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Michigan's Ride on the North American Plate

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Abstract

The activity examines the evidence for plate tectonic theory from the stratigraphic column, or rock sequence, of Michigan. It uses a series of structured questions asking students to examine the evidence provided to formulate and test their own hypothesis about the movement of the area we now call Michigan over geological time. The activity has been used successfully with students over a number of years.

Background

The basic premise to the theory of plate tectonics is that the position of continents and oceans change over geologic time. As early 1912, Alfred Wegener used the association of rock types and climate zones to support his nascent hypothesis of continental drift. The rock layers preserved on each continent reflect the influence of the latitude/climate zone of the continent at the time they formed, sea level, topography/bathymetry, and concentration of greenhouse gases in the atmosphere. This activity looks at the position of North America over the last 542 Ma (million years) as the continent drifted through different climate zones. The position of the continents is derived from magnetic data stored in basaltic lava flows the day they solidified. Students use paleogeographic maps to estimate latitude and climate zones at several geologic periods. Then, latitudes are matched with the common rock types associated within them. The activity concludes by comparing the stratigraphic column of Michigan to see how the rock record reflects the tectonic path and the climate zones transgressed. This activity is designed to address HSCE Code: E3.r3f Describe how the direction and rate of movement for the North American plate has affected the local climate over the last 600 million years aimed at middle and high school students. The activity was modified for North America, with the permission of co-author Chris King, from The British Isles through Geologic Time from Investigating the Science of the Earth, SoE2: Geological Changes – Earth's structure and plate tectonics (Earth Science Teachers Association, 1996).

Activity

In Step 1 students look at six paleogeograhic maps (Figure 1) and estimate the approximate latitude of Michigan on North America at a specific time in the past. The outline of North America conveniently shows the indentation of Hudson Bay, which is a coastal feature younger than the maps shown. Michigan is about 10 degrees of latitude from Hudson Bay. We found that students are commonly accurate within 5 to 10 degrees on the latitude. Note that being a few degrees off can "bump" the location into an adjacent climate zone but will not greatly change the results of the lesson. The students also use Table 1 to correlate their latitude estimate to a climate zone (equatorial, arid, etc.). We provide an answer key at the end of this article.

In Step 2 students plot their data on a time vs. latitude graph (Figure 2). In general, the six data points define a pattern like a check-mark (see answer key). Students need to plot each of the data points by estimating the time (in millions of years) and latitude (in degrees, north or south). The step concludes with four questions to see if the students show understanding of their graphs. For the last question, students can read the climate zone off the graph. In broadest terms, Michigan has passed through four climate zones in the past (equatorial, arid, Mediterranean, and temperate). The students should note we passed through each of these zones in each hemisphere. In greatest detail, because the continent drifted south in the Devonian, a student could say North America passed through the zones three times (equatorial to temperate, temperate to equatorial, then equatorial to temperate).

In Step 3 students are asked to look closely at the depositional environments associated with specific climate zones (Table 1) and select two environments and associated rocks that form in that climate zone. Of course, the exact rock type that forms is influenced by many factors—especially sea level (think of depositional environments on land versus environments in the ocean), topography (steeply dipping rivers in mountains versus low gradient rivers on the plains or near the ocean), and water depth (shallow marine ecosystems producing abundant fossils versus deeper ocean)—as well as climate. Note that some rock types are almost unique to a particular climate zone (such as coal to equatorial or evaporites to arid) and some are ubiquitous (such as sandstone). To simplify the lesson, we introduce some geology shorthand for rock names: lss for limestone, dolo for dolostone, sh for shale, ss for sandstone. You might write these on the board for students to use during the activity.

In Step 4 students look closely at the Stratigraphic Succession of Michigan (Michigan Department of Conservation, 1964) and rank the common rock types during each geologic period. The Stratigraphic Succession represents the rocks of the state over time. If you lived in the central part of the Lower Peninsula, it represents the rocks under your feet. Outward toward the edge of the Michigan basin, the younger rocks have been eroded away. Getting the abundance of rocks in the exact order is not critical. However, a complete list and some key rock types, such as salt in the Silurian and coal in the Carboniferous (commonly called Mississippian and Pennsylvanian in North America), are important.

