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by

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TABLE OF CONTENTS

	Page
Abstract	1
Introduction	1
Design Approach and Development Activities	3
Overview to the DIGS Project	3
Design Framework	4
Plate Boundaries Module	5
Personal Involvement	7
Participants	8
Unit Overview	9
Plate Boundaries	9
Student Response Sheet	9
Unit Assessment	11
Rubric and Scoring	12
Scoring of Plate Boundaries Knowledge Assessment	13
ITEM Plate Boundaries	13
1. Divergent	14
2. Convergent	17
3. Transform	22
ITEM 4a	25
ITEM 4b	26
Scoring of Student Response Sheet	28
ITEM A1	28
ITEM A2	28
ITEM A3	28
ITEM B5	29
ITEM B7	29
ITEM C2	30
ITEM C3	30
ITEM Divergent Boundary Cross-Section	31
ITEM Convergent Boundary Cross-Section	32
ITEM Transform Boundary Cross-Section	32
ITEM E1	34
ITEM E2	35
ITEM E3	36
ITEM E4	37
ITEM E5	38
ITEM E6	39
ITEM E7	40
ITEM F1	42
ITEM F2	42
ITEM G1	42
ITEM G2	42

Page

ITEM G3	43
Scoring of Unit Assessment	43
ITEM A1	43
ITEM A2	44
ITEM B1	46
ITEM B2	47
ITEM C1	47
ITEM C2	51
ITEM C3	58
ITEM C4	59
Scoring of Students' Think-Aloud Data on Unit Assessment Task	61
Think-Aloud, Medium High (Student ID 09-1)	61
ITEM A1	61
ITEM A2	62
ITEM B1	62
ITEM B2	63
ITEM C1	64
ITEM C2	65
Additional Notes	66
Think-Aloud, Medium Low (Student ID 04-2)	66
ITEM A1	66
ITEM A2	67
ITEM B1	67
ITEM B2	69
ITEM C1	69
ITEM C2	70
ITEM C3	71
ITEM C4	72
Ongoing Analysis	72
References	73
Appendix A: Plate Boundaries Knowledge Assessment	75
Appendix B: Student Response Sheet	78
Appendix C: Seismic Eruption Tutorial	84
Appendix D: Unit Assessment	88
Appendix E: Class A Student Data	93
Appendix F: Student Cross-Sections	98

ABSTRACT

A content-based rubric was designed to score students' data from an experimental middle-school plate boundaries unit which integrates technology-based learning and an inquiry-based framework. Data from one class was scored as were two "think-aloud" protocols. The rubric and scoring were designed to assess the success of the unit at promoting the development of inquiry skills and to identify the parts of the curriculum which need improvement.

INTRODUCTION

Before the Cold War, the American educational system had a very different approach to science education than it does today. Then, science education was designed for the top students who were expected to be the scientists of tomorrow. In the post-Sputnik era, this approach has changed because there is recognition that we need to develop a broad base of scientifically literate citizens in order to insure a democracy. Specifically, because technology is all around us, society needs the knowledge and skills to take advantage of technology in order to continue progress as a society. Currently, the goal is for all Americans to be scientifically literate so they can make decisions that affect their everyday lives, such as making a decisions as to whether to test for radon in their homes, etc. (Rutherford & Ahlgren, 1989).

Thus, the implications for science education are large. Specifically, the question is HOW do we educate our students in science in order to promote a scientifically-literate society? Scientific literacy consists of different forms of knowledge (Perkins, 1986).These include **content knowledge, process skills**, e.g., evaluation of evidence, communication, and importantly inquiry; and **understanding the nature of science**, i.e., that it is a dynamic discipline. Science reform efforts are currently focusing on inquiry skills as a means to promote scientific literacy. For example, science education reform efforts in Taiwan, a high performing country on science achievement tests, are focusing on engaging students in inquiry-based learning (Wu & Hsieh, 2006). They assert that instead of memorizing definitions and facts, students should develop meaningful understandings and conduct scientific explanations by exploring natural and scientific phenomena (Taiwan Ministry of Education, 1999). The United States is also trying to implement changes along these lines, for example, the NSES (1996) refers to inquiry in terms of the following set of skills: 1) identify questions and concepts that guide scientific investigations, 2) design and conduct scientific investigations, 3) use technology to improve investigations and communications, 4) formulate and revise scientific explanations and models using logic and evidence, 5) recognize and analyze alternative explanations and models, and 6) communicate and defend a scientific argument. However, there is a great deal of data suggesting that students are not developing these essential science process skills. For example, formulating, evaluating, and communicating explanations have been identified as essential features of classroom inquiry (National Research Council [NRC], 1996, 2000); however, most middle-school students have trouble constructing scientific explanations of phenomena (Wu & Hsieh, 2006). Instead, they have a tendency to generate incoherent explanations on the basis of personal ideas (Driver, Guesne, & Tiberghien, 1985; Driver, Leach, Millar, & Scott, 1996) and are not able to make logical relationships between evidence and explanations (Kuhn, Amsel, & O'Loughlin, 1988).

Developing these inquiry skills is of extreme importance to science reform efforts and to scientific literacy, and several projects are underway to develop and study the strategies to do this. One of these projects is the Data Sets for Inquiry in Geoscience (DIGS; Quellmalz, Zalles, Gobert, 2005). Data Sets for Inquiry in Geoscience (DIGS) is a two-year National Science Foundation-funded project (NSF GEO #0507828) that has developed inquiry modules to supplement existing geoscience content curriculum.

DESIGN APPROACH AND DEVELOPMENT ACTIVITIES

Overview to the DIGS Project

The DIGS modules consist of weeklong curriculum units and 1-2-day performance assessments on commonly-taught secondary-level geoscience topics, namely, plate boundaries (middle school) and climate (high school). The modules provide extended inquiry-based investigations employing real geoscience data sets from, for example, the USGS (United States Geological Survey) and visualizations. The models also include performance assessments that provide evidence of geoscience knowledge and inquiry strategies not typically captured in traditional test formats. These units and assessments are designed to yield evidence of students' inquiry skills within the context of geoscience phenomena. The first goal of this project is to study the impacts on student learning of Web-based supplementary curriculum modules that engage middle and secondary-level students in projects in which students use real data sets, visualizations, and software tools to conduct inquiry-based investigations. The second goal is to develop design principles, specification shells, and prototypes of performance assessments that will provide evidence of both students' geoscientific knowledge and inquiry skills (including data literacy skills) and students' skills at using, analyzing, and interpreting technology-based geoscience data sets. The third goal is to develop scenarios based on the specification shells that describe curriculum modules and performance assessments that can be developed for other geoscience standards and curriculum programs (Zalles, Quellmalz, Gobert & Pallant, 2007).

Design Framework

Figure 1 displays the structure of the DIGS modules. Students complete 4-5 day supplementary curriculum units on important geoscience topics. In the process, they examine authentic, publicly-available data sets with the help of appropriate software tools that permit students to select, simulate, and represent the data in different ways. The performance assessments present tasks that require that students transfer the inquiry skills practiced in the units to new, yet conceptually-related problems. The assessment results provide data on the students' interactions with and manipulation of the visualizations and data sets which can, in turn, be used to document the development of inquiry skills (Zalles et al, 2007).

Figure 1. DIGS Module Design

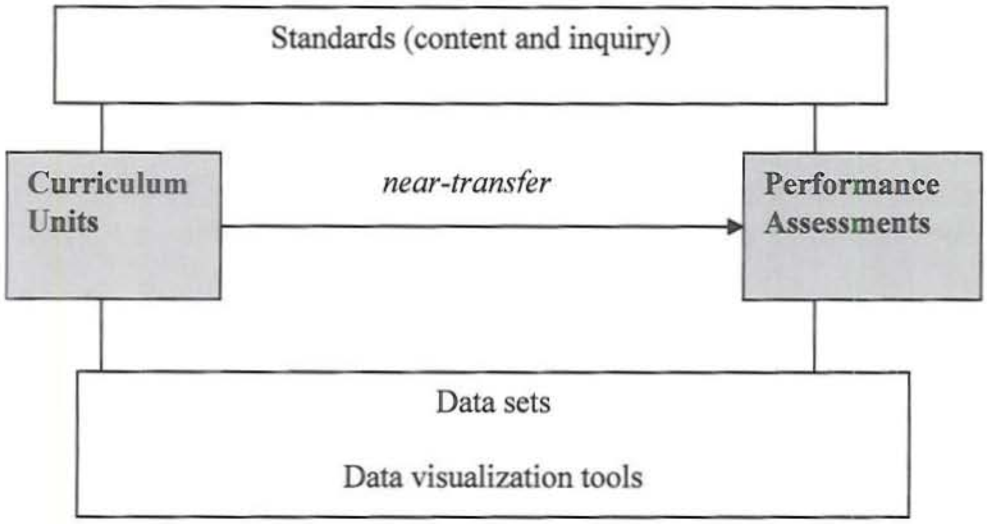


Plate Boundaries Module

The plate boundaries module, *On Shaky Ground: Understanding Earthquake Activity Along Plate Boundaries*, engages students in the use of a time-based simulation to explore the relationship between earthquakes and the characteristics of plate boundaries in the Earth's crust. The tool, Seismic Eruption, simulates multiple decades of three-dimensional data about earthquakes around the world (Jones, 2006).

The unit is designed to take approximately four days and the assessment takes one day. The unit's components are designed to elicit the scientific inquiry abilities identified in national science standards (NSES, 1996). The students: *hypothesize* about the likelihoods of earthquakes at locations around the world, *observe* earthquake patterns along divergent, convergent, and transform boundaries, *collect data* and compare earthquake depth, magnitude, frequency, and location along the different plate boundaries (convergent, divergent, transform) , *analyze* earthquake data sets from United States Geologic Survey database in data tables and in map representations, *"develop"* visualizations of plate boundaries (i.e., create cross-sections using the Seismic eruption tool, draw cross-sections, etc.), and *relate and communicate* interactions of the plates to the emergent pattern of earthquakes. In the assessment, the students run and analyze historical simulations of parallel earthquake data sets but on a type of plate boundary different from the one investigated in the unit.

Figure 2 displays a two-dimensional overhead view of earthquake activity between 1960 and the present in the Seismic Eruption tool, in relation to plate boundaries. Figure 3 displays a cross-sectional view of earthquake activity between 1960 and 2007 at the Mid-Atlantic ridge location specified in Figure 2, plus the key for interpreting the symbols.

Figure 2. Plate boundaries and simulated earthquake activity

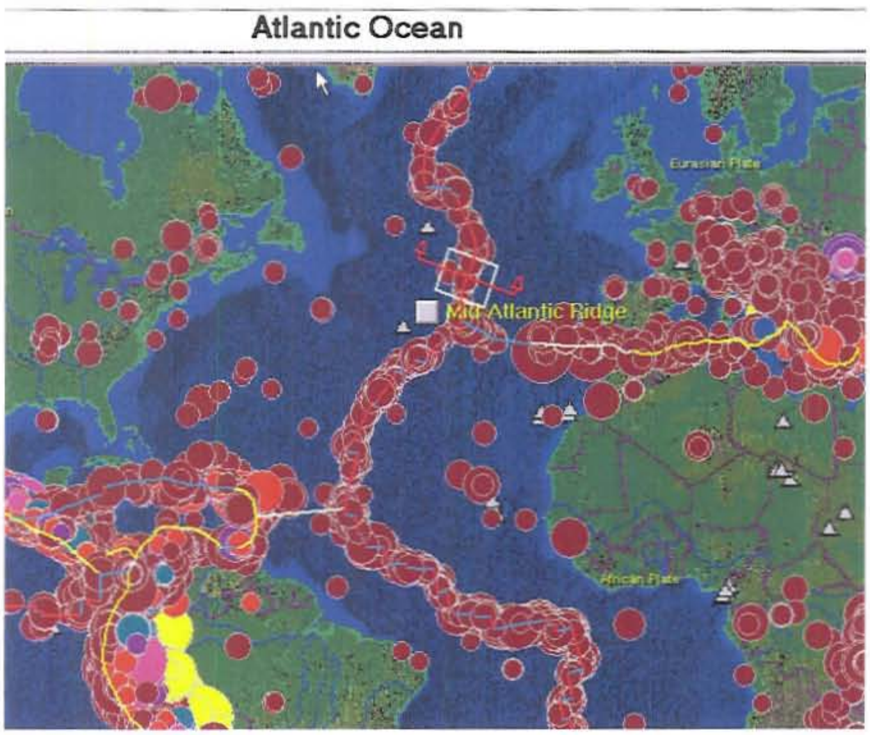
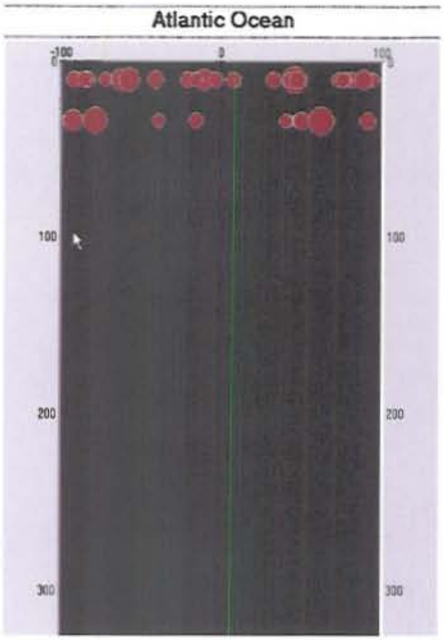
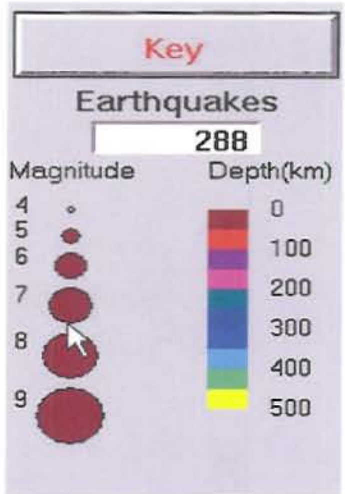


Figure 3. Cross-sectional view of earthquake simulation





Personal Involvement

In the fall of 2006 I became involved with Professor Janice D. Gobert. and her associates on the DIGS project, namely, Amy Pallant from The Concord Consortium, and Edys Quellmalz and Dan Zalles from SRI International in Palo Alto, CA. I served as an intern on the DIGS project. My tasks as part of my internship included: serving as a "participant" in the initial pilot unit of On Shaky Ground by doing a think-aloud for the unit as though I were a student. After this pilot curriculum was run in a school in the Fall of 2006, I coded the data for the first set of feedback forms from the students who participated in this run. From January through May 2007 I worked on constructing a rubric for scoring student responses to the current version of On Shaky Ground, based on the data from one representative class. I was also responsible for coding the data from this class, along with scoring two think-alouds on the assessment task. This rubric is designed to assess the effectiveness of this curriculum at eliciting students' inquiry skills, and the analysis of the scored data from this class will assist in addressing what parts of the unit need to be improved. For the purposes of this paper, we will refer to this class as Class A.

Participants

On Shaky Ground was first pilot tested in two 9th grade classes of a public high school in a suburb of Boston, Massachusetts. The second round of pilot testing was conducted on 15 8th grade classes in a similar community during January and February 2007. In this school, plate boundaries are taught in 8th grade instead of the more typical 9th grade. Class A, which consisted of 21 students, was chosen from this second set of classes, as a representative class of the 15 which participated.

In each of these classes, two students identified by their teacher as being medium-high and medium-low in terms of science achievement were observed "thinking aloud" as they responded to the assessment prompts. Analysis of these transcripts will show how well the prompts elicited the intended inquiry skills and content knowledge (Quellmalz and Haydel, 2003) and provide partial evidence of the content and construct validity of the items (Zalles et al, 2007).

In this paper students from Class A are referred to by their identity number, which was assigned to preserve the students' anonymity. Students worked in groups of twos and threes. In Class A there were nine groups of two and one group of three. The first two digits of the identity number identify which group the student was in, and the second digit identifies the member of the group.

Unit Overview

Plate Boundaries

The section entitled Plate Boundaries is intended to provide an index of the prior knowledge that the students had going into the unit; this prior knowledge assessment can be found in Appendix A. In this part of the unit, students are asked to draw and describe all three boundaries. Specifically, they are asked to include arrows that show the direction of plate movement, labels that describe whether the plate is oceanic or continental, any geologically significant features found along the boundaries, and where they think the earthquakes occur at each boundary. Afterward they are shown a map of earthquakes around the world and asked how they relate to plate boundaries and how this information supports or refutes the theory of plate tectonics. This is an example of the types of questions that elicit inquiry-based learning, which is the goal of the DIGS project.

Student Response Sheet

The section entitled Student Response Sheet is the main bulk of the unit, and can be found in Appendix B. For part A, students predict what kind of earthquake hazards there are at three cities around the globe, and are asked to assign a number on a Likert scale to each city regarding the risk of a major earthquake hazard. The students are also asked to explain their reasoning on why they assigned that number. This question is revisited at the end of the section in part G to see how much the students learned.

In part B the students familiarize themselves with the Seismic Eruption software (Jones, 2006). They look at maps which showed earthquakes worldwide, and were also able to view cross-sections of the crust to see what kind of patterns the earthquakes made. The students are asked to answer a series of simple data-literacy questions.

Part C prompts the students to come up with characteristics of the earthquakes they observed at different plate boundaries in part B. C1 asks them to brainstorm a list of patterns and characteristics. C2 asks a general question about the occurrence of earthquakes at plate boundaries, while C3 is more specific in asking for characteristics of the earthquakes at the three different boundaries.

In Part D the students revisit to the Seismic Eruption software and print out screenshots of cross-sections they take at each of the three boundaries. The instructions for this can be found in Appendix C. These cross-sections are used for answering questions in the next part, but also can be evaluated to determine the skill the students have with using the software and picking out locations that will show useful data.

For Part E, the students answer questions about the characteristics of earthquakes at the three different boundaries. They are asked to elaborate on the magnitude, depth, frequency, and location of the earthquakes. Then the students are asked to explain how the movements of the plates at each boundary account for the patterns in the earthquake data on which they just elaborated. This part guides the students in first having them identify patterns and then having the students attempt to explain them.

Part F prompts students to apply their knowledge by presenting them with two tables of earthquake data. They are asked to identify the type of boundary represented by each table, and to give three pieces of evidence each to back up their claim.

Part G contains the exact same questions from part A, revisited. If this curriculum is successful at promoting students' inquiry skills, then there should be an increase in students' score in part G over part A.

Unit Assessment

The final section is the Unit Assessment, which can be found in Appendix D. Unlike the first two sections, students completed this part of the curriculum individually. This section focuses on the differences between the three types of convergent boundaries: continental-continental, continental-oceanic, and oceanic-oceanic in different locations than on the original task. This is designed this way so that we could evaluate how well the students carry over the skills they developed during the main portion of the unit.

Questions A1 and A2 ask what similarities and differences, respectively, one might expect to find between the three types of convergent boundaries, and ask the students to state what they are basing their hypothesis on. The goal of these questions is twofold: to see what sort of knowledge the students are using from the curricular unit on the end-of-unit assessment, and to prompt them to make predictions on a transfer task regarding different types of specific convergent boundaries (continental-continental, oceanic-oceanic, and oceanic-continental).

In part B they are shown a map of the world with earthquakes marked and with three locations pointed out, along with three cross-sections. They are asked to describe what they see in the cross-sections and told to match them up with the locations of the world map and note what type of boundaries they are. This section makes available more data for the students to use, but requires them to use what they have learned to identify from the visualizations the type of boundary depicted.

In part C the students are prompted to draw conclusions. C1 asks them to complete a table by listing the magnitudes, depths, and locations of the earthquakes at each of the three boundaries. This question assesses how much content knowledge the student comes away with. C2 prompts them to sketch the three types of convergent boundaries, much like in the Plate Boundaries section, though they are only specifically asked to label the location of the earthquakes, and the question does not mention geologically significant features. Its intent is to bring about understanding by having the students make a 2-D representation of a 3-D mental model. It also brings to light misconceptions the students may have about the processes along these boundaries.

In question C3 the students are asked to describe how the processes along each boundary result in the patterns of earthquakes exhibited in the data. This question is similar to C2, but asks for the response in words instead of a drawing. Finally, in C4 asks them to look at a certain location on the map from part B and predict the likelihood of a big earthquake (magnitude greater than 6.5) in the next 50 years, and to explain their reasoning. This provides an index of 3 inquiry skills, namely, data interpretations from visualizations, making predictions, and defending and communicating a scientific objective.

Rubric and Scoring

The development of the rubric and the scoring of the data for Class A were two iterative processes which depended heavily on each other. As changes were made to the rubric, the students' data were re-coded; if there were too many high or low scores in the students' responses, the rubric was adjusted to be more balanced in terms of producing a bell curve for the data. In doing this it was assumed that the data from Class A would represent a range of responses; for example, the class includes students who are on IEPs

(Individual Education Plans) and who are ELL (English Language Learners). The final coding of students' data from Class A can be found in Appendix E.

Throughout the rubric, two main schemes for coding data were used. The first type are questions out of 1 point. This was used when an answer was either correct or incorrect. The second, more widely used system was out of 2 points. This broke down into 2 points for students who demonstrated full understanding or provided all of the information asked for, 1 point for students who demonstrated partial understanding or provided only part of the information asked for, and 0 points for students who demonstrated no understanding or provided little or none of the information asked for. For a few items questions are scored out of 3 points; this is noted and expanded upon in the rubric.

Scoring of Plate Boundaries Knowledge Assessment

This section is supposed to give a representation of what kind of information the students have going into the unit. However, the teacher of Class A was uncomfortable in letting their students do this section without any kind of introduction to the material, and thus did some preliminary teaching on the subject. As the rubric was written with the intent of creating a bell-curve on some questions, it may need to be revised or rewritten to accurately score a class which did not get a review.

The Plate Boundaries prior knowledge assessment can be found in Appendix A.

ITEM Plate Boundaries

Question

In the boxes below draw a picture of the three different types of plate boundaries. Plate boundaries are best described by the interactions of the two plates. In your drawing include the following:

a) arrows that show the direction of plate movement
b) labels that describe whether the plate is oceanic or continental
c) any geologically significant features found along the boundaries

d) where you think earthquakes occur at each boundary
Write a description of what you have drawn.

1. Divergent

Rubric

Arrows:

1 point for arrows showing plate movement away from each other

0 points for anything else

(Rationale: This is either right or wrong.)

Plates:

1 point for correct labeling of the types of plates: oceanic-oceanic or continental-continental

0 points for anything else.

(Rationale: The student either correctly labels the plates or doesn't.)

Features:

2 points for ridging/new sea floor (for oceanic-oceanic) or rifting (for continental-continental) in correct location

1 point for incorrect location or an incorrect geological feature

0 points for no correct geological features, more than one incorrect geological feature, or an incorrect geological feature and a misplaced geological feature.

(Rationale: Another way to think of this scoring is to assume they start out with two points and subtract one for each misplaced or incorrect feature.)

Quakes:

1 point for correct location of earthquakes at the boundary

0 points for anything else.

(Rationale: This is either right or wrong.)

Description:

2 points for a relatively thorough description with no noticeable inaccuracies that mentions in some capacity that magma comes up through the gap and/or that new crust/ocean floor is formed or some sort of causal mechanism

1 point for a sparser description (does not mention the magma coming up through the gap or some sort of causal mechanism), or one or two minor inaccuracies (such as an incorrect geological feature)

0 points for a completely incorrect description, a sparser description with a minor inaccuracy, or nonsense.

(Rationale: This is intended to have 2 points reflect that the student demonstrates sufficient knowledge about this boundary, 1 point to show they have the right idea but also have some misconceptions, or do not fully demonstrate their knowledge, and 0 points to show the student has no idea what they are talking about. A 3-point scale was discussed, but we did not see enough differentiation between the 2-point responses in Class A to justify further distinction.)

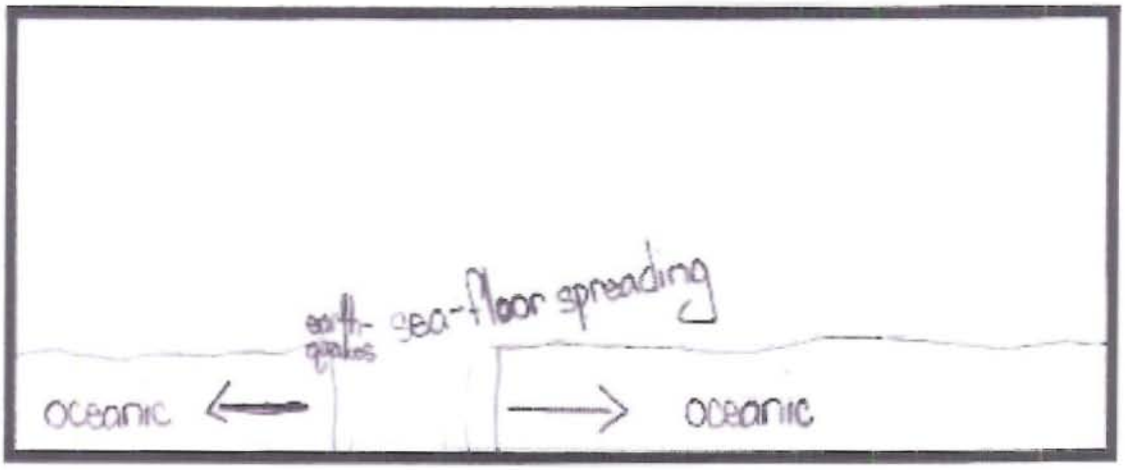
If the student describes a boundary other than divergent, all of these categories receive a score of 0.

If the student leaves the description blank, it is scored with a dash (-) on the grading sheet to indicate missing data. If the student leaves the diagram blank as well, all the items receive a dash.

Illustrative Examples of Student Work

Arrows: 1; Plates: 1; Features: 2; Quakes: 1 (Student ID 01-1)

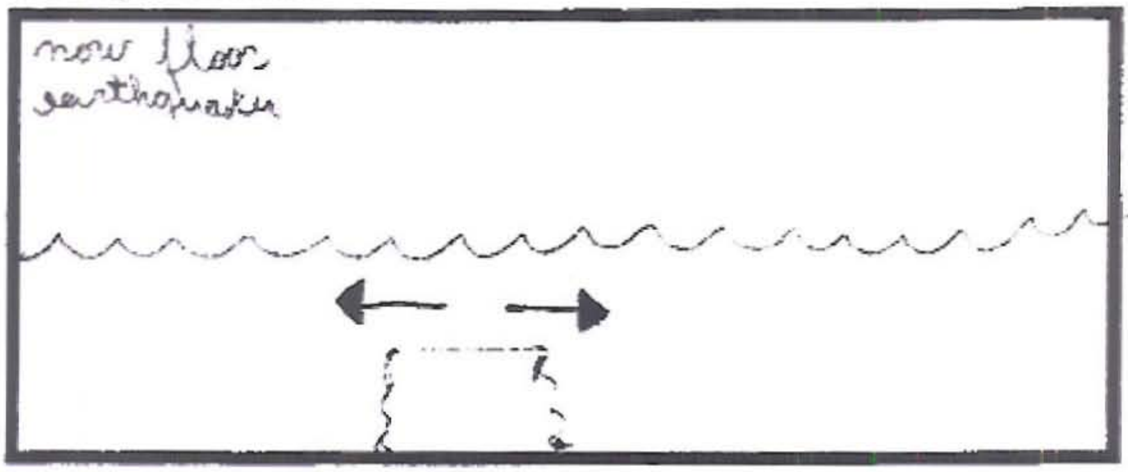
1. Divergent Boundaries



Explanation of Scores:
This student correctly shows the plates moving away from each other. They are labeled as oceanic and oceanic. Sea-floor spreading is an acceptable geological feature, and is correctly placed at the boundary. The earthquakes are also correctly placed at the boundary.

Arrows: 1; Plates: 0; Features: 0; Quakes: 0 (Student ID 06-2)

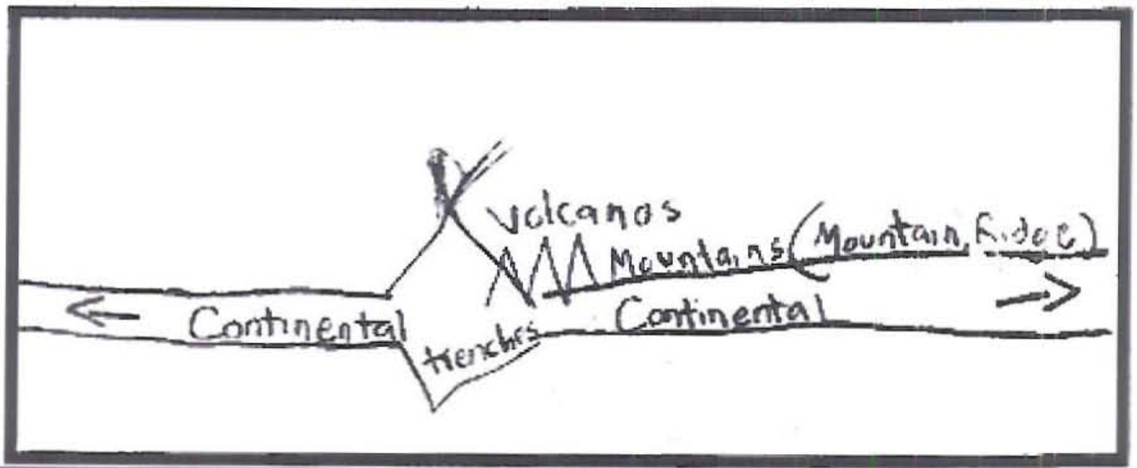
1. Divergent Boundaries



Explanation of Scores:
The only thing this student shows correctly are the two plates moving away from each other. They are not labeled as continental or oceanic, there are no geological features, and no earthquakes shown.

