Playing Wegener in a Mock World – A Laboratory Exercise for Introductory Earth-History Classes

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ABSTRACT

We provide the outline for a relatively simple but effective laboratory exercise covering the key aspects of plate-tectonic reconstruction. This exercise is designed for an introductory Earth-history class but can be easily modified for other audiences. The objective of the exercise is to reconstruct the geological history (that is, the tectonics, eustacy, and orogenesis) of a mock world that has a different arrangement of lithospheric plates than Earth. Various stratigraphic sections with associated lithological and paleontological information provide all of the necessary historical information, and a present-day physiographic map provides modern geographic constraints. The expected stratigraphic record of a simple two-continent system undergoing a typical Wilson cycle is provided as background for the exercise. A series of questions is used to guide students through the geological history of the mock world and each question requires simultaneous evaluation of several pieces of evidence. The exercise was judged to be effective at helping students synthesize skills from several previous labs and a survey indicates that students thought it was both challenging and fun.

Keywords: Education – geoscience; education – laboratory; plate tectonics; stratigraphy, historical geology, paleoecology.

Introduction

Alfred Wegener (1915) proposed the hypothesis of continental drift based on the correlation of structure, lithology, and fossils among major continents. Although his concept of continental drift has been altered significantly since he first proposed it, Wegener's concept of continental motion through geologic time remains one of the key landmarks in the history of geological thought. The principles and observations that he used to reassemble past continental positions continue to play a fundamental role in our efforts to reconstruct Earth history and thus represent key concepts for any introductory historical-geology class.

In the 1960s, geologists determined that plate motions were accommodated by the creation and destruction of lithosphere along mid-ocean ridges and subduction zones (Vine and Matthews, 1962; Isacks and others, 1968; Kearey and Vine, 1996). In accordance with this new plate-tectonic paradigm, it became clear that continental margins represent an important archive of historical tectonic information. Continental margins may be active or passive and each type of margin leaves its own distinct signature in the geologic record. Active margins are often characterized by mountain building and/or volcanism and preserve complex sequences of clastic, igneous, and metamorphic rocks. Passive margins are normally characterized by tectonic quiescence and preserve stratigraphic sequences that are predominantly controlled by sediment supply and thermal subsidence. Intracratonic sedimentary deposits are also important in deciphering the geologic past. As eustatic sea level rises, large epicontinental seas can flood the interior lowlands of continents, leaving behind thick deposits of sediment. In each case, the geological record is unique.

In an effort to produce a "hands-on" historical-geology lab that helps students understand the techniques and reasoning that geologists use to reconstruct tectonic events and produce paleogeographic maps, we recently developed an exercise that asks students to reconstruct the tectonic history of a hypothetical world using a simplified set of lithospheric plates and associated stratigraphic columns with fossil assemblages. The lab attempts to incorporate several different techniques that are often dealt with individually in other historical-geology laboratory exercises (for example, terrane analysis – Bykerk-Kaufman (1989), paleobiogeographic provinces – Rowland (1984), Shea, (1987)) in an effort to show students the multidisciplinary approach to historical reconstruction. By using a mock world that is characterized by a much simpler tectonic setting than the Earth, the lab focuses on teaching students the logic and methodology of reconstructing geological history rather than the details of a more complex real-world example. We did, however, use the real sequence of geologic periods because it helps students learn the geologic time scale. In this way, the lab provides a good preparation for later labs that deal with real examples using Earth's geological record.

We have designed the lab to focus on the following five key geological concepts:

1) the difference between active and passive margins,
2) the physiographic and stratigraphic features produced through the convergence and divergence of continental and oceanic plates,
3) the origin and growth of major continents through the accretion of island arcs and microcontinents,
4) eustatic changes in sea level and their effect upon the stratigraphic record, and

5) the concept of faunal succession and the use of fossils for paleogeographic reconstruction.