In Step 5 the students complete two columns so that they can compare the rocks associated with climate zones with the rocks in Michigan. Again, results will vary depending on which climate zones a student selects. However, some clear patterns emerge and should be stressed (see the answer key). For example, Cambrian sandstones could result from both equatorial and arid climates. Reefs flourished as the continent entered a Mediterranean climate in the Silurian. The presence of evaporites also hints that the continent was near an arid climate. In the Carboniferous, the state's coal layers provide evidence of an equatorial climate. The youngest bedrock in the state, the "red beds" near Ionia, likely formed in a tropical climate.

In Step 6 students interpret their correlations and synthesize their observations. The high level of detailed agreement between the expected rocks in a climate zone and the observed rocks in Michigan provides a "local" connection for drifting continents and changing environments over hundreds of millions of years.

Through carrying out this activity, students are 'doing science' as opposed to just learning about science (although they do this at the same time). They carry out the scientific investigational activities of examining evidence, seeking patterns in the evidence,

using the evidence to formulate hypotheses, and then checking the hypotheses against the evidence.

Additions and Extensions

Many of the rock types in Table 1 can be collected in the state or in adjacent states, as well as purchased at low prices at the annual MSTA conference or at local shows of gem and mineral clubs. As you move through the lesson, they can serve as a refresher on rock types and a connection to the real world.

The Stratigraphic Succession in Michigan can become difficult to read when copied, especially with regard to small detail such as the salt deposits. To enhance understanding and use of the column, such features may need to be discussed with students or a larger version made available. The lead author may be contacted for a higher resolution version of the stratigraphic sequence or other figures.

Different geologists have posted their paleogeographic maps online. These maps are more detailed than Figure 1 and provide additional information. We chose to use Figure 1 for its simplicity and as an introduction to the topic. The Paleomap Project of Christopher Scotese (http://scotese.com/paleocli.htm) has maps of the continents at different times and several animations that show drifting continents with changing climates. Ron Blakley's Paleogeography (http://jan.ucc.nau.edu/rcb7/) has numerous beautiful illustrations that would complement this lesson. Extending the lesson to include additional maps will help the students connect to ancient Earth. The History of the Earth poster (http://www.chronos.org/pdfs/k-12.pdf) from the Chronos website is an excellent synthesis of paleogeography, changing plate boundaries, and life over time.

References

Earth Science Teachers Association, 1996, The British Isles through Geologic Time from Investigating the Science of the Earth, SoE2: Geological Changes – Earth's structure and plate tectonics, http://www.nationalstemcentre.org.uk/elibrary/file/4041/Geological%20changes%20-%20earth's%20structure%20and%20plate%20tectonics.pdf .

Michigan Department of Conservation, 1964, Stratigraphic Succession in Michigan.

Michigan Climate Over Time Lab

Step 1. Determining Michigan's Latitude

Use The Movement of Continents over Geological Time (Figure 1), to estimate the latitude of Michigan for each of the geologic periods shown. Record ages in millions of years (Ma). Climate zones are listed in Table 1. Record your observations:

Geologic Period	Latitude of Michigan	Age in Ma	Climate Zone
Cambrian	_____	_____	_____
Devonian	_____	_____	_____
Carboniferous	_____	_____	_____
Permian/Triassic	_____	_____	_____
Jurassic	_____	_____	_____
Cretaceous/Tertiary	_____	_____	_____

Step 2. Plotting the Latitude Data

Plot your latitude data for each geologic period in the space provided on the Michigan's Changing Latitude (Figure 2).

a. About when did Michigan reach its maximum southern latitude?

b. About when did Michigan cross the equator?

c. About when did Michigan reach its maximum northern latitude?

d. How many climate zones has Michigan experienced in the last 520 Ma?

Step 3. Relating Climate Zones to Rocks and Their Environment

Most of the sedimentary rocks that formed in Michigan since the onset of the Cambrian formed in an ocean (sea) environment. Table 1 summarizes the influence of climate on the environments where rocks form as well as the types of rocks that form. **For each climate zone, list two environments that exemplify that climate and a rock type that could form in each environment:**

Climate	Environment 1	Rock 1	Environment 2	Rock 2
Polar				
Temperate				
Mediterranean				
Arid/Semi-arid				
Equatorial				

Step 4. Michigan's Rocks over Time

The **Stratigraphic Succession in Michigan** (Figure 3) shows the sedimentary rocks that formed in the state since the onset of the Cambrian.