Arrows: 1; Plates: 1; Features: 0; Quakes: 0 (Student ID 09-2)

1. Divergent Boundaries

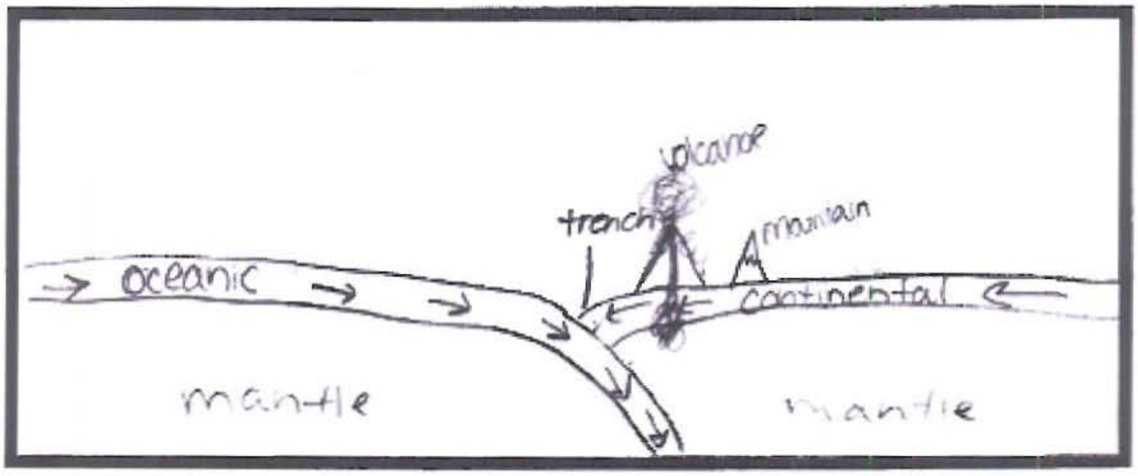


Explanation of Scores:

This student correctly shows the two plates moving away from each other, and labels them as continental and continental. While the trench is a correct feature correctly placed, in continental-continental divergent boundaries mountains and volcanoes do not occur. This student also does not show where the earthquakes are.

Arrows: 0; Plates: 0; Features: 0; Quakes: 0; Description: 0 (Student ID 08-2)

1. Divergent Boundaries



Write a description of what you have drawn:

I drew oceanic crust going under the continental crust because it's more dense. It can cause a trench to form at that boundary also it can cause mountains and volcanoes to form

Explanation of Scores:

This student drew a convergent boundary instead of a divergent one.

Score of 2:
"Two oceanic pieces of crust move away from each & magma from the mantle fills in the crack & cools. This creates new sea floor & causes earthquakes." (Student ID 01-1)
Explanation of Score:
This student correctly describes a divergent boundary and mentions that magma fills the space left by the spreading plates. There are no noticeable inaccuracies.

Score of 1:
"Convection currents in the mantle push crusts appart from each other. This often results in mountains being formed." (Student ID 10-2)
Explanation of Score:
While the underlying causal mechanism is correct, the student drew on their diagram a continental-continental boundary. This type of boundary does not create mountains.

Score of 1:
"This plate boundary is a divergent boundary. Two plates are pulling away from each other. Both are oceanic crusts. At these boundaries, mid-ocean ridges form." (Student ID 02-2)
Explanation of Score:
This description does not mention magma coming up to fill the gap or any sort of causal mechanism. It also does not have any obvious inaccuracies.

Score of 0:
"If continental and continental goes together it goes away from each other" (Student ID 02-1)
Explanation of Score:
This description is completely inaccurate.

Score of 0:
"I have drawn the oceanic & continental crust colliding and creating volcanoes, mountains & earthquakes." (Student ID 04-2)
This is a description of a convergent boundary, and therefore completely incorrect.

Score of 0:
"The ocecanic cruts moves away from the continental crust, so does the continental crust. As they move apart this boundary can form volcanoes, mts, and can also cause earthquakes." (Student ID 04-1)
This description does not include a mention of magma filling the gap or a causal mechanism. It also incorrectly identifies mountains as a geological feature occurring at this type of boundary.

2. Convergent

Rubric

Arrows:

1 point for arrows showing plate movement toward each other
0 points for anything else

(Rationale: This is either right or wrong.)

Plates:

1 point for correct labeling of the types of plates: oceanic-oceanic or continental-oceanic if subduction is shown (oceanic must be going under continental), continental-continental if it is not

0 points for anything else

(Rationale: This is either right or wrong.)

Features:

2 points for trenches, mountains or volcanoes in correct location

1 point for one misplaced geological feature or one incorrect geological feature. A volcano is considered misplaced if it is not completely on the plate that is not being subducted.

0 points for no correct geological features, more than one incorrect geological feature, or an incorrect geological feature and a misplaced geological feature.

(Rationale: Another way to think of this scoring is to assume they start out with two points and subtract one for each misplaced or incorrect feature.)

Quakes:

Oceanic-continental or oceanic-oceanic:

2 point for correct location of earthquakes along the plate being subducted

1 point for earthquakes only at the surface contact or only deep on the plate being subducted

0 points for no earthquakes shown or at an incorrect location

Continental-continental:

2 points for earthquakes along the colliding plates

1 point for earthquakes just at the contact

0 points for no earthquakes shown or at an incorrect location

(Rationale: While the correct answer is of course having the earthquakes all along the subducted plate, the vast majority of students in Class A only showed them as occurring at one point of the swath. We wanted a distinction between the students who got it completely correct and those who were only partially correct. The continental-continental boundary is also on a scale of 2 points so as to be consistent with the boundaries involving subduction.)

Description:

2 points for a relatively thorough description with no obvious inaccuracies that mentions subduction in some sort of capacity (if appropriate) and at least one correct geological feature

1 point for a sparser description that does not mention a correct geological feature, mentions an incorrect geological feature, or other inaccuracies (such as the continental plate going under the oceanic one)

0 points for a completely incorrect description, one with too many inaccuracies, or nonsense.

(Rationale: This is intended to have 2 points reflect that the student demonstrates sufficient knowledge about this boundary, 1 point to show they have the right idea but also have some misconceptions, or do not fully demonstrate their knowledge, and 0 points to show the student has no idea what they are talking about.)

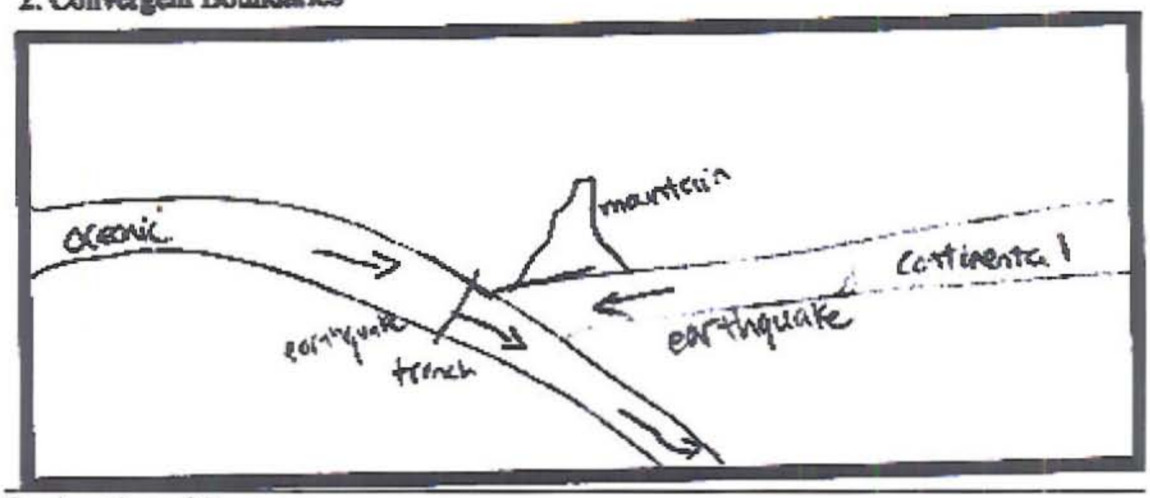
If the student describes a boundary other than convergent, all of these categories receive a score of 0.

If the student leaves the description blank, it is scored with an dash (-) on the grading sheet. If the student leaves the diagram blank as well, all the categories receive a dash.

Illustrative Examples of Student Work

Arrows: 1; Plates: 1; Features: 2; Earthquakes: 1 (Student ID 03-1)

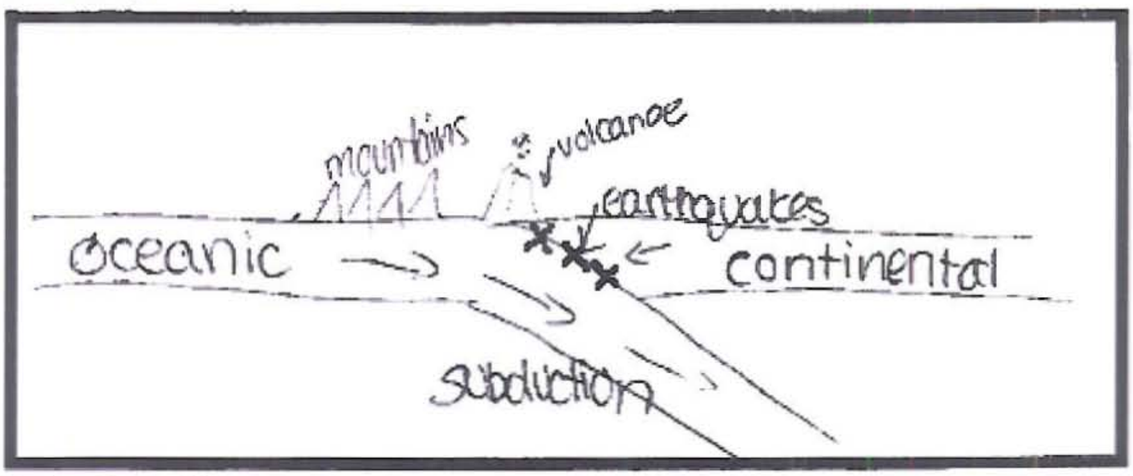
2. Convergent Boundaries



Explanation of Scores:
Correctly shows the two plates moving towards each other, with the oceanic being subducted under the continental. A mountain and a trench are roughly in the correct place. Earthquakes are only shown at the contact point.

Arrows: 1; Plates: 1; Features: 1; Earthquakes: 2 (Student ID 03-2)

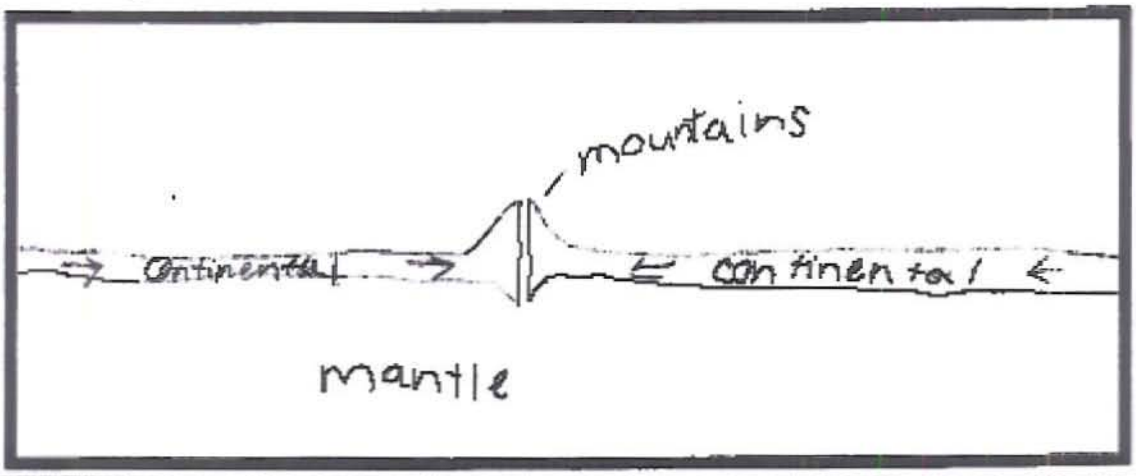
2. Convergent Boundaries



Explanation of Scores:
Correctly shows the two plates moving toward each other, with the oceanic being subducted under the continental. A volcano is misplaced, being on the plate that is being subducted. Earthquakes are correctly shown going down along the subducted plate.

Arrows: 1; Plates: 1; Features: 2; Earthquakes: 0 (Student ID 08-2)

2. Convergent Boundaries

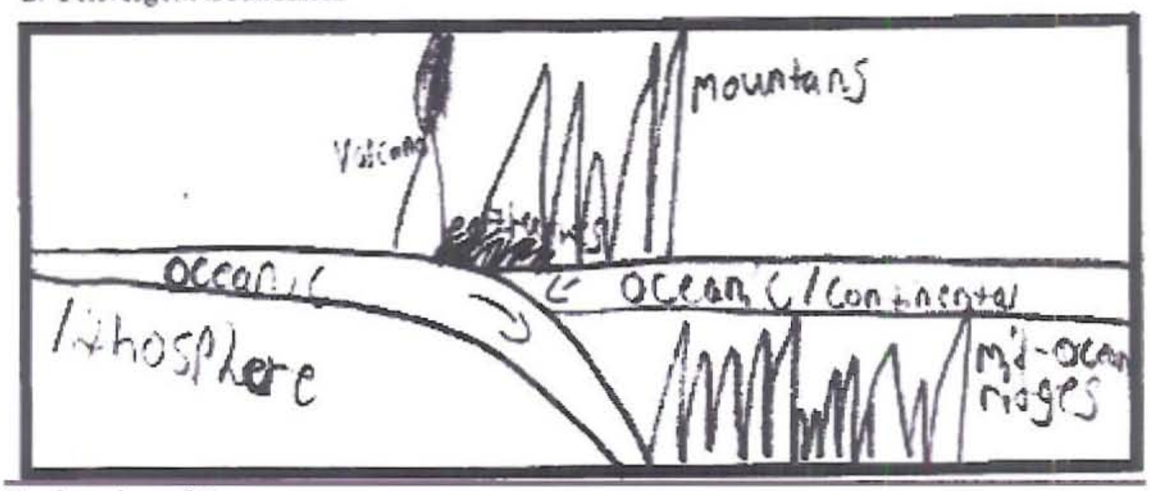


Explanation of Scores:

This student correctly shows a continental-continental convergent boundary, with the two plates moving towards each other, but neither one being subducted. They correctly place mountains along the boundary. However, they do not label where the earthquakes are.

Arrows: 1; Plates: 1; Features: 0; Earthquakes: 1 (Student ID 09-1)

2. Convergent Boundaries

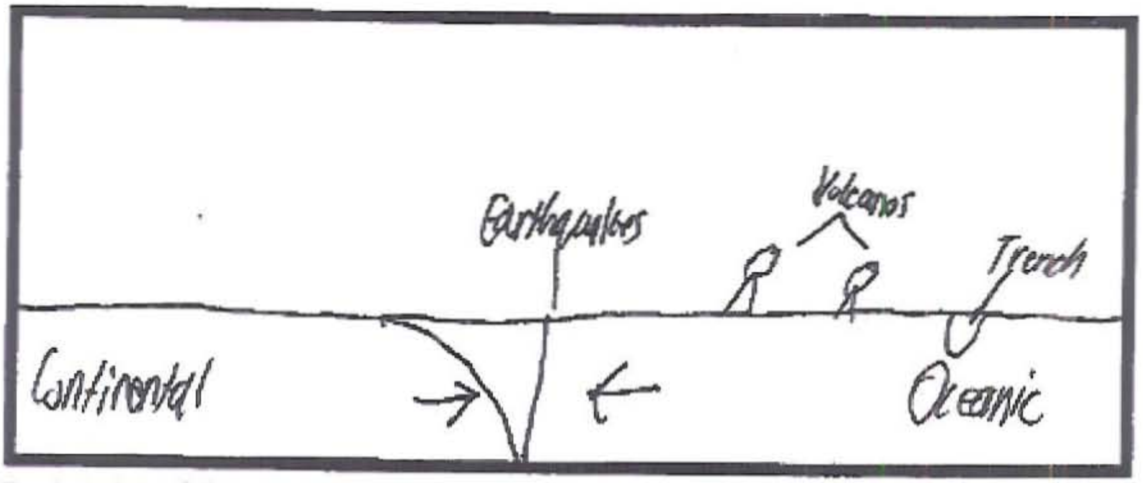


Explanation of Scores:

Correctly shows the two plates moving toward each other, with an oceanic plate being subducted under an oceanic/continental one. This student has both misplaced a volcano and incorrectly put mid-ocean ridges in the mantle under the plate not being subducted. They label earthquakes as occurring only at the contact point.

Arrows: 1; Plates: 0; Features: 1; Earthquakes: 1 (Student ID 02-2)

2. Convergent Boundaries

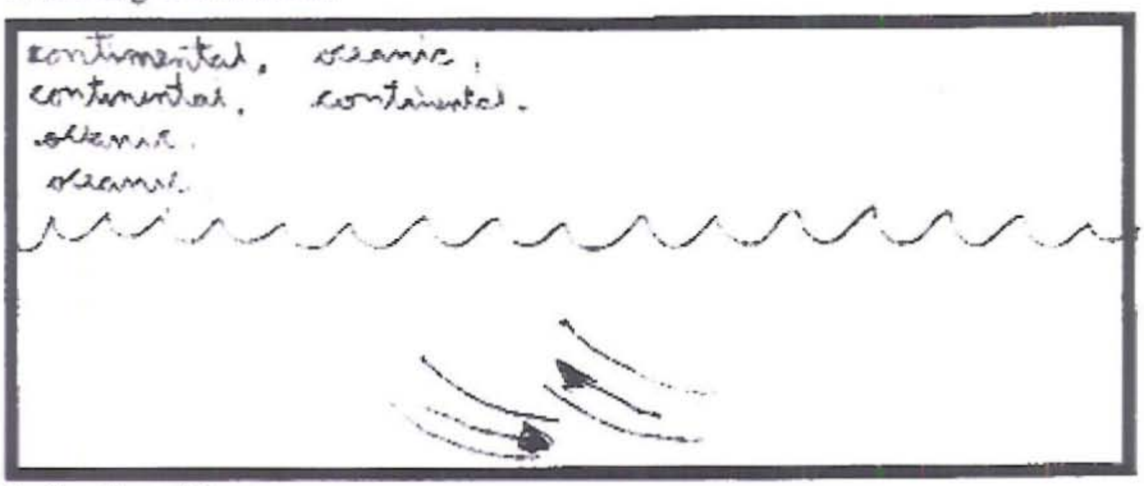


Explanation of Scores:

Correctly shows the two plates moving toward each other, but incorrectly shows the continental going under the oceanic. A trench is misplaced. The earthquakes are shown as being only at the deepest point.

Arrows: 1; Plates: 0; Features: 0; Earthquakes: 0 (Student ID 06-2)

2. Convergent Boundaries



Explanation of Scores:

This student correctly shows two plates moving toward each other. However, they are not correctly labeled. Even if the combinations written in the top left corner were taken into account, there is no indication of which plate is subducted in an oceanic-continental combination, and of course there IS no subduction for a continental-continental convergent boundary. There are no geological features, and no indication of where the earthquakes are.

Score of 2:

"I have drawn a piece of oceanic and continental crust colliding. The oceanic crust, being more dense, is being subducted. This crust melts back into the mantle. This adds pressure, sometimes creating volcanoes." (Student ID 01-2)

Explanation of Score:
Mentions subduction and volcanoes. While the explanation supplied for the existence of the volcanoes is not completely correct, it is small and trivial enough to overlook.

Score of 1:
"I have drawn two oceanic crusts colliding and it creates mountains & earthquakes. This can also be shown with a continental plate & oceanic plate." (Student ID 04-2)
Explanation of Score:
Mentions a correct geological feature, but does not mention subduction.

Score of 1:
"I have drawn one plate moving under the other and subducting." (Student ID 07-2)
Explanation of Score:
Mentions subduction, but no geological features.

Score of 1:
"I drew 2 continental crusts colliding into each other causing mountains to form. This could also happen with two oceanic plates." (Student ID 08-2)
Explanation of Score:
This is inaccurate, as the type of boundary formed by continental-continental (no subduction) is not similar to that formed by oceanic-oceanic, which does exhibit subduction.

Score of 1:
"At a convergent boundary, the oceanic crust (densest) goes under either the other oceanic crust or the continental crust. These can form earthquakes of the highest magnitude, mountains, volcanoes, and mid-ocean ridges." (Student ID 09-1)
Explanation of Score:
Mentions and incorrect geological feature.

Score of 0:
"on the ocean floor the plates move against one another and crash. The ocean floor moves and makes the earth move" (Student ID 06-2)
Explanation of Score:
Nonsense.

3. Transform

Rubric

Arrows:

1 point for arrows showing plate movement sliding along each other
0 points for anything else

(Rationale: This is either right or wrong.)

Plates:

1 point for if the plates are labeled (any combination is acceptable)
0 points if they are not

(Rationale: The student either labels the plates or doesn't.)

Features:

This section is not graded.

(Rationale: There are really no features at this type of boundary for students at this grade level to know about.)

Quakes:

1 point for correct location of earthquakes at the boundary

0 points for anything else.

(Rationale: This is either right or wrong.)

Description:

2 points if they assert that a transform boundary is two plates sliding past each other and either that this causes earthquakes or no significant geological features

1 point for a sparser description that just has the plates sliding past each other, or some inaccuracies such as incorrect geological features

0 points for a completely incorrect description or nonsense

(Rationale: There is not nearly as much information on this boundary to write about as there are on the other two, but we wanted to keep the grading consistent, so we stuck with the 2-point framework and made the distinction between 1 and 2 points as how much detail the student goes into.)

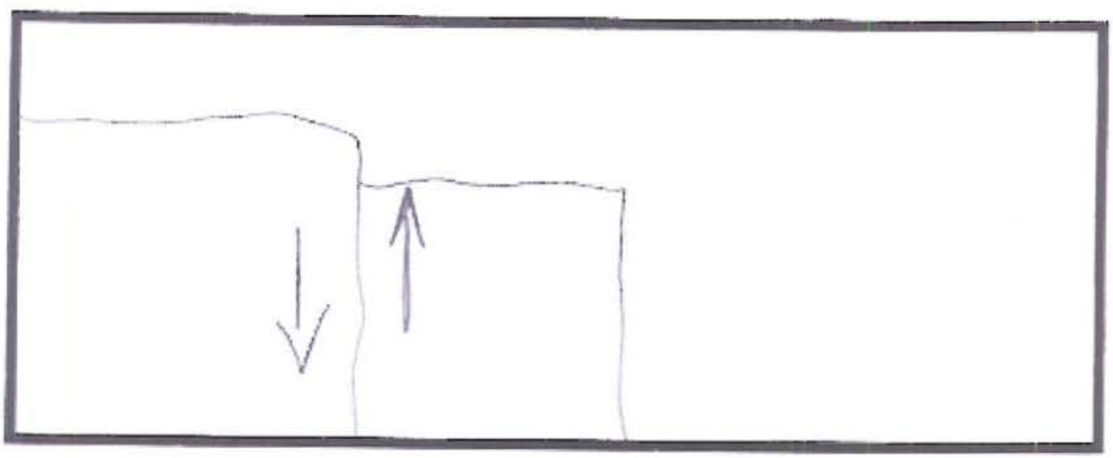
If the student describes a boundary other than transform, all of these categories receive a score of 0.

If the student leaves the description blank, it is scored with an dash (-) on the grading sheet. If the student leaves the diagram blank as well, all the categories receive a dash.

__**Illustrative Examples of Student Work**__

Arrows: 1; Plates: 0; Quakes: 0 (Student ID 01-1)

3. Transform Boundaries

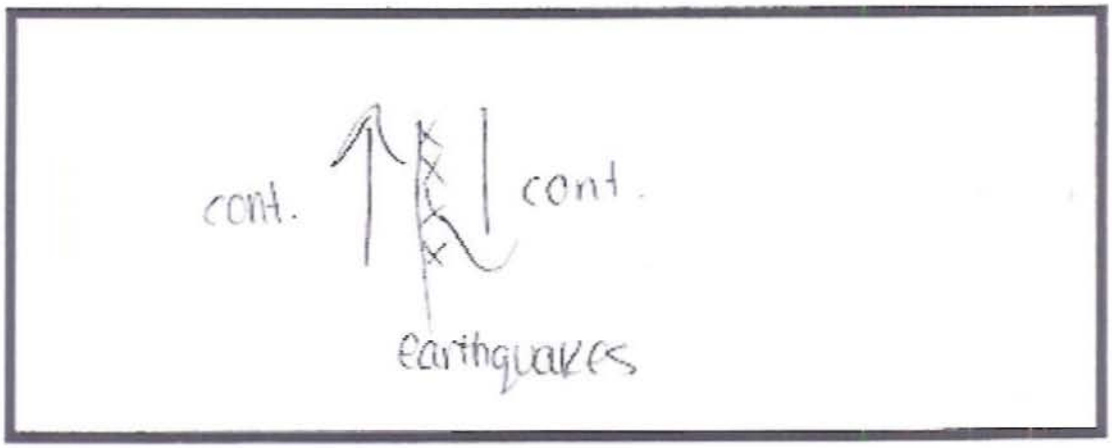


Explanation of Scores:

This student correctly shows the two plates moving past each other, but does not label the plates or indicate where there are earthquakes.

Arrows: 1; Plates: 1; Quakes: 1 (Student ID 03-2)

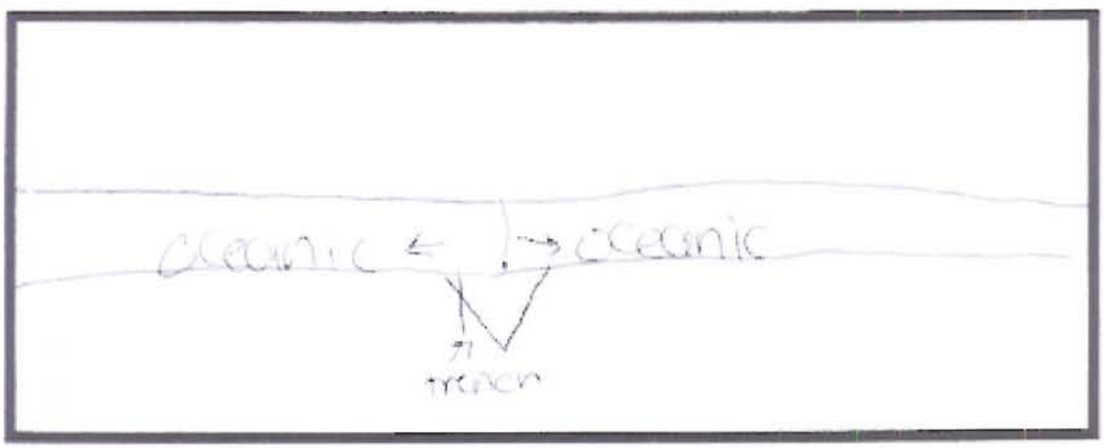
3. Transform Boundaries



Explanation of Scores:
This student correctly shows the two plates moving past each other, labels the plates, and has the earthquakes in the correct location.

Arrows: 0; Plates:0; Quakes: 0 (Student ID 04-2)

3. Transform Boundaries



Explanation of Scores:
This student drew a divergent boundary instead of a transform.

Score of 2:
"I have drawn two pieces of continental crust trying to move past each other and getting stuck sometimes and slipping past each other creating earthquakes." (Student ID 01-2)
Explanation of Score:
Mentions the plates slipping past each other cause earthquakes.

Score of 2:
"This plate boundary is a transform boundary. Two continental plates slide past each other. There aren't any geologic features that occur at these boundaries." (Student ID 02-2)

Explanation of Score:
Mentions the plates slipping past each other and the lack of identifiable geologic features.

Score of 1:
"One plate sliding pass another" (Student ID 02-1)
Explanation of Score:
Mentions the plates sliding past each other but nothing else.

Score of 1:
"When two plates slide past each other causing earthquakes, and mid-ocean ridges and mnts." (Student ID 07-1)
Inaccurately identifies two geological features as occurring.

Score of 0:
"I have drawn two oceanic crusts moving apart and creating trenches & earthquakes." (Student ID 04-2)
Explanation of Score:
This is a description of a divergent boundary and therefore completely incorrect.

ITEM 4a

Question

The following image shows a map of recent earthquakes on Earth. The black dots mark the locations of individual earthquakes. How does the location of earthquakes relate to the location of plate boundaries?

Rubric:

2 points for stating the earthquakes are located along plate boundaries and mentioning a causal mechanism

1 point for simply stating they are located along plate boundaries

0 points for failure to do this, nonsense, or not answering the question

(Rationale: This question was originally on a 1-point, right-or-wrong scale, but Amy Pallant (an associate of Janice Gobert who is also working on the DIGS project) suggested adding a score of 2 for those students who understood the underlying causal mechanism.)

Score of 2:
"The earthquakes are all on plate boundaries & this makes sense because whenever plates interact, and earthquake can be produced." (Student ID 01-1)
Explanation of Score:
States that the earthquakes are along plate boundaries and identifies plate interaction as a causal mechanism.

Score of 1:
"The location of the earthquakes are around the plate boundaries." (Student ID 04-1)
Explanation of Score:
States the earthquakes are located along plate boundaries, but does not identify a causal mechanism.

Score of 0:
"The earthquakes are related to the plate boundaries because to movement of the earthquake can make the plate boundaries spread apart" (Student ID 02-1)
Explanation of Score:
Does not state that earthquakes are located along plate boundaries. Also confuses cause with effect for divergent boundaries.

Score of 0:
"Most of the volcanoes are on the plate boundaries." (Student ID 09-2)
Explanation of Score:
Does not answer the question.

This question is not strictly content-based, but is still within the scope of this rubric. It was analyzed in two categories based strictly on the information the student gave. Similar questions appear throughout the unit.

ITEM 4b

Question

How does this information help support or refute the theory of plate tectonics?

Rubric:

Answer

1 point for stating that the information supports the theory of plate tectonics
0 points for not doing so

(Rationale: This is either right or wrong. Note that the student must actually STATE the information supports the theory of plate tectonics, not just imply it.)

Logic:

2 points for identifying the motion of plates as the causal mechanism for the earthquakes

1 point for mentioning that there is a pattern to the earthquakes, or mentioning that plates move but not identifying this motion as the causal mechanism

0 points for none of these.

(Rationale: Almost without exception, the highest-level answers given by students in Class A mention the movement of the plates, and the students who gave medium-to-low level answers at least realized that there was some overall pattern to the locations of earthquakes.)

Illustrative Examples of Student Work

Answer: 1; Logic: 2
"This supports plate tectonics. Plate tectonics states that the plates are in constant motion & earthquakes can only be caused when plates are moving, so this map supports plate tectonics." (Student ID 01-1)
Explanation of Scores:
They correctly say it supports plate tectonics and mentions that the plate motion is what causes the earthquakes.