These represent some of the key topics that had been covered in our class during the weeks leading up to the lab, but it is important to note that simple changes in emphasis could reorient the exercise to concentrate on almost any aspect of historical geology.

Since the students in ESCI 402 (Earth History) at the University of New Hampshire have a wide range of geologic backgrounds (from no geology to several classes of some Earth-science class), we chose to focus on the concepts that had been practiced in previous labs (rock and fossil identification, stratigraphic correlation, and geologic maps). However, the exercise could be modified according to the background of most any introductory class and the difficulty level can be controlled by adjusting the specificity and complexity of the questions asked. Hand samples or photographs could be substituted for some of the symbols in the columns in order to give students practice in identifying rock types.

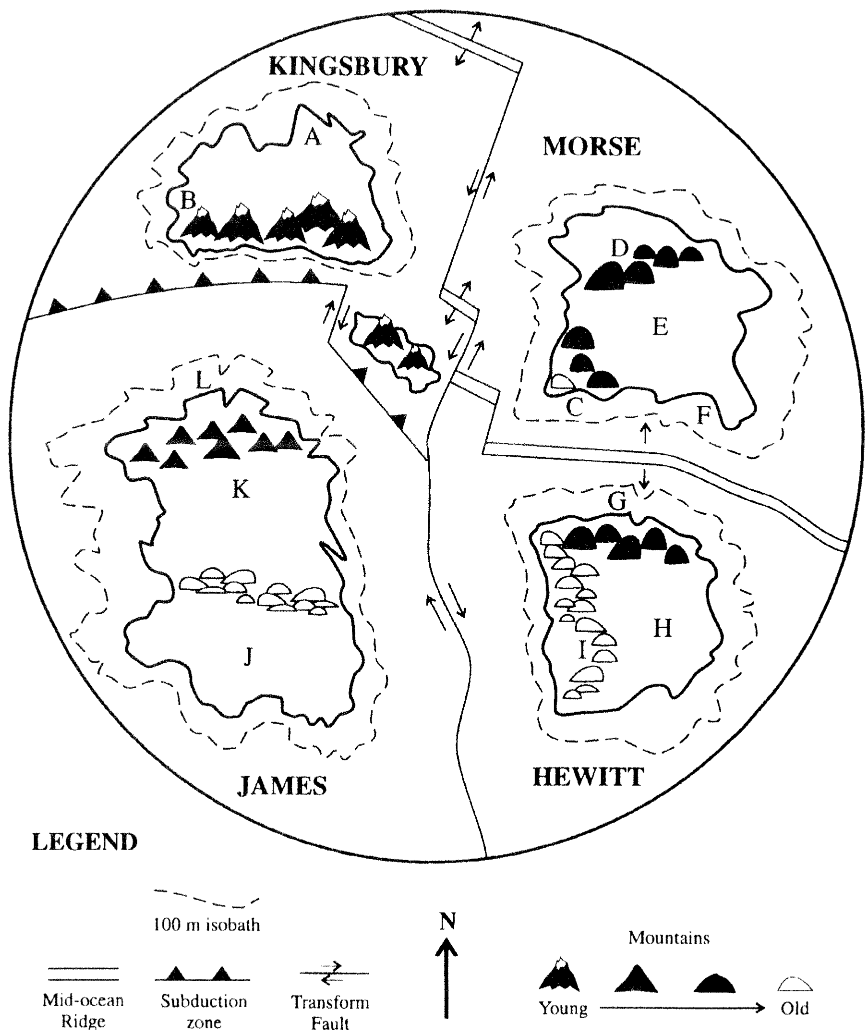

Figure 1. Map of the hypothetical world used in this lab exercise. Mountain ranges, volcanic arcs, and plate boundaries provide modern geographic and tectonic constraints on the reconstruction of the geological history of this new world. Continents are named after buildings on the University of New Hampshire campus.

