesy towards Event Supervisors and Tournament Personnel." The Dynamic Planet Event Supervisor can deduct points from a team's final score at their discretion if the team fails to uphold the Student's Pledge.

- You are only allowed to use a calculator and four 8.5" x 11" sheets of notes during the exam. All other materials are prohibited. **No phones allowed.** You can use either pencil or blue or black pen to complete the exam.

- An illegible response will be an incorrect response. Thus, **write neatly**.

- Be sure you have **thirteen pages in the Exam Booklet** and **four pages in the Answer Sheet**. If you do not have all of the pages in the Exam or Answer Sheet, alert the Event Supervisor immediately.

- The Event Supervisor will **not** answer questions regarding the content of the exam.

FORMAT

- **The exam is 75 points** and consists of six sections: Geologic Timeline (5 points), Quantitative Reasoning (5 points), Definitions (15 points), Multiple Choice (25 points), Diagram Creation (5 points), and Case Studies (20 points). All questions on the exam are weighted equally.

- You will have **50 minutes to complete the entire exam**. You can pace yourself and divide the exam however you choose. (Hint: The questions are *not* arranged by difficulty level.)

- Ties will first be broken by the highest score on the Multiple Choice section, followed by the highest score on the Case Studies section, followed by the highest score on the Definitions section, followed by the highest score on the Quantitative Reasoning section.

Exam by:
Jeffrey Rubel (Pembroke Hill '13, Williams College '17)

SECTION 1: GEOLOGIC TIMELINE

5 Questions, 5 Points

Directions: *Complete the geologic timeline below with the appropriate time periods. The timeline progresses from the bottom of the page to the top. Record your answers on your Answer Sheet in the blanks corresponding to the questions.*

EON	ERA	PERIOD
**** Question 1 ****	Cenozoic	Quaternary
		Neogene
		**** Question 4 ****
	**** Question 2 ****	Cretaceous
		Jurassic
		Triassic
	Paleozoic	Permian
		Pennsylvanian
		Mississippian
		Devonian
		Silurian
		**** Question 5 ****
		Cambrian
Proterozoic	Neoproterozoic	
	Mesoproterozoic	
	**** Question 3 ****	
Archean	Neoarchean	
	Mesoarchean	
	Paleoarchean	
	Eoarchean	
Hadean		

• CONTINUE TO SECTION 2 •

SECTION 2: QUANTITATIVE REASONING

5 Questions, 5 Points

Directions: *Answer each question in this section with a decimal rounded to the nearest tenth of a degree. Report all answers as decimals. Write your final answer on the Answer Sheet. Use this page for any scratch work. No partial credit will be given.*

1. The rate of isostatic rebound in parts of Great Britain is 10 cm per century.[1] Assuming (incorrectly) that the rebound occurs linearly, how many centimeters will the land in Great Britain rise in next three years? Report your answer in centimeters.

2. A stratigraphic bed in an outcrop has a true dip amount and direction of 40º N. The surface of the ground is flat and level, and the distance between the upper and lower exposed contacts of the bed is 200 meters. What is the true thickness of the bed? Report your answer in meters, rounded to the nearest whole number.

3. During an orogeny, a pebble is stretched from an original length of 15 cm to a new length of 18 cm. This stretching occurs in the horizontal direction. There is no vertical change. Calculate the normal strain on the pebble. Report your answer in centimeters.

4. When a volcano erupts, 60% of the total gaseous emissions are water, and 25% of the total gaseous emissions are carbon dioxide.[2] If a volcano releases 12 cubic kilometers of water in an eruption, how much carbon dioxide did the volcano release in the same eruption? Report your answer in cubic kilometers.

5. This year, an earthquake hit the town of Saxby with a magnitude of 8 (as measured on the Richter scale). Last year, the town was hit by a magnitude 5 earthquake. How much bigger is this year's earthquake compared to last year's?

• CONTINUE TO SECTION 3 •

[1] Gray, Louise. "England is sinking while Scotland rises above sea levels, according to new study." *Telegraph*. 7 October 2009.
[2] Technically, carbon dioxide emissions from a volcano can range from 10-40% according to Sirgurdsson et al. 2000 – but let's not get stuck on the details.

SECTION 3: DEFINITIONS

15 Questions, 15 Points

Directions: *For each of the definitions below, write the correct word or phrase on the corresponding blank of your Answer Sheet.*

1. The scientist who proposed the theory of continental drift in 1915; this scientist was the first person to realize that the Earth's continents moved through time. Be sure to give the *first and last name* of this scientist.

2. The scientist who, in partnership with Bruce Heezen, created the first scientific map of the Atlantic Ocean floor, revealing the presence of the mid-ocean ridge. Be sure to give the *first and last name* of this scientist.

3. This is another name for the North American Craton; the igneous/metamorphic basement complex of this craton was formed 1.0 to 1.5 billion years ago; through accretion, land has been added to this craton to form North America.

4. The mountain range in the United States that formed when the oceanic plate Iapetus began colliding with the North American Craton in the Paleozoic (~450 Ma), creating an active plate boundary; subsequent collisions throughout the Paleozoic continued to build this mountain range.

5. This volcanic hotspot is one of only a few underlying the United States; in the past, this hotspot formed the Snake River Plain and led to large-scale volcanism in Oregon, Nevada, Idaho, and Wyoming.

