Connecting textbook facts to geologic research methods in middle school science using Arc9 GIS, plate tectonics data, and beach sands

Abstract

To teach middle school students geologic research methods, we developed an inquiry that combines current computer technology, hands-on laboratory experience, and constructivist education concepts. Our inquiry introduced seventh graders to a geographic information system, basic plate tectonics concepts, and source rock analyses. We tested this inquiry at Hellgate Elementary School in Missoula, Montana. Students used currently known data regarding topography/bathymetry, earthquake distribution, and volcano distribution, and they recorded new data regarding sand composition and morphology from several beach sands collected from around the world. Then they used Arc9 GIS to make connections between current plate tectonics processes and nearby beach sand compositions. Finally, they extrapolated their connections regarding current environments to deduce ancient tectonic settings from ancient sandstone compositions. Students learned concepts pertinent to the rest of the earth science curriculum. Hellgate students enjoyed the investigation, made new connections between seemingly unrelated topics (plate tectonics vs beach sands), and gained an appreciation for geologic research and the scientific method.

Introduction

Articles focusing on how middle school students experience actual geologic research methods are sparse. Curricula that teach students how geologists use the present to study the past can allow students to better understand relationships between modern earth processes and ancient environments. We describe a four-part inquiry that allows middle school students to perform geologic research using observations, analytic equipment, and quantitative data regarding earth processes. This inquiry was tested at Hellgate Middle School in Missoula, Montana. Our inquiry combines group participation in constructing students' own categories for beach sand compositions and plate boundary types with geographic information system software (Arc9 GIS). Students answer the question, "How are plate tectonics and sand related?" We tested the four-part inquiry as the first section of an earth science unit for seventh graders that built upon previous Arc9 GIS lessons. One of our goals was to integrate many practices used in geologic studies that are consistent with the National Science Education Standards (NRC, 1996). Practices include assessment of quantitative and spatial data, sample categorization, hypothesis generation and testing, sampling strategies, limits of laboratory methods, and comparison of laboratory models to natural and ancient settings.

Standard instruction on plate tectonics in middle schools includes the history of plate tectonics theory, the distribution of earthquakes, volcanoes, and fossils, the Pangean fit of the continents, and the age of oceanic crust. By relating analyses of beach sands to standard plate tectonics exercises, our inquiry allows students to discover connections between seemingly unrelated processes (e.g., earthquakes and deposition). Our inquiry focuses on simple observations and assumes no prior geologic knowledge, but introduces multiple disciplines including geography, plate tectonics, sedimentary processes, source rock analysis, and earth history. Students integrate data from earthquakes, volcanoes, topography/bathymetry, and geochronology to discern types of plate boundaries. Then they use observations and analyses of beach sands to relate types of beach sands to types of current plate boundaries and continental margins. Finally, they discern ancient tectonic environments through observations and analyses of ancient sandstones.

Students construct their own categories through observations with Arc9 GIS and stereographic microscopes to 1) become familiar with mapping technology used in scientific research, 2) learn about to plate tectonic processes, 3) recognize connections between current plate boundaries and beach sands, and 4) gain a first-hand look at research methods geologists use to discern Earth's history.

Teachers can refer to the experiences gained by the students in this inquiry during subsequent instruction. The inquiry ties explicitly to content standards for middle school students, such as the nature of science, scientific inquiry, and science technology.

Beach Sands and Plate Tectonics

Geologic Concepts

Because the concept of plate tectonics is well presented in seventh grade science textbooks, this article focuses on the relationship between plate tectonics and beach sands. Sand compositions are influenced by the source rock (the rock that broke down to produce the sand), sedimentary processes, and the paths that link the source rock to the place where the sand is deposited. The primary control on all of these factors, including sand composition, is plate tectonics. Scientists have evaluated the effect of modern tectonic processes on modern sand compositions. They have extrapolated their findings to ancient sandstone compositions in order to determine the tectonic setting necessary to produce those sandstone compositions. For example, Crook (1974), Schwab (1975), and Dickinson and Suczek (1979) showed that careful analyses of the quartz grains, feldspar grains, and rock fragments contained in sand reveal trends that point to possible plate tectonic environments present during the formation of the source rock. Today, researchers routinely plot the proportions of minerals onto triangle diagrams to ascertain trends in the data (see Figure 1). A high proportion of quartz and a low proportion of rock fragments signify a "*continental block*" environment; a high proportion of quartz and a low proportion of feldspar signify a "*recycled orogen*" environment; and a low proportion of quartz signifies a "*magmatic arc*" environment (Figure 2 and glossary). We use these basic ideas as the foundation for introducing geologic research methods to middle school students.