Lab Set-Up

For this exercise we provided the class with three basic pieces of information: (1) a modern tectonic/physiographic map that shows the present location of different plates, the types of plate boundaries, the location of physiographic features such as mountain ranges and mid-ocean ridges, and the location of stratigraphic sections (Figure 1), (2) twelve stratigraphic columns (see, for example, Figure 2) that correspond to the labeled locations on the plates with a legend of lithologies that shows the tectonic environment that each lithology represents (Figure 3), and (3) an example that illustrates the lithological and paleontological succession that would be expected for two continents experiencing a classic Wilson cycle (Figure 4).

The modern physiographic map shows that the hypothetical world (actually a "half-world" since we deal with only one hemisphere for the sake of ease of visualization) contains four lithospheric plates in its modern arrangement (Figure 1). Each plate has one central land-mass composed of continental crust surrounded by areas of oceanic crust. All three fundamental types of plate boundary are present (convergent, divergent, transform). Continents are characterized by various physiographic features such as mountain ranges and volcanic arcs, which represent areas of present or past tectonic activity.

The stratigraphic sections (Figure 2) provide the historical information for each land-mass, and their locations are labeled on the map by different letters. Isotopic ages are provided for the crystalline basement of each section, and a succession of different lithologies and fossil assemblages is superimposed on the basement rock. The lithological and paleontological succession in each section represents the archive of information that students use to reconstruct the tectonic history of the various plates in this hypothetical world. The lithologies reflect the tectonic events and/or sea-level changes occurring at that location in geologic history. The legend helps students link tectonic environments with their corresponding lithologies (Figure 3). For example, a lithology of arkose interbedded with basalt flows represents a rift