Answer: 1; Logic: 1
"This information helps support the theory of plate tectonics because earthquakes only occur where there is some movement underground." (Student ID 01-2)
Explanation of Scores:
They correctly say that it supports plate tectonics. The student recognizes that there is a pattern to the earthquakes, but does not identify the motion of plates to be the cause.

Answer:1; Logic: 0
"This evidence supports the theory of plate tectonics." (Student ID 05-1)
Explanation of Scores:
They correctly say that it supports plate tectonics, but offers no explanation.

Answer: 0; Logic: 2
"The reason for these earthquakes is from plate movement and interaction." (Student ID 05-2)
Explanation of Scores:
The student does not state which hypothesis the information supports, but correctly identifies motion of the plates as the causal mechanism for the earthquakes.

Answer: 0; Logic: 1
"This information helps because it proves that the plates are in constant motion and it shows that there are boundaries." (Student ID 04-1)
The student notes that the plates move but does not identify it as the causal mechanism. They also do not state which hypothesis the information supports.

Answer: 0; Logic: 1
"It helps because it shows where most of the plate boundaries are." (Student ID 04-2)
Identifies that there is a pattern to the location of the earthquakes, but does not state which hypothesis the information supports.

Answer: 0; Logic: 0
"There is a chain of volcanoes that are in the shape of Africas coastline" (Student ID 09-2)
Does not state which hypothesis the information supports and mentions neither the motion of plates nor that the location of the earthquakes have a pattern.

Scoring of Student Response Sheet

This scoring corresponds to the curricular part of the unit.

ITEM A1

Question

Very High Risk: 1 High Risk: 2 Medium Risk: 3 Low Risk: 4

On the scale of 1 to 4 above, where 1 equals very high risk and 4 equals low risk, what is the likelihood of a serious earthquake hazard near Cordoba, Argentina? What are you basing your hypothesis on? Please include reasons even if you are unsure, you will have a chance to revisit these later.

Rubric:

2 points for Likert of 1
1 point for Likert of 2
0 points for Likert of 3 or 4

(Rationale: Cordoba is near an active convergent boundary, and Amy Pallant indicated the correct answer to be 1: Very High Risk. We felt that students at this grade level would not make as large a distinction between Very High and High, and (for example) High and Medium. Thus students got "partial credit" for a Likert of 2.)

ITEM A2

Question

On the scale of 1 to 4 above, where 1 equals very high risk and 4 equals low risk, what is the likelihood of a serious earthquake hazard near Debre Tabor, Ethiopia? What are you basing your hypothesis on?

Rubric:

1 point for Likert of 3
0 points for Likert of 1, 2, or 4

(Rationale: Debre Tabor is near a divergent boundary. While there is a very low chance of a major earthquake, there are still earthquakes on a regular basis.)

ITEM A3

Question

On the scale of 1 to 4 above, where 1 equals very high risk and 4 equals low risk, what is the likelihood of a serious earthquake hazard near Hengshan, China? What are you basing your hypothesis on?

Rubric:

1 point for Likert of 4
0 points for Likert of 1, 2, or 3

(Rationale: Hengshan is not near a plate boundary, and not at risk for boundary-related earthquakes.)

Section B reflects data-literacy. Two of these questions were scored to identify those students who do not understand how to use the software.

ITEM B5

Question

Increase the EQ cutoff number (to 6.5) by clicking the up or down arrow. Then click the Repeat button. How does the total number of earthquakes change? Explain the change in the numbers.

Rubric:

1 point for saying the number decreases
0 points for not
(Rationale: This is either right or wrong.)

Illustrative Examples of Student Work

Score of 1:
"There are less 6.5 magnitude quakes around the world." (Student ID 01-1)
Explanation of Score:
They got the question right.

ITEM B7

Question

Not all data are numbers. The circles in this software are considered Data. What three types of data do these circles represent?

Rubric:

1 saying they represent location, size, and depth
0 points for not
(Rationale: This is either right or wrong.)

Illustrative Examples of Student Work

Score of 1:
"The depth, magnitude, & location of the quakes." (Student ID 01-1)
Explanation of Score:
They got the question right.

Item C1 was done as a class by Class A and was not scored. For classes where this was not a group activity there might be merit into looking at the responses on a deeper level, but coding this question on content is not a priority.

ITEM C2

Question

What comments can you make about the occurrence of earthquakes and the location of plate boundaries?

Rubric:

2 points for stating that quakes occur on or near boundaries and earthquakes at different types of boundaries have different characteristics

1 point for stating that quakes occur on or near boundaries OR earthquakes at different types of boundaries have different characteristics

0 points for stating neither.

(Rationale: Amy Pallant came up with this coding scheme.)

Illustrative Examples of Student Work

Score of 1:
"Almost all quakes occur on or near plate boundaries." (Student ID 01-1)
Explanation of Score:
They identified that earthquakes occur on or near boundaries, but not that earthquakes at different types of boundaries have different characteristics.

Score of 1:
"Different boundaries have different types of eqs" (Student ID 08-1)
Explanation of Score:
They noted that earthquakes at different types of boundaries have different characteristics, but not that earthquakes occur on or near plate boundaries.

Score of 0:
"They occur in clusters and specific areas." (Student ID 05-1)
Explanation of Score:
They stated neither that earthquakes at different boundaries have different characteristics nor that earthquakes occur on or near plate boundaries.

ITEM C3

Question

What comments can you make about the patterns of earthquakes along each of the plate boundaries?

Rubric:

Divergent:

1 point per correct observation: shallow, narrow, low magnitude, tend to zigzag on oceanic/oceanic boundaries, infrequent

Convergent:

1 point per correct observation: thick, on one side of boundary and shallow to deep as they "move away" from boundary, large variation in magnitude. Most frequent occurrences of earthquakes.

Transform:

1 point per correct observation: shallow, infrequent, low magnitude (few large magnitude)

(Rationale: Amy Pallant came up with this coding scheme.)

The scoring of the cross-sections was mainly done to see the quality of the information the students had to work with for questions E1 through E4. However, the rubric could also be used to help assess the skill level the students had in obtaining useful data.

ITEM Divergent Boundary Cross-Section

<u>Rubric</u>:

2 points for a small cluster of shallow earthquakes centered at the boundary line

1 point if the cluster is more than halfway to the edge of the picture or a few earthquakes greater than 6.5

0 points if it shows earthquakes along the length of the graph (resembling continental-continental convergent), if it has several large or deep earthquakes, if it obviously shows a different boundary other than divergent, or other major things that would majorly skew someone's perspective about divergent boundaries

(Rationale: The scoring is supposed to show how well this cross-section represents a "typical" divergent boundary.)

<u>Illustrative Examples of Student Work</u>

Note: Scans of students' cross-sections are too large to be inserted into the text and can be found in Appendix F.

Score of 2:
Group 01
Explanation of Score:
Small cluster of shallow earthquakes centered at the boundary line.

Score of 1:
Group 05
Explanation of Score:
Exhibits some larger earthquakes.

Score of 1:
Group 09
Explanation of Score:
Significantly off-center.

Score of 0:
Group 04
Explanation of Score:
Shows several large earthquakes.

Score of 0:
Group 02
Explanation of Score:
Pattern of earthquakes not consistent with divergent boundary; resembles a continental-continental convergent boundary.

ITEM Convergent Boundary Cross-Section

Rubric:

2 points if it clearly shows subduction

1 point if it only vaguely shows subduction (it may have too many "other" earthquakes cluttering up the graph to clearly see the diagonally-downward curve, but it is visible if one knows what one is looking for)

0 points for not showing subduction.

(Rationale: The most important feature to understand for a convergent boundary is subduction. If the cross-section clearly show subduction, it is unlikely that there will be any anomalies in frequency or strength of earthquakes. The teacher of Class A instructed their students to make sure they were taking a cross-section of an oceanic-continental boundary, but other teachers may not. For the purposes of scoring these cross-sections on how well they represent a "typical" convergent boundary, a continental-continental boundary will not suffice.)

Illustrative Examples of Student Work

Note: Scans of students' cross-sections are too large to be inserted into the text and can be found in Appendix F.

Score of 2:
Group 01
Explanation of Score:
Clearly shows subduction.

Score of 1:
Group 03
Explanation of Score:
Only vaguely shows subduction.

Score of 0:
Group 07
Explanation of Score:
Does not show subduction.

ITEM Transform Boundary Cross-Section

Rubric:

California boundary:

2 points for a line of shallow, very frequent earthquakes with some of them being high magnitudes

1 point if the earthquakes are not very frequent, there aren't any high-magnitude earthquakes, or there are a few deep ones

0 points if there are many deep ones or very few quakes

(Rationale: The transform boundary was the most difficult to score, seeing how it can exhibit two very different profiles. A "California boundary" are those cross-sections which show the boundary between the North American and Pacific plates according to their screenshot.)

Other boundary:

2 points for few, shallow, weak earthquakes roughly distributed evenly in a line

1 point for a few earthquakes being over magnitude 6 or a few deep earthquakes, some asymmetry

0 points for many earthquakes, many high-magnitude earthquakes, or many deep earthquakes

(Rationale: The scoring is supposed to show how well this cross-section represents a "typical", non-Californian transform boundary.)

Illustrative Examples of Student Work
(Note: Scans can be found in Appendix F)

California boundary

Score of 2:
Group 02
Explanation of Score:
Clearly shows a line of shallow, very frequent earthquakes, several with high magnitudes.

Score of 1:
Group 08
Explanation of Score:
Earthquakes not as frequent.

Score of 0:
Group 09
Explanation of Score:
Very few quakes.

Other

Score of 1:
Group 05
Explanation of Score:
Some asymmetry, a few large quakes

Score of 0:
Group 01
Explanation of Score:
Several large, deep quakes

Several of the students' cross-sections were substandard in representing a boundary. For this reason, E1 through E4 were coded on how closely the students' responses were to what their cross-sections showed.

ITEM E1

Question

Compare the depths of earthquakes along each boundary. What comments can you make about the depth of earthquakes along each type of boundary?

Rubric:

2 points for correctly identifying the relative depth of all three boundaries

1 point for correctly identifying only two OR just the deepest boundary if it was significantly deeper than the other two

0 points for not meeting the requirements for 1 or 2 points.

(Rationale: We wanted the score to reflect how much correct information and how complete an answer they gave.)

Illustrative Examples of Student Work

Score of 2:

"At transform & divergent boundaries, the earthquakes are shallow. At convergent boundaries, the quakes are deep." (Student ID 01-1)

Explanation of Score:

Correctly identifies all three boundaries.

Score of 2:

"None of the earthquakes are really deep, but you could tell what kind of boundary it was by looking at the earthquakes." (Student ID 06-1)

Explanation of Score:

Correctly identifies all three boundaries as shown by their cross-sections. Their convergent cross-section was very off-center and only showed the shallower side of the subducting plate, which was not significantly deeper than their cross-sections of transform and divergent boundaries.

Score of 1:

"On the convergent boundary there is more depth and the location is exactly on the plate boundary so there are more earthquakes." (Student ID 04-1)

Explanation of Score:

Only identifies the deepest boundary.

Score of 0:

"The divergent boundries are the deepest. The convergent boundries are the most crowded. The transformed are the most spread out." (Student ID 09-2)

This student had a continental-continental convergent boundary. While their divergent cross-section did indeed show the deepest quakes, it was only by a small margin, and they did not mention the similarity in depth to the other two boundary types. They also mention concentrations and frequencies of earthquakes, which was not part of the question.

ITEM E2

Question

Compare the magnitude of earthquakes along each boundary. What comments can you make about the magnitude of earthquakes along each type of boundary?

Rubric:

2 points for correctly identifying the relative maximum magnitude of all three boundaries

1 point for correctly identifying only two

0 points for less than this

(Rationale: We wanted the score to reflect how much correct information and how complete an answer they gave.)

Illustrative Examples of Student Work

Score of 2:

"At transform & convergent boundaries, there are many medium-sized quakes. At divergent boundaries, the quakes are very low magnitude." (01-1)

Explanation of Score:

Correctly identifies the relative maximum magnitudes of all three boundaries according to their cross-sections.

Score of 1:

"On the transform boundary there is much less magnitude of earthquakes. On the convergent there is high magnitude. On the divergent there is medium magnitude." (Student ID 04-1)

Explanation of Score:

Incorrectly identifies the transform boundary as having the smallest magnitude earthquakes, while their cross-section shows it actually has the largest.

Score of 1:

"The magnitude of the earthquakes for the three boundaries are actually very similar. The convergent boundary is still the deepest, as it should be according to our notes, but despite the lack of earthquakes for the other two boundaries the magnitudes were still very similar to the convergent magnitudes." (Student ID 09-1)

Explanation of Score:

Incorrectly identifies the transform boundary as having similar magnitudes to the convergent and divergent boundaries, while their cross-section shows it to have significantly smaller magnitudes.

Score of 0:

"Convergent boundaries have the biggest magnitude. Divergent boundaries have fairly deep earthquakes and the transformed boundries are shallow." (Student ID 09-2)

Explanation of Score:
Only identifies the magnitude of one boundary; gives irrelevant information for the other two.

Score of 0:
"I don't think that we chose active plates to cross section, because our earthquakes were really small, especially the divergent boundary." (Student ID 06-1)
Explanation of Score:
Contradicts their cross-sections, which show their transform and convergent boundaries exhibiting earthquakes of magnitude 7 and greater.

ITEM E3

Question

Compare the frequency of earthquakes along each boundary. What comments can you make about the frequency of earthquakes along each type of boundary?

Rubric:

2 points for correctly identifying the relative frequency of all three boundaries
1 point for correctly identifying only two of the boundaries
0 points for less than this.

(Rationale: We wanted the score to reflect how much correct information and how complete an answer they gave.)

Illustrative Examples of Student Work

Score of 2:
"On convergent & transform boundaries, earthquakes occur very frequently. On divergent boundaries, there are very few quakes." (Student ID 01-1)
Explanation for Score:
Correctly identifies three boundaries.

Score of 1:
"Convergent boundary very frequent. Transform boundary less frequent." (Student ID 04-1)
Explanation of Score:
Correctly identifies only two boundaries.

Score of 1:
"The divergent doesn't have hardly any earthquakes, transform has a lot, but they are all spread out, and convergent is most dense." (Student ID 06-1)
Explanation of Score:
Correctly identifies only two boundaries; gives irrelevant information for the third.

Score of 0:
"There are many on the convergent and divergent boundaries but not as much on the transform." (Student ID 10-1)

Explanation of Score:
Their cross-sections show the convergent and transform boundaries with relatively frequent earthquakes and divergent with relatively few. They only correctly identify the frequency of earthquakes of the convergent boundary.

ITEM E4

Question

Compare the location of earthquakes along each type of boundary. What comments can you make about the location of earthquakes along each type of boundary?

Rubric:

2 points for stating correct locations earthquakes along each of the three boundaries (according to their cross-sections); 1 point for only stating the locations for two boundaries OR not noting subduction or depth at the convergent boundary when it is present; 0 points for only stating the locations of earthquakes for two boundaries AND not noting subduction or depth at the convergent boundary when it is present, or only stating the location of earthquakes for one or no boundaries.
(Rationale: We wanted the score to reflect how much correct information and how complete an answer they gave, according to what their cross-sections showed. If the subduction was clearly visible on their cross-sections and they did not note that, we wanted that to be reflected in their score.)

Illustrative Examples of Student Work

Score of 2:
"On all three plate boundaries, the locations are very similar. On all three boundaries, the locations are very near the top of the boundaries, with only a few scattered earthquakes in the middle." (Student ID 09-1)
Explanation of Score:
States clear, recognizable patterns of earthquakes for all three of the boundaries. In this case, their cross-section for the convergent boundary did not show subduction.

Score of 2:
"Both transform and divergent boundaries have earthquakes that form along the plate boundary. Convergent boundaries have earthquakes that occur deeper into the plate." (Student ID 03-1)
Explanation of Score:
States clear, recognizable patterns of earthquakes for all three of the boundaries, and notes the depth at the convergent boundary.

Score of 1:
"Earthquakes occur on or around the location of a transform or divergent boundary. Earthquakes occur farther away from a convergent boundary." (Student ID 01-1)
Explanation of Score:
States clear, recognizable patterns of earthquakes for all three boundaries, but does not note convergence or depth at their convergent boundary.

Score of 1:
"Both the convergent and divergent boundries had earthquakes consentrated in one area but the earthquakes at the convergent boundry were more spread out, and were in the middle of subduction." (Student ID 05-1)
Explanation of Score:
Only stated clear, recognizable patterns of earthquakes for two boundaries.

Score of 0:
"The divergent earthquakes occur at the plate boundary, but the convergent and divergent are all spread out." (Student ID 06-1)
Explanation of Score:
Only stated clear, recognizable patterns for two boundaries AND did not note subduction at their convergent boundaries.

At this point it seems the students in Class A were taught which characteristics were supposed to be representative of which boundary, as even students with severely misrepresentational cross-sections got these questions factually correct. Thus these three questions were scored on factual correctness, and not on what the students' cross-sections showed. This part of the rubric may need to be rewritten if this is not typical in other classes.

ITEM E5

Question

Describe how the movement of plates along a divergent boundary account for the patterns of earthquakes you have been describing.

Rubric:

2 points for an answer that states that the earthquakes are rare, shallow, and weak because the two plates moving apart cause little vibration, or that since the two plates are moving away, the earthquakes are formed on that line

1 point for partially correct explanations that have factual errors or confuse cause with effect, or an assertion that the rare, shallow and weak quakes are caused by the two plates moving away from each other with no further explanation

0 points for not fulfilling the requirements for 1 or 2 points

(Rationale: "Pattern" could be interpreted either as the location or the characteristics of the earthquakes, so we allowed for both. If the student made some small errors in the explanation or were not thorough enough, we wanted that reflected in their score.)

Illustrative Examples of Student Work

Score of 2:
"There is very little vibration when the plates move away from each other, so there are very few earthquakes." (Student ID 01-1)
Explanation of Score:
Correctly identifies the rarity of earthquakes being due to low vibration as plates move away from each other.

Score of 2:
"Because the two plates are spreading apart it is not going to cause many earthquakes because it is not colliding." (Student ID 10-1)
Explanation of Score:
"Not colliding" is close enough to having little vibration.

Score of 2:
"The two plates at the boundary move away from each other and the earthquakes occur at the point where they separate." (Student ID 05-2)
Explanation of Score:
Correctly identifies the cause of the pattern of the earthquakes forming along the boundary.

Score of 1:
"When two plates move apart, they cause rare, shallow and weak quakes." (Student ID 02-1)
Explanation of Score:
Stated that the root cause is two plates moving apart, but does not explain enough WHY that causes the pattern of earthquakes shown.

Score of 1:
"The new crust that is created makes more movement in the plate boundary causing earthquakes to occur in the middle." (Student ID 04-1)
Explanation of Score:
They have the basic idea, but there are some factual errors in their explanation, such as confusing cause with effect.

Score of 0:
"All the earthquakes occur on the line." (Student ID 06-1)
Explanation of Score:
Does not answer the question.

ITEM E6

Question

Describe how the movement of plates along a convergent boundary account for the patterns of earthquakes you have been describing.

Rubric:

2 points for pinpointing subduction as the cause of frequent, deep, and mid-to-large size earthquakes

1 point for partially correct explanations, mention of subduction but not of the characteristics of the earthquakes, or no mention of subduction but mention of collision causing the characteristics of the earthquakes

0 points for not meeting the criteria for 1 or 2 points

(Rationale: At this point virtually all the students in Class A were talking about subduction, even those whose cross-sections did not clearly show it, so we assumed they had learned about the "proper" characteristics of a convergent boundary. We also wanted the score to reflect into how much detail the student went.)

Illustrative Examples of Student Work

Score of 2:
"The two plates move toward each other and one is subducted under the other. That is why the earthquakes are deep and medium-sized." (Student ID 01-1)
Explanation of Score:
Mentions subduction as the cause and the characteristics of the resultant earthquakes.

Score of 1:
"Convergent boundaries are colliding against each other so that causes a lot of earthquakes." (Student ID 10-1)
Explanation of Score:
States collision instead of subduction.

Score of 1:
"The subducting plate at this boundry causes a lot of movement beneth the surface. The point where the less dense plate subducts is where the earth quakes occur." (Student ID 05-1)
Explanation of Score:
Factual errors; states the less dense plate subducts instead of the more dense plate.

Score of 1:
"The earthquakes occur where there is subduction." (Student ID 06-1)
Explanation of Score:
Does not state the characteristics of the resultant earthquakes.

Score of 0:
"The movement of plates is evident by the scattered, high amount, level of earthquakes, which are also mostly where the plates meet." (Student ID 09-1)
Does not answer the question.

Score of 0:
"When two plates move toward each other, they cause frequence, shallow, and deep earthquakes." (Student ID 02-1)
Explanation of Score:
Does not state subduction or collision.

ITEM E7

Question

Describe how the movement of plates along a transform boundary account for the patterns of earthquakes you have been describing.

<u>Rubric</u>:

2 points for identifying the plates moving past each other as the cause of the earthquakes, and saying they're shallow or other type of characteristic (they can say there are many and strong OR few and weak because it depends on what kind of transform boundary one is looking at)

1 point for identifying the plates moving past each other as the cause of earthquakes but not stating a characteristic of those earthquakes, or just saying that the slippage causes the earthquakes to be along the boundary

0 points for not meeting the requirements of 1 or 2 points

(Rationale: Unlike the convergent boundary, on this question as many students in Class A said transform earthquakes were frequent and strong as said they were weak and infrequent, so we allowed either as a correct answer. We also wanted the score to reflect into how much detail the student went.)

<u>Illustrative Examples of Student Work</u>

Score of 2:
"The two plates jolt past each other, creating high-magnitude quakes." (Student ID 01-1)
Explanation of Score:
Identifies the plates moving past each other as the cause of the earthquakes and provides a characteristic (high-magnitude earthquakes are seen along continental-continental transform boundaries).

Score of 1:
"In a transform boundary, the plates grind against each other to create vibrations. Earthquakes are formed along this line." (Student ID 03-2)
Explanation of Score:
Slippage is identified as causing the earthquakes, and it is stated that they occur along the boundary line.

Score of 1:
"Transform boundaries occur when 2 plates slide past each other. The sometimes get stuck and create pressure. The pressure is then released and the plates are jolted past each other causing earthquakes." (Student ID 10-2)
Explanation of Score:
The plates moving past each other is identified as the cause of the earthquakes, but no characteristics are given.

Score of 0:
"The earthquakes are spread out all over, because when the plates move, there is more space for earthquakes to happen." (Student ID 06-1)
Explanation of Score:
Nonsense.

Score of 0:
"When two plates slide past each other, they cause frequence, shallow, and weak earthquakes." (Student ID 02-1)

Explanation of Score:
Does not identify the cause of the earthquakes.

ITEM F1

Question

What kind of plate boundary is represented by the date from Table 1?

Rubric:

Answer:

- 1 point for convergent
- 0 points for transform or divergent

Evidence:

- 1 point each: many earthquakes, deep earthquakes, strong earthquakes

(Rationale: This coding scheme was supplied by Amy Pallant.)

ITEM F2

Question

What kind of plate boundary is represented by the data from Table 2?

Rubric:

Answer:

- 2 points for transform
- 1 point for divergent
- 0 points for convergent

Evidence:

- 1 point each: few earthquakes, shallow earthquakes, weak earthquakes

(Rationale: This coding scheme was supplied by Amy Pallant. She felt that the characteristics of divergent and transform earthquakes are similar enough so those saying this boundary is divergent should get "half-credit".)

ITEM G1

Question

What is the likelihood of a serious earthquake hazard you expect to find at Cordoba, Argentina? What are you basing your hypothesis on?

Rubric:

- 2 points for Likert of 1 (very high)
- 1 point for Likert of 2 (high)
- 0 points for Likert of 3 or 4 (medium, low) or not indicated

(Rationale: Same scheme as A1.)

ITEM G2

Question

What is the likelihood of a serious earthquake hazard you expect to find at Debre Tabor, Ethiopia? What are you basing your hypothesis on?

Rubric:

1 point for Likert of 3 (medium)

0 points for Likert of 1, 2, or 4 (very high, high, and low) or not indicated

(Rationale: Same scheme as A2.)

ITEM G3

Question

What is the likelihood of a serious earthquake hazard you expect to find at Hengshan, China? What are you basing your hypothesis on?

Rubric:

1 point for Likert of 4 (low)

0 points for Likert of 1, 2, or 3 (very high, high, and medium) or not indicated

(Rationale: Same scheme as A3.)

Scoring of Unit Assessment

This part of the unit assesses how well the students carry over skills developed in the main part of the unit.

ITEM A1

Question

What similarities in earthquake patterns might you expect to find between oceanic-continental, oceanic-oceanic, and continental-continental convergent boundaries? What are you basing your hypothesis on?

Rubric:

2 points for recognizing that a continental-continental boundary will be different from the other two, even if they get details wrong (such as saying all quakes will be deep)

1 point for saying they will all be deep, or have the same magnitude, or cause earthquakes and mountains because they are all convergent boundaries

0 points for clearly incorrect statements, such as saying oceanic-oceanic and continental-continental will be similar

(Rationale: This is being scored strictly on content. For 2 points, the fact that they realized that continental-continental boundaries would be different is much more important than if they still say all the earthquakes will be deep. After that the most common sentiment in Class A was that since they were all convergent boundaries, some sort of characteristic would be the same, such as them being deep, high-magnitude, or frequent.)

Illustrative Examples of Student Work

Score of 2:

"At each of these convergent boundaries, crust is coming toward each other. When oceanic crust is involved at the boundary, subduction occurs. Therefore, these earthquakes will be deeper. At all convergent boundaries, the earthquakes' magnitude are usually high." (Student ID 05-2)

Explanation of Score:
Recognizes that a continental-continental boundary would be different, even though it incorrectly states that at convergent boundaries the magnitudes are high.

Score of 1:
"I think that at all of these kinds of convergent boundaries, there will be a large number of earthquakes. All three of these happen the same way. At each convergent boundary, two crusts are pushing toward each other. (--> <--)" (Student ID 10-2)
Explanation of Score:
States that all three boundaries will have a large number of earthquakes.

Score of 1:
At all convergent boundaries, earthquakes will be deep & medium-sized. I'm basing this on all of the convergent boundaries we saw on the WISE program." (Student ID 01-1)
Explanation of Score:
States that at all three boundaries the pattern of earthquakes will be similar.

Score of 0:
"I expect to find that the oceanic-oceanic earthquakes are not as big because they may have deteriorated over time because of all of the water and materials going over it, the continental-continental I expect to be a little bit harder impact because they probably haven't deteriorated as much." (Student ID 04-2)
Explanation of Score:
This is clearly incorrect.

ITEM A2

Question

What differences in earthquake patterns might you expect to find between oceanic-continental, oceanic-oceanic, and continental-continental convergent boundaries? What are you basing your hypothesis on?

Rubric:

2 points for recognizing that a continental-continental boundary will be different from the other two

1 point if they have a few minor details incorrect, do not recognize continental-continental as being different, or if they recognize that the characteristics of the earthquakes would be different at different types of boundaries but not specifying how

0 points for clearly incorrect statements or gibberish

(Rationale: This is being scored strictly on content. Realizing that continental-continental boundaries would be different is still the most important thing we are looking for while scoring this. After that the most common sentiment in Class A was that the characteristics of the earthquakes at different boundaries would differ somehow, but did not specify how.)

Illustrative Examples of Student Work

Score of 2:
"Between the three types of convergent boundaries there are many differences. First, at a continental-continental boundary no plate is being subducted unlike the other two so the quakes won't be as deep. Also this type of boundary mountains are formed." (Student ID 01-2)
Explanation of Score:
Student correctly recognized that a continental-continental boundary would differ from the other two.

Score of 1:
"Oceanic continental is subduction so I think it is the cause for the biggest earthquakes. Continental-continental is the smallest. Finally. Oceanic-oceanic has the medium amount of earthquakes. They aren't the same crust. They all don't create volcanoes. They all don't oceanic crust." (Student ID 07-1)
Explanation of Score:
Do not specifically recognize continental-continental as being different from the other two.

Score of 1:
"When oceanic crust meets continental they oceanic crust sinks under it because it is less dense. When continental and continental meet they do not do this." (Student ID 10-1)
Explanation of Score:
Minor incorrect details (stating that the oceanic crust is less dense). Does not mention oceanic-oceanic boundary as also having subduction.

Score of 1:
"Some differences might be the magnitudes or depth of the earthquakes. I base my hypothesis on what I have learned so far." (Student ID 05-3)
Explanation of Score:
Recognizes that the characteristics of the earthquakes might be different at different boundaries, but not how.

Score of 0:
"Oceanic-continental is domenated by the oceantic because, its bigger and the continental is "defeted". (Student ID 07-2)
Explanation of Score:
Nonsense.

Score of 0:
"Differences in earthquake patterns on convergent boundaries, are that on oceanic-oceanic plates in the middle of the oceans, the earthquakes sizes could be different from those of oceanic-continental, and continental-continental which aren't on plate boundaries." (Student ID 09-1)

Explanation of Score:
States that oceanic-continental and continental-continental boundaries "aren't on plate boundaries", which is clearly incorrect.

ITEM B1

Question

Next to each picture on the next page summarize the data and describe the patterns of earthquakes along each boundary.

Rubric:

For each picture:

2 points for noting the presence (or absence, for picture B) of subduction (quakes getting diagonally deeper) or other causal mechanisms and noting the characteristics of the earthquakes, or doing just one of these but to a high level of accurate detail

1 point for doing just one of those

0 points for clearly incorrect comments or no summary at all.

(Rationale: Enough students in Class A made specific mention of subduction that it would be considered important while scoring this section. We also wanted how much detail they went into to be reflected in their score.)

Illustrative Examples of Student Work

Score of 2, Picture A:
"This cross-section shows earthquakes getting deeper from the left. This means that the more dense subducted plate, oceanic, is on the left, moving toward the right." (Student ID 01-2)
Explanation for Score:
Notes the presence of subduction and a characteristic of the earthquakes.

Score of 2, Picture A:
"This data shows that there are high-magnitude earthquakes in deep depths. The magnitude of the earthquakes is mostly equal. As the earthquakes go if deeper depths their quantity decreases. They are packed together. There is high risk of high magnitude earthquakes." (Student ID 04-1)
Explanation of Score:
Does not note the presence of subduction, but provides many details of the characteristics of the earthquakes.