Learning About Tectonics from Sand Compositions

Teachers will need access to a variety of sands for this investigation. These samples can be collected during travel or by having students correspond with classes around the world to request sand samples. In this example, we used 5 beach sands from around the world to illustrate relationships between tectonic environments and source rocks for sands. These sands came from Florida, Costa Rica, Fiji, Hawaii, and Japan. The students may or may not infer the same geologic interpretations as geologists have, but we include brief and simple descriptions of geologists' current interpretations here for reference.

Our analyses revealed that Florida sand contained a high proportion of quartz and a low proportion of rock fragments because the eastern margin of North America has been tectonically inactive for over 150 million years. The sand that collects on Florida's shores has traveled far enough and has had enough time for most minerals to break down either physically or chemically. Quartz, however, is quite resistant to physical and chemical weathering, so it is abundant in this environment.

Sand from Costa Rica contained a high proportion of rock fragments because Costa Rica sits over an ocean-continent subduction zone that is producing an active continental volcanic arc. Volcanoes such as Arenal are shedding new material onto nearby beaches. The lack of distance and time between the formation of rock and the deposition of sand results in a higher proportion of rock fragments that have yet to break down physically and chemically.

Fiji sand contained a large predominance of volcanic rock fragments. The Fiji islands sit on the tectonically active margin between the Australian and Pacific plates. Ocean-ocean subduction produced volcanic islands that are now undergoing deformation due to the stress of plate interactions. The volcanic rocks are eroding, and the resulting rock fragments are being deposited nearby.

Hawaiian sand had a high proportion of rock fragments because Hawaii was formed due to volcanism from a hot spot, and Hawaiian volcanoes continue to shed new volcanic rock fragments onto nearby beaches. Note that Hawaii is not close to a plate margin, but is the result of a hot spot. The information obtained from beach sands must be considered with other data such as earthquake activity, volcanism, topography, and geochronology to infer an accurate geologic interpretation.

Sand from Japan was comprised of a high proportion of rock fragments because Japan rests above an active subduction zone. Mount Fuji is a volcano that sheds new volcanic rock fragments onto nearby beaches.

Investigation 1: Beach Sand Characterization

After a brief introduction to the inquiry and discussion of the research instructions, the students break into small groups of 3 to 5 students. Each group will need a stereographic microscope, a pair of needle-nose pliers, a small sheet of graph paper, and small samples (~20 grams) of beach sands in plastic containers. Note that universities near beaches often are willing to supply a sample of sand.

Each group observes the sands through the stereographic microscopes, and constructs three categories of sand grain composition for each sample based on their observations. Students should consider color, size, shape, number, and any other characteristics they observe. Using the needle-nose pliers, they spread the sand grains into one layer on the graph paper so that each category covers a certain number of graph paper squares. The grains should touch each other without overlapping (Figure 3). To calculate the percentage of grains per category, students divide the number of covered squares of each category by the total number of covered squares. Then they record the characteristics of each of their categories (color, size, shape, etc.), as well as the percentage of the total sample that each category represents. Students produce a triangle diagram illustrating the percentages of grains per category for each of the 5 samples (refer to Figure 1 for sample of a triangle diagram). The investigation takes between 1 and 1.5 hours.

Investigation 2: Plate Boundaries Characterization Using Arc9 GIS

The plate boundaries phase of the inquiry is a modified version of *Discovering Plate Boundaries, a Data Rich Classroom Exercise* (Sawyer, 2002) and requires computers with Arc9 GIS software. Software is available through ESRI education grants. Datasets may be downloaded from *http://terra.rice.edu/plateboundary/* (website last accessed 5/2006).