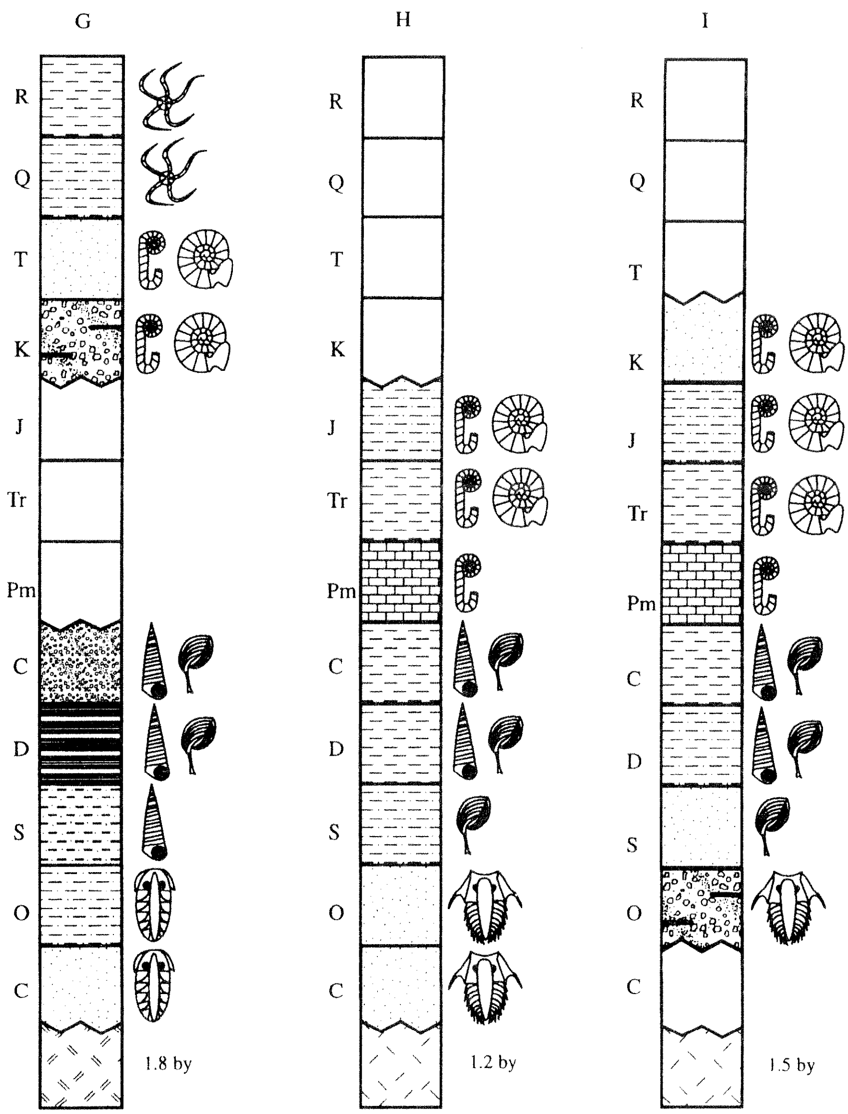

Figure 2. Three of the twelve stratigraphic columns used in this lab exercise.

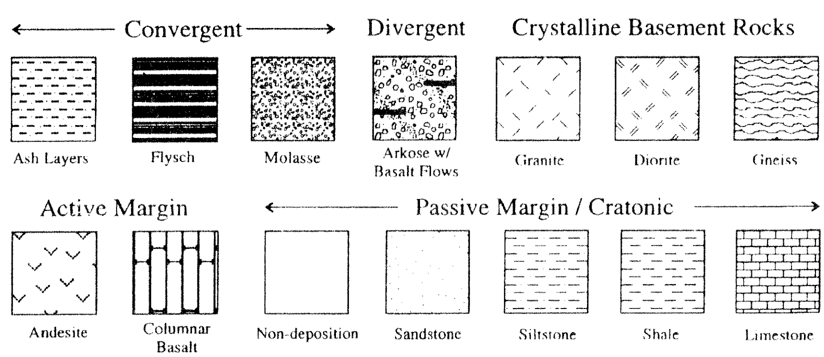

Figure 3. Key to the different lithologies in this lab and their tectonic significance. Convergent margins are represented in the lithological record by ash, flysch and molasse deposits. Divergent (rifting) margins are represented by arkoses interbedded with basalts. Crystalline basement rock that forms the core of continental landmasses is either granite, diorite, or gneiss. Passive margins and cratonic sequences are represented by sandstone, siltstone, shale, and limestone. Active continental margins are characterized by andesite whereas active oceanic margins (that is, island arcs) are characterized by basalt.

basin (divergent plate margin), whereas a succession of ash, flysch, and molasse represents deposition in the foredeep as two continents begin to collide (convergent plate margin).

Fossil assemblages help students determine which continents were sutured together in the geological past. Fossil assemblages in various sections converge when the continents on which those sections are located approach each other. Each section is referenced to a geological time scale that has 12 major divisions, corresponding to the periods of the Phanerozoic (Cambrian-Recent). Intervals of non-deposition (unconformities) are also seen in some of the stratigraphic columns.

Given the complexity of information, an example was given to students to help them understand how the pieces of information fit to form a paleogeographic model (Figure 4). The example shows the tectonic history of two continents undergoing a classic Wilson cycle and provides the corresponding stratigraphic sections that would be produced on the margin of each continent. Each continent is characterized by cratonic basement rocks of particular isotopic age. Initially (Cambrian-Ordovician), Column A exhibits passive-margin sedimentation whereas Column B undergoes erosion. Beginning in the Silurian, the influx of volcanic rocks in Column B shows that this margin became active. As Continent A converges with Continent B (Devonian), ash deposits are laid down in Column A. Each column shows flysch and molasse deposition as well as a merging of fossil assemblages as the two continents collide and suture (Carboniferous-Permian). After a period of uplift and erosion (represented by an unconformity in the sections during the Triassic-Jurassic), the continents begin to rift apart in the Cretaceous with Column B preserving classic rift-basin lithologies (arkoses interbedded with basalt flows). After rifting, Column B records passive-margin sedimentation and divergent fossil assemblages while Column A records continued erosion (Tertiary-Recent). This practice example, although simpler than the real exercise, provides most of the basic relationships between tectonics, lithology, and paleontology that are necessary