6. This type of landform is a depression formed by the downward displacement of a section of crust between two nearly parallel fault lines.

7. The measurement of land elevation and land features relative to sea level (the underwater equivalent of this term is bathymetry).

8. A fragment of crustal material formed on, or broken off from, one tectonic plate and accreted onto another plate.

9. Term used to describe the cyclic opening and closing of ocean basins due to the movement of the Earth's plates.

10. Magma or molten rock that has reached the surface of the Earth.

11. This layer of the Earth's crust extends from around 100 km to 700 km below the Earth's surface; heat from within the Earth keeps this layer malleable, lubricating tectonic plates and allowing them to move.

12. This layer of the Earth is between the crust and the outer core; it composes ~85% of the Earth's volume, and it is made primarily of silicate rock rich in magnesium and iron.

13. The type of crust that is composed primarily of granite and other felsic rocks; this type of crust is thicker and less dense than the other type of crust.

14. When two plates collide with each other or come together, the boundary between the two plates is known as this type of boundary.

15. Pieces of the Earth's crust that "float" on the asthenosphere and make up the lithosphere.

• CONTINUE TO SECTION 4 •

SECTION 4: MULTIPLE CHOICE

25 Questions, 25 Points

Directions: *For each of the following questions, select the best possible answer from the choices provided. Mark the corresponding letter on your Answer Sheet. Be sure to use capital letters (e.g., A, B, etc.).*

1. In which of the following regions would you expect to find the thickest sequence of sedimentary rocks?
   (A) On continental platforms
   (B) Along mid-ocean ridges
   (C) In the middle of an ocean basin (away from a ridge)
   (D) On continental shelves
   (E) All of the above would have equally thick sedimentary sequences

2. How would the formation of a supercontinent affect global sea level?
   (A) Lead to an increase in sea level
   (B) Lead to a decrease in sea level
   (C) Lead to more local variations in relative sea level
   (D) Have no effect on sea level
   (E) Create greater millennial-scale sea level variability

3. Continent-continent convergence is associated with:
   I. Compressive stresses
   II. Basaltic magmas
   III. Intermediate depth earthquakes
   (A) I and II only
   (B) II and III only
   (C) I and III only
   (D) I, II, and III
   (E) None of the above

4. Which of the following situations is most likely to undergo mass wasting?
   (A) A dry, moderate slope of unconsolidated sediment
   (B) A wet, moderate slope of unconsolidated sediment
   (C) A dry, steep slope of unconsolidated sediment
   (D) A wet, steep slope of unconsolidated sediment
   (E) All of the above are equally likely to undergo mass wasting

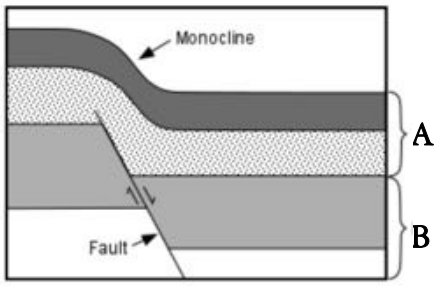
5. The following step(s) is/are important in the conversion of organic material into petroleum:
   I. Burial and sediment deposition
   II. Heat and pressure
   III. Magma and lava formation
   (A) I and II only
   (B) II and III only
   (C) I and III only
   (D) I, II, and III
   (E) None of the above

6. The removal of the dense root of a mountain can happen because of convection in the asthenosphere. What happens after this root is removed?
   (A) The mountain shrinks due to continued convection
   (B) Often, the mountain turns into a volcano
   (C) Earthquakes propagate through the continent
   (D) Isostatic rebound leads to more mountain building
   (E) More than one of the above

7. As lithospheric plates move away from the mid-ocean ridge, they become:
   (A) Thinner and less dense
   (B) Thicker and less dense
   (C) Thinner and more dense
   (D) Thicker and more dense
   (E) Rainbows and unicorns

8. Which of the following is **not** a cause of mountain building?
   (A) Rifting
   (B) Convergence at convergent plate boundaries
   (C) Continental collisions
   (D) Oceanic and continental crust collisions
   (E) All of the above cause mountain building

9. Which of the following is **not** a primary input of carbon dioxide into the atmosphere?
   (A) Mantle outgassing
   (B) Metamorphism of carbonate rocks
   (C) Respiration of organic matter
   (D) Weathering of silicate rocks
   (E) All of the above are CO_2 inputs



10. In the figure above:
    (A) "A" represents ductile rocks; "B" represents brittle rocks
    (B) "A" represents brittle rocks; "B" represents ductile rocks
    (C) "A" and "B" both represent ductile rocks
    (D) "A" and "B" both represent brittle rocks
    (E) There is not enough information to tell

11. On a visit to Yellowstone National Park, Ben and Laura are hiking when Ben notices the following table on a sign and asks: "Which of the following best describes the Yellowstone magma?" Laura, as a very smart geologist, knows immediately. Which row does she point to?