For each geologic period below, list the dominant rock types in decreasing order of abundance. Under "Other," list the presence of any coal beds, reefs, or evaporites (halite, anhydrite, and gypsum).

Geologic Period	Rock Abundance	Other
Cambrian	_____ > _____ > _____	_____
Ordovician	_____ > _____ > _____	_____
Silurian	_____ > _____ > _____	_____
Devonian	_____ > _____ > _____	_____
Carboniferous	_____ > _____ > _____	_____
Jurassic	_____ > _____ > _____	_____

Step 5. Compare Rocks/Climate Zones to Michigan's Rock Record

If the evidence we have used about plate tectonics and climate are correct, the environments and rock types from Table 1 should match the rocks in Michigan during the appropriate geologic periods. **Check your observations in Step 3 against what you recorded in Step 4.** If your rock types do not match, you might need to think carefully about what this shows or check the Geological Characteristics of Different Climatic Zones to see if those rock types are included. You will need to refer to your plot from Step 2 to determine the climate zone of Michigan during the Silurian. Record your observations for each period:

Geologic Period	Rocks Based on the Climate Zones	Rocks in Michigan
Cambrian		
Silurian		
Devonian		
Carboniferous		
Jurassic		

Step 6. Making Connections

During which geologic periods do the rocks of the climate zone match well with those actually seen in Michigan?

During which geologic periods do the rocks of the climate zone not match with those actually seen in Michigan? Explain why you think these two different types of data do not match.

As Michigan crossed the equator which rocks were deposited?

Are these rocks what are expected based on the climate zone chart?

Write a brief paragraph that summarizes your observations and supports or refutes the connections between climate zones, rock types, and the movement of North America. This is your hypothesis based on the evidence you have been using.