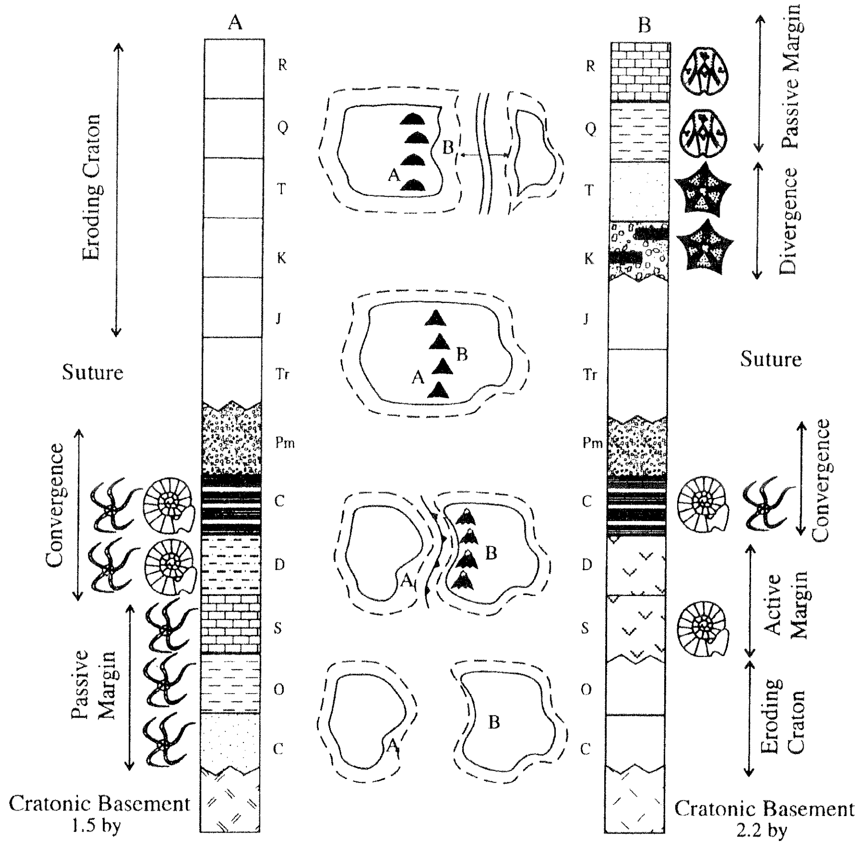

Figure 4. An example included in the laboratory exercise that illustrates the relationship between tectonics and the stratigraphic record during a simplified Wilson cycle. Note how the succession of lithologies and fossil assemblages track tectonic and paleogeographic changes through geological history.

to carry out the rest of the lab. The only additional source of evidence available to students relates to changes in eustatic sea level. Students learn that lowland continental interiors are flooded during periods of high sea level. Marine deposits left behind by these epicontinental seas (and preserved in sections located within continental interiors) thus provide a clue as to the timing of first-order changes in sea level.

Presentation of the Lab

Students teamed up in groups of 2-5 people, and each group received a copy of the 12 stratigraphic columns and a sheet with outlines of the 4 lithospheric plates. Each individual student was given a packet containing instructions, the legend, a physiographic/tectonic map of the mock world, the illustrated example, and a series of specific questions. Questions were devised to help lead the students through the various levels of information in a systematic manner. When the students reach the last question, they have studied each of the lines of evidence needed to explain and visualize the motion of the continents through time. We found the questions to be a critical component of the laboratory exercise. Those students who attempted to jump ahead of the questions would typically get overwhelmed.