	SiO_2 content	Fe/Mg content	Temperature
(A)	<50%	<5%	>1100ºC
(B)	<50%	>5%	>1100ºC
(C)	>50%	<5%	>1100ºC
(D)	>50%	>5%	<1100ºC
(E)	>50%	<5%	<1100ºC

(Percentages are percent of total magma mass)

12. Which of the following should be *increased* to melt a rock and create magma?
    I. The temperature
    II. The pressure
    III. The water content
    (A) I and II only
    (B) II and III only
    (C) I and III only
    (D) I, II, and III
    (E) None of the above

13. During the Permo-Triassic mass extinction, atmospheric carbon dioxide levels rose. How did the presence of Pangea contribute to this rise?
    (A) Albedo effect of the planet increased temperatures
    (B) Continental weathering decreased with less coastline
    (C) Rerouting of ocean circulation stopped carbon storage
    (D) All of the above
    (E) None of the above

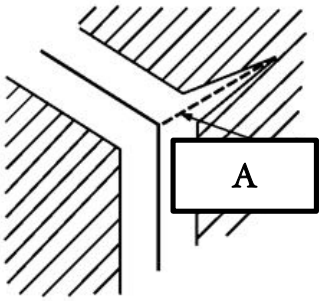
14. Astrobiologists believe plate tectonics is integral to life on a planet. Why?
    (A) Tectonics generate a planet's magnetic field, deflecting solar winds
    (B) Tectonics stabilize a planet's temperature through the carbon cycle
    (C) Tectonics drive global nutrient cycling, providing life-supporting nutrients
    (D) Both (B) and (C) but not (A)
    (E) All of the above are correct

15. Which of the following is **not** evidence for plate tectonics?
    (A) Striped patterns of magnetic reversals in the Earth's crust
    (B) Fossils of the same species on different continents
    (C) Law of superposition with sedimentary rock deposition
    (D) Presence of a mid-ocean ridge
    (E) All of the above are evidence for plate tectonics

16. Why are major earthquakes occurring along subduction zones particularly hazardous?
    (A) They can cause tsunamis
    (B) They can lead to volcanic eruptions
    (C) They can increase rates of seafloor spreading
    (D) They can lead to oil and natural gas leaks
    (E) In the past, they have caused mass extinctions

17. If you were looking for a metallic mineral deposit (e.g., gold, silver), where might you look?
    (A) Within active volcanoes near continental centers
    (B) In earthquake-prone regions of the world
    (C) Beneath extinct volcanoes above subduction zones
    (D) Anywhere along the edge of the continental shelf
    (E) In a jewelry store

18. What is the tectonic setting for a rift basin?
    (A) Within continental lithosphere on cratons
    (B) Extending from the margins towards the interiors of cratons
    (C) Along passive continental margins
    (D) In the abyssal ocean
    (E) On the inner wall of a subduction zone trench



19. What type of sedimentary basin is "A" in the diagram above?
    (A) Oceanic rift basin
    (B) Aulacogen
    (C) Passive margin basin
    (D) Fore-arc basin
    (E) Trench

20. There is a leading hypothesis that the formation of the Isthmus of Panama led to Northern Hemisphere Glaciation. What is the best explanation for this hypothesis?
    (A) The formation of the Isthmus increased North Atlantic Deepwater Formation, which removed heat from the Northern Hemisphere, cooling the climate and leading to ice sheet formation
    (B) The formation of the Isthmus funneled warm water circulation northward, leading to more evaporation and precipitation – and thus ice sheet formation – in the Northern Hemisphere
    (C) The formation of the Isthmus led to the formation of thermohaline circulation in the Atlantic, which led to the temporary formation of an Atlantic El Niño event and, therefore, cooling
    (D) None of the above
    (E) Don't pick (E)

21. Which of the following is/are climatic effect(s) of supercontinents?
    I. Mega-monsoons
    II. Arid deserts in continental interiors
    III. Extreme seasonality
    (A) I only
    (B) II only
    (C) I and II only
    (D) II and III only
    (E) I, II, and III

22. Why are the great American deserts on the east side of the Rocky Mountains?
    (A) Hot, dry air forms on the backside of mountains due to changing wind patterns
    (B) Due to the mountain's geology, erosion off the east side creates sandy, desert soils, which do not hold moisture
    (C) Water in the air rains out on the west side of the mountains, so the air is drier when it makes it to the east side of the mountains
    (D) The roots of the mountains create isostatic adjustment effects that lower the water table on the east side of the mountain range
    (E) None of the above

23. Which of the following will **not** raise global mean sea level?
    (A) Increase in the total length of the mid-ocean ridges
    (B) Biological pump maximization with nutrient changes
    (C) Production of low density ocean crust from high spreading rates
    (D) Emplacement of Large Igneous Provinces
    (E) All of the above raise sea level

24. In the early Oligocene, Antarctic glaciation began. Why?
    (A) Closure of a South Pacific seaway
    (B) Start of the short-lived South Atlantic Deepwater Formation
    (C) Mountain building events in the Himalayas
    (D) Formation of the Antarctic circumpolar current
    (E) Evolution of whales in the Miocene

25. In the Neoproterozoic, the Earth went through phases where it was completely covered by ice and glaciers. This was "Snowball Earth." Which of the following could explain the onset of Snowball Earth?
    I. The break-up of Rodinia
    II. The ice-albedo feedback loop
    III. The orographic precipitation effect
    (A) I and II only
    (B) II and III only
    (C) I and III only
    (D) I, II, and III
    (E) None of the above