In their research groups, students use Arc9 GIS to analyze various types of map data concerning plate boundaries. Map data include seismicity, volcanology, topography/bathymetry, and age of seafloor (Figure 4). Each group receives only one of the four map datasets on their computer. We emphasize that each group member must take an active part in the data analysis because they each will teach other students about their dataset in the following section of the investigation (Figure 5). After familiarizing themselves with their information, they overlay their map data onto a map of the global plate boundaries saved on each computer. By observing the features that the two maps have in common, the students construct a classification scheme for the world's plate boundaries. They write descriptions for 3-5 different types of plate boundaries and give each a number such as boundary type 1, boundary type 2, and so on. Descriptions are based purely on their observations, and include simple terms such as high or low topography, continuous or discontinuous distribution, clustered or scattered volcanoes, shallow or deep earthquakes, etc. Finally, students create a new plate boundary map on Arc9 GIS containing different classes of lines based on the categories they developed.

Students use a different color to represent each boundary type. This section of the investigation takes between 1 and 1.5 hours.

Next, students prepare to share their results with their class members. Each group member receives a digital copy of the group's dataset and the new map that the group created. Students break into new groups so that each group has one member who studied the seismology map, one who studied the volcanology map, one who studied the topography/bathymetry map, and one member who studied the geochronology map. Every member of the group became the expert on their field in the previous part of the investigation, but each member has only studied one type of data. The group analyzes each of the four map datasets, and each member explains the appropriate features of their map, including what the data are, how they are symbolized, and what the most important characteristics are. Then they discuss each member's new map based on the categories each previous group developed. Students may be advised to overlay each of the new maps and to perform a query using GIS to discern similarities between the four classification schemes. The goal for the new groups is to create and record a combined classification scheme that considers data from each of the four areas of specialty. For example, students might develop the following description of a plate boundary: plate boundary type A has shallow earthquakes directly on the plate boundary, has sparse or no volcanoes, lies on a bathymetric high with deeper water to either side, and follows a line of young seafloor. Their analyses result in a final plate boundary map composed of different classes of lines based on their combined classification scheme using a different color for each boundary type (Figure 6). This requires between 1 and 1.5 hours.

Investigation 3: Spatial Integration of Beach Sand and Plate Boundary Types Using Arc9 GIS

Once students have categorized the types of beach sands and the types of plate boundaries, they receive digital data on the locations of their beach sand samples. They overlay these data onto their new plate boundary map and perform a distance query using GIS regarding the beach sand location and the nearest plate boundary. Then they infer what type of sand could be expected based on proximity to various plate boundary types. They record their inferences and explanations in their science notebooks. This analysis lasts between 0.5 and 1 hour.

Investigation 4: Extending Source Rock Analyses to Ancient Geologic Environments

Students perform another sand classification using stereographic microscopes on an ancient sandstone rock that has been partially crushed into sand. They use the skills gained through the inquiry to infer what type of plate boundary the sandstone was near at the time of deposition. They present their results, inferences, and explanations to the class. They are assessed based on their ability to support their inferences using their sand and plate boundary classification schemes. This application takes between 0.5 and 1 hour.

Implications and Extensions

Our inquiry introduces students to numerous earth science topics included in the National Science Education Standards. Furthermore, it allows them to employ research methods that geologists use to understand modern and ancient earth processes. Teachers can build the rest of the earth science curriculum around this inquiry by relating it to other topics and processes such as minerals, rocks, earth history, climate change, river processes, and planetary science. We include brief descriptions of possible extensions for teacher reference below.

Minerals—Students can use geologists' categories (as opposed to creating their own categories) to perform source rock analyses. This involves identifying and sorting quartz minerals, feldspar minerals, and rock fragments from sand.

Rocks—Teachers can do a similar inquiry, but with rocks and their locations. Care must be taken to determine whether the rock comes from a modern or an ancient tectonic environment.

Earth history—The ancient sand used for the inquiry assessment can be the cornerstone for introducing deep time, paleontology, and relative and absolute dating.

Climate—Plate location is one of the controlling factors of climate. Students can research how the positions of the continents have affected ocean currents, thereby affecting climate through time. Also, volcanism due to plate tectonics has had local and global effects on climate.

River Processes—The inquiry relates plate tectonic environments to beach sedimentation. River processes are inherent in transporting sediment from the source to the depositional basin. The inquiry can serve as a staging point for discussion and research regarding rivers. Also, students can collect sand from local rivers and compare the sand composition and texture to the surrounding geologic setting.