To help organize the data, the students were first asked to cut the stratigraphic columns apart and group them based on the age of the basement rock. Each basement-rock type was then given a unique color. The students then cut out the continents and colored in each section of the continent with the corresponding basement-rock color. This helped them to identify the major cratons in the mock world. Mountain ranges define the boundaries between the various cratonic basements present within each continent. With this preliminary cratonic information in hand, most students could see how the cratons might have been arranged in the past, but the questions forced them to move sequentially through geological time. The right answers required using all of the clues provided, and those who tried to put the continents together at first glance quickly realized that the puzzle wasn't that easy.

Using a series of specific questions, we led the students through the exercise in the following steps:

1) Students first identified the stratigraphic sections located in continental interiors. Using the sedimentary record of these sections, they were asked to identify the pattern of sea-level change. We modeled a transgression from the Cambrian to the Permian and a regression from the Permian to the Recent.
2) Students were then asked to determine how many landmasses were present in the Ordovician. The answer to this question can be found by grouping the columns together based on the fossil record. For example, in Figure 2, Columns H and I were both part of the same landmass in the Ordovician, whereas Column G was not.
3) We then told the students that two of the continents (Hewitt and Morse) were sutured at one time. The students were asked to determine when the continents began moving toward each other, when they collided, and when they rifted. Answers to these questions required evaluation of both the lithological and paleontological information.
4) Students were then asked to work out the history of two different exotic terranes that had been sutured onto major continents and discuss how they think this might have happened. The students were not told specifically what kind of terranes they were. For example, column L on "James" (Figure 1) represents an island arc,

	Yes	Some-what	No
Do you think this lab was challenging?	73%	23%	4%
Do you think the lab was fun?	81%	19%	0%
Do you think this lab helped you to better understand orogenic events?	85%	11%	4%
Do you think this lab helped you to better understand how lithology and fossils are used to interpret the Earth's history?	77%	19%	4%

Table 1. Results of the student survey (26 students surveyed).

which formed in the Pennsylvanian and was sutured to the main continent in the Quaternary.

5) Finally, the students were asked to sketch a paleogeographic map for two different periods of geological history. To help conceptualize this, the students were told to organize the cutouts in whatever arrangement they felt the stratigraphic data indicated for that specific time interval. Then they were asked to sketch the general shape of the landmasses and to label where each of the stratigraphic columns was located.

Effectiveness of Lab

We felt that the lab was both educational and enjoyable for the students in ESCI 402. The exercise required active participation by the lab instructor in order to focus the students on key pieces of information and to generate good (and sometimes heated) discussion between students as they struggled to find the correct answers. We found it to be one of the more dynamic labs of the semester and one that serves as a good synthesis of various skills covered during previous weeks.

The students were surveyed a week after the lab was completed to determine their opinions on the exercise and to receive suggestions on how to improve the lab for future classes. The results of this survey were encouraging (Table 1). Most of the students felt the lab was both challenging and fun – a balance that is often difficult to reach in introductory laboratory exercises. Several students commented on having to use all the skills that they had learned in previous labs to piece together the plate-tectonic puzzle. As always, many students appreciated the hands-on approach that this type of exercise offers. More importantly, the students felt the lab helped them understand the significance of fossils and lithology in interpreting geological history. Some students thought the lab was somewhat confusing, while others disliked the length of the lab (though every student was able to finish within the three-hour lab period).

Conclusions

Helping students understand how plate tectonics can affect the Earth's surface over geological time represents one of the most fundamental goals of any Earth-history class. We found that this exercise serves as an excellent way to familiarize students with the procedures that geologists use to investigate tectonic history. By providing a mock world with a different geological history than Earth, the exercise stresses the generality of the procedures and encourages students to focus on scientific process rather than end results. The exercise forces students to turn to their own abilities to reconstruct a geological history that they won't find outlined in their textbooks.

Availability of Lab Materials

A complete set of materials for this laboratory exercise can be downloaded from http://tischler.unh.edu//esci402.html.

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