• CONTINUE TO SECTION 5 •

SECTION 5: DIAGRAM CREATION

5 Questions, 5 Points

Directions: *For each of the following questions, draw an appropriate image in the corresponding box on your Answer Sheet.*

- *Each question will either ask you to draw a cross-section (view of a vertical slice of the Earth, like at a road cut) or a map view (a bird's eye view of the Earth of the surface/topography of the planet).*
- *Note the compass directions provided with each box to help you orient your drawing. For all the cross sections, north is into the page.*
- *Be sure to label your rock layers with letters. Use "A" for the oldest rock layer and progress up the alphabet (B, C, D, etc.) for progressively younger rock layers.*

1. Map View: There is a syncline with a vertical axial plane and a fold axis that plunges 50º S.

2. Cross Section: There is a normal fault after erosion with a strike directly into the page and a dip of 45º W. The fault cuts through horizontal bedding.

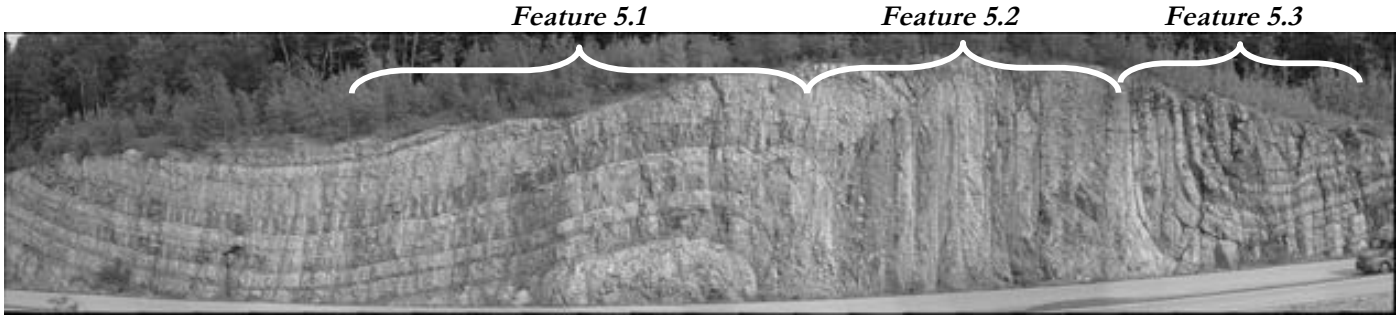
3. Cross Section: There is an anticline with beds on the west limb dipping approximately 30º W and beds on the east limb overturned and dipping 60º W. The anticline has a horizontal fold axis that points into the page.

4. Map View: There is a reverse fault with a strike of 90º (E) and a dip of 75º S that cuts through horizontal bedding.

5. Multiple, Multiple Choice: *Rather than drawing a picture, answer the following question based on the cross section below.*

   The cross section below is from a road cut near the Vermont-Massachusetts border[3] and shows signs of the Taconic Orogeny. There are three distinct sections in the outcrop. For each of these sections, what feature is shown? Choose from the options below, and write the appropriate letter on your Answer Sheet. No partial credit.

   (A) Syncline
   (B) Anticline
   (C) Transform fault
   (D) Reverse fault
   (E) Normal fault
   (F) Horizontal bedding
   (G) Vertical bedding
   (H) Volcanic event



• CONTINUE TO SECTION 6 •

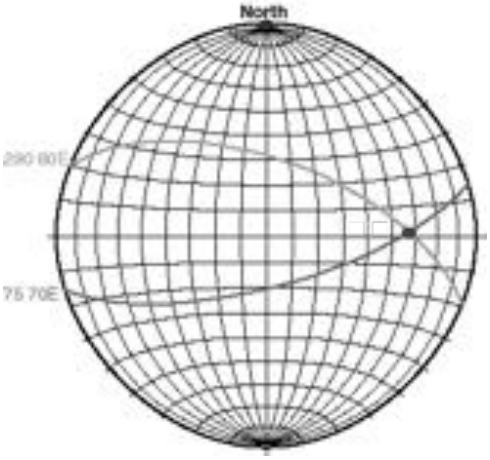
[3] Gigapan image by Paul Karabinos, Williams College.

SECTION 6: CASE STUDIES

20 Questions, 20 Points

Directions: *For each of the figures in this section, answer the accompanying questions. The questions will range in format, though most are multiple choice or single letter choices. Mark your answers in the appropriate blanks on your Answer Sheet.*