Figure 1. Movement of Continents Over Time

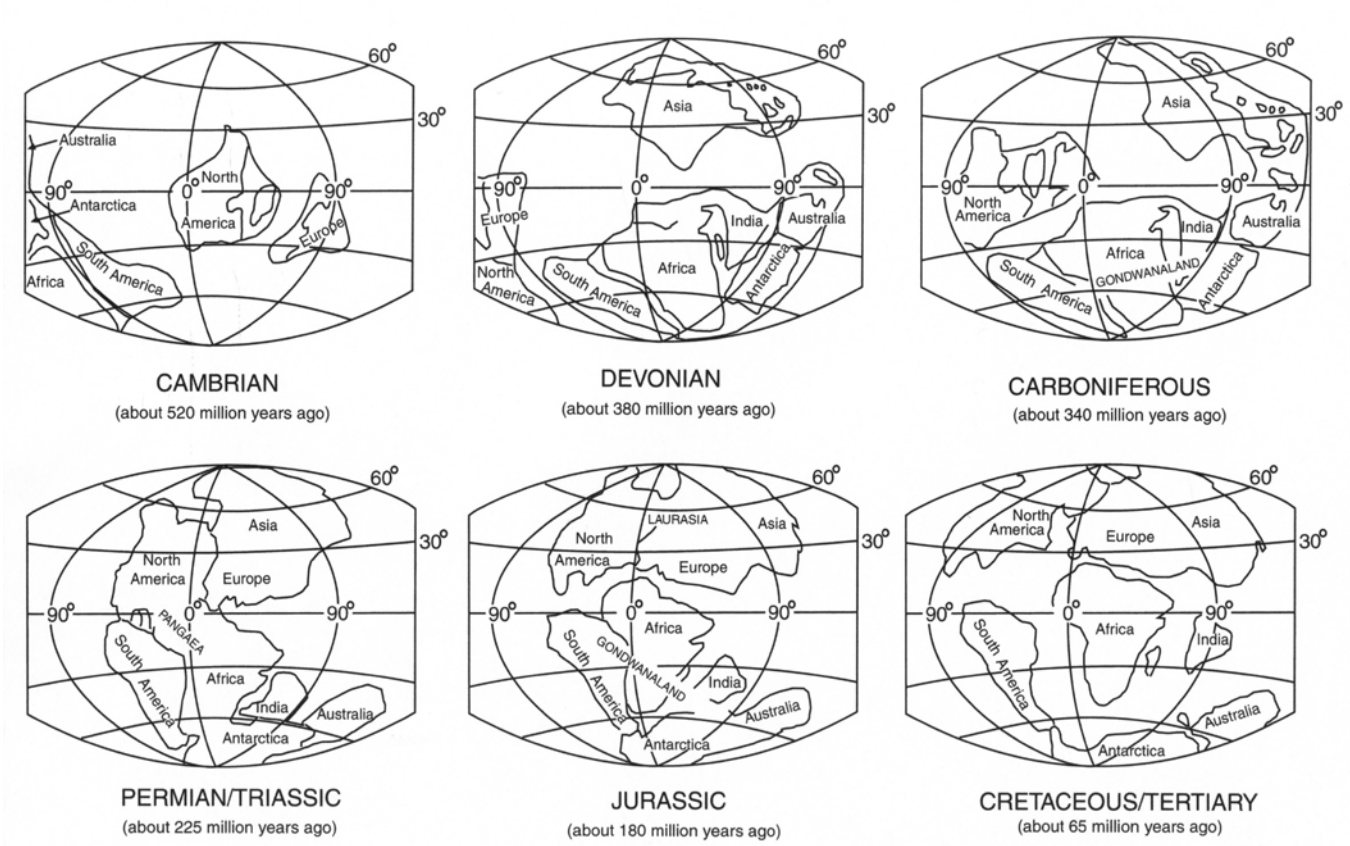


Figure 2. Michigan's Changing