Planetary Science—Students can compare plate tectonics activity on Earth to that on other planets. Furthermore, students can research new photographs and data from the Mars expeditions (see NASA website) to make correlations with Earth's wind, river, and tectonic processes.

Conclusions

The students involved with this inquiry performed geologic research analyses to answer a specific question. They were able to extrapolate current processes to ancient environments in the same ways geologists do. They enjoyed the hands-on applications that geologists use, and they were prepared to continue through the rest of the earth science curriculum.

Glossary

Continental block—This environment includes 1) tectonically inactive mid-continent areas, and 2) uplifted fault blocks containing igneous and metamorphic continental crust (Figure 7A). Continental block environments produce sands rich in quartz and poor in rock fragments because the time and distance from the source rock to the point of sedimentation are great enough to break down particles that are more susceptible to weathering than quartz.

Recycled orogen—This environment includes several types of mountain-building settings (Figure 7B) that ultimately result in the erosion of sedimentary rocks, hence the *recycling* of sediments. The mountain-building settings include 1) subduction zones where oceanic materials are scraped onto the overriding plate, creating a highland susceptible to weathering and erosion that can shed sediments back into the subduction zone or onto the overriding plate, 2) continental collision zones where sedimentary rock along the margin of one plate is thrust up in a series of folds and faults, creating a structurally high region susceptible to weathering and erosion, and 3) any zone of compression which produces thickened, and therefore uplifted, continental crust, allowing weathering and erosion.

Magmatic Arc—This environment includes volcanic chain settings, including volcanic island chains and volcano chains along continental margins (Figure 7C).

References

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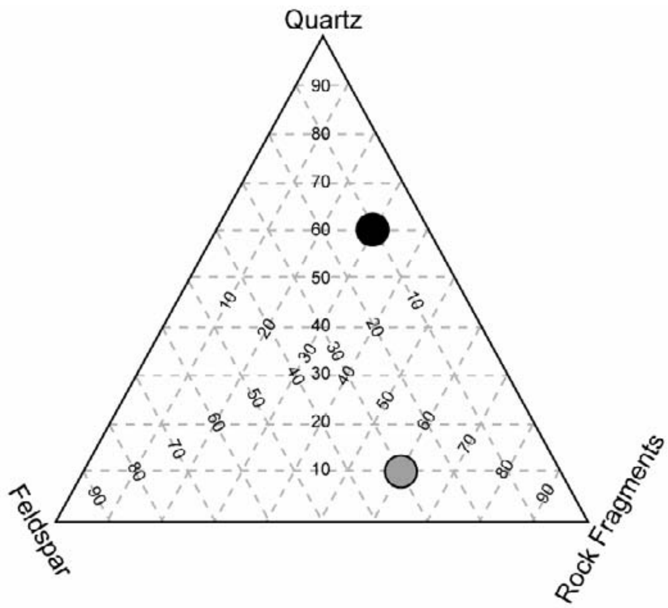


Figure 1. Triangle diagram showing the constituents of two hypothetical samples (black and gray circles). The black circle contains 60% quartz, 10% feldspar, and 30% rock fragments. The gray circle contains 10% quartz, 30% feldspar, and 60% rock fragments.

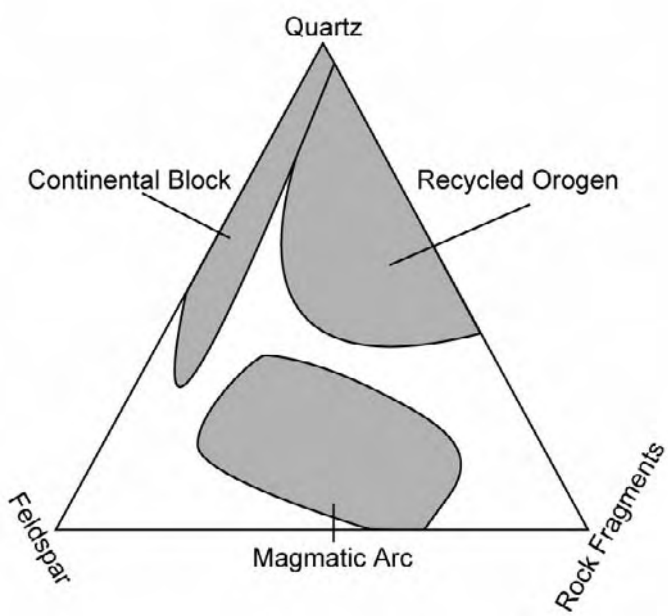


Figure 2. Triangle diagram showing geologists' interpretation of which tectonic setting produces particular percentages of mineralogical constituents (Dickinson and Suczek, 1979). A summary of each tectonic setting is provided in the glossary.