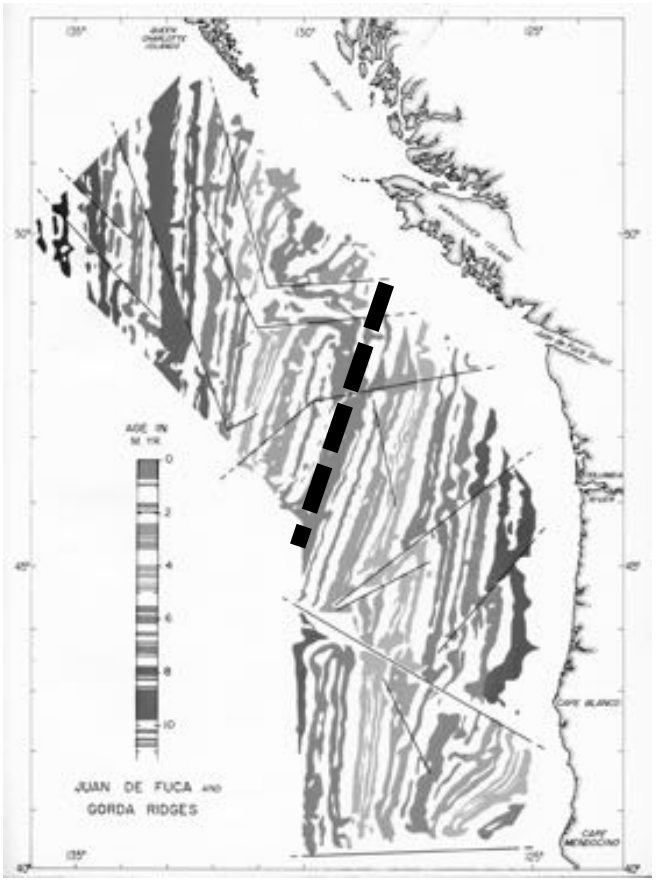
CASE 1: *A structural geologist found two planes in a field across a large fold, and she plotted the bedding planes on this stereonet. Use the following stereonet to answer questions 1 and 2.*



1. What is the trend and plunge of the fold axis?
   (A) 290º, 60º
   (B) 75º, 70º
   (C) 70º, 60º
   (D) 90º, 30º
   (E) 45º, 85º

2. In the second plane (75, 70 E), what does the "70º E" represent?
   (A) Strike
   (B) Dip
   (C) Trend
   (D) Plunge
   (E) 70% is the score I'll get on this exam

CASE 2: *An oceanography team collected a map of magnetic data off the coast of Vancouver Island and Cape Blanco.*[4] *In the map, the magnetic anomalies are gray-scaled by age. The ridge is denoted with a dotted line. Use the following magnetic anomaly map to answer questions 3 and 4.*

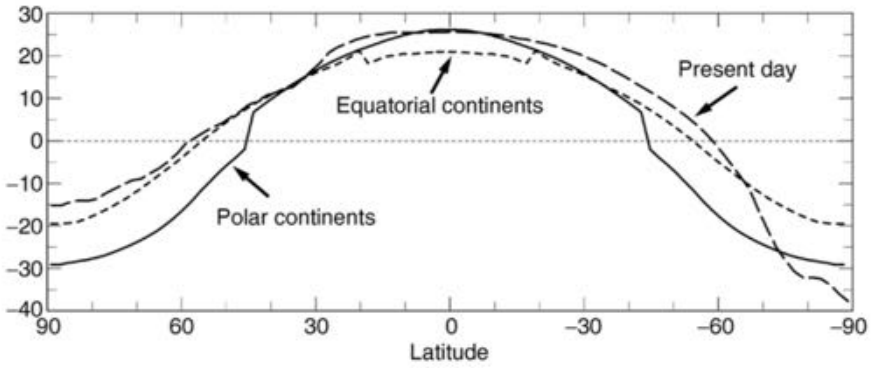


3. A sample of rock collected from the dark gray area would be ___ than a sample collected from the lighter gray area.
   (A) Older
   (B) Younger
   (C) Less magnetic
   (D) More magnetic
   (E) Silly question! They are identical!

4. What is the element in the ocean's crust recording the magnetic anomalies?
   (A) Nickel
   (B) Copper
   (C) Carbon
   (D) Hydrogen
   (E) Iron

[4] This map is from: Vine, F. J., Spreading of the ocean floor: new evidence. *Science*, *154*, 1405-1415, 1966.

CASE 3: *A climate modeler conducts three simulations to see how continent location affects latitudinal temperature differences. The graph below shows her results. The y-axis measures temperature variance, and the x-axis shows latitude. The three lines are labeled with the three simulation conditions: continents clustered at the poles; continents clustered at the equator; present day continental configuration.*[5] *Use the graph to answer questions 5 and 6.*



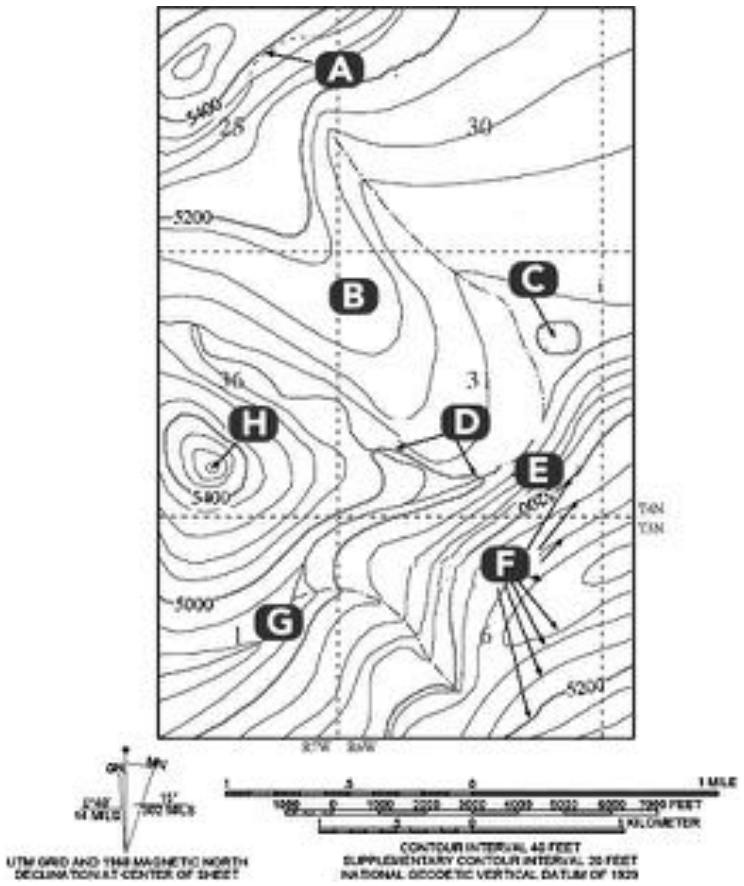
5. Which continental configuration leads to the smallest difference in temperature between the poles and the equator?
   (A) Polar continents
   (B) Equatorial continents
   (C) Present day continents
   (D) All three are equal
   (E) Not enough information to tell