Latitude and Climate Over Geologic Time

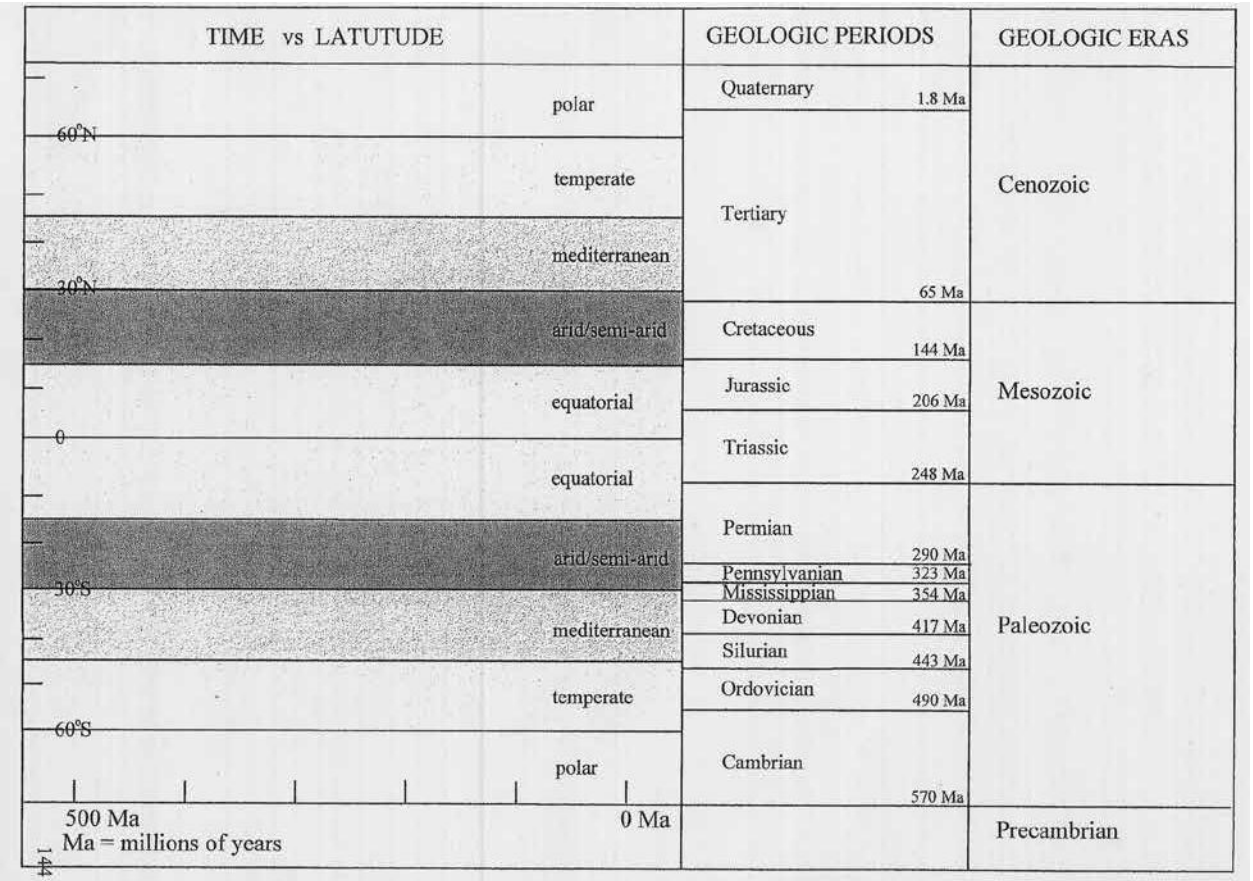
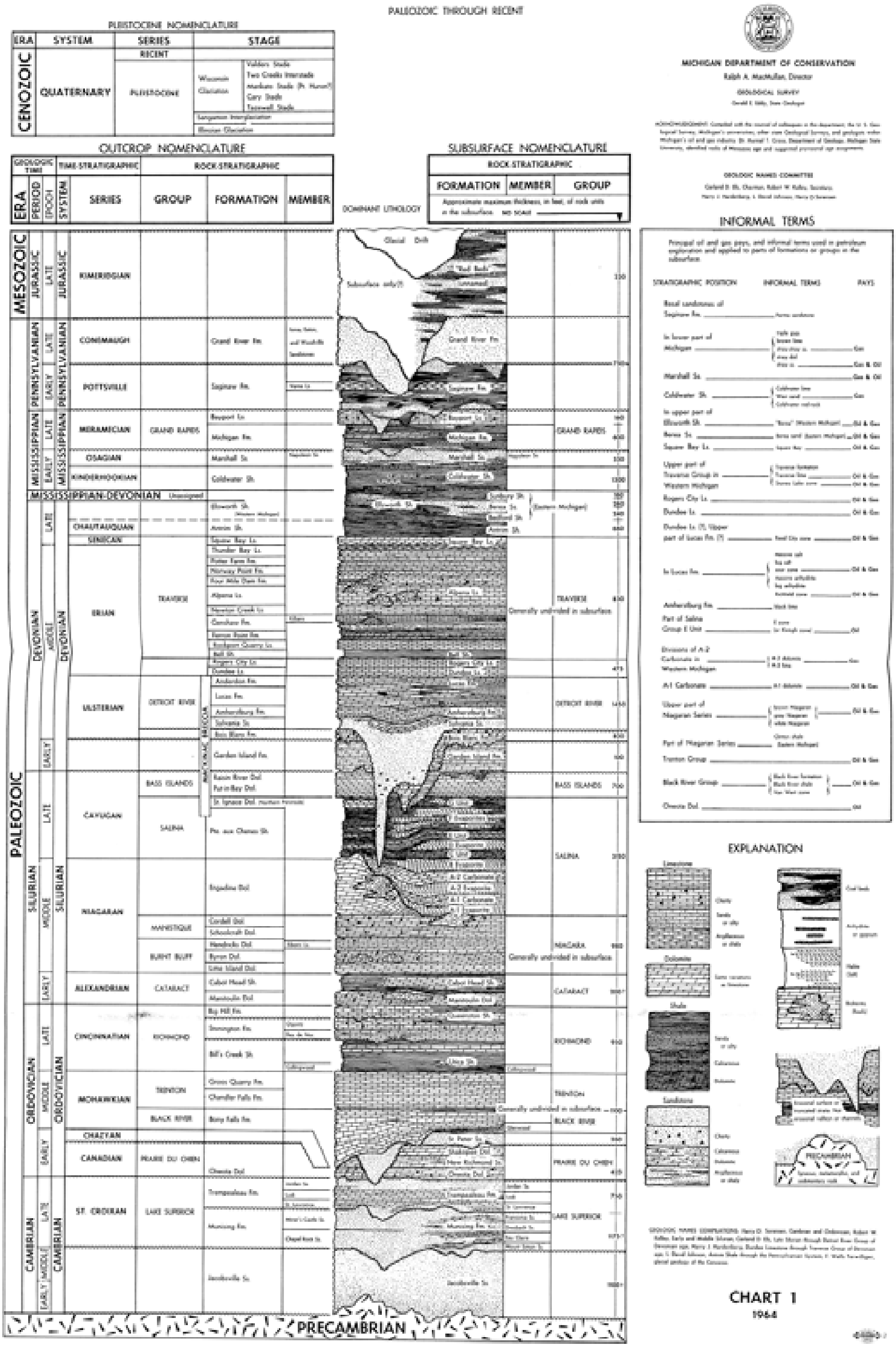