Score of 1, Picture B:
"The data shows the earthquakes aren't really deep, or high in magnitudes." (Student ID 05-3)
Explanation of Score:
Notes a characteristic of the earthquakes, but not the absence of subduction.

Score of 1, Picture B:
"This is C. C is a cont-cont convergent, so it wouldn't have subduction. This cross section doesn't have subduction, so it must be C." (Student ID 08-1)

Explanation of Score:
Notes the absence of subduction, but not any other characteristics of the earthquakes.

Score of 0, Picture B:
"This is a continental-continental boundary & at location C." (Student ID 01-1)
Explanation of Score:
Does not include a summary.

Score of 0, Picture B:
"alot deep earthquakes" (Student ID 02-1)
Explanation of Score:
On this picture there are actually no deep earthquakes.

Score of 0, Picture B:
"because it have only reds points" (Student ID 06-2)
Explanation of Score:
Gibberish.

ITEM B2

Question

Describe and label each picture with the type of convergent boundary (continental-continental, continental-oceanic, oceanic-oceanic) and the letter it corresponds to with the map above.

Rubric:

Picture A:
- 2 points for oceanic-continental boundary at location A
- 1 point for either
- 0 points for none

Picture B:
- 2 points for continental-continental boundary at location C
- 1 point for either
- 0 points for none

Picture C:
- 2 points for oceanic-oceanic boundary at location B
- 1 point for either
- 0 points for none

(Rationale: The two categories were either right or wrong.)

ITEM C1

Question

Compare the magnitude, depth, and location of earthquake epicenters along the convergent boundaries by completing the table below

Rubric:

First Column (magnitude):

Continental-continental: small/medium, less than oceanic-oceanic

Oceanic-oceanic: medium/large, less than or equal to continental-oceanic

Continental-oceanic: medium/large

1 point for each correct boundary

(Rationale: The range of answers for this column was greater than for depth, so we gave a greater degree of latitude for the correct answers. Because of this we put in the second criterion for two of the boundaries to ensure they had the relative magnitude correct as well. We deliberately did not put a limiting factor on continental-oceanic so that if a student put large for oceanic-oceanic and medium for continental-oceanic, they would only lose 1 point and not 2.)

Second Column (depth):

Continental-continental: shallow

Continental-oceanic: medium/deep (must be less than or equal to oceanic-oceanic)

Oceanic-oceanic: deep

1 point for each correct boundary

Exception: If they answer continental-continental: deep, continental-oceanic: medium, oceanic-oceanic: shallow, they get 1 point total.

(Rationale: This column was much more straightforward than the first. Several students in Class A put continental-oceanic as "deep", so we allowed for this in the correct answers. We specified that it still needed to be less than or equal to oceanic-oceanic for the case where the student puts oceanic-oceanic as "medium" and continental-oceanic as "deep". Set up this way, both are incorrect and the student loses 2 points. The exception is set up because in this case, the student has clearly mixed up the continental-continental and oceanic-oceanic boundaries, but correctly identified the continental-oceanic.)

Third Column (location):

Continental-continental: scattered

Continental-oceanic – along the boundary

Oceanic-oceanic – along the boundary

1 point for each correct boundary

(Rationale: This coding scheme is very straightforward and was supplied by Amy Pallant.)

Illustrative Examples of Student Work

Magnitude

Score of 3:

Continental-continental: *small/medium*

Oceanic-oceanic: *medium*

Continental-oceanic: *large* (Student ID 01-2)

Explanation of Score:

Correctly identifies the magnitude of all three boundaries absolutely and relatively.

Score of 2:

Continental-continental: *large*

Oceanic-oceanic: *medium*

Continental-oceanic: *medium* (Student ID 01-1)
Explanation of Score:
Incorrectly identifies continental-continental earthquakes as having large magnitudes.

Score of 1:
Continental-continental: *large*
Oceanic-oceanic: *large*
Continental-oceanic: *medium* (Student ID 03-1)
Explanation of Score:
Continental-continental is incorrect. While the other two boundaries fall within the acceptable ranges, they incorrectly have oceanic-oceanic as having larger magnitude earthquakes than continental-oceanic.

Score of 0:
Continental-continental: *large*
Oceanic-oceanic: *small*
Continental-oceanic: *small* (Student ID 02-1)
Explanation of Score:
All three boundaries outside acceptable ranges.

Depth

Score of 3:
Continental-continental: *shallow*
Continental-oceanic: *deep*
Oceanic-oceanic: *deep* (Student ID 01-2)
Explanation of Score:
All three boundaries are within acceptable ranges. Continental-oceanic is less than or equal to oceanic-oceanic, and is therefore correct.

Score of 3:
Continental-continental: *shallow*
Continental-oceanic: *medium*
Oceanic-oceanic: *deep* (Student ID 02-2)
Explanation of Score:
All three boundaries are within acceptable ranges.

Score of 2:
Continental-continental: *shallow*
Continental-oceanic: *medium depth*
Oceanic-oceanic: (blank) (Student ID 04-2)
Explanation of Score:
Both stated boundaries are correct.

Score of 1:
Continental-continental: *shallow*
Continental-oceanic: *deep*
Oceanic-oceanic: *medium depth* (Student ID 01-1)
Explanation of Score:
Oceanic-oceanic is incorrect. While continental-oceanic is within the acceptable range, it is not less than or equal to oceanic-oceanic, and thus is also incorrect. Continental-continental is correct.

Score of 1:
Continental-continental: *deep*
Continental-oceanic: *medium depth*
Oceanic-oceanic: *medium depth* (Student ID 02-1)
Explanation of Score:
Only continental-oceanic is within acceptable ranges.

Score of 1:
Continental-continental: *deep*
Continental-oceanic: *medium depth*
Oceanic-oceanic: *shallow* (Student ID 04-1)
Explanation of Score:
Scored according to the exception.

Score of 0:
Continental-continental: *medium depth*
Continental-oceanic: *deep*
Oceanic-oceanic: *shallow* (Student ID 10-1)
Explanation of Score:
Continental-continental and oceanic-oceanic are incorrect. Continental-oceanic is not less than or equal to oceanic-oceanic, and is also incorrect.

Location

Score of 3:
Continental-continental: *scattered*
Continental-oceanic: *on the boundary*
Oceanic-oceanic: *on the boundary* (Student ID 05-1)
Explanation of Score:
All three boundaries correct.

Score of 2:
Continental-continental: *scattered*
Continental-oceanic: *medium*
Oceanic-oceanic: *on boundary* (Student ID 02-2)

Explanation of Score:
Correctly identifies continental-continental and oceanic-oceanic. "Medium" not a valid answer.

Score of 1:
Continental-continental: *scattered/on*
Continental-oceanic: *scattered*
Oceanic-oceanic: *scattered* (Student ID 01-2)
Explanation of Score:
Only correctly identifies continental-continental.

Score of 0:
Continental-continental: *on the boundary*
Continental-oceanic: *scattered*
Oceanic-oceanic: *scattered* (Student ID 01-1)
Explanation of Score:
All three boundaries incorrect.

ITEM C2

Question

Draw a sketch of the different convergent boundaries. Draw and label the location of the earthquakes along the boundaries.

Rubric:

Oceanic-continental:

3 points for showing earthquakes all along the subducted plate

2 points for just showing the earthquakes at the contact point or deep within the plate

1 point for not showing earthquakes and/or showing the continental plate being subducted

0 points for obvious lack of understanding such as not showing subduction, or random doodles

(Rationale: Once again, while most of the students in Class A only showed earthquakes at one point, we wanted to allow for those students who correctly showed them all along the subducting plate. Showing the continental plate being subducted was error enough for that to be reflected in the score, but not as severely as not showing subduction at all. The question specifically instructed to show earthquakes, so we wanted it reflected in the score if they didn't. This deviation from the 2-point template was made to allow distinction between a partially complete sufficient answer and a fully complete sufficient answer.)

Oceanic-oceanic:

3 points for showing earthquakes all along the subducted plate

2 points for just showing the earthquakes at the contact point or deep within the plate

1 point for not showing earthquakes

0 points for obvious lack of understanding such as not showing subduction, or random doodles

(Rationale: Similar to that for oceanic-continental. We could not think of an analogous error for this boundary to showing the continental crust being subducted in oceanic-continental.)

Continental-Continental:

3 points for not showing subduction and having the earthquakes scattered along the plates

2 points for not showing subduction and having the earthquakes at just the contact point

1 point for not showing earthquakes

0 points for obvious lack of understanding such as showing subduction, or random doodles

(Rationale: We originally had this on a 2-point scale, but added a category for 3 points for those students who more correctly represented the locations of the earthquakes.)

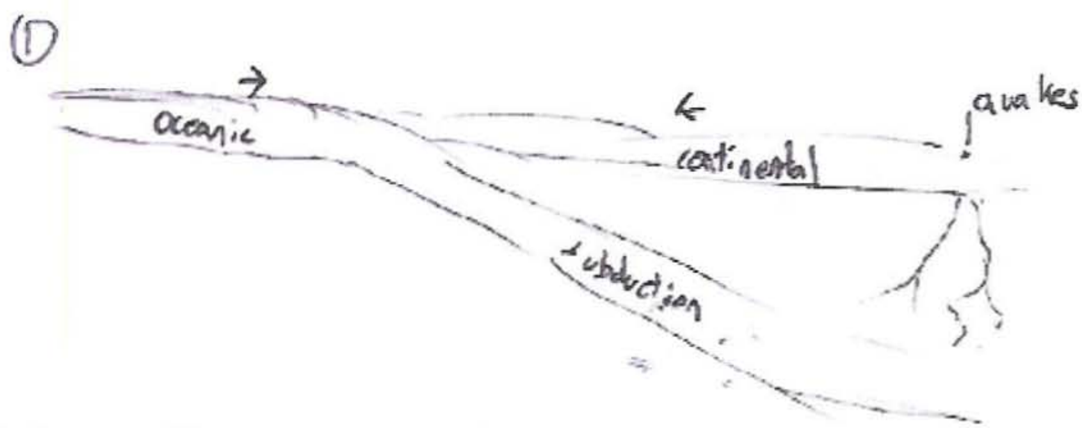
Illustrative Examples of Student Work

Oceanic-continental

Score of 3: (Student ID 03-1)

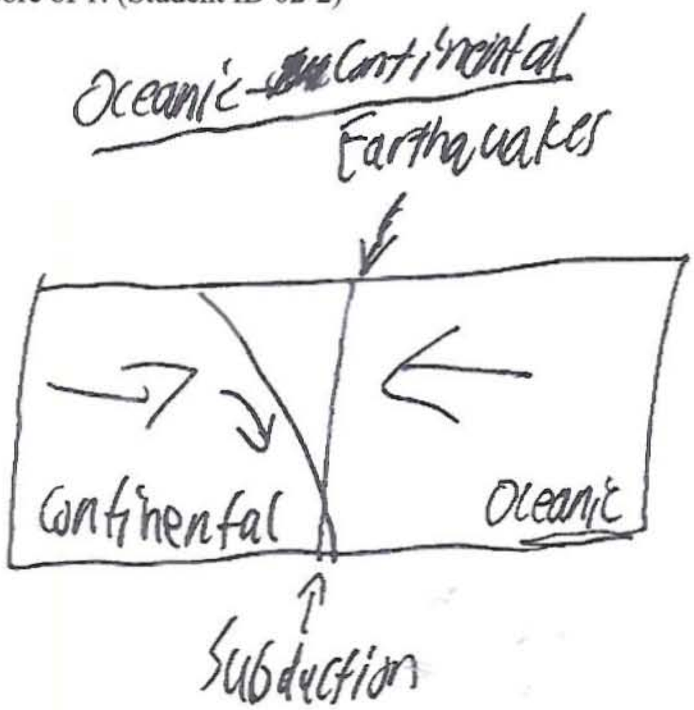
Explanation of Score:
Correctly shows the oceanic plate being subducted under the continental one and earthquakes all along the subducting oceanic plate.

Score of 2: (Student ID 01-2)



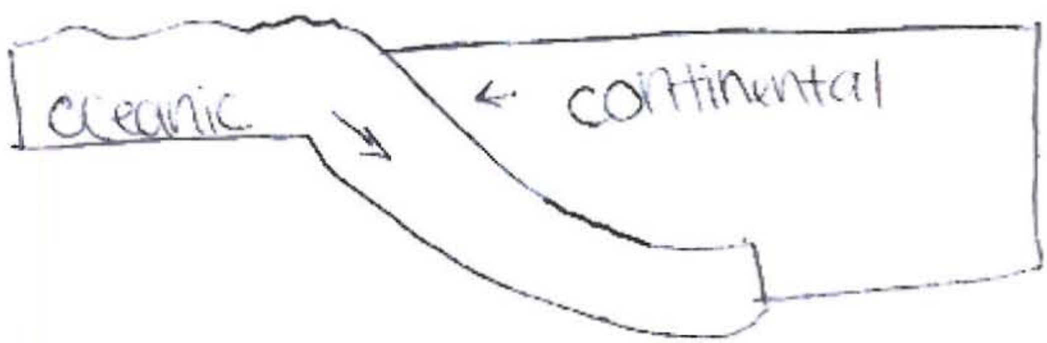
Explanation of Score:
Correctly shows subduction, but only shows earthquakes at the deepest point of the subducted plate.

Score of 1: (Student ID 02-2)



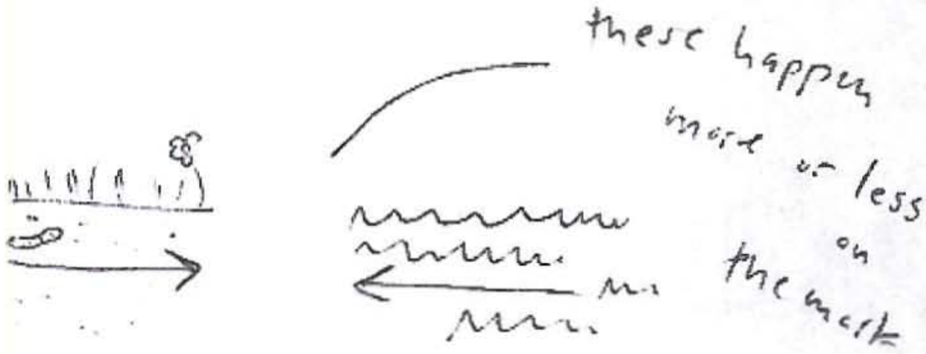
Explanation of Score:
Incorrectly shows the continental plate being subducted.

Score of 1: (Student ID 04-2)



Explanation of Score:
Correctly shows oceanic plate being subducted under the continental plate, but does not show earthquakes.

Score of 0: (Student ID 06-1)



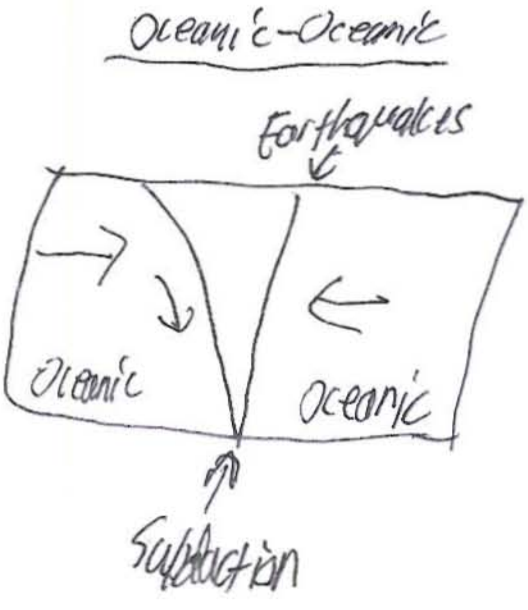
Explanation of Score:
Clearly shows a lack of understanding.

Oceanic-oceanic

Score of 3: (Student ID 03-1)

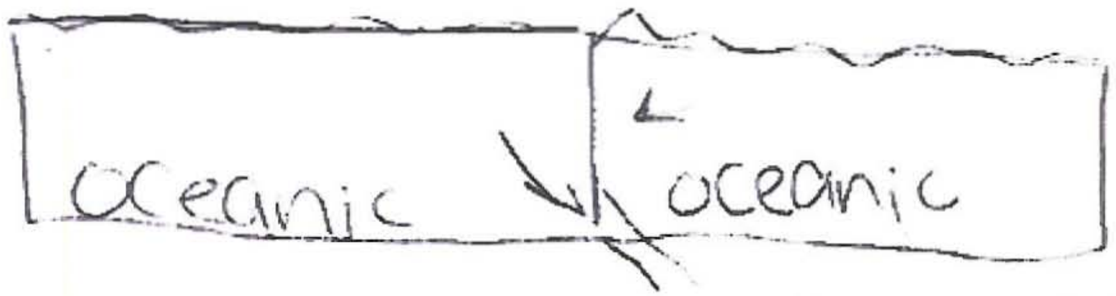
Explanation of Score:
Correctly shows subduction and earthquakes all along the subducted plate.

Score of 2: (Student ID 02-2)



Explanation of Score:
Correctly shows subduction, but only shows earthquakes at the deepest point of the subducted plate.

Score of 1: (Student ID 04-2)

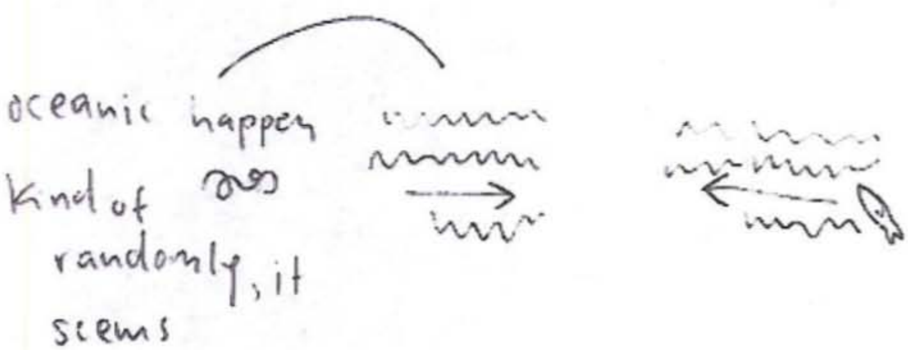


Explanation of Score:
Correctly shows subduction, but does not show earthquakes.

Score of 0: (Student ID 05-1)

Explanation of Score:
Incorrectly does not show subduction.

Score of 0: (Student ID 06-1)



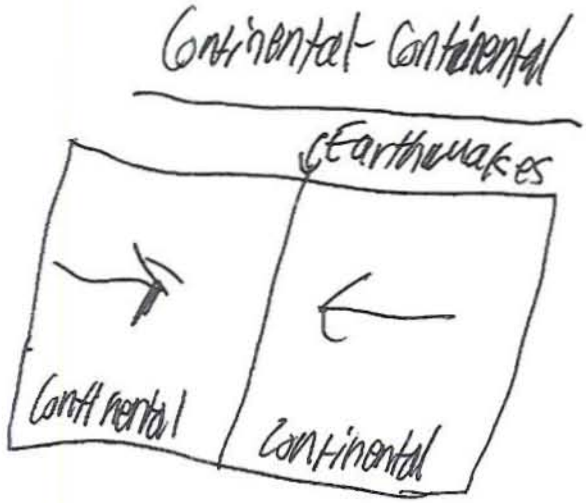
Explanation of Score:
Clearly shows a lack of understanding.

Continental-continental

Score of 3: (Student ID 03-1)

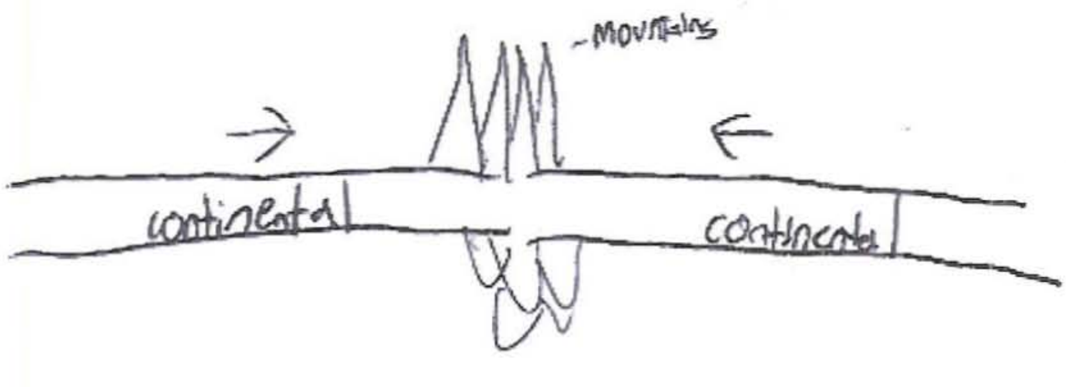
Explanation of Score:
Does not show subduction, and correctly shows earthquakes scattered along the plates.

Score of 2: (Student ID 02-2)



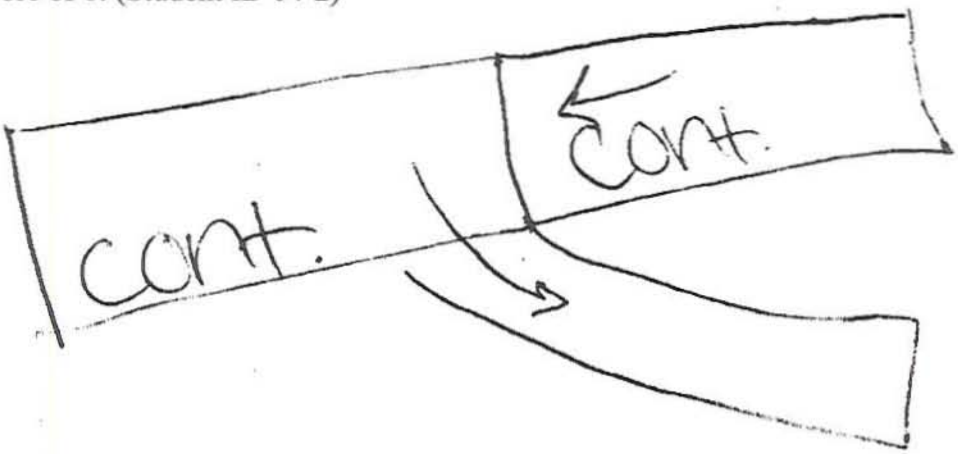
Explanation of Score:
Correctly does not show subduction, but only has earthquakes at the contact point between the two plates.

Score of 1: (Student ID 01-2)



Explanation of Score:
Correctly does not show subduction, but does not show earthquakes.

Score of 0: (Student ID 04-2)



Explanation of Score:
Incorrectly shows subduction.

Score of 0: (Student ID 06-1)

Explanation of Score:
Clearly shows a lack of understanding.

ITEM C3

Question

Explain how the process along each type of boundary helps describe the patterns you see with the data.

Rubric:

2 points for fully explaining how subduction causes the characteristics of the earthquakes for oceanic-oceanic and continental-oceanic boundaries, and how lack of subduction causes the characteristics of the earthquakes for continental-continental boundaries

1 point for only fully explaining two boundaries, explaining the process but not the resultant pattern or characteristics of earthquakes, or not being detailed enough

0 points for not meeting the criteria for 1 or 2 points

(Rationale: We wanted this scoring to reflect how completely and correctly the student answered the question.)

Illustrative Examples of Student Work

Score of 2:

"At both oceanic-oceanic boundaries and oceanic-continental boundaries, subduction occurs and that is why earthquakes are so deep. At continental-continental boundaries, there is no subduction and that is why earthquakes are shallow there. At all these boundaries, quakes are relatively large because the plates are moving towards each other." (Student ID 01-1)

Explanation of Score:

Fully and correctly explains all three boundaries.

Score of 1:

"At the two types of boundarys where subduction occurs you can see the patterns in the earthquakes. Subduction makes one plate go down far underground while still moving to the left or right. The subducted plates cause the quakes which is why they are so deep and away from the boundary." (Student ID 01-2)

Explanation of Score:

Omits the explanation for continental-continental boundaries.

Score of 1:

"If 2 oceanic plates crashed there would be subduction because there are different ages of oceanic crust. If 2 continental plates crashed there would be no subduction because they are the same age. Instead they would collide creating mountains. If continental-oceanic crashes there would be subduction because they have different ages." (Student ID 04-1)

Explanation of Score:

Explains the processes, but not how it exhibits the patterns seen in the data.

Score of 1:

"For the continental-oceanic boundry one plate is subducting and we see the earthquakes happen wher the plate is subducting. For the other convergent boundries

two of the same plates are crashing up against each other and we see somewhat scattered earthquakes." (Student ID 05-1)
Explanation of Score:
Incorrectly describes one of the boundaries (asserting that the oceanic-oceanic boundary has no subduction).

Score of 1:
"This process along each boundary is collision. They are all colliding whether it turning into subduction they are all colliding with one another. Because of this collision it creates bigger and deeper earthquakes." (Student ID 07-1)
Explanation of Score:
Not detailed enough; does not state which boundaries exhibit subduction.

Score of 0:
"The process along each boundary has important data. Magnitude of the boundary can detect how many or how deep the earthquakes will be." (Student ID 02-1)
Explanation of Score:
Nonsense.

Score of 0:
"continental/continental = deep, big, right on boundary. Continental/oceanic = medium, medium, more or less on mark. Oceanic/oceanic = shallow, small, way off" (Student ID 06-1)
Explanation of Score:
Does not answer the question.

ITEM C4

Question

Look at the data from location C on the map. Predict the likelihood of big earthquakes (magnitude greater than 6.5) occurring there within the next 50 years. Explain your reasoning.

Rubric:

Answer:

2 points for saying there is a low risk
1 point for saying there is a medium risk
0 points for saying there is a high risk

(Rationale: This is slightly more complicated than simply being right or wrong, so we included a score for the "middle ground".)

Logic:

2 points for reasoning that it is on a continental-continental boundary and there haven't been any large quakes since the 1960s
1 point for noting just one of these reasons
0 points for not stating either of these reasons

(Rationale: This part is graded purely on content and independent of their score for the answer.)

<u>Illustrative Examples of Student Work</u>

Answer: 2; Logic: 2
"I would say there is a medium to low risk because continental-continental convergent boundaries usually cause weak earthquakes. There aren't any large earthquakes since 1960's so I think there won't be many in the future." (Student ID 02-2)
Explanation of Scores:
Correctly identifies the risk as low and notes the two correct reasons.

Answer: 2; Logic: 1
"I don't really think there will be a big earthquake here in 50 years, but if I saw the data more clearly I would probably be able to guess. If there are big dots there, then yes, there probably will be a big quake in the next 50 years. But if there are just small dots, no." (Student ID 06-1)
Explanation of Scores:
Correctly identifies the risk as low and notes one of the reasons, that the region does not have a history of large quakes.

Answer: 2; Logic: 0
"I think the won't be any big earthquakes will happen greater than 6.5 because even though there are mountains, it won't just start happen suddenly." (Student ID 02-1)
Explanation of Scores:
Correctly identifies the risk as low, but does not give any valid reasons.

Answer: 1; Logic: 1
"I think the likelihood is medium. I think this because they haven't had a real big one in a long time. There is still a chance of one happening though because of the power convergent boundaries can do." (Student ID 07-1)
Explanation of Scores:
Identifies the risk as medium and only gives one valid reason.

Answer: 1; Logic: 0
"I think there is a medium risk of an earthquake hitting location C on the map. The reasoning is that the Indian Plate and the Eurasian Plate joined millions of years ago; and there have been many 6 magnitude earthquakes there before, leaving the possibility of another 6.5 or above occurring within the next 50 years." (Student ID 09-1)
Explanation of Scores:
Identifies the risk as medium, but does not give any valid reasons.

Answer: 0; Logic: 0
"At location C, it is likely for a large quake to occur. Two plates are smashing into each other & causing huge vibrations. These vibrations have a large chance of triggering a 6.5 magnitude earthquake in the next 50 years." (Student ID 01-1)
Explanation of Scores:
Incorrectly identifies the risk as high; does not give any valid reasons.

Scoring of Students' Think-Aloud Data on Unit Assessment Task

In addition to the data taken from Class A, two students, one classified as medium-high and one classified as medium-low in terms of science achievement by the teacher, completed a think-aloud of the unit assessment. Think-alouds can be used as a valuable tool in determining how well a question assesses the knowledge and inquiry skills of the student.

Students worked on answering the questions while talking out loud about what they were doing on the unit assessment inquiry task. These assessments were recorded using an iPod with a voice recorder and then scored. While the scoring of the paper unit assessments (i.e., what the students wrote on their papers) did not differ significantly from the think-alouds for these two students, the disparities in their think aloud data were interesting. For example, on higher-level questions, the students often goes into more detail verbally than on paper. Evaluation of the think-aloud is especially useful on strictly content-based questions. While on paper a student might be correct in listing a fact, their reasoning behind this fact may be erroneous.

Think-Aloud, Medium High (Student ID 09-1)

ITEM A1

Time

0:48

Notes

Response on Assessment:

"On all 3 boundary types, the results would be the same; volcanoes, mountains, earthquakes, and other landforms. Also they would both be created the same way, with the denser plate going beneath the other."

Student's Think-Aloud Protocol:

For all three, same type of boundary movement, denser plate goes under, oceanic-oceanic produces mid-ocean ridge, always produce earthquakes, mountains, volcanoes

All three create same types of landforms, created by denser plate going under.

Score
1
Rationale
Does not recognize that continental-continental does not have subduction.

ITEM A2
Time
3:30
Notes
Response on Assessment:
"differences in earthquake patterns on convergent boundaries, are that on oceanic-oceanic plates in the middle of the oceans, the earthquakes sizes could be different from those of oceanic-continental, and continental-continental which aren't on plate boundaries."

Student's Think-Aloud Protocol:
Differences are that if mountain is formed in oceanic-oceanic, it becomes a mid-ocean ridge, while it's "visible to the eye on land". The sizes of earthquakes could be different due to different locations. Sometimes the earthquakes are on land. The closer they are to the boundary, the bigger the earthquake. Between South America and Africa it's oceanic-oceanic, and it's where some of the biggest earthquakes are.

Score
0
Rationale
These statements are clearly factually incorrect.

ITEM B1
Times
7:57, 9:47, 10:04
Notes
Response on Assessment:
Top picture: "The pattern here is that the farther away from 0 you get (on the negative side), the shallower the earthquakes are. As you get closer to 0, the earthquakes get deeper."