6. A climatologist looks at this graph and says, "I think albedo – at least partially – explains this data." Do you agree?
   (A) Yes, because oceans have a higher albedo than continents
   (B) Yes, because continents have a higher albedo than oceans
   (C) No, because oceans have a higher albedo than continents
   (D) No, because continents have a higher albedo than oceans
   (E) Is albedo even a real word?

CASE 4: *Your friend discovers this topographic map of your neighborhood. He's hoping to use the map to find new, exciting locations for upcoming social gatherings (yay!). But he doesn't know how to read topographic maps, so he's come to you – the Science Olympian – for help. Use the map below to answer questions 7 and 8. Mark the appropriate letter from the map (options A through H) on your Answer Sheet.*

7. Your friend wants to host a bonfire (with s'mores!) on top of the highest hill in the neighborhood. What letter on the map marks the highest hill?

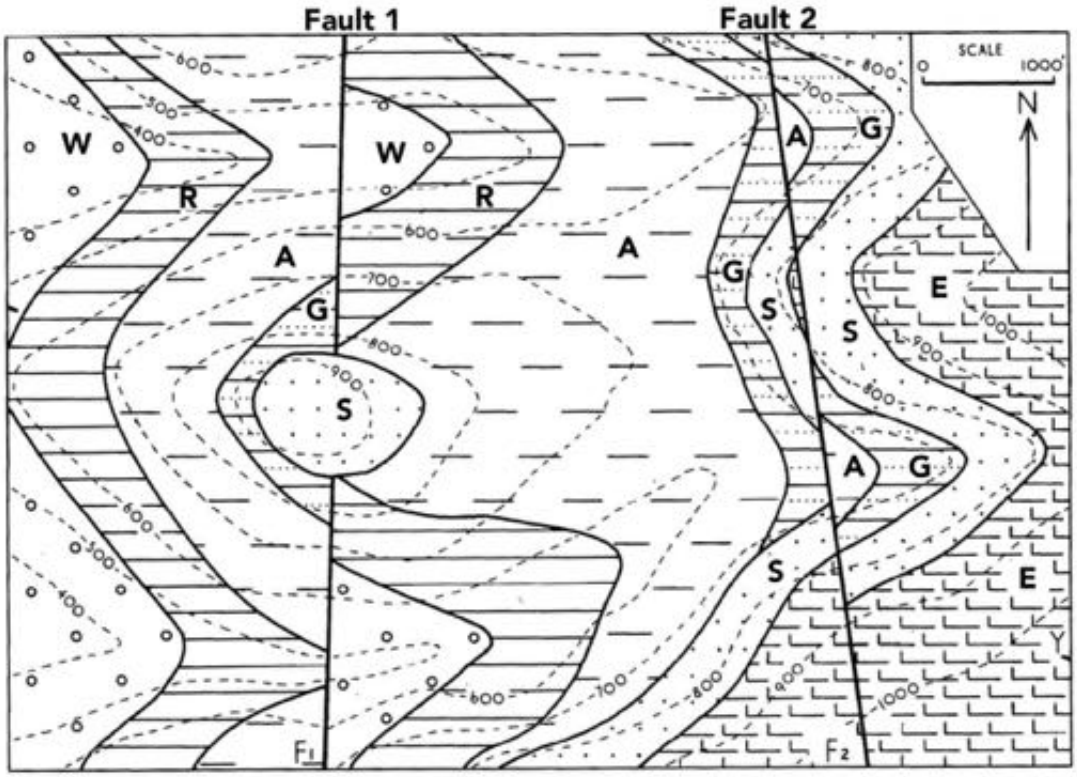
8. Your friend wants to find the best spot for sledding in the winter. In his mind, the best sledding is on the steepest slope. What letter on the map marks the best sledding spot (steepest slope)?



[5] This graph is based on data from studies by Barron et al., 1984 and Hay et al., 1990a. The graph itself is from a textbook chapter by Robert DeConto ("Plate Tectonics and Climate Change"). Study tip: This chapter is great reading for Dynamic Planet!