table 1. Geological Characteristics of Different Climate Zones

Climate	Latitude	Environment Exemplified	Rocks that could form	Other Notes
Polar	60°N - 90°N and 60°S - 90°S	On land: ice-covered or affected by cold …….. In the sea: shallow tidal seas	Tillite; varved silts …… Sandstones; mudstones; shales	
Temperate	40°N - 60°N and 40°S - 60°S	On land: rivers …… In the sea: shallow tidal seas	Conglomerates; sandstones; siltstones …….. Sandstones; mudstones; shales	…… Ancient shallow sea rocks may contain fossils such as trilobites, graptolites, brachiopods or ammonites
Mediterranean	30°N – 40°N and 30°S – 40°S	On land: rivers …….. In the sea: coral reefs and lagoons in shallow seas	Conglomerates; sandstones; siltstones; palaeosols; …….. Oolitic limestones; shelly limestones	…….. Ancient rocks may contain fossils such as corals, trilobites, brachiopods
Arid/Semi-Arid	15°N - 30°N and 15°S - 30°S	On land: deserts …….. In the sea: coral reefs, lagoons, hot coastal basins	Red sandstones (“red beds”); conglomerates; evaporites, e.g. rocksalt …… Oolitic limestones; shelly limestones; evaporites e.g. rocksalt	
Equatorial	15°N - 15°S	On land: equatorial swamps ……. In the sea: coral reefs, and lagoons in shallow areas	Sandstones; shales, with coal …… Limestones with a wide variety of fossils	Coal may contain plant fossils


PALEOZOIC THROUGH RECENT
PLEISTOCENE NOMENCLATURE
ERA
SYSTEM
SERIES
STAGE
CENOZOIC
QUATERNARY
RECENT
OUTCROP NOMENCLATURE
SUBSURFACE NOMENCLATURE
ROCK STRATIGRAPHIC
FORMATION
MEMBER
GROUP
SERIES
DOMINANT LITHOLOGY
MESOZOIC
PALEOZOIC
JURASSIC
PENNSYLVANIAN
MISSISSIPPIAN
DEVONIAN
SILURIAN
ORDOVICIAN
CAMBRIAN
MISSISSIPPIAN-DEVONIAN
MICHIGAN DEPARTMENT OF CONSERVATION
Ralph A. MacMullan, Director
GEOLOGICAL SURVEY
INFORMAL TERMS
EXPLANATION
PRECAMBRIAN
CHART 1
1964

Michigan's Ride on the North American Plate Answer Key

Step 1. Determining Michigan's Latitude

Use The Movement of Continents over Geological Time (Figure 1), to estimate the latitude of Michigan for each of the geologic periods shown. Record ages in millions of years (Ma). Climate zones are listed in Table 1. Record your observations:

Geologic Period	Latitude of Michigan	Age in Ma	Climate Zone
Cambrian	10-20° S	520	Equatorial à Arid/Semi-Arid
Devonian	40-50° S	380	Mediterranean à Temperate
Carboniferous	10-20° S	340	Equatorial à Arid/Semi-Arid
Permian/Triassic	20-25° N	225	Arid/Semi-Arid
Jurassic	30-35° N	180	Arid/Semi-Arid à Mediterranean
Cretaceous/Tertiary	40-45° N	65_	Temperate

Step 2. Plotting the Latitude Data

Plot your latitude data for each geologic period in the space provided on the Michigan's Changing Latitude (Figure 2).

a. About when did Michigan reach its maximum southern latitude?
During the Devonian, about 380 Ma

b. About when did Michigan cross the equator?
Around the Permian, about 300 Ma

c. About when did Michigan reach its maximum northern latitude?
During the Cretaceous/Tertiary, about 65 Ma

d. How many climate zones has Michigan experienced in the last 520 Ma?
Michigan has experienced four climate zones (equatorial, arid/semi-arid, Mediterranean, and temperate) in each hemisphere.