Middle picture: "Most of these earthquakes aren't very deep, being concentrated from 0 – 100 km, and all scattered from -750 to 0 on the far right."

Third Picture: "The pattern here is the closer to 0 it gets (the earthquake), the shallower it is, and the farther away it gets negatively, it gets deeper, stopping from about 300 to 400 km deep."

Student's Think-Aloud Protocol:
B is somewhere in Japan, C is somewhere in Asia, A is in Chile

Top picture: They're kind of scattered around, most are around -500, most of the least deep ones then it goes down from there. Lowest it reaches in kilometers is around 300. There are a few scattered ones on the positive side. No real repeating pattern, except it gets deeper as it gets closer to zero, not as deep further away. Cluster away from there that is just scattered.

Middle picture: Most aren't very deep, 0-100. Most are located at the top, 0-500-neg 500s.

Third Picture: Big concentration of not incredibly deep ones around 0 from 0 to 150 or 200. Below that going to the left and down, it becomes deeper and less frequent along 300 and 400. A few, maybe 10 to 15, around 500.

Scores
Response on Assessment:
B1a: 1
B1b: 1
B1c: 1
Think-Aloud Protocol:
B1a: 1
B1b: 1
B1c: 2
Rationale
Response on Assessment:
B1a: Same.
B1b: Same.
B1c: Does not note earthquakes getting diagonally deeper.
Think-Aloud Protocol:
B1a: Does not note subduction or getting diagonally deeper.
B1b: Does not note absence of subduction.
B1c: Notes subduction (the earthquakes getting diagonally deeper).

ITEM B2
Times
14:26, 15:43, 17:23
Notes
Response on Assessment:
Same as below.

Think-Aloud Protocol:
Middle: Location C because you see a continental-continental boundary because it's India and the Eurasian plate. Only red and a few oranges on map (same as this cross-section)

A is continental-oceanic, because it's the Nazca plate which is ocean and the South America plate which is land.

Leaves B as oceanic-oceanic.

A is third picture because it has all the types of earthquakes and B doesn't reach down to yellow ones, but A does, and there's yellow on the third picture.

First B o-o
Middle C c-c
Third A o-c

Scores
B2a: 0
B2b: 2
B2c: 0

ITEM C1

Time
17:55
Notes
Response on Assessment:
c-c: Magnitude: "small"; Depth: "small"; Location: "on the boundary line"

o-c: Magnitude: "medium"; Depth: "deep"; Location: "scattered"

o-o: Magnitude: "medium"; Depth: "medium depth"; Location: "scarred"

Think-Aloud Protocol:
c-c: magnitude small because all the ones on the middle picture are shallow and not many big circles. Depth small too. Location: on the boundary line because all of them are concentrated at the very top.

o-c: magnitude medium because although there are a lot of small ones, there are many more big ones than on continental-continental especially the ones that aren't very deep Depth is deep because it's the only one that reaches down to 400/500. Location scattered

o-o: magnitude medium because not many magnitudes of 8 or 9. Depth medium goes to 300 but does not reach 400 or 500. Location is scattered because they go down but there is a cluster around 100 positively on the top that doesn't fit with the rest of the group.

Scores
Magnitudes: 3
Depths: 1
Locations: 0

ITEM C2

Times

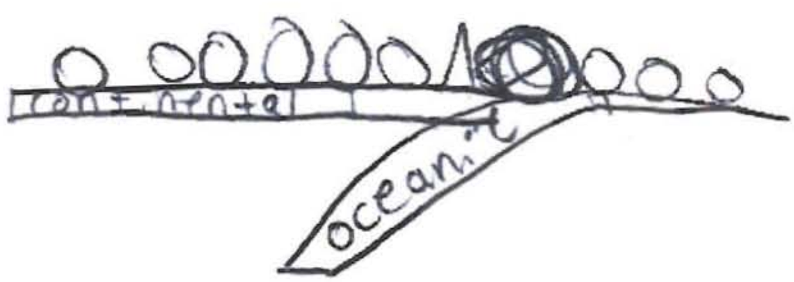
21:34, 23:00, 23:45

Notes

Response on Assessment:

o-c:

Oceanic - Continental

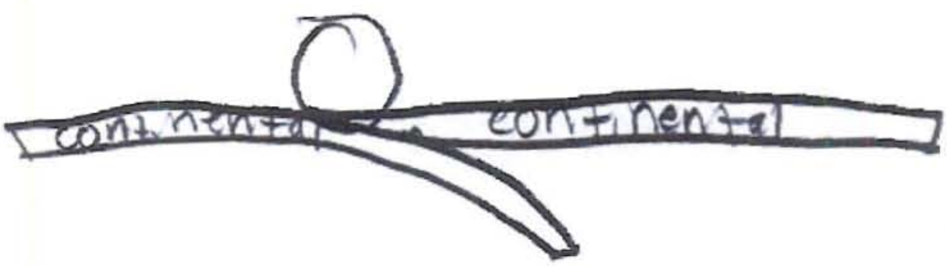


o-o:

Oceanic-Oceanic

c-c:

Continental-continental



Think-Aloud Protocol:
o-c: since the oceanic crust is denser than the continental, it goes under it, pushing the continental up and earthquakes would occur "right around here" where the two meet. Also creates mountains.

o-o: wouldn't really matter which one goes below, well it really matters which one is denser but you don't know for sure, earthquakes occur "right there"

c-c: also wouldn't matter because you don't know which one (I'm assuming he's saying you don't know which continental boundary is denser and gets subducted), earthquakes would occur "right there"

Scores
Oceanic-continental: 2
Oceanic-oceanic: *Response on Assessment*: 2; *Think-Aloud Protocol*: 1
Continental-continental: 0
Rationale
Oceanic-continental: Just has earthquakes at contact point.
Oceanic-oceanic: *Response on Assessment*: Just has earthquakes at the contact point.
Think-Aloud Protocol: No idea what "right there" means.
Continental-continental: Has subduction.

Additional Notes
Time
24:45

I kind of don't understand o-o and o-c or maybe two of them because with o-o and c-c it's, you still don't know which one would go under the other, so maybe only one of them would

Tape cuts off.

Think-Aloud, Medium Low (Student ID 04-2)

ITEM A1
Time
3:10
Notes
Response on Assessment:
"I expect to find that the oceanic-oceanic earthquakes are not as big because they may have deteriorated over time because of all the water and materials going over it, the continental-continental I expect to be a little bit harder impact because they probably haven't deteriorated as much."

Think-Aloud Protocol:
I expect to find that the oceanic-oceanic crusts will make not as hard as an impact because maybe they've deteriorated more because of all the water and minerals that are going over it. The continental might hit harder and cause them more bigger magnitude and deeper earthquakes possibly. The oceanic-continental I don't know what you'd find because it's a mix of both. The oceanic crust might be denser and it might not be as tough and hard because of all the material and water that has gone over it.

Score
0
Rationale
These statements are factually incorrect.

ITEM A2
Time
5:46
Notes
Response on Assessment:
"I think that the oceanic-oceanic wouldn't happen as often because of the deterioration over time and I think the continental-continental might be a little more frequent"

Think-Aloud Protocol:
I think the difference is going to be that in the oceanic-oceanic I think that they might not be as often as the continental-continental, they might be a lot smaller and you can't feel them or know they're there, because the plates might have deteriorated and be a little bit smaller.

Score
0
Rationale
These statements are factually incorrect.

ITEM B1
Times
9:15/14:10, 10:44/14:45, 12:00/15:50
Notes
Response on Assessment:
Top picture: "A. I think that it is oceanic-continental because it is on the coast of South America and they go deeper because of subduction. The pattern is more scattered about."

Middle picture: "C. Because it is on a land mass and because it is not directly near a plate boundary but it is very close to one. I think it is scattered because it is on a land mass and because it depends on where the siesmic waves hit."

Third picture: "B. Because it is in the middle of an ocean and because it is right on a plate boundary the earthquakes would be more frequent, larger in magnitude and bigger in depth. I think it isn't scattered because it is harder to go straight down so it goes diagonal."

Think-Aloud Protocol:
I think it (first picture, location A) is oceanic-continental because it's on the coast of South America and next to the ocean and also because the earthquakes go pretty deep, and I would think that with oceanic-continental the earthquakes would go deep because of subduction.

I think that the patterns for the first one is that it's scattered more because the oceanic-continental is more difficult to always hit in the same place because they could always crush more and scatter them.

I think that the second one is C because its obviously continental-continental because it's in the middle of a piece of land, because it's not directly on a plate boundary it's closer to one so the earthquakes probably wouldn't be as deep but they'd still be pretty frequent.

I think that the second one is also very scattered because it's on a land mass and when two plates hit together it sends out seismic waves everywhere and where it hits can go along with the pattern of how frequent they are.

I think that the last one is B and it's oceanic-oceanic because it's pretty much in the middle of an ocean and it's right on a plate boundary so there would most likely be more earthquakes and they'd possibly have a bigger magnitude and larger depth than most earthquakes.

I think the last one isn't as scattered when it goes down, it goes kind of in a diagonal line. I think it's because it's an ocean and when it goes down it's harder for it to go straight down, so it goes more in a diagonal line.

Scores
B1a: 2
B1b: 1
B1c: 2
Rationale
B1a: Notes presence of subduction
B1b: Does not note the absence of subduction, but notes the shallow, weaker earthquakes
B1c: Notes presence of subduction

ITEM B2

Times

8:43, 10:44, 12:00

Notes

Response on Assessment:

Top picture: A, o-c

Middle picture: C, not specified

Third picture: B, not specified

Think-Aloud Protocol:

I think that the first one is going to be A and I think that it's oceanic-continental.

I think that the second one is C because its obviously continental-continental

I think that the last one is B and it's oceanic-oceanic

Scores

B2a: 2

B2b: *Response on Assessment*: 1; *Think-Aloud Protocol*: 2

B2c: *Response on Assessment*: 1; *Think-Aloud Protocol*: 2

ITEM C1

Time

17:10

Notes

Response on Assessment:

c-c: Magnitude: "medium"; Depth: "shallow"; Location: "scattered"

o-c: Magnitude: "large"; Depth: "medium depth"; Location: blank

o-o: everything blank

Think-Aloud Protocol:

c-c: magnitude more medium because on the cross-section it shows that there are some large earthquakes, but not many. Depth: very shallow, because it is harder on a landmass to go farther down than it would be in oceanic-oceanic. Location: more scattered than directly on the boundary because it is harder for earthquakes on a landmass to stay in one area so they were scattered about instead of just staying on the plate boundary

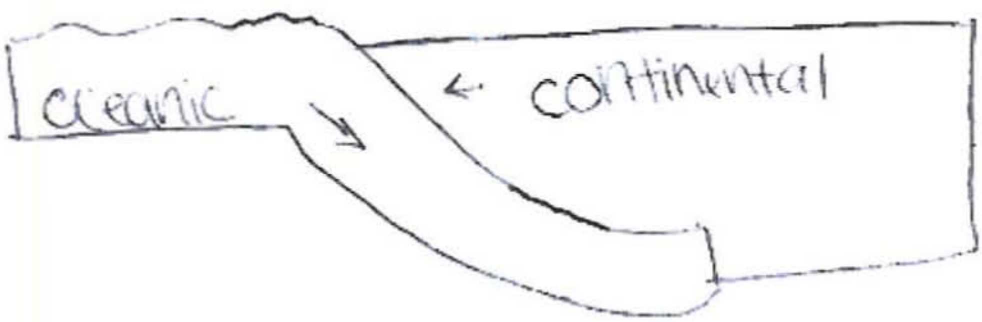
o-c: the magnitude is high because when they hit together they might have more force because it's two different places hitting each other and it makes it more forceful. Depth: medium, because it's on a coastline and it doesn't go all the way down because sometimes it may hit the landmass and not be able to go all the way down. Location:

more scattered because of the same reason that it is hard for an earthquake to stay directly on the boundary when it's dealing with a landmass.

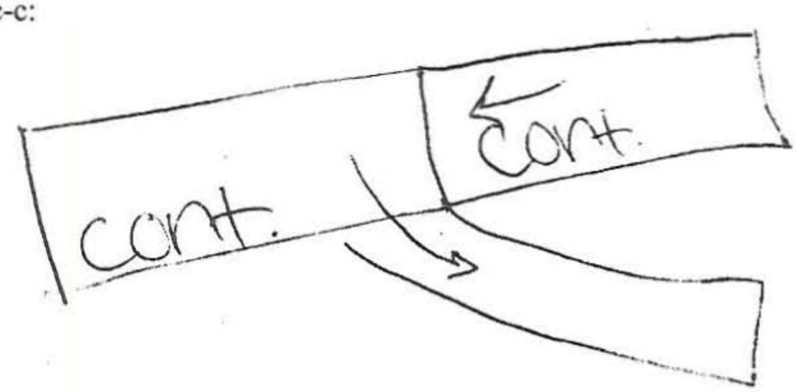
o-o: medium magnitude because the force wouldn't be as hard because the deterioration. Depth: very deep because it doesn't have to deal with a landmass so it'd be easier to go farther down. Location: very close to the boundary and not as scattered because it doesn't have to deal with a landmass and having to go through all of the rock, with the oceanic it has to go through water, plates deteriorated

Scores
Magnitudes: *Response on Assessment*: 2; *Think-Aloud Protocol*: 3
Depths: *Response on Assessment*: 2; *Think-Aloud Protocol*: 3
Locations: *Response on Assessment*: 1; *Think-Aloud Protocol*: 2

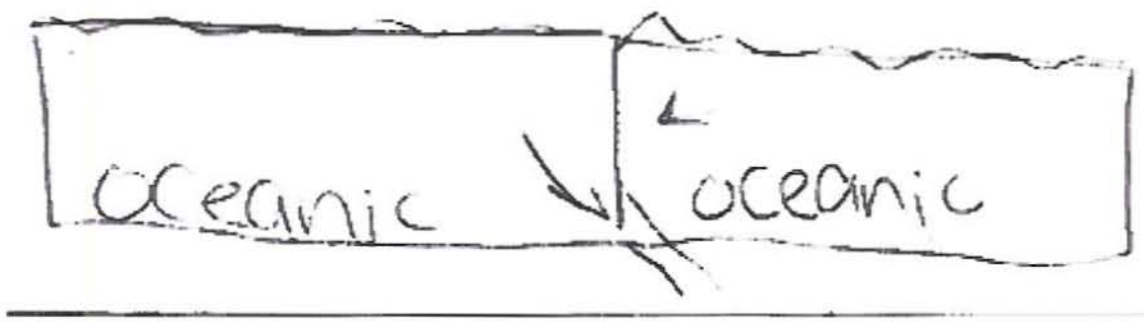
ITEM C2
Time
3:15 (second half), 3:45, 4:00
Notes
Response on Assessment:
o-c:



c-c:



o-o:



Think-Aloud Protocol:
o-c: The oceanic crust would probably subduct under the continental crust because it's less dense for being with the water the whole time in.

c-c: I think that it's kind of hard to tell which one to subduct but it would most likely be the more denser and older one.

o-o: Once again, it'd be harder to tell which one would subduct because they're both the same type of crust.

Scores
Oceanic-continental: 1
Oceanic-oceanic: 1
Continental-continental: 0
Rationale
Oceanic-continental: Shows subduction, but not location of earthquakes.
Oceanic-oceanic: Shows subduction, but not location of earthquakes.
Continental-continental: Has subduction.

ITEM C3
Time
5:15
Notes
Response on Assessment:
blank

Think-Aloud Protocol:
Because they're convergent, because there's so many different types of this boundary because there are three different ways for the crusts to combine, the process is probably a little different for all of them. With the o-o, the force isn't as great because of the deterioration and possibly because it's on water. With the o-c, because there's an oceanic crust involved the force probably still won't be as great but it would definitely be greater than oceanic-oceanic. C-c is different because they are both on much harder, would hit with much greater force because of the way they're formed.

Score
0
Rationale
These statements are factually incorrect.

ITEM C4
Time
6:30
Notes
Response on Assessment:
blank

Think-Aloud Protocol:
I think that in the next 50 years the likelihood of big earthquakes is great because it is two continental crusts hitting together. I don't think they'll be huge, but I think there will be some greater than 6.5 because it is not directly on the crust on the plate boundary so I think that the likelihood there is to have larger earthquakes than they've been having.

Scores
Answer: 0
Logic: 0
Rationale
Said there would be a high likelihood of large earthquakes; reasons given were factually incorrect.

ONGOING ANALYSIS

As of the time of this writing (May 2007), the DIGS project is still in the analyses phase of the project. A total of 100 assessments of the plate boundary module are needed to score to meet the requirements of the original proposal which was funded by the National Science Foundation. In addition, a subset of students' data for the curricular unit must also be scored using the rubric described herein. Also, an inquiry-based rubric must be written and used to score students' inquiry skills, as briefly described herein and outlined by the NSES (1996). Finally, specification shells for other scenarios must be developed that describe additional modules that could be developed on other commonly taught geoscience topics using the DIGS design principles. I will continue to be involved in the DIGS project in the coming months, revising the content rubric, scoring new sets of both content and inquiry data in order to earn co-authorship for forthcoming paper(s) on this project.

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APPENDIX A

On Shaky Ground:
Understanding Earthquake Activity Along Plate Boundaries

(designed to get at prior knowledge, implemented after day 1 in implementation)

Plate Boundaries

In the boxes below draw a picture of the three different types of plate boundaries. Plate boundaries are best described by the interactions of the two plates. In your drawing include the following:

a. Arrows that show the direction of plate movement.
b. Labels that describe whether the plate is oceanic or continental.
c. Any geologically significant features found along the boundaries.
d. Where you think earthquakes occur at each boundary.

1. Divergent Boundaries

Write a description of what you have drawn:

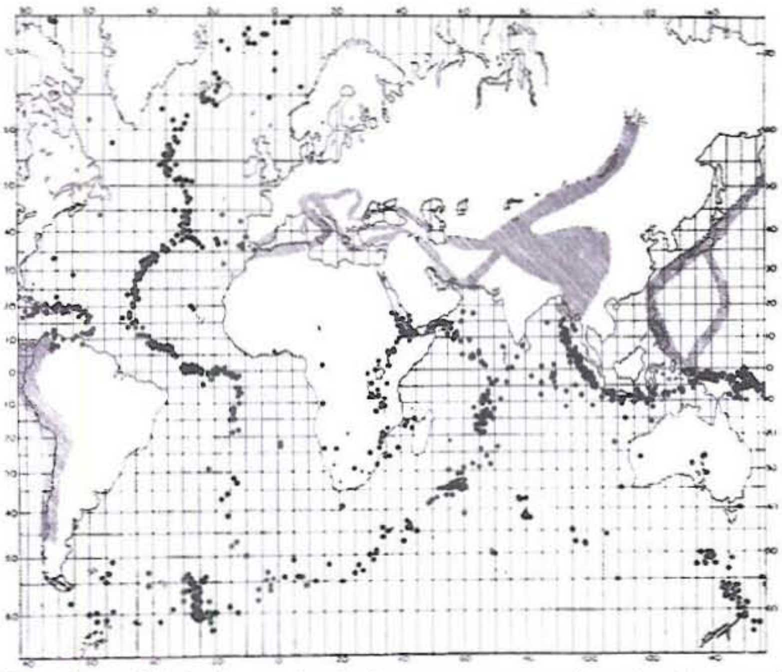
2. Convergent Boundaries

Write a description of what you have drawn:

3. Transform Boundaries

Write a description of what you have drawn:

4. The following image shows a map of recent earthquakes on Earth. The black dots mark the locations of individual earthquakes. How does the location of the earthquakes relate to the location of plate boundaries?



How does this information help support or refute the theory of plate tectonics?

APPENDIX B

On Shaky Ground: Understanding Earthquake Activity Along Plate Boundaries

Student Response Sheet

Part A: Develop a Hypothesis
Use the following scale to answer the questions below:

Very High Risk	High Risk	Medium Risk	Low Risk.	
1	2	3		4

A1.On the scale of 1 to 4 above, where one equals very high risk and 4 equals low risk, what is the likelihood of a serious earthquake hazard near Cordoba, Argentina? What are you basing your hypothesis on? Please include reasons even if you are unsure, you will have a chance to revisit these later.)

A2. On the scale of 1 to 4 above, where one equals very high risk and 4 equals low risk, what is the likelihood of a serious earthquake hazard near Debre Tabor, Ethiopia? What are you basing your hypothesis on?

A3. On the scale of 1 to 4 above, where one equals very high risk and 4 equals low risk, what is the likelihood of a serious earthquake hazard near Hengshan, China? What are you basing your hypothesis on?

Read the instructions in the Student Booklet.

Part B: Current Earthquakes around the World

While looking at the software, look at the map key on the right-hand side of the map and the controls below the map to help answer the following questions.

B1. What do the differently **colored** circles represent?

____

B2. What do the differently **sized** circles represent?

____

B3. Which parts of the world appear to have the most frequent earthquakes? (Compare the number of earthquakes in one area of the world to another for the same period of time.)

____

B4. According to the data in this program, how many earthquakes have occurred around the world from 1960 to the present?

____

B5. Increase the EQ Cutoff number (to 6.5) by clicking the up or down arrow. Then click the **Repeat** button. How does the total number of earthquakes change? Explain the change in the numbers.

____

____

B6. For this question, you should have the plate boundaries showing on your world map (if not, click the **Plates** button in the lower right corner).

Click the **Key** button in the upper right corner of the software, and then record what the different color plate boundaries represent.

Red boundaries represent ________________________.
Blue boundaries represent ________________________.
Yellow boundaries represent ________________________.
White boundaries represent ________________________.

B7. Not all data are numbers. The circles in this software are considered Data. What three types of data do these circles represent?

____

____

Read the instructions in the Student Booklet.

Part C: Observing the Data

C1. Brainstorm a list of patterns and characteristics you observed.

____
____
____
____
____
____
____

Using your observations answer the questions below to help describe and classify the data.

C2. What comments can you make about the occurrence of earthquakes and the location of plate boundaries?

C3. What comments can you make about the patterns of earthquakes along each of the plate boundaries? (For example, do they occur in narrow bands? Wide bands? Are they deep? Shallow?)

a. Describe observations for divergent boundaries:

b. Describe observations for convergent boundaries:

c. Describe observations for transform boundaries:

Read the instructions in the Student Booklet.

Part D: Collecting Data

In a separate document called "Plate Pictures" you will collect data on plate boundaries from around the world.

Read the instructions in the Student Booklet.

Part E: Analysis

E1. Compare the depths of earthquakes along each boundary. What comments can you make about the depth of earthquakes along each type of boundary?

E2. Compare the magnitude of earthquakes along each boundary. What comments can you make about the magnitude of earthquakes along each type of boundary?

E3. Compare the frequency of earthquakes along each boundary. What comments can you make about the frequency of earthquakes along each type of boundary?

E4. Compare the location of earthquakes along each type of boundary. What comments can you make about the location of earthquakes along each type of boundary?

E5. Describe how the movement of plates along a divergent boundary account for the patterns of earthquakes you have been describing?

E6. Describe how the movement of plates along a convergent boundary account for the patterns of earthquakes you have been describing?

E7. Describe how the movement of plates along a transform boundary account for the patterns of earthquakes you have been describing?

Read the instructions in the Student Booklet.

Part F: Applying Your Understanding

F1. What kind of plate boundary is represented by the data from Table 1?

____

Include three pieces of evidence supporting your conclusion.

F1a: Evidence______________________

F1b: Evidence______________________

F1c: Evidence______________________

F2. What kind of plate boundary is represented by the data from Table 2?

____

Include three pieces of evidence supporting your conclusion.

F2a: Evidence______________________

F2b: Evidence______________________

F2c: Evidence______________________

Read the instructions in the Student Booklet.

Part G: Conclude and Persuade

Use the questions below to help shape your conclusions; draw illustrations to support your conclusions. If necessary, you can continue your conclusions on a separate sheet of paper.

G1. What is the likelihood of a serious earthquake hazard you expect to find at Cordoba, Argentina? What are you basing your hypothesis on?

____

____

____

____

G2. What is the likelihood of a serious earthquake hazard you expect to find at Debre Tabor, Ethiopia? What are you basing your hypothesis on?

G3. What is the likelihood of a serious earthquake hazard you expect to find at Hengshan, China? What are you basing your hypothesis on?

APPENDIX C

Seismic Eruption Tutorial: A Closer Look

Constructing a Cross Section

Geologists like to analyze problems (such as the geologic history of an area, the layers and patterns of rocks below the Earth's surface, or the movements of plates on Earth) by constructing cross-sectional views. They do this by drawing a line through a portion of a map. In other words, if you could slice through a portion of Earth, pull away one half, and look at it from the side, you would be able to view what is going on below the surface.

Imagine you had a frosted cake and you were asked the following two questions: How many layers does the cake have and what are the layers made of? How would you tell? You wouldn't be able to answer without cutting the cake and looking at the cake from the side.

This software allows you to create a cross section and view the locations of the epicenters of the earthquakes below the surface. It is a different way to visualize the data. In this case, the software creates a graph where the top of the graph represents Earth's surface and the side of the graph represents kilometers below the surface. You will now create a cross section.

1. Launch the *Seismic Eruption* program if it is not open already.

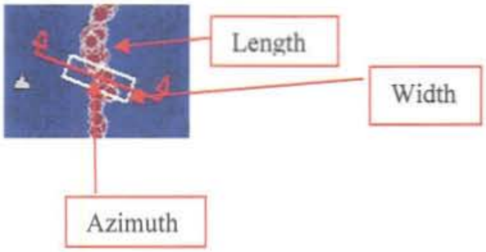
2. Go to the World View. By clicking the world button in the middle of the screen.

3. Go to the **Control Menu** and select "Set-up Cross-Section view." (You will create a cross section by creating a square around the area on the surface map you want to view as a cross section.)

4. The following control box will pop up. In the example below, the settings are 5 degrees azimuth, and a geographical area 100 kilometers long and 100 kilometers wide. Continue reading for explanations of each box.

5. Begin by clicking anywhere on the map. This will cause an icon like the one below (see image in step 4) to appear on your screen.

6. You can leave the icon in the location you clicked or you can drag it to another place by clicking and dragging the icon to a new location.



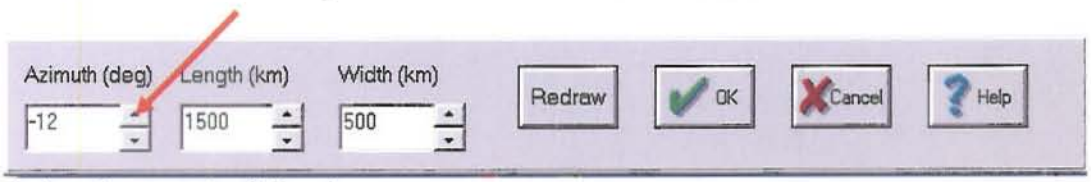
7. Now change the length of the white box. Increase the number in the window to 1500 by using the arrows or typing in new numbers.

8. Click the **redraw** button (not the **OK** button) and watch what happens to the icon.

9. Now change the width of the white box. Increase the number in the window to 500 by using the arrows or typing in new numbers.

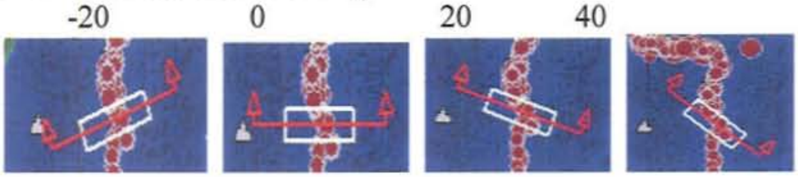
10. Click the **redraw** button and watch what happens to the icon on the map.

11. Now you can change the azimuth. (The azimuth is the horizontal angular distance from a reference direction, so it will change how the red line is drawn in comparison to the bottom of the screen.) Change the azimuth numbers by clicking on the arrows to the numbers as shown in the pictures that follow and click **redraw**.

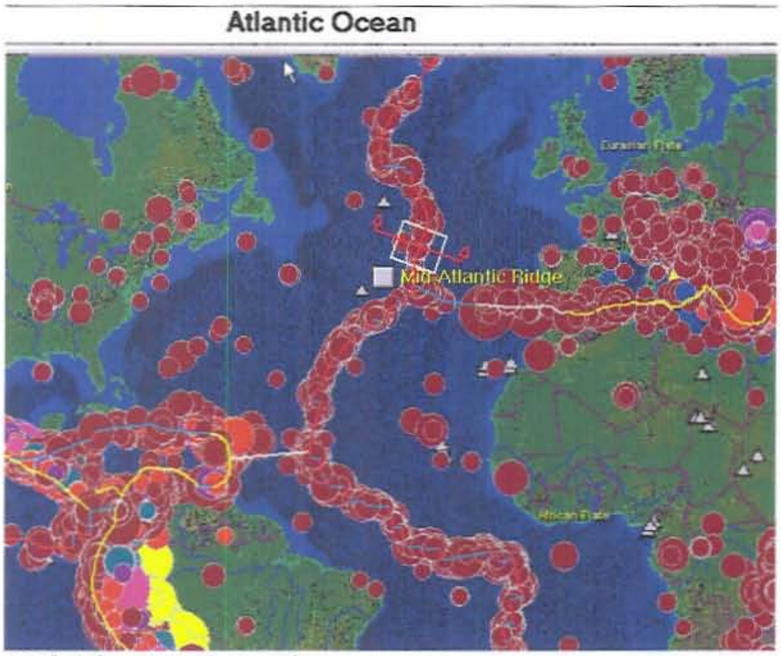


Azimuth set at the following:

-20 0 20 40



Now let's look at a cross section:



Mid-Atlantic ridge with cross section icon

12. Place the cross section tool anywhere along the Mid-Atlantic Ridge. **Be sure to place the azimuth so that it perpendicular (a ninety-degree angle) relative to the plate boundary and crosses over the plate boundary. Ideally you want the boundary to be approximately in the center of icon.**

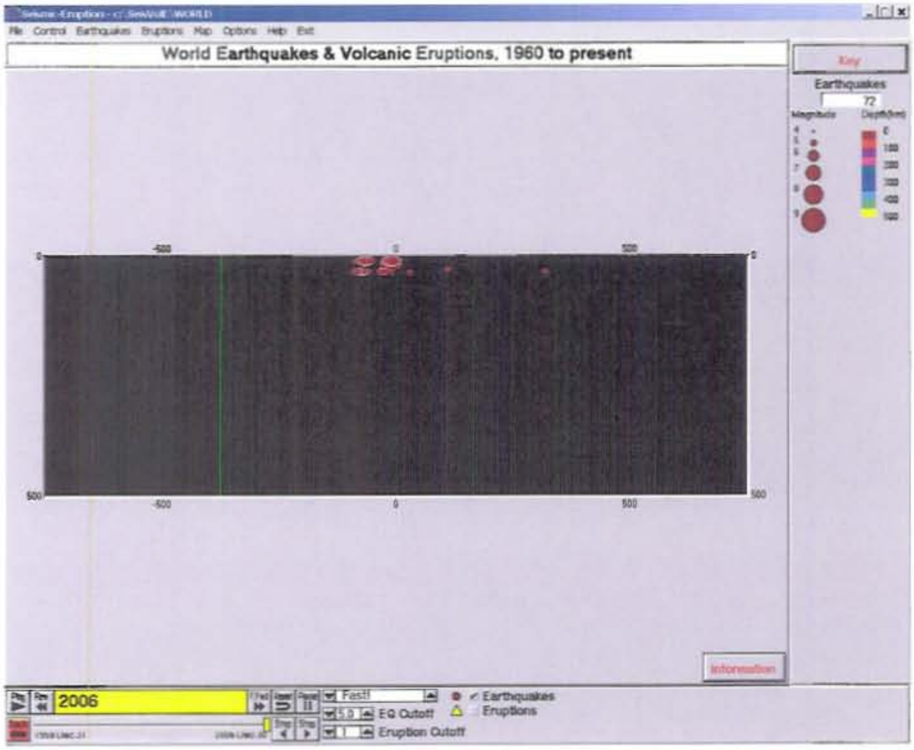
You must be very careful to place your mouse where you want the cross section tool to cross the boundary. This should be where the earthquakes are located. See how the tool crosses the boundary in the image, above.
After you have placed your tool across a boundary, click the **plates** button again to ensure you have the tool where you want it.