CASE 5: *You found two maps in the basement of the University of Saxby's Geology Department. The first map shows the geology of Saxby, and the second map shows the geology of the nearby town of Greylock. On the first map, rock units are noted with letters. Use the Map of Saxby to answer questions 9-11, and the Map of Greylock to answer questions 12 and 13.*

Geologic Map of Saxby

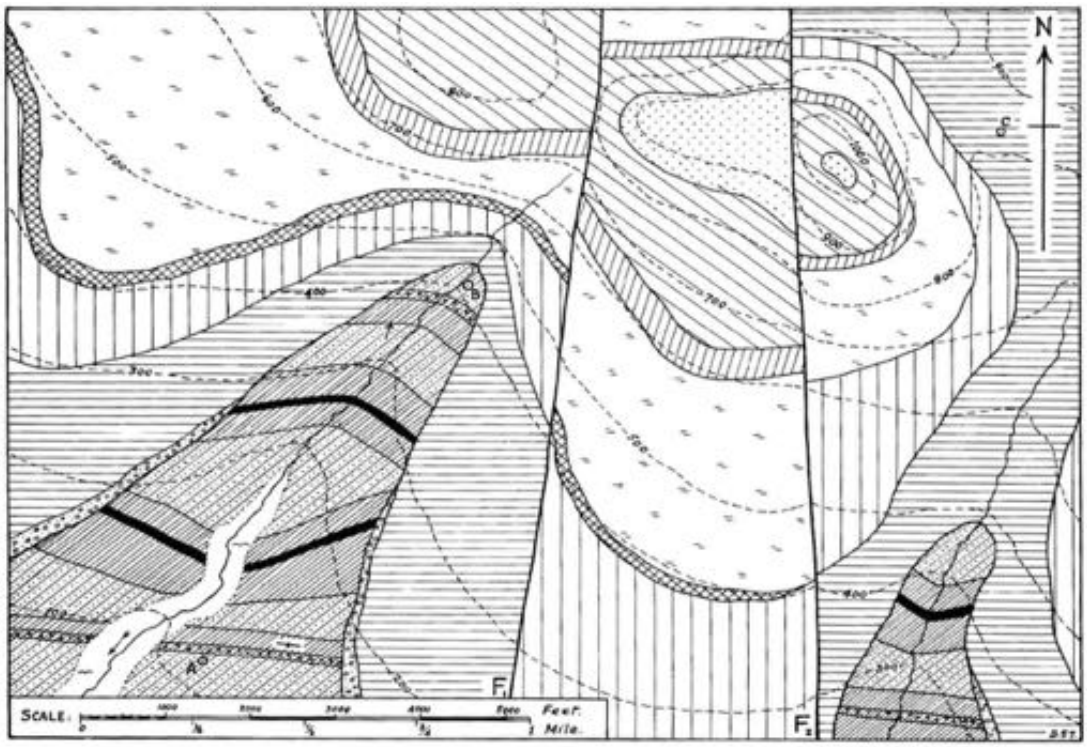


9. What is the youngest lithographic unit in Saxby?

10. Two faults occurred in Saxby. Which fault is older? (If there is not enough information to determine which is older, write "NA" on your Answer Sheet.)

11. Looking at Fault 1, which side of the fault – east or west – was uplifted? (If there is not enough information to tell, write "NA" on your Answer Sheet.)