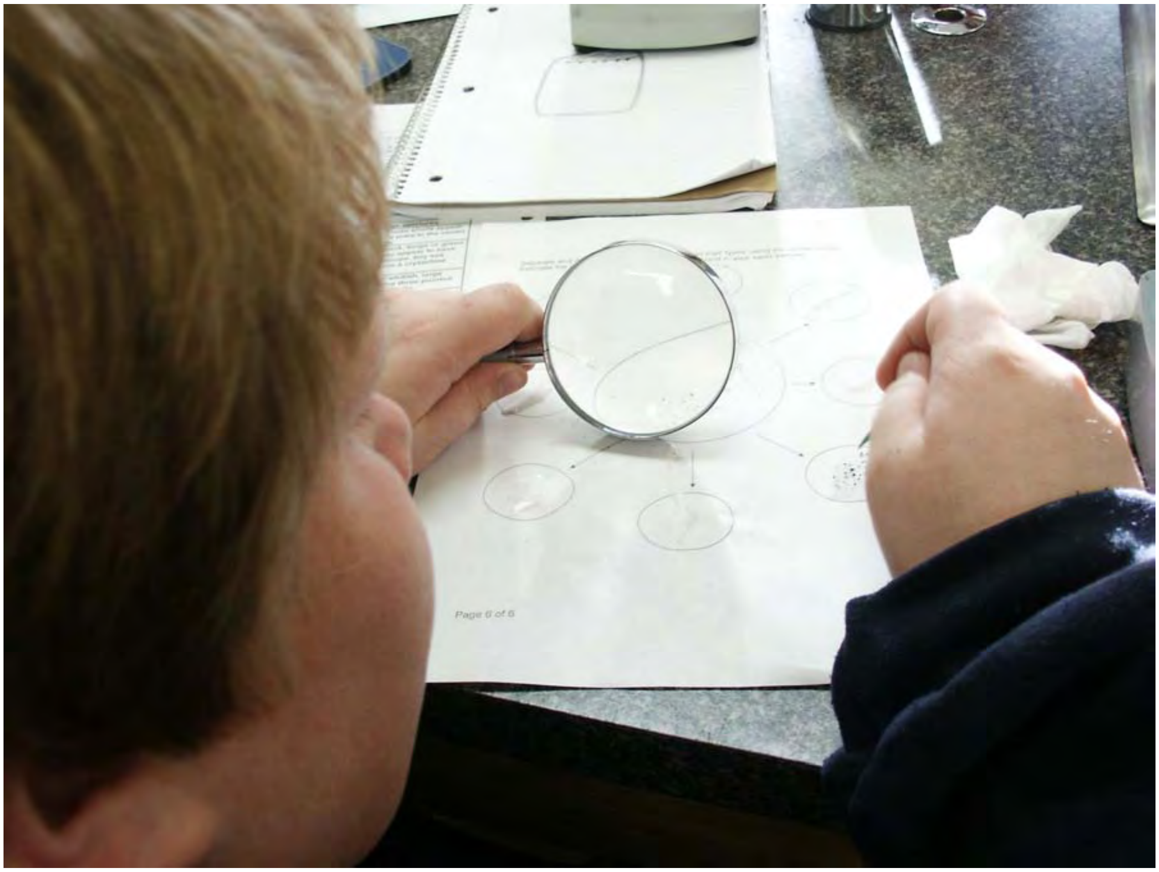
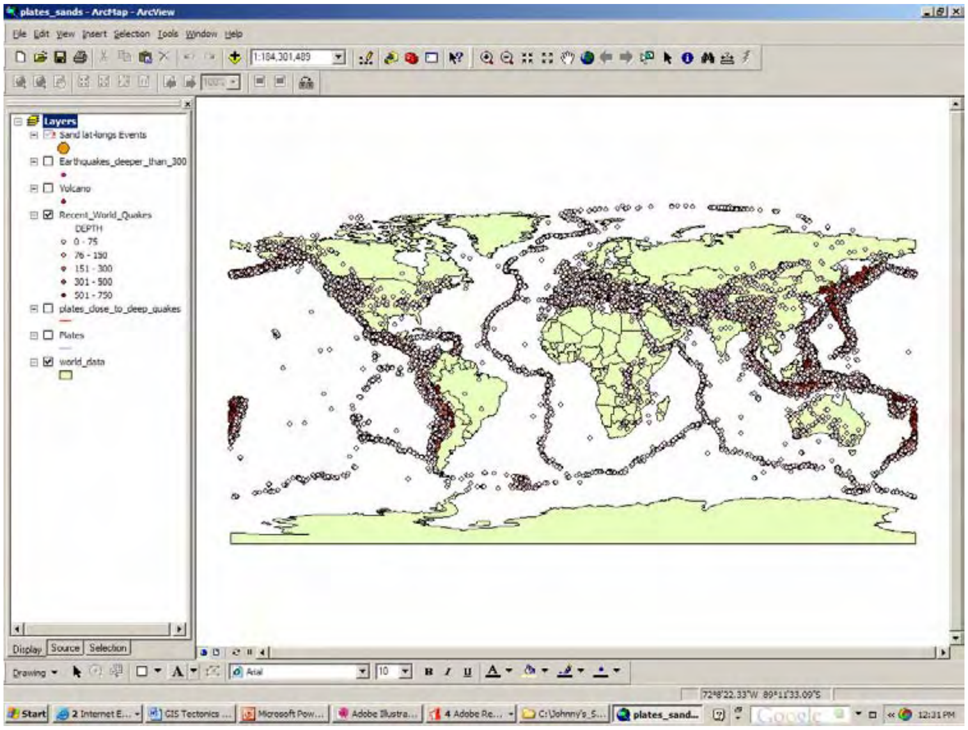