13. Click the "OK" button to save what you have set up.

14. View the cross section by going to the **Control Menu**, selecting "Mapview/3D/Cross-section," and clicking the "Cross section view."

Below is a picture of a cross section of the Mid-Atlantic Ridge. The cross section's x-axis represents width and the y-axis represents its depth. In the example, the width is 1500 kilometers and the image shows depths to 500 kilometers below the surface.

In this view we can see the depth of earthquakes that have occurred over the last 50 or so years by looking at the circles. If a circle is plotted over another circle, that means the epicenters were at the same depth and in the same location, but occurred at different times.


World Earthquakes & Volcanic Eruptions, 1960 to present
Key
Earthquakes
72
2006
EQ Cutoff
Eruption Cutoff
Earthquakes
Eruptions
Information

APPENDIX D

On Shaky Ground Unit Assessment

Name______________________________**Date**_______________________________

Class _____________________________**Teacher**___________________________________

Overview

In the "On Shaky Ground" unit you have focused your inquiry on comparing divergent, convergent, and transform boundaries. In this assessment you will use the same skills to compare and contrast **different types of convergent boundaries**. For example, are the earthquake patterns for oceanic-continental convergent boundaries the same as those for oceanic-oceanic convergent boundaries or for continental-continental convergent boundaries?

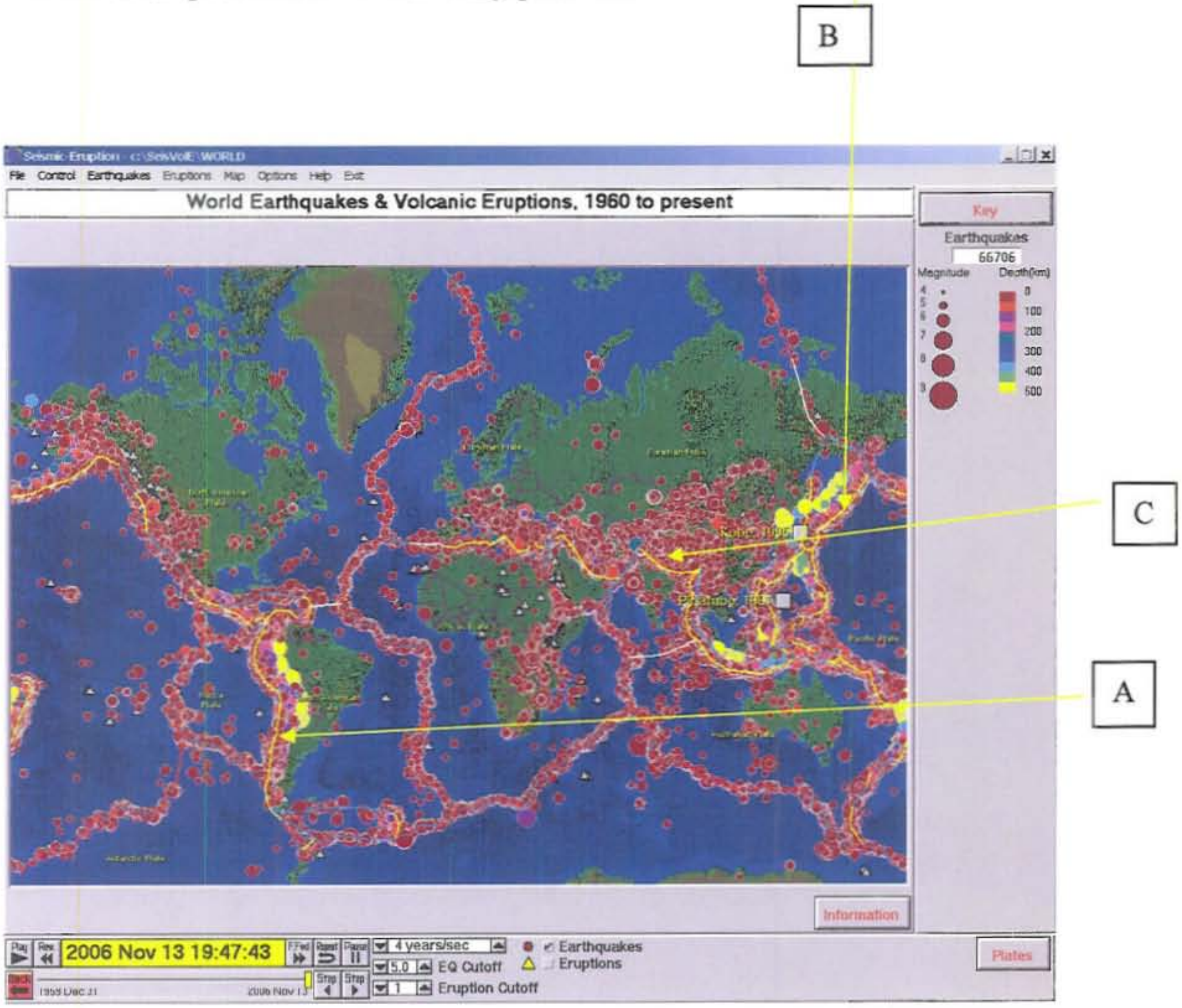
Part A: How do convergent boundaries compare?

A1. What similarities in earthquake patterns might you expect to find between oceanic-continental, oceanic-oceanic, and continental-continental convergent boundaries? What are you basing your hypothesis on?

A2. What differences in earthquake patterns might you expect to find between oceanic-continental, oceanic-oceanic, and continental-continental convergent boundaries? What are you basing your hypothesis on?

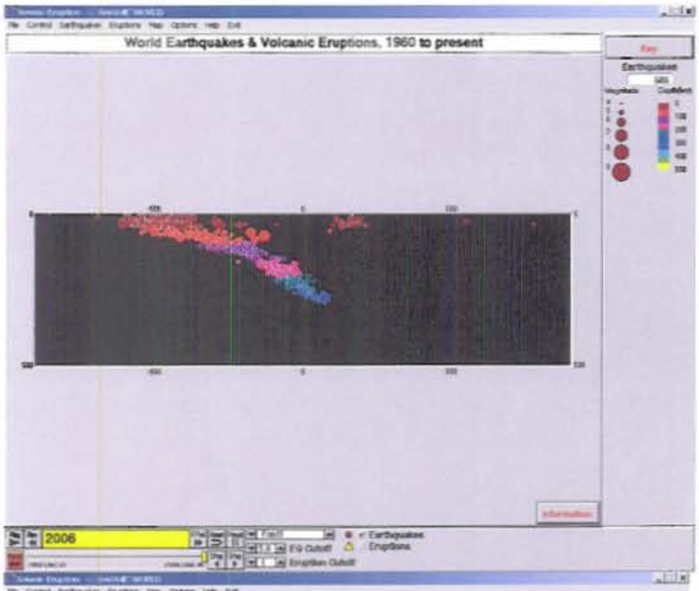
Part B: Analyze Data

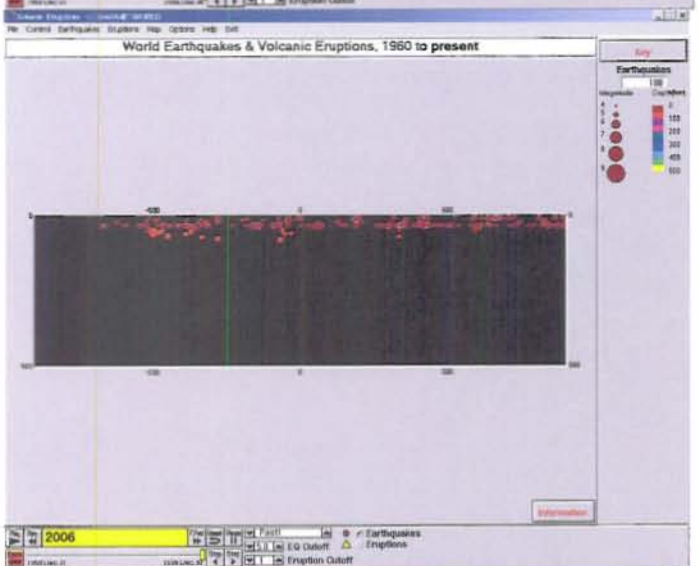
Look at the map to answer the following questions.

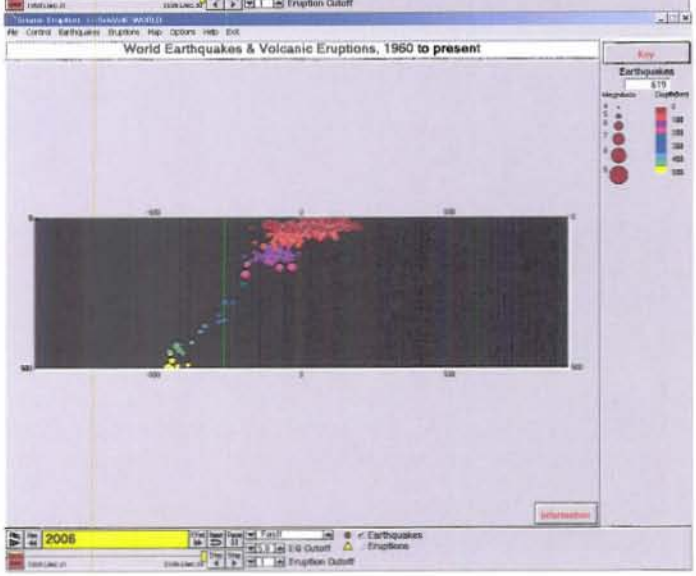


B1. On the next page are cross-sections of convergent boundaries labeled on the world map above. Next to each picture on the next page summarize the data and describe the patterns of earthquakes along each boundary.

B2. Then, describe and label each picture with the type of convergent boundary (continental-continental, continental-oceanic, oceanic-oceanic) and the letter it corresponds to with the map above.


World Earthquakes & Volcanic Eruptions, 1960 to present
Key
Earthquakes
2006
Earthquakes
Eruptions
EQ Cutoff
Eruption Cutoff


World Earthquakes & Volcanic Eruptions, 1960 to present
Key
Earthquakes
2006
Earthquakes
Eruptions
EQ Cutoff
Eruption Cutoff


World Earthquakes & Volcanic Eruptions, 1960 to present
Key
Earthquakes
2006
Earthquakes
Eruptions
EQ Cutoff
Eruption Cutoff

Part C: Conclusions

C1. Compare the magnitude, depth and location of earthquake epicenters along the convergent boundaries by completing the table below:

	Magnitude (small, medium, large)	Depth (shallow, medium depth, deep)	Location (On the boundary--scattered etc.)
Continental-Continental convergent boundary			
Continental- oceanic convergent boundary			
Oceanic- Oceanic convergent boundary			

C2. Draw a sketch of the different convergent boundaries. Draw and label the location of the earthquakes along the boundaries.

C3. Explain how the process along <u>each</u> type of boundary helps describe the patterns you see with the data.

C4. Look at the data for location C on the map. Predict the likelihood of big earthquakes (magnitude greater than 6.5) occurring there within the next 50 years. Explain your reasoning.

Appendix E

Prior Knowledge

Student ID	D arrows	D plates	D features	D quakes	D description	C arrows	C plates	C features	C quakes	C description	T arrows
01-1	1	1	2	1	2	1	1	1	1	2	1
01-2	1	1	2	0	2	1	1	2	1	2	1
02-1	1	1	0	0	0	1	1	2	0	1	1
02-2	1	1	2	1	1	1	0	1	1	1	1
03-1	1	1	2	1	2	1	1	2	1	2	1
03-2	1	1	2	1	2	1	1	1	2	2	1
04-1	1	0	0	0	0	1	1	1	0	2	1
04-2	0	0	0	0	0	1	0	0	0	1	0
05-1	1	1	2	1	2	0	1	1	1	2	1
05-2	1	1	0	0	1	1	1	2	1	2	1
05-3	-	-	-	-	-	-	-	-	-	-	-
06-1	1	1	1	1	1	1	0	0	0	1	1
06-2	1	0	0	0	2	1	0	0	0	0	-
07-1	1	1	0	0	2	1	1	0	0	2	1
07-2	1	0	0	0	0	1	1	0	0	1	-
08-1	1	1	2	0	2	1	1	2	0	2	1
08-2	0	0	0	0	0	1	1	2	0	1	1
09-1	1	1	0	0	1	1	1	0	1	1	0
09-2	1	1	0	0	0	1	1	1	0	2	1
10-1	1	0	0	1	2	1	1	0	1	1	1
10-2	1	1	0	0	1	1	1	2	0	2	1

Daniels 94

Student Response Sheet

Student ID	T quakes	T description	4a	4b answer	4b logic	A1 Lickert	A1 answer	A2 Lickert	A2 answer	A3 Lickert	A3 answer
01-1	0	2	2	1	2	3	0	2	0	4	1
01-2	1	2	1	1	1	2 or 3	1	2	0	4	1
02-1	0	1	0	1	0	1	1	3	1	4	1
02-2	1	2	1	1	1	1	1	3	1	4	1
03-1	0	2	1	1	2	2	1	3	1	4	1
03-2	1	2	1	1	2	2	1	3	1	4	1
04-1	0	2	1	0	1	3	0	1	0	2	0
04-2	0	0	2	0	1	3	0	1	0	2	0
05-1	1	2	1	1	0	1	2	4	0	2	0
05-2	1	2	2	0	2	1	2	4	0	2	0
05-3	-	-	-	-	-	-	-	-	-	-	-
06-1	0	1	1	0	2	-	-	-	-	-	-
06-2	-	-	-	-	-	-	-	-	-	-	-
07-1	0	1	1	1	1	2	1	2	0	4	1
07-2	-	-	1	-	-	2	1	2	0	4	1
08-1	0	1	2	0	1	2	1	1	0	3	0
08-2	0	2	1	1	2	2	1	1	0	3	0
09-1	1	-	1	1	1	3	0	1	0	4	1
09-2	0	2	0	0	0	3	0	1	0	4	1
10-1	1	2	1	0	1	1	2	3	1	2	0
10-2	1	2	1	-	-	1	2	3	1	1	0

Daniels 95

Student Cross-Sections / **Student Response Sheet, continued**

Student ID	B5	B7	C3 D	C3 C	C3 T	Divergent	Convergent	Transform	T comment	E1	E2	E3	E4	E5	E6	E7	F1 answer	F1 evidence
01-1	1	1	4	2	2	2	2	0		2	2	2	1	2	2	2	1	2
01-2	1	1	4	5	3					2	2	2	1	1	2	2	1	2
02-1	1	1	2	2	2	0	0	2	California	2	2	2	2	1	0	0	1	3
02-2	1	1	3	3	3					2	2	2	2	1	0	0	1	3
03-1	1	1	3	3	2	2	1	2	California	2	2	2	2	2	2	2	1	3
03-2	1	1	3	3	3					2	2	2	2	2	2	1	1	3
04-1	1	1	4	3	3	0	1	1		1	1	1	2	1	1	0	1	3
04-2	1	1	4	4	4					1	1	2	2	1	1	0	1	3
05-1	1	1	3	3	3	1	2	1		1	2	2	1	1	1	2	1	3
05-2	1	1	3	3	3					2	2	2	2	2	1	1	1	3
05-3	1	1	1	3	1					2	2	2	2	2	1	1	1	3
06-1	1	1	2	3	2	2	1	2	California	2	0	1	0	0	1	0	1	3
06-2	1	1	1	3	2					2	0	1	0	0	1	0	1	3
07-1	1	1	2	2	0	2	0	1		2	2	2	2	1	2	0	-	-
07-2	1	1	3	2	0					-	-	-	-	-	-	-	-	-
08-1	1	1	4	3	3	2	1	1	California	2	2	2	0	2	2	2	1	3
08-2	1	1	3	2	2					2	2	2	1	2	2	0	1	3
09-1	1	1	2	1	1	1	0	0	California	0	1	2	2	0	0	1	1	3
09-2	1	1	3	1	1					0	0	2	-	-	-	-	-	-
10-1	1	1	4	4	1	2	1	2	California	2	1	0	1	2	1	1	1	0
10-2	1	1	2	4	2					2	1	0	1	2	1	1	1	0

Daniels 96

Student ID	F2 answer	G1 Lickert	G1 answer	G2 Lickert	G2 answer	G3 Lickert	G3 answer	Unit Assessment				
								A1	A2	B1a	B1b	B1c
01-1	1	2	1	1	0	4	1	1	1	0	0	0
01-2	1	2	1	1	0	4	1	2	2	2	2	2
02-1	1	3	0	2	0	3	0	0	0	1	0	0
02-2	1	3	0	2	0	3	0	1	1	1	1	1
03-1	1	1	2	3	1	4	1	1	2	2	2	2
03-2	1	1	2	3	1	4	1	1	2	1	-	-
04-1	2	1	2	3	1	3	0	1	2	2	2	2
04-2	2	1	2	3	1	3	0	0	0	2	1	2
05-1	1	2	1	2 or 3	1	4	1	0	0	2	1	1
05-2	1	1	2	2 or 3	1	4	1	2	2	2	2	2
05-3	1	1	2	2 or 3	1	4	1	1	1	2	1	2
06-1	2	2	1	3 or 4	1	2	0	1	1	1	1	1
06-2	2	2	1	3 or 4	1	2	0	0	0	0	0	0
07-1	-	-	-	-	-	-	-	1	1	2	1	1
07-2	-	-	-	-	-	-	-	1	0	1	1	1
08-1	2	-	0	-	0	-	0	2	2	1	1	1
08-2	2	2	1	3 or 4	1	2	0	1	2	2	2	2
09-1	2	2	1	1	0	3	0	1	0	1	1	1
09-2	-	-	-	-	-	-	-	1	1	1	2	1
10-1	1	1	2	2	0	4	1	1	1	1	1	1
10-2	1	2	1	2	0	4	1	1	0	0	0	0
							TOL Medium-High (09-1)	1	0	1	1	2
							TOL Medium-Low (04-2)	0	0	2	1	2

Daniels 97

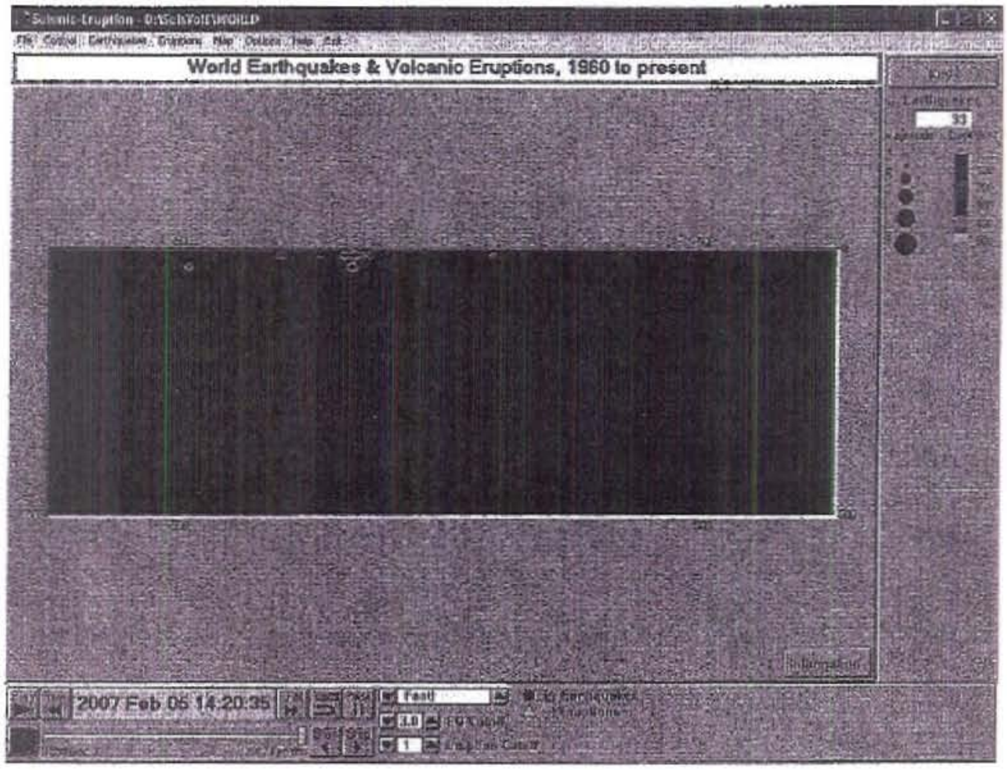
Student ID	B2a	B2b	B2c	C1a	C1b	C1c	C2 o-o	C2 c-c	C3	C4 answer	C4 logic
01-1	0	2	0	2	1	0	2	2	2	0	0
01-2	2	2	2	3	3	1	2	1	1	2	2
02-1	2	2	2	0	1	1	0	0	0	2	0
02-2	1	2	2	3	3	2	2	2	2	2	2
03-1	2	2	2	1	1	1	3	3	1	0	0
03-2	-	-	-	-	-	-	-	-	-	-	-
04-1	0	0	0	1	1	0	2	1	1	0	0
04-2	2	1	1	2	2	1	1	0	-	-	-
05-1	2	2	2	3	3	3	0	2	1	0	0
05-2	2	2	2	3	3	3	3	3	-	-	-
05-3	2	2	2	3	3	3	3	3	-	-	-
06-1	2	0	0	1	1	1	0	0	0	2	1
06-2	1	1	1	3	-	-	-	-	-	-	-
07-1	2	2	2	3	3	1	3	3	1	1	1
07-2	1	2	1	3	3	0	-	-	-	-	-
08-1	1	2	2	3	3	3	3	3	2	1	1
08-2	2	2	2	3	3	1	3	3	2	2	2
09-1	0	2	0	3	1	0	2	0	-	1	0
09-2	1	1	1	2	3	3	1	0	0	0	0
10-1	1	0	0	1	0	1	2	1	0	0	0
10-2	1	0	0	1	1	0	1	0	1	0	0
TOL Medium-High (09-1)	0	2	0	3	1	0	1	0	-	-	-
TOL Medium-Low (04-2)	2	2	2	3	3	2	1	0	0	0	0

Appendix F

Group 1

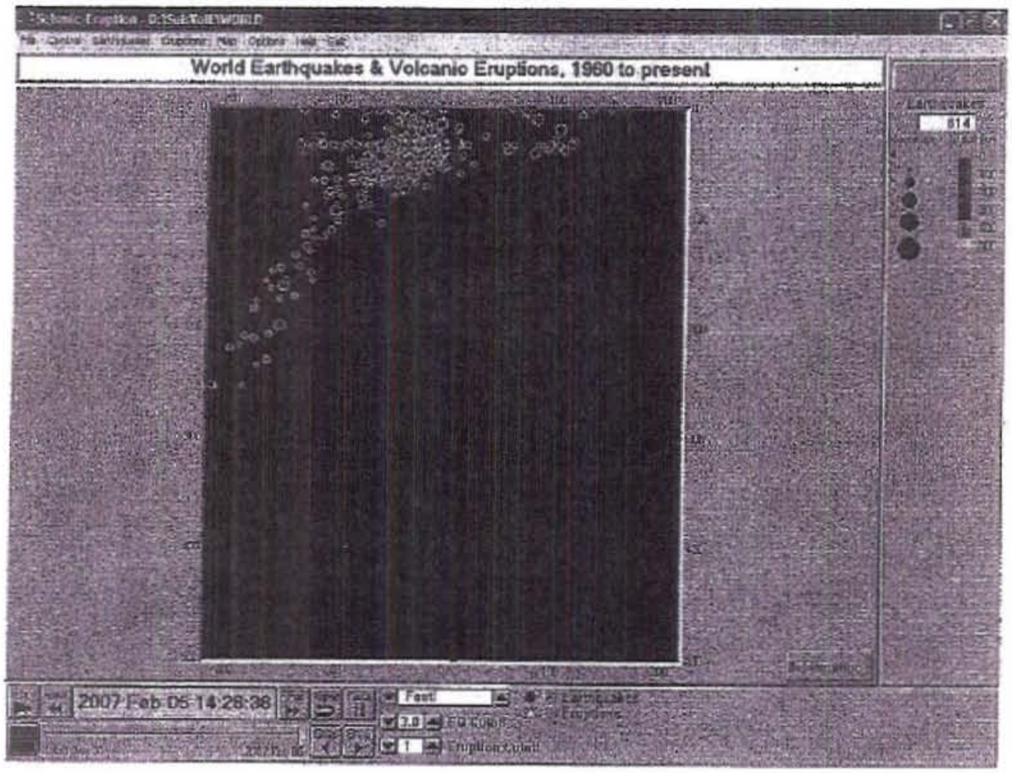
Divergent Boundary

North American Plate and African Plate



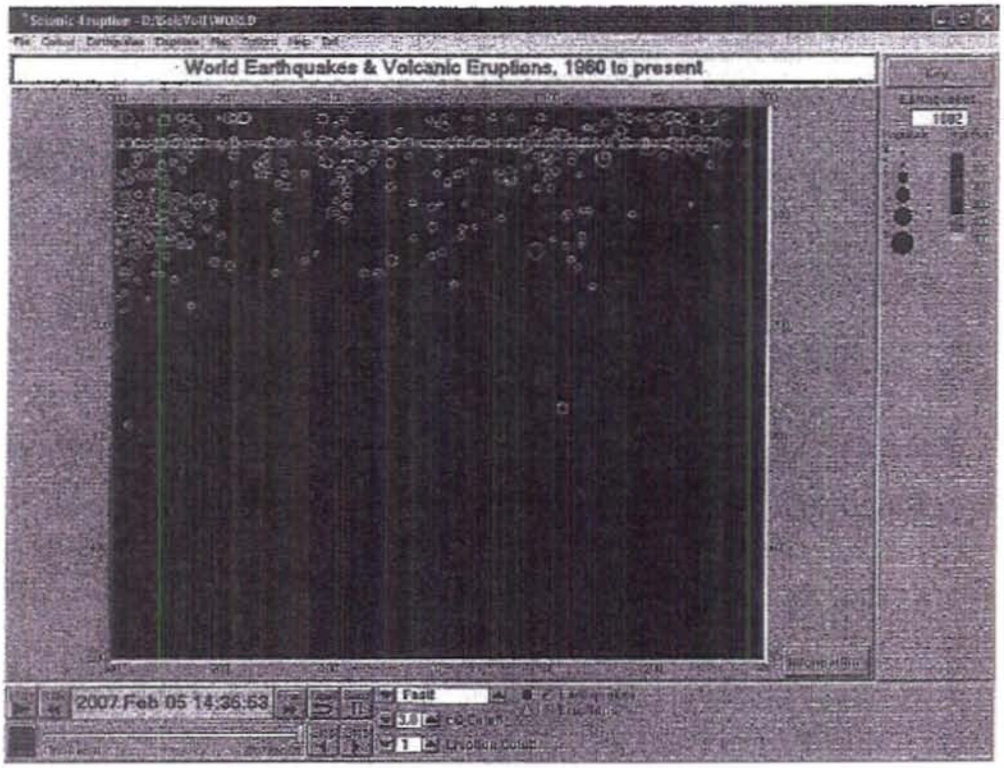
Convergent Boundary

Pacific Plate and North American/Eurasian Plates



Transform Boundary

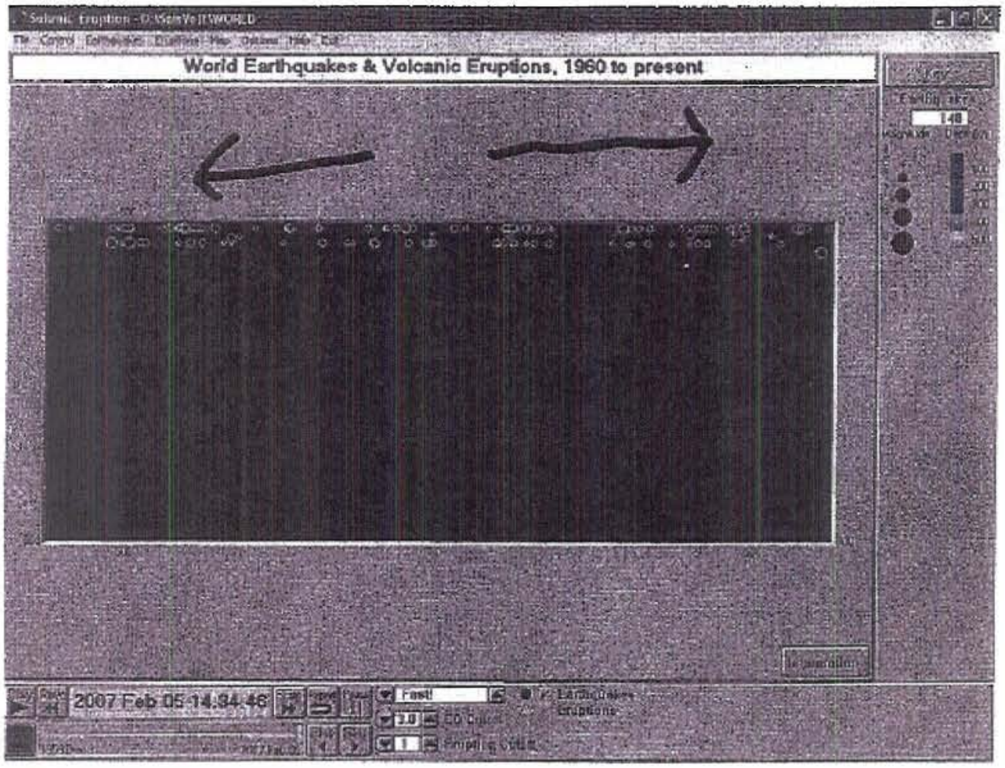
Antarctica Plate and South American Plate