Geologic Map of Greylock

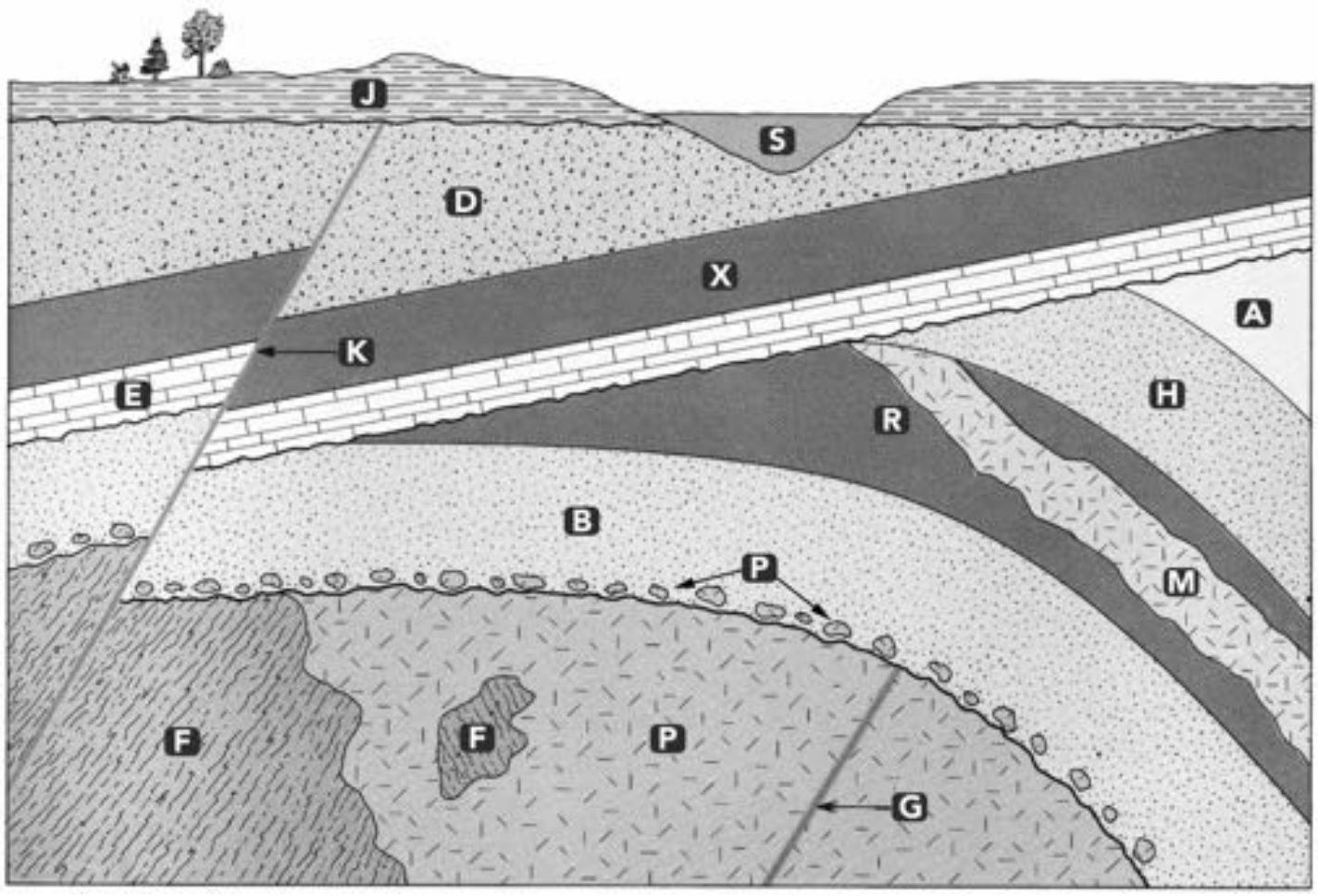


12. What type of fold is shown in the map?

13. Two faults (F1 and F2) occurred in Greylock. Which fault is older? (If there is not enough information to determine which is older, write "NA" on your Answer Sheet.)

CASE 6: *While exploring the basement of the University of Saxby's Geology Department, you found this cross section of rocks in the nearby Pembroke Valley.*[6] *On the cross section, different rock units and structural events are denoted with letters. Use the cross section to answer questions 14-18. For questions 14-16, write the letter of the correct rock unit in the corresponding blank on your Answer Sheet.*

Cross Section of the Pembroke Valley



14. What rock unit was deposited/formed/intruded *after* Unit H?

15. What rock unit is the *oldest* in the cross section?

16. What is the *youngest* intrusive event in the cross section?

17. What type of fault is K?
    (A) Normal fault
    (B) Reverse fault
    (C) Thrust fault
    (D) Strike-slip fault
    (E) It's a fold, not a fault

18. How many unconformities are in the cross section?

[6] The maps and cross section in Cases 5 and 6 are pulled from Structural Geology (GEOS 301) labs at Williams College, taught by Paul Karabinos. In the words of Paul: "If there's one thing you should learn in a geosciences class, it's how to read a map."

CASE 7: *A Science Olympiad test writer, upon nearing the end of the Dynamic Planet exam he was writing, realized that said exam was long and challenging. Thus, in order to offer students some mild form of relief, he decided to include two (hopefully) easy questions at the end of the exam. (You're welcome.)*

19. Who, in partnership with Marie Tharp (pictured), created the first scientific map of the Atlantic Ocean floor, revealing the presence of the mid-ocean ridge?[7]

(A) Alfred Wegener
(B) Bruce Heezen
(C) SueAnn Wright
(D) Harry Hess
(E) Kimberly Cho

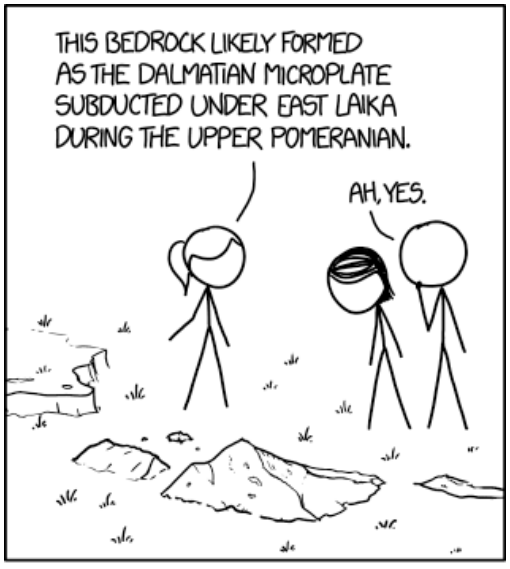
20. Select the geology pun(s).

I. As one tectonic plate slides into another, it says: "It's not my fault. I just couldn't take the pressure!"
II. What's a geologist's favorite breakfast? Pangeacakes.
III. Two rocks sit on a hillside. The little rock looks at the big rock and says: "Sometimes, I take you for granite."

(A) I only
(B) II only
(C) III only
(D) I, II, and III
(E) Puns are a waste of my time.

• • • • •

CONGRATULATIONS!
YOU HAVE COMPLETED THE DYNAMIC PLANET EXAM.



[7] Yes, this actually is a gimme point. Actually, it's two gimme points. ☺