Step 3. Relating Climate Zones to Rocks and Their Environment

Most of the sedimentary rocks that formed in Michigan since the onset of the Cambrian formed in an ocean (sea) environment. Table 1 summarizes the influence of climate on the environments where rocks form as well as the types of rocks that form. **For each climate zone, list two environments that exemplify that climate and a rock type that could form in each environment:**

Climate	Environment 1	Rock 1	Environment 2	Rock 2
Polar	*Ice*	*tillite*	*Sea*	*Mudstone*
Temperate	*Rivers*	*ss*	*Sea*	*ss, sh*
Mediterranean	*Rivers*	*ss*	*Reefs*	*Lss*
Arid/Semi-arid	*Deserts*	*ss (red)*	*Sea*	*lss, evaporates*
Equatorial	*Swamps*	*coal*	*Reefs*	*lss, fossils*

Step 4. Michigan's Rocks over Time

The **Stratigraphic Succession in Michigan** (Figure 3) shows the sedimentary rocks that formed in the state since the onset of the Cambrian.

For each geologic period below, list the dominant rock types in decreasing order of abundance. Under "Other," list the presence of any coal beds, reefs, or evaporites (halite, anhydrite, and gypsum).

Geologic Period	Rock Abundance	Other
Cambrian	*ss* > *dolo ss* > _____	_____
Silurian	*dolo lss* > *sh* > _____	*reefs, halite (salt)*
Devonian	*dolo lss* > *sh* > *ss*	*reefs*
Carboniferous	*h* > *ss* > _____	*coal, gypsum/anhydrite*
Jurassic	*sh* > *ss* > _____	*red beds*

Step 5. Compare Rocks/Climate Zones to Michigan's Rock Record

If the evidence we have used about plate tectonics and climate are correct, the environments and rock types from Table 1 should match the rocks in Michigan during the appropriate geologic periods. **Check your observations in Step 3 against what you recorded in Step 4.** If your rock types do not match, you might need to think carefully about what this shows or check the Geological Characteristics of Different Climatic Zones to see if those rock types are included. You will need to refer to your plot from Step 2 to determine the climate zone of Michigan during the Silurian. Record your observations for each period:

Geologic Period	Rocks Based on the Climate Zones	Rocks in Michigan
Cambrian	*Equatorial: ss, sh, coal, lss, fossils* *Arid/Semi-Arid: ss, lss, evaporites*	*ss* *dolo ss*
Silurian	*Mediterranean: ss, lss*	*dolo lss* *sh* *halite (salt)*
Devonian	*Mediterranean: ss, lss, reefs* *Temperate: ss, sh*	*dolo lss* *sh* *ss* *reefs*
Carboniferous	*Equatorial: ss, sh, coal, lss, fossils* *Arid/Semi-Arid: ss, lss, evaporites*	*sh* *ss* *coal* *evaporites (gypsum/anhydrite)*
Jurassic	*Arid/Semi-Arid: red ss, lss, evaporites* *Mediterranean: ss, lss, reefs*	*sh* *ss* *red beds*

Step 6: Making Connections

a. During which geologic periods do the rocks of the climate zone match well with those actually seen in Michigan?

Devonian, Carboniferous, Jurassic

b. During which geologic periods do the rocks of the climate zone not match with those actually seen in Michigan? Explain why you think these two different types of data do not match.

Cambrian, Silurian
These periods are ambiguous because sandstone is able to be formed under multiple different environmental conditions.

c. As Michigan crossed the equator, which rocks were deposited?

Coal, shale, sandstone

d. Are these rocks expected based on the climate zone chart?

Yes, land environments in equatorial climate zones should show sandstone, shale, and coal.

e. Write a brief paragraph that summarizes your observations and supports or refutes the connections between climate zones, rock types, and the movement of North America. This is your hypothesis based on the evidence you have been using.

Answers here will vary, but students should note correlations between expected rock types based on climate and rock types found during specific geologic periods in Michigan's stratigraphic column. These findings are aligned with climate zones experienced by North America as it traveled to its present day location. It can also be noted that some periods, such as the Cambrian and Silurian, do not give clear correlations between rock type and climate zone, as the rock types found can be formed under various conditions.