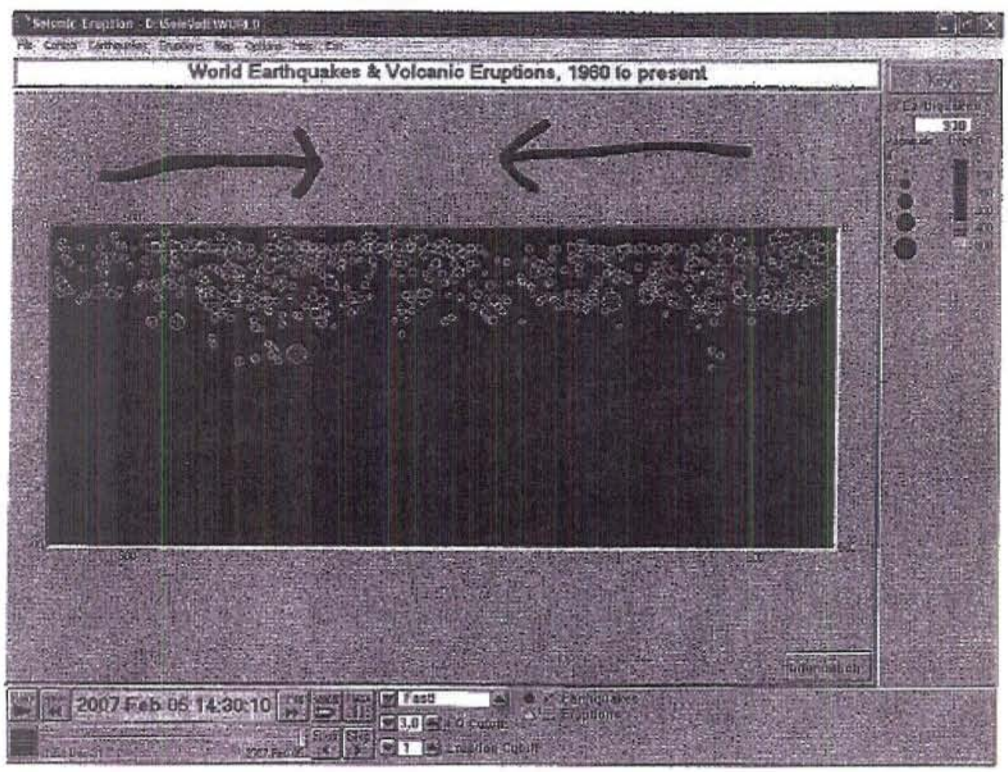
Daniels 100

Group 2

Divergent Boundary
African Plate and South American Plate

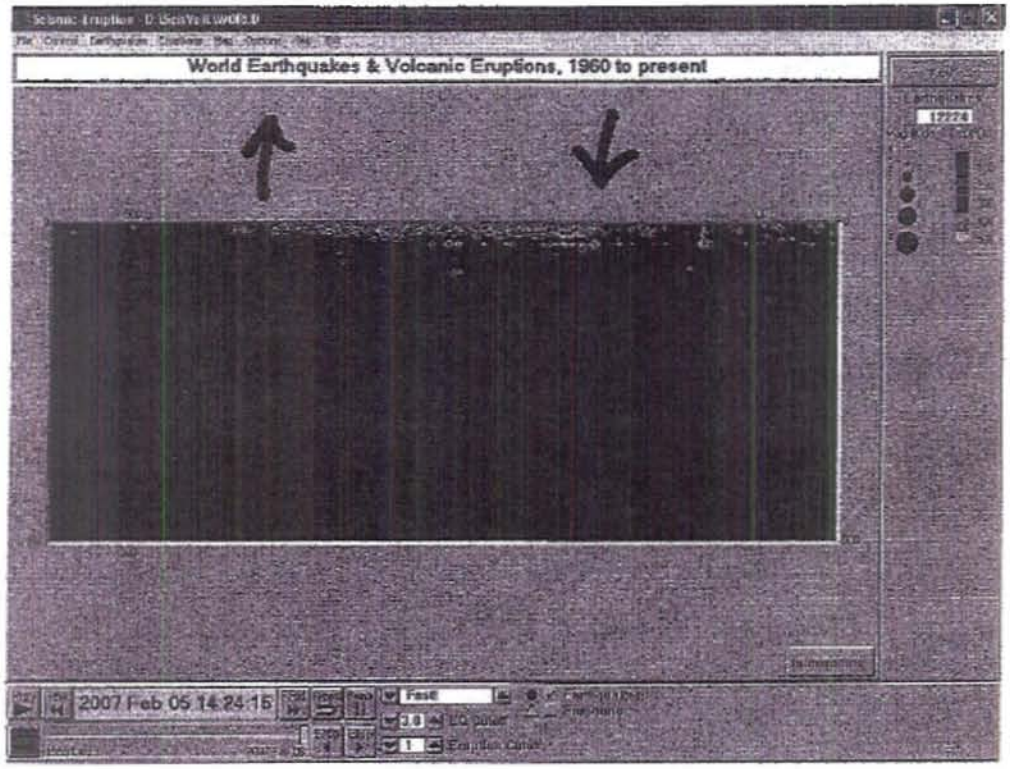


Convergent Boundary
South American Plate and Nazca Plate



Daniels 101

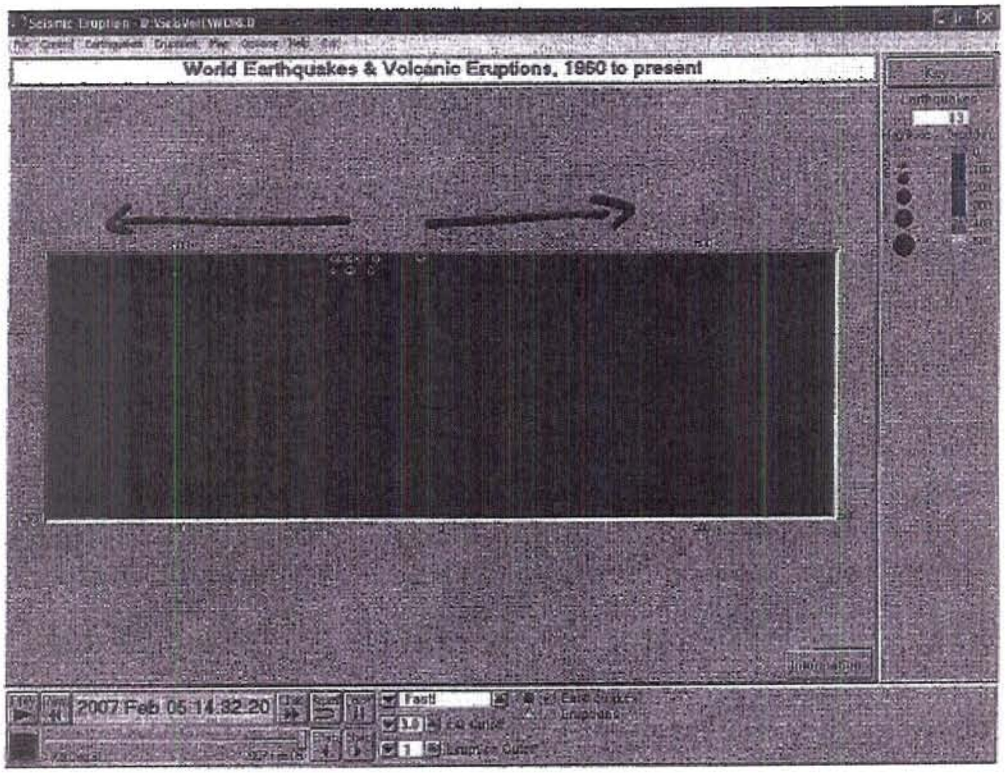
Transtorm Boundaries
North American Plate and Pacific Plate



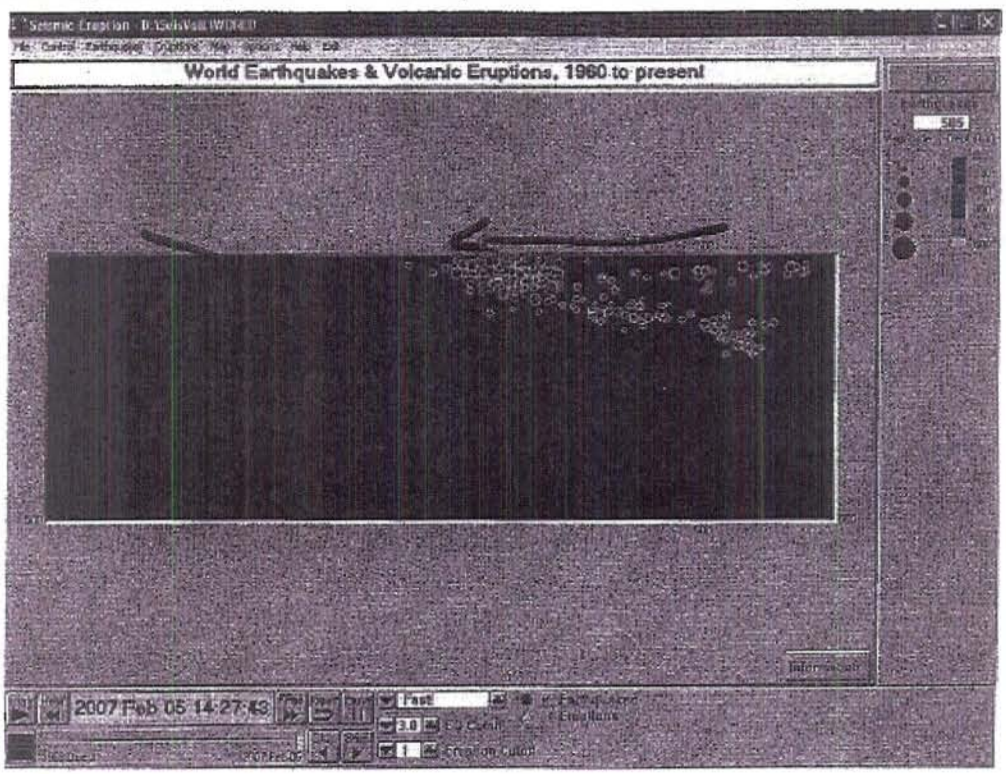
Daniels 102

Group 03

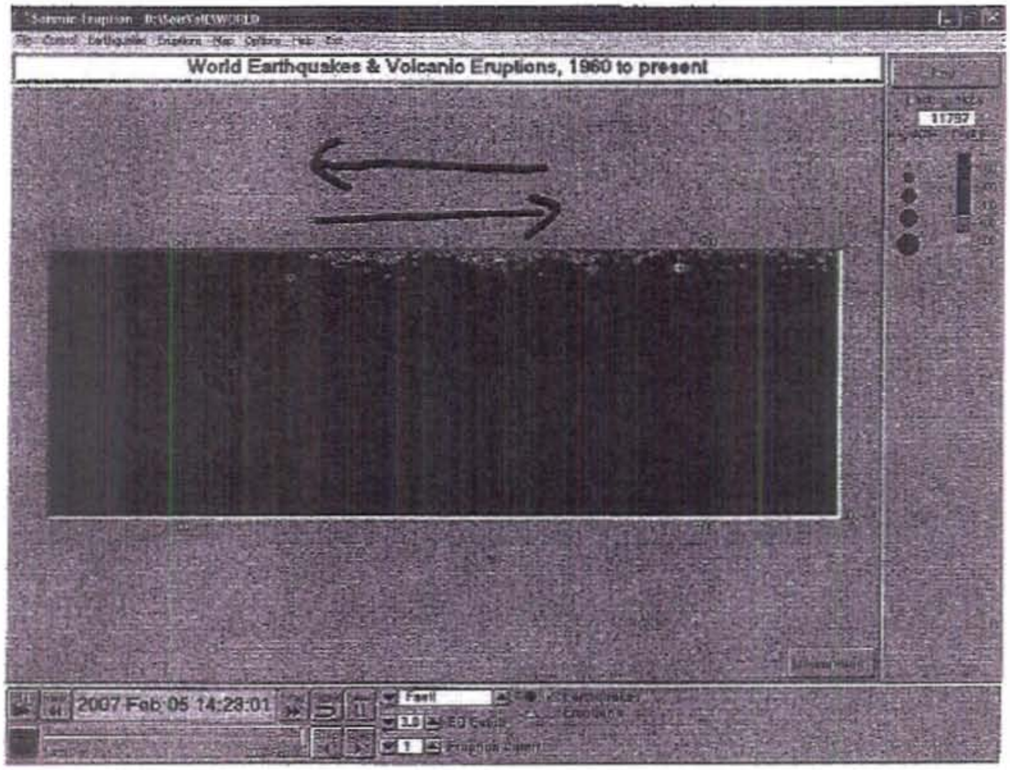
Divergent boundary between the Australian plate and the Antarctic plate



Convergent boundary between the Nazca plate and the South American plate



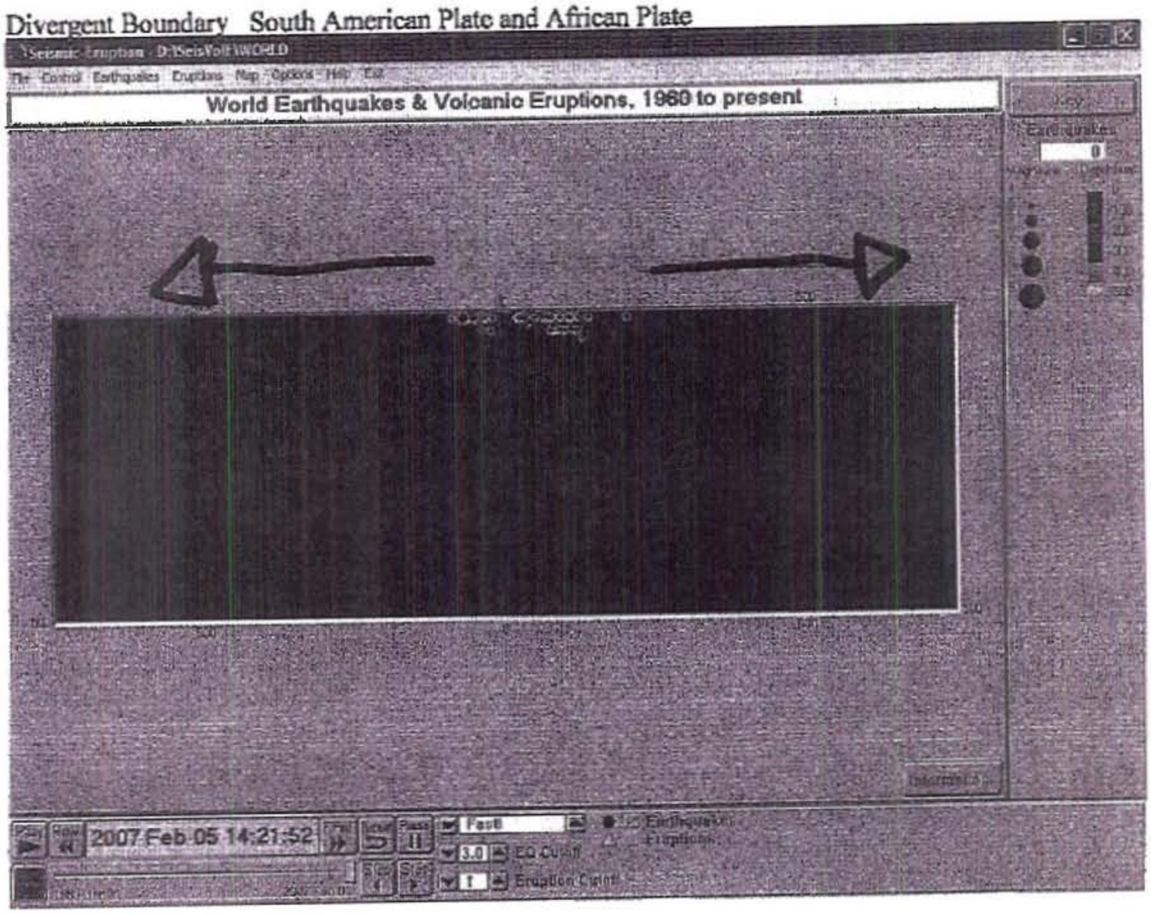
Transform boundary between the Pacific plate and the North American plate.



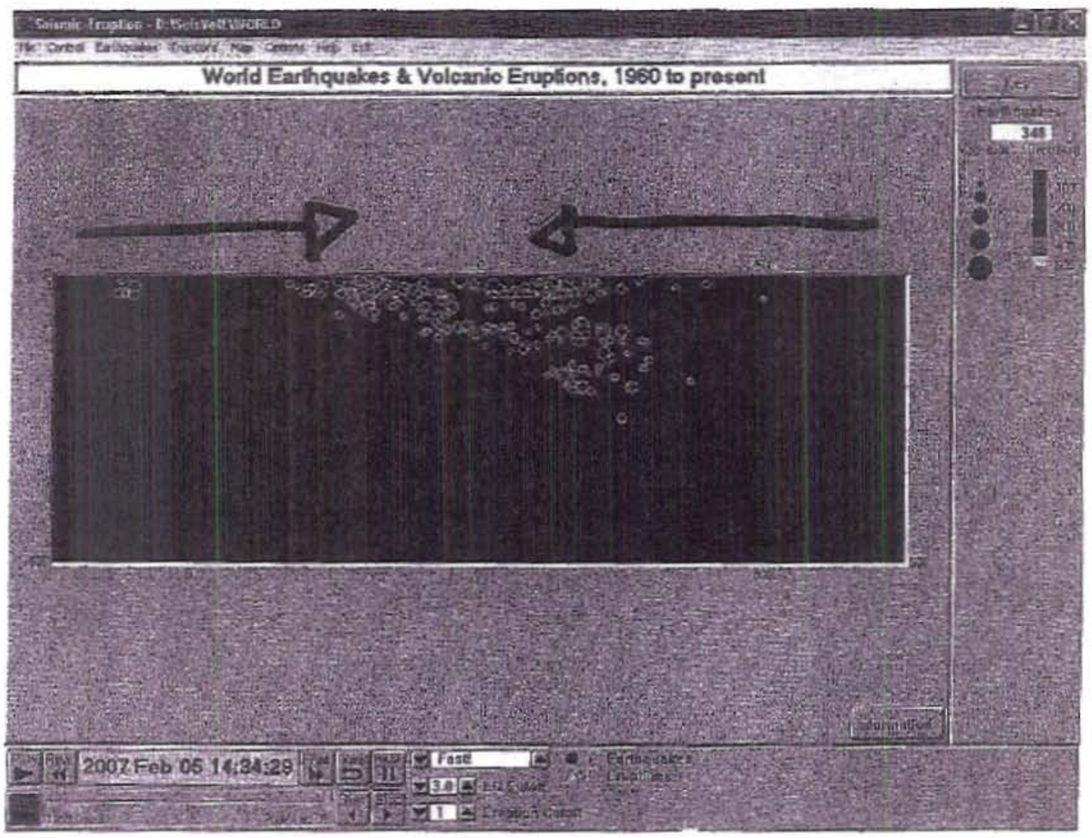
Daniels 104

Group 04

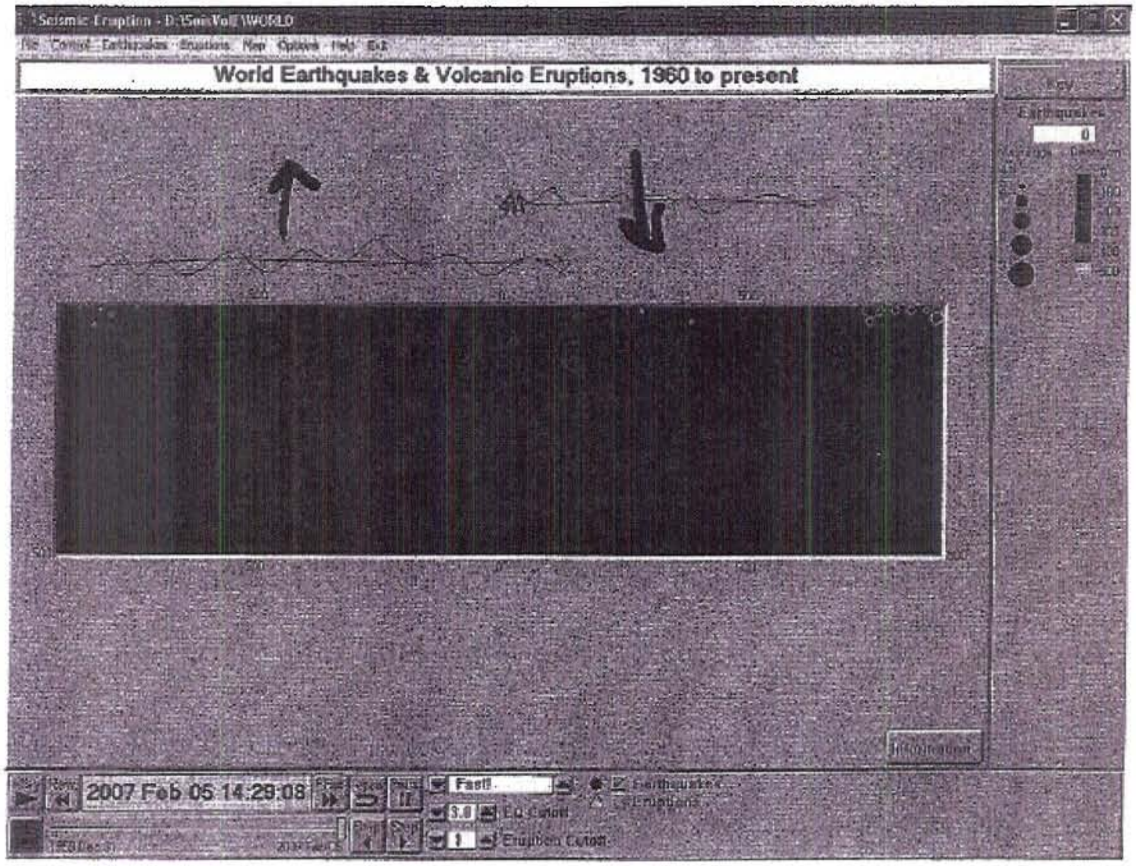
Divergent Boundary   South American Plate and African Plate



Convergent Boundary   Nazca Plate and South American Plate



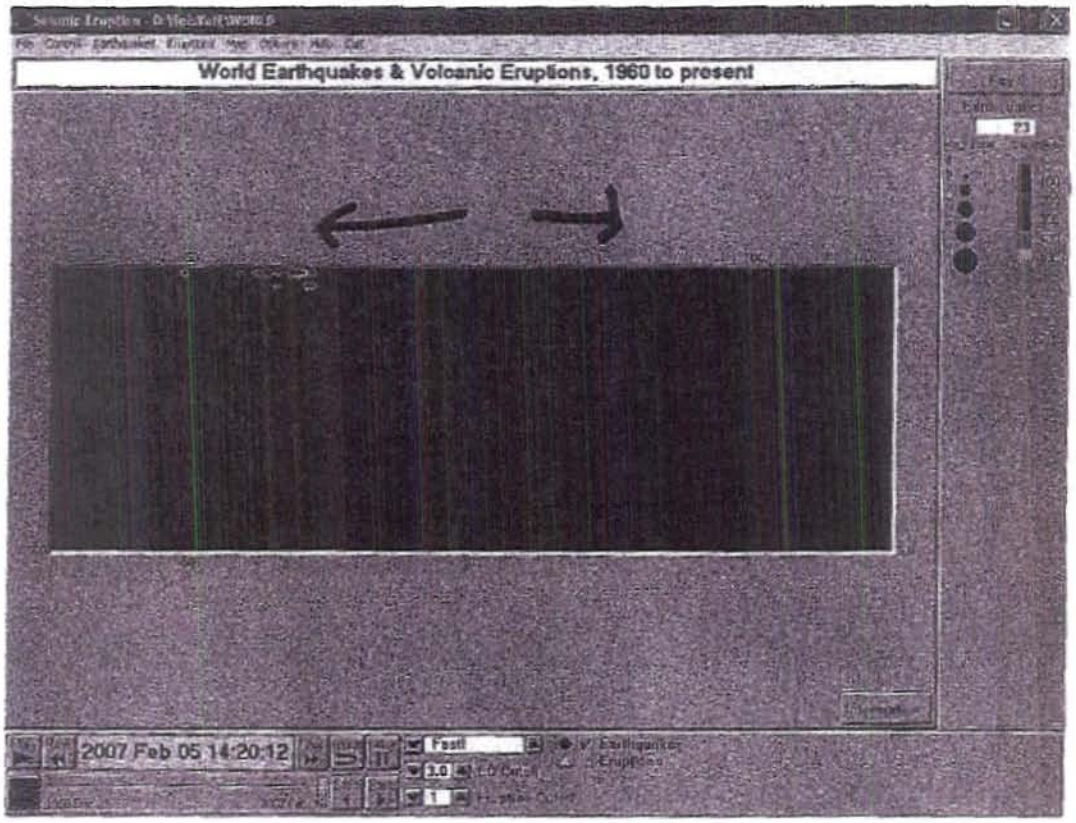
Transform Boundary Caribbean Plate and North American Plate



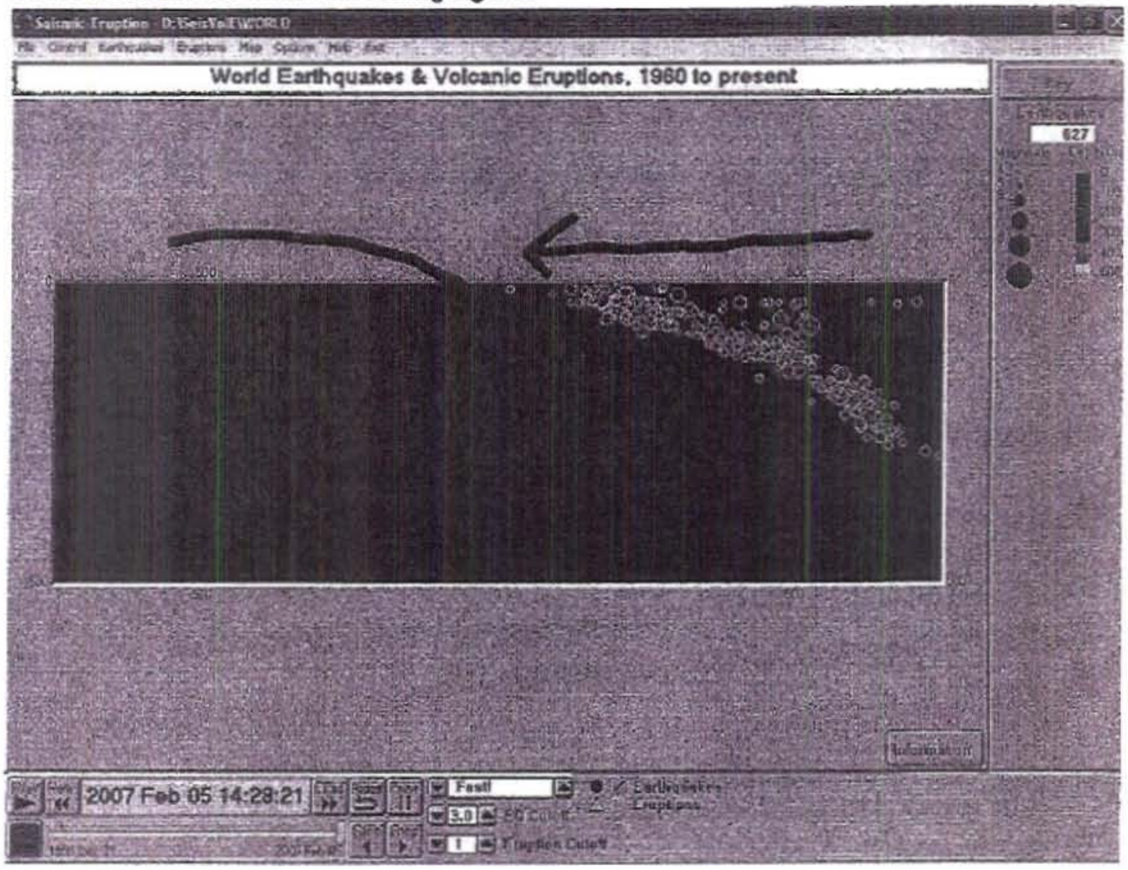
Danids 106

Group 05

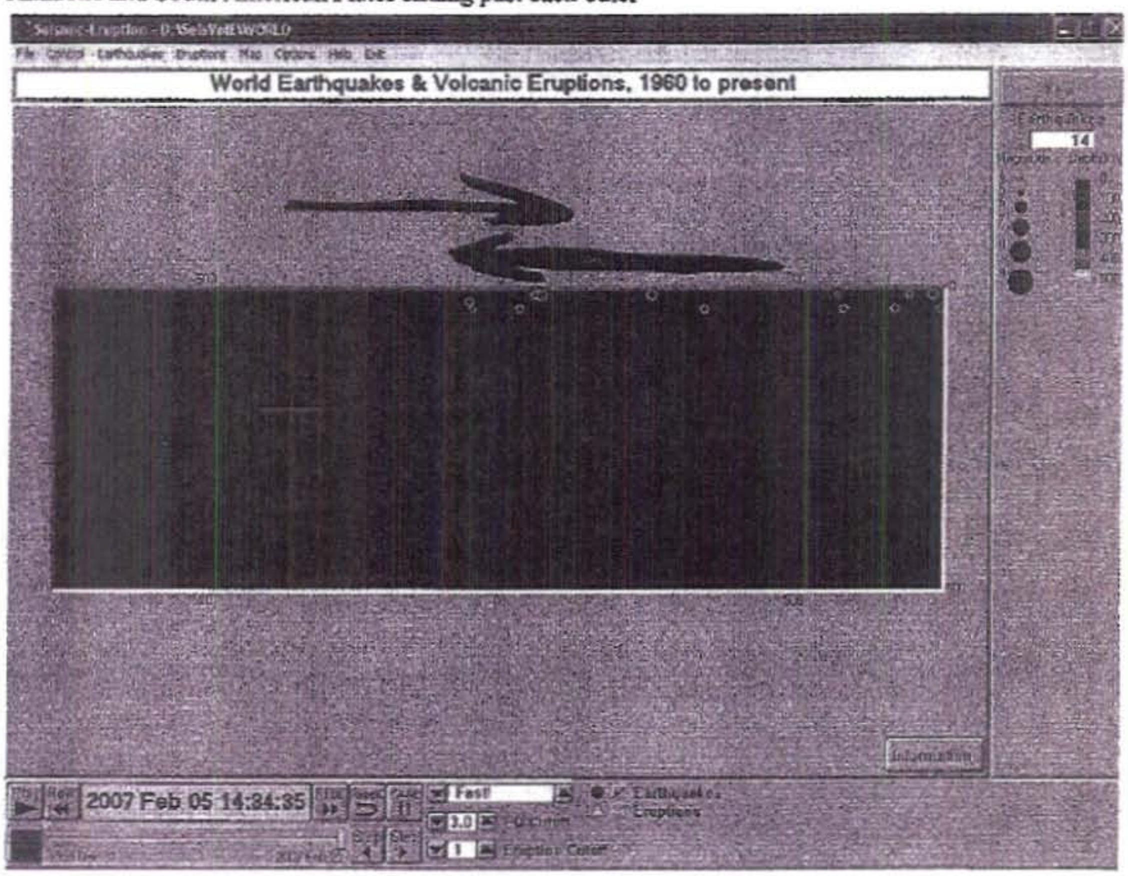
Divergent boundary
Mid-Atlantic Ridge- South American and African Plates are separating