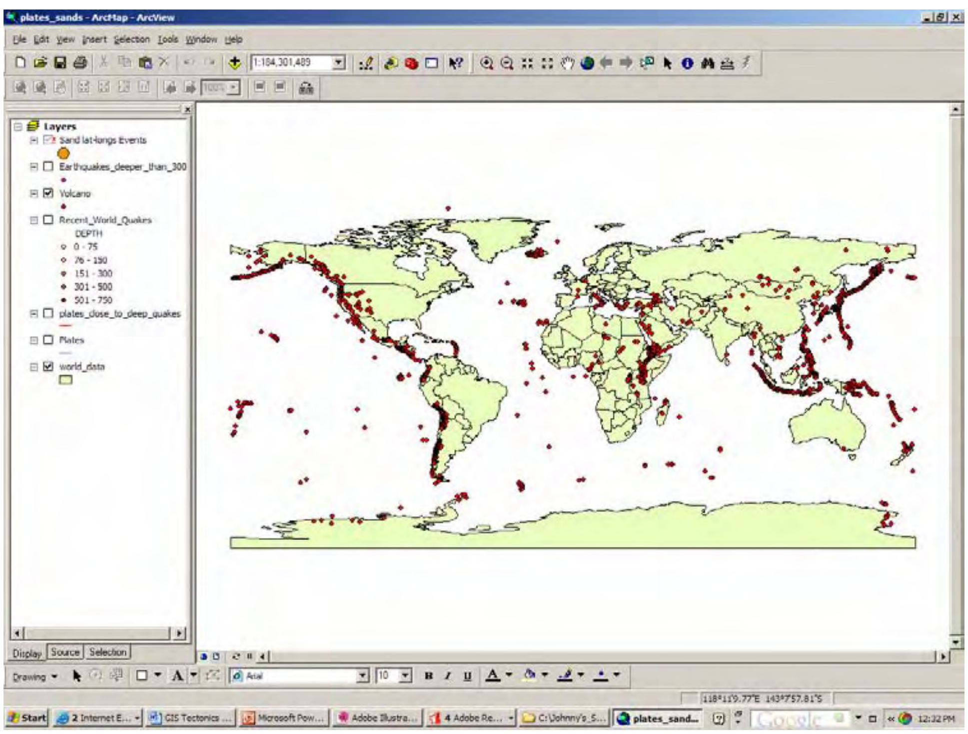


Figure 3. Photograph of a 7th grade student separating sand grains according to his own classification scheme based on color, size, and shape of the sand grains.



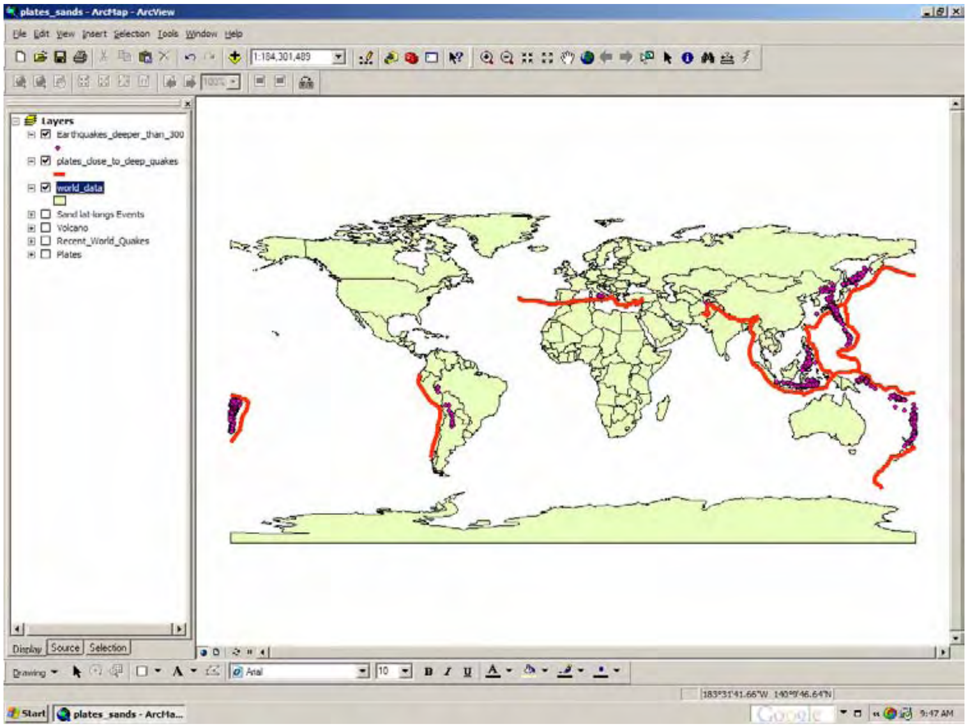
A.



B.

Figure 4. Arc9 GIS screenshots of global earthquake (A) and volcano (B) data.

Figure 5. Three 7th graders discussing relationships between plate boundaries to create their own classification schemes for plate boundaries, following the *Discovering Plate Boundaries* investigation by Sawyer (2002).



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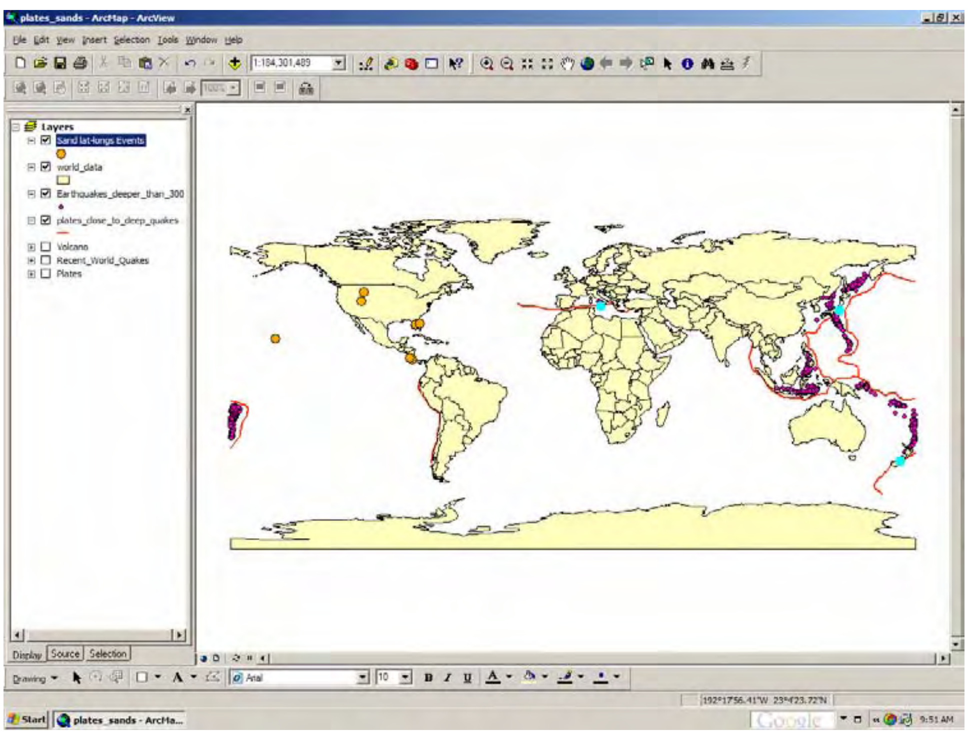

B.

Figure 6. Arc9 GIS screenshots of students' queries regarding the proximity of plate boundaries to deep earthquakes (A), and regarding the proximity of those plate boundaries to specific types of sand compositions shown as blue circles (B).

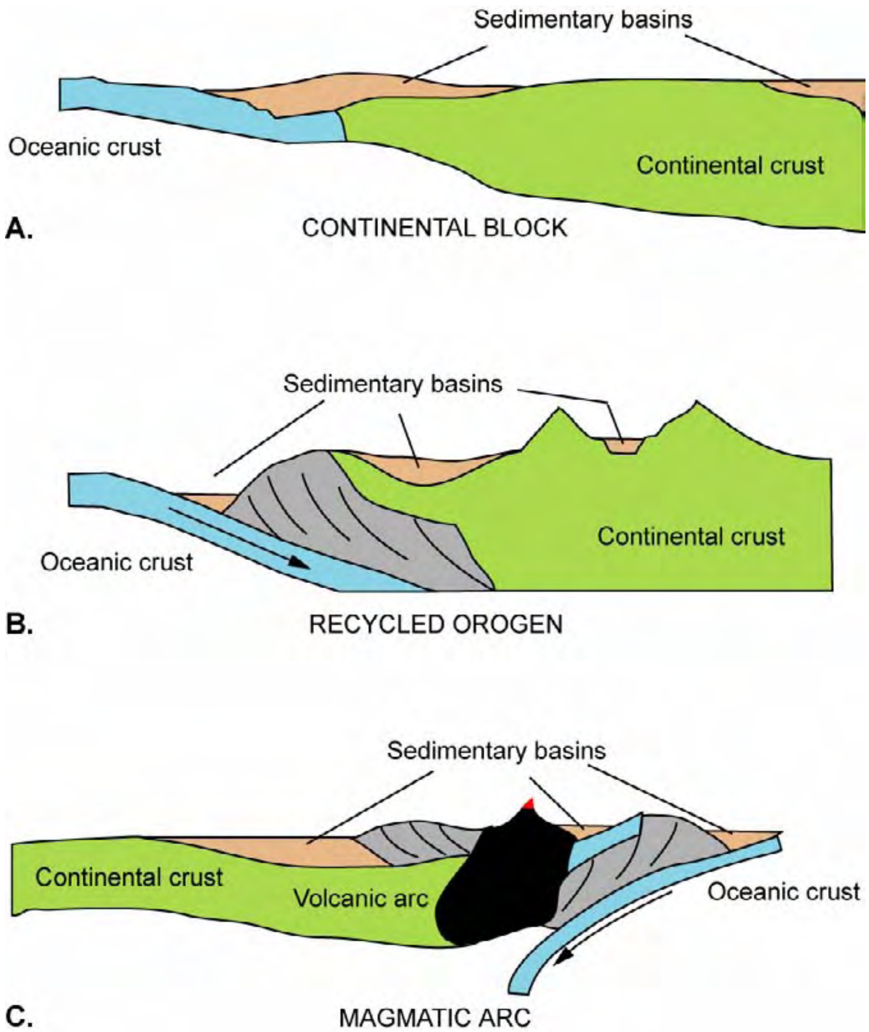

Figure 7. Generalized tectonic environments and their sedimentary basins (from Dickinson and Suczek, 1979). Summaries are provided in the glossary.