Convergent boundary
South American and Nazca Plate coming together

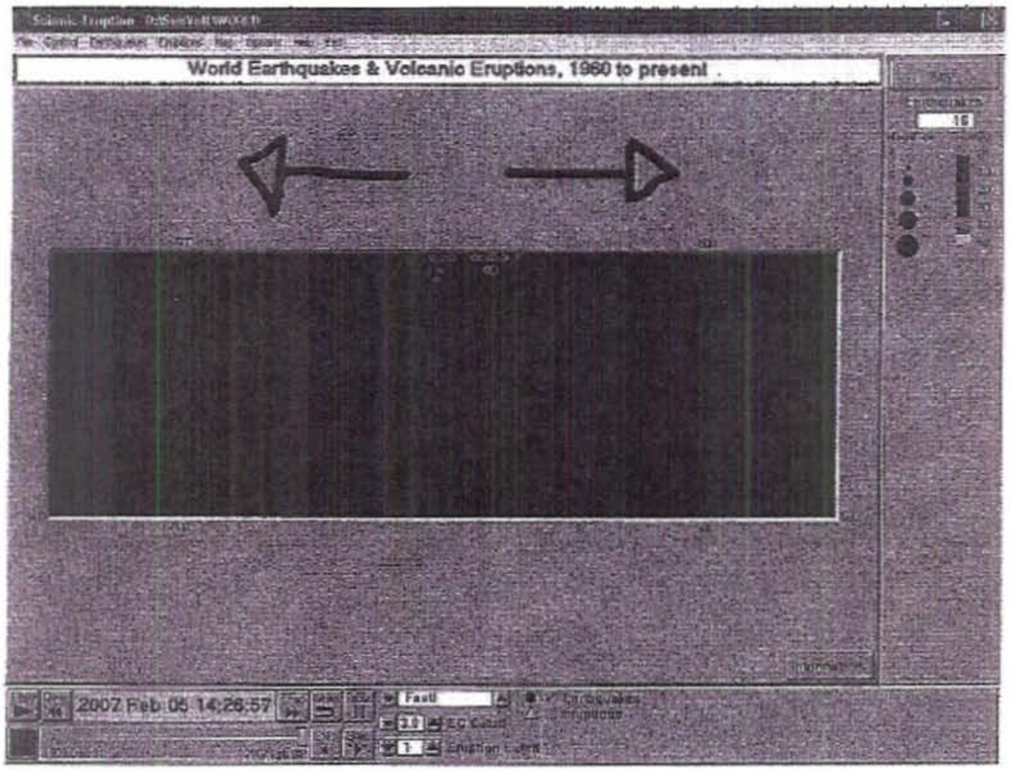


Transform boundary
Antarctic and South American Plates sliding past each other

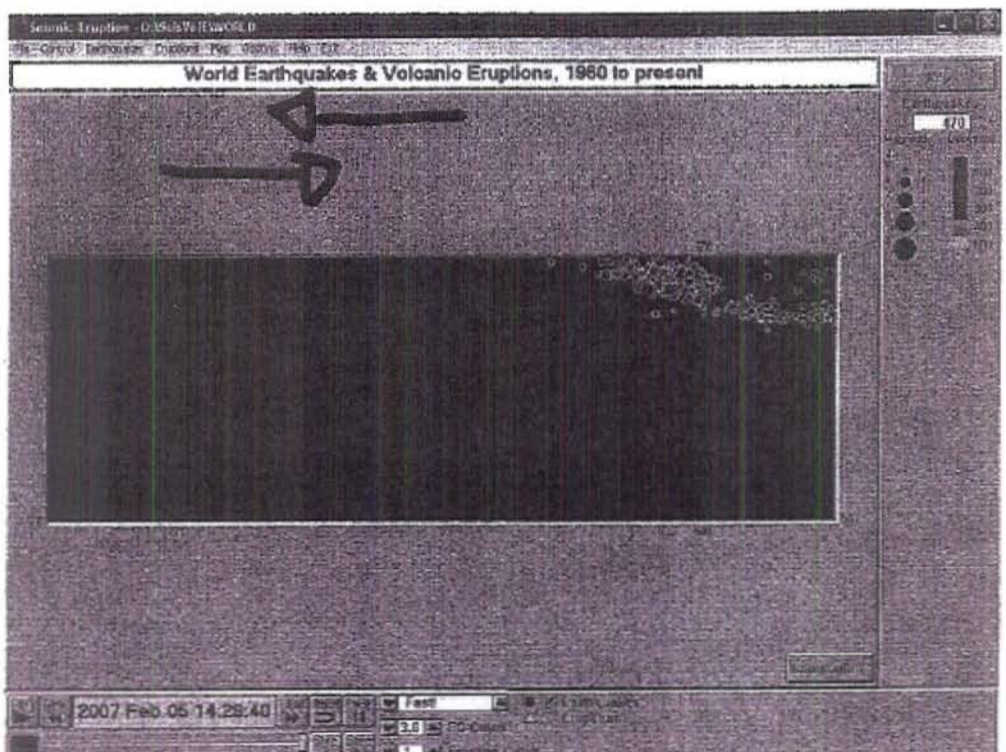


Group 06

divergent boundary
Eurasian plate and North American

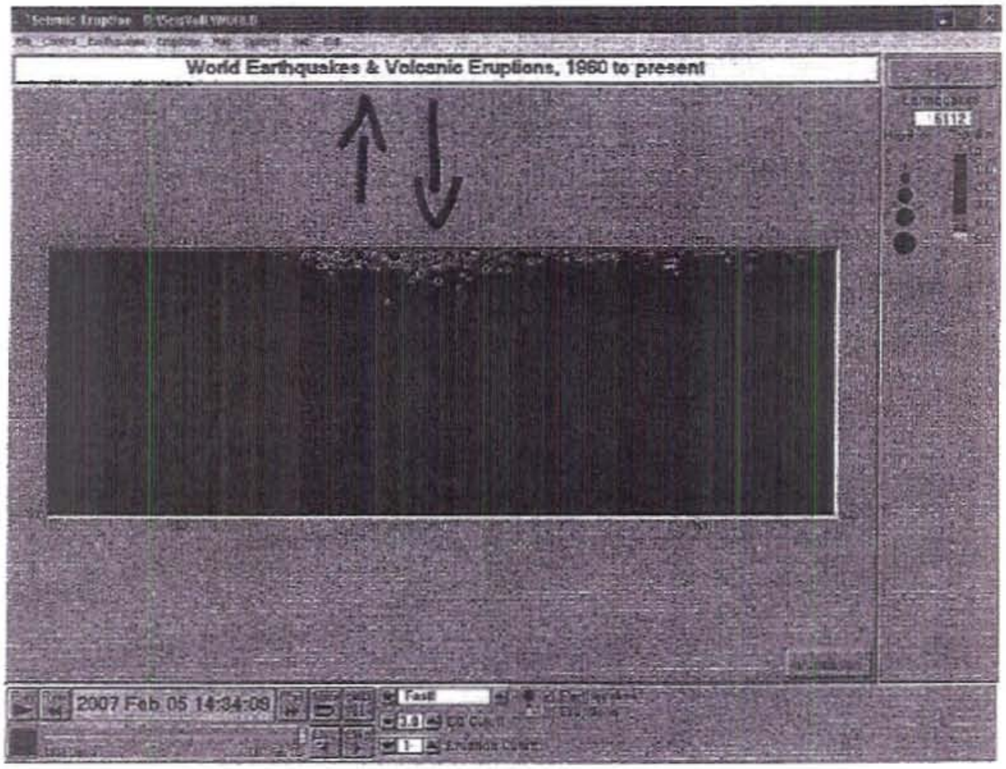


convergent boundary
Nazca and South American plate



transform boundary

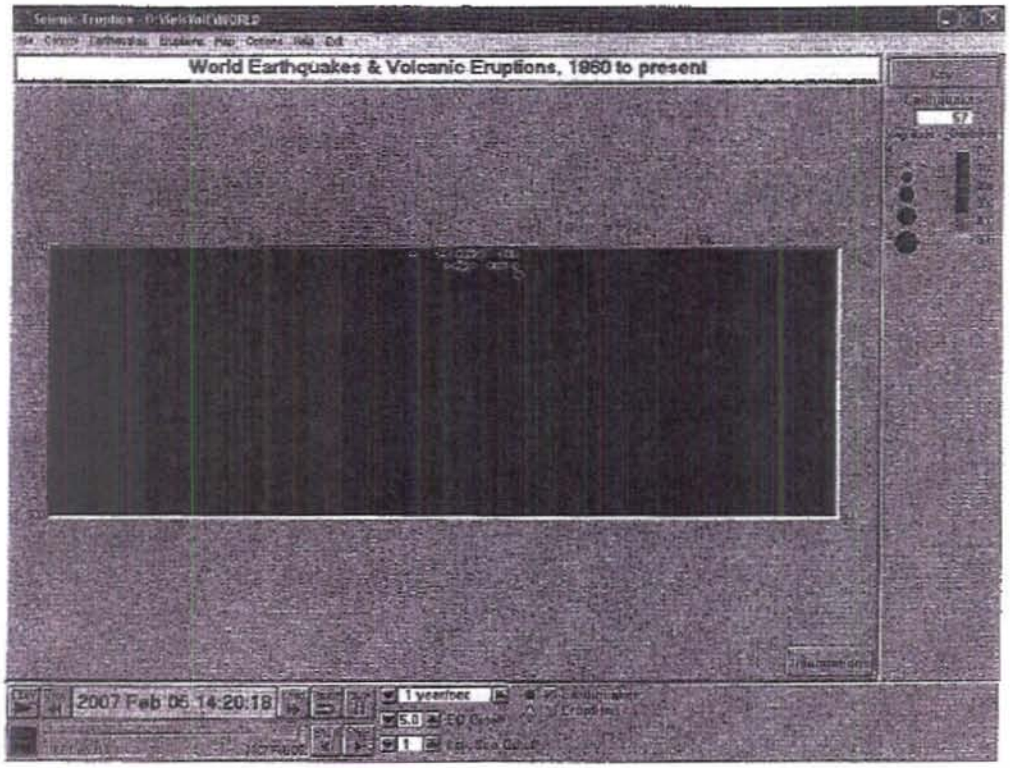
North American and Pacific Plate



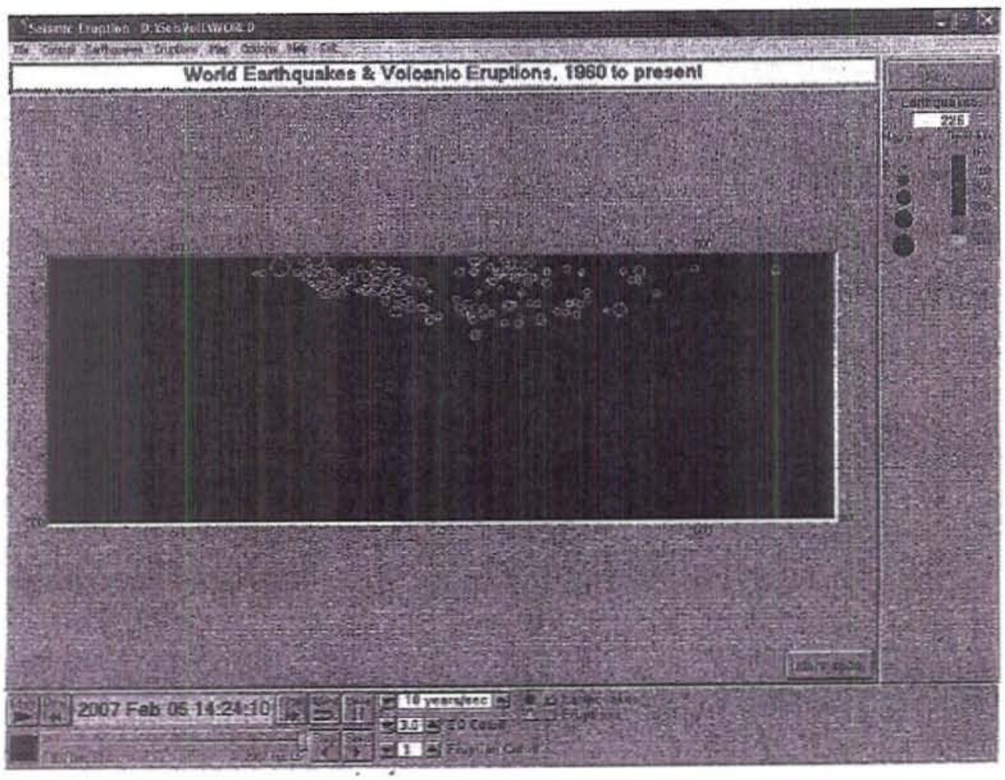
Daniels 110

Group 07

Divergent boundry.
Mid Atlantic ridge;African and South American plates.

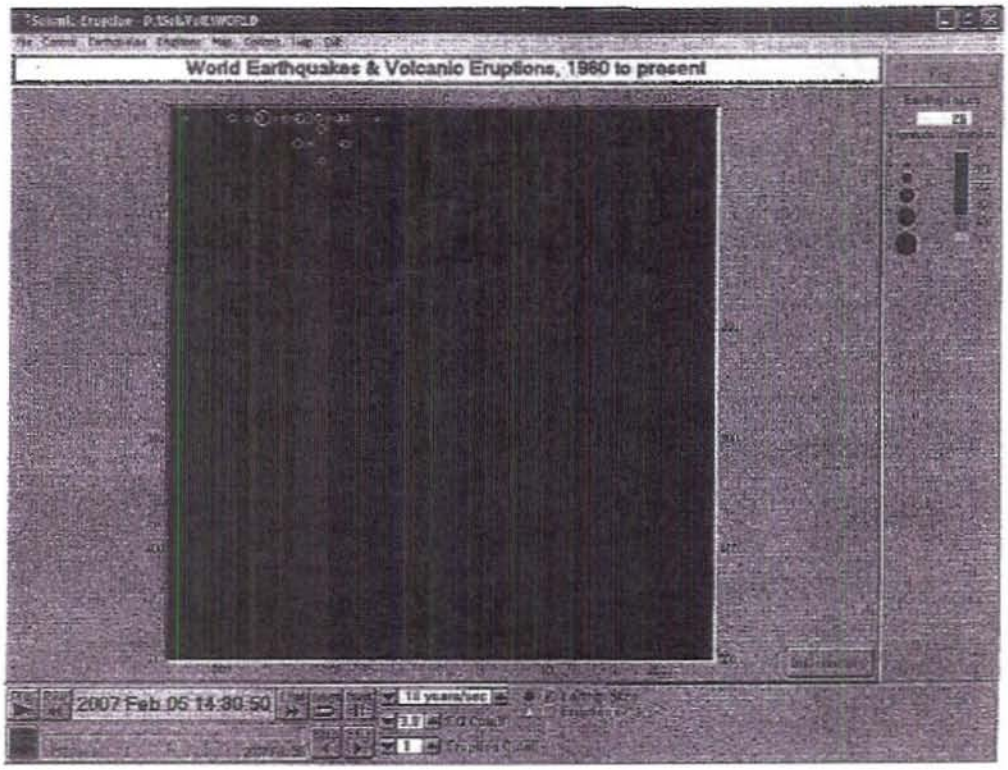


Convergent boundary
South American and Nazca plates.



Daniels 111

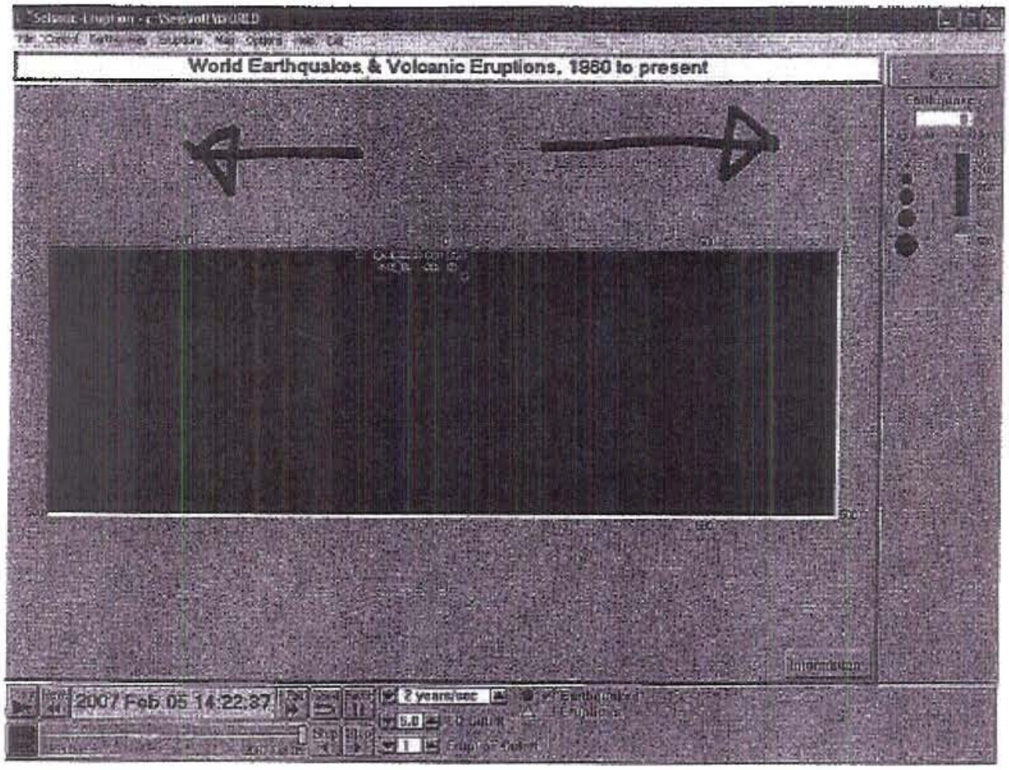
Transform boundary
South American and Antarctic plates



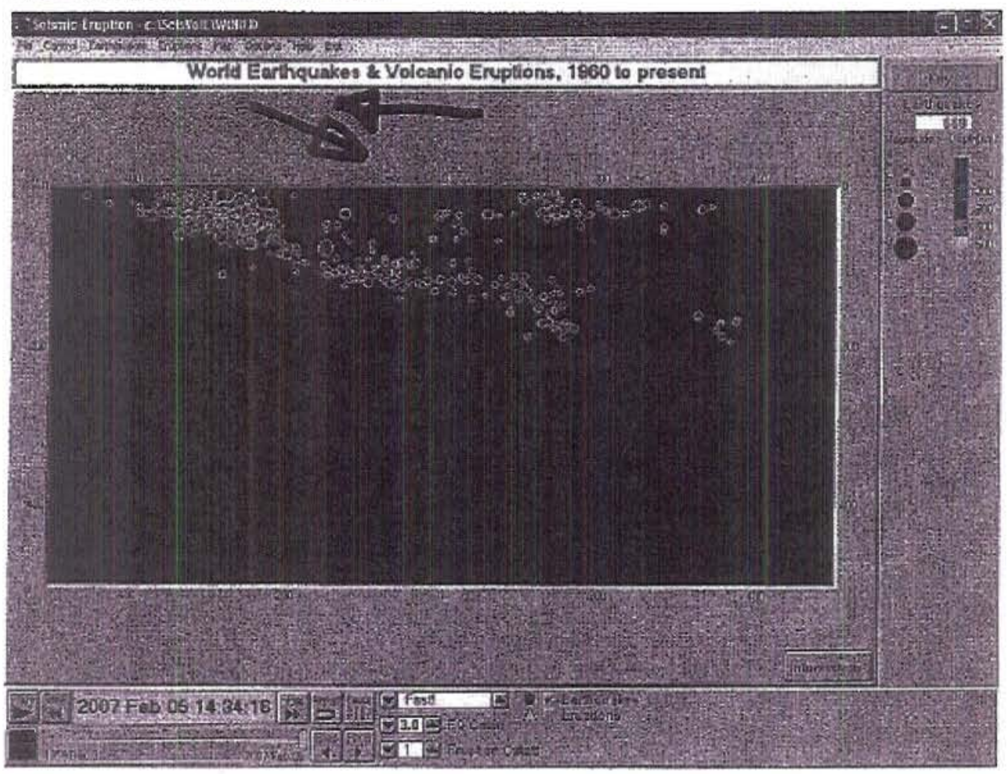
Daniels 112

Group 08

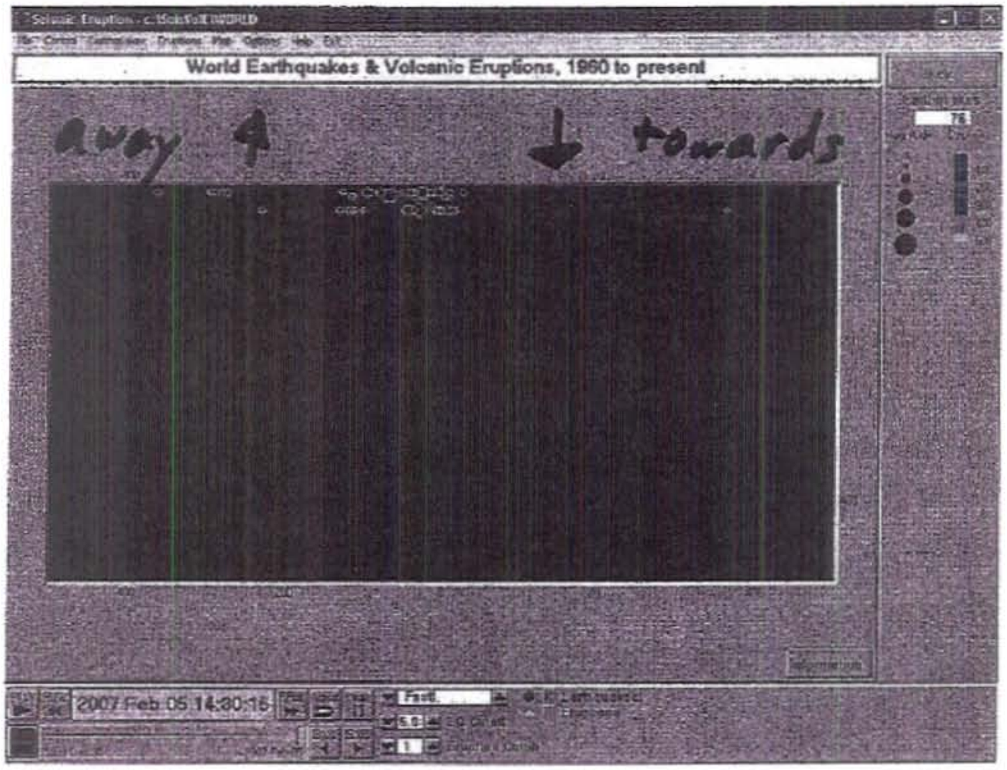
Divergent
Eurasian and North Atlantic



convergent
Nazca and South American Plates

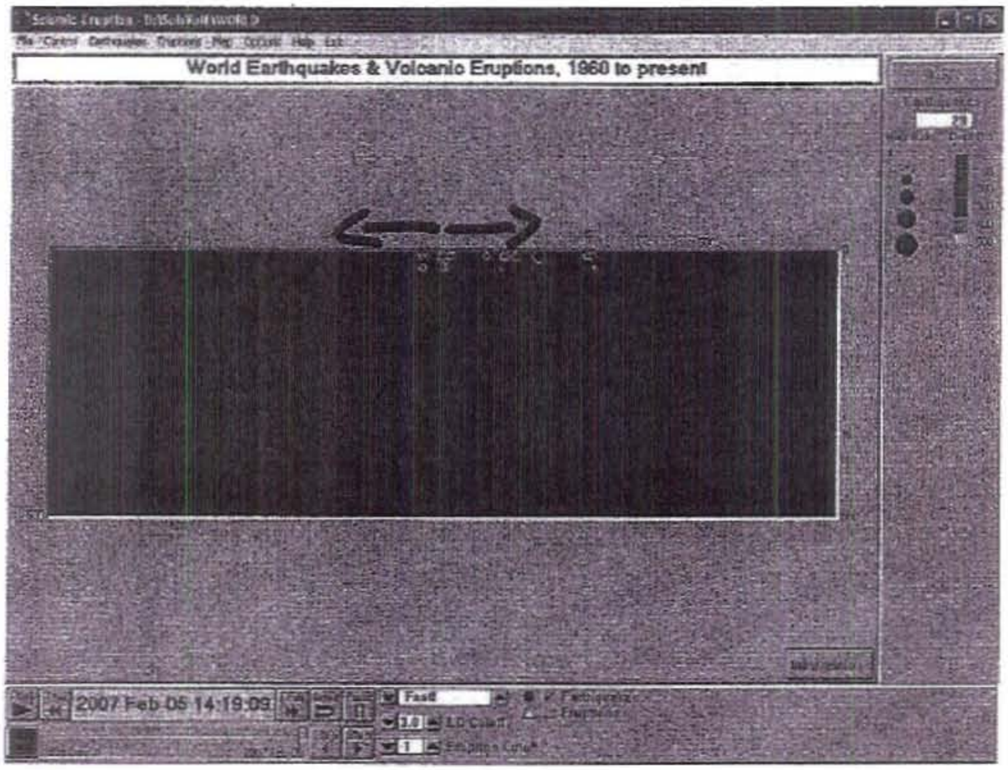


Transnform
Pacific and North American Plates

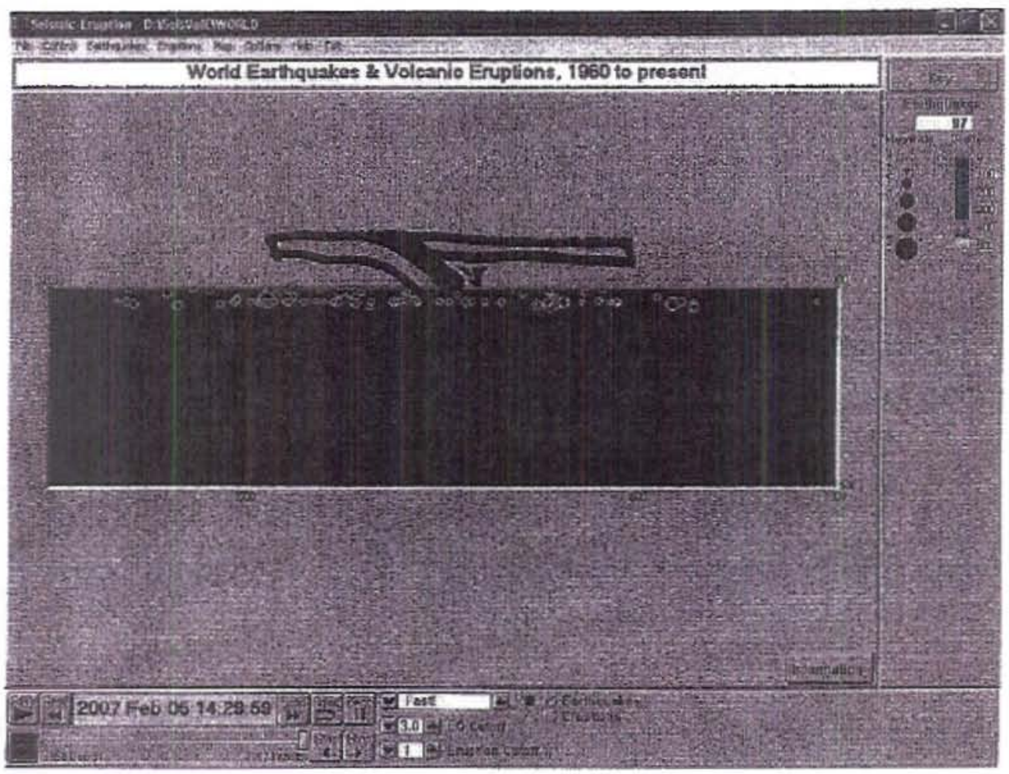


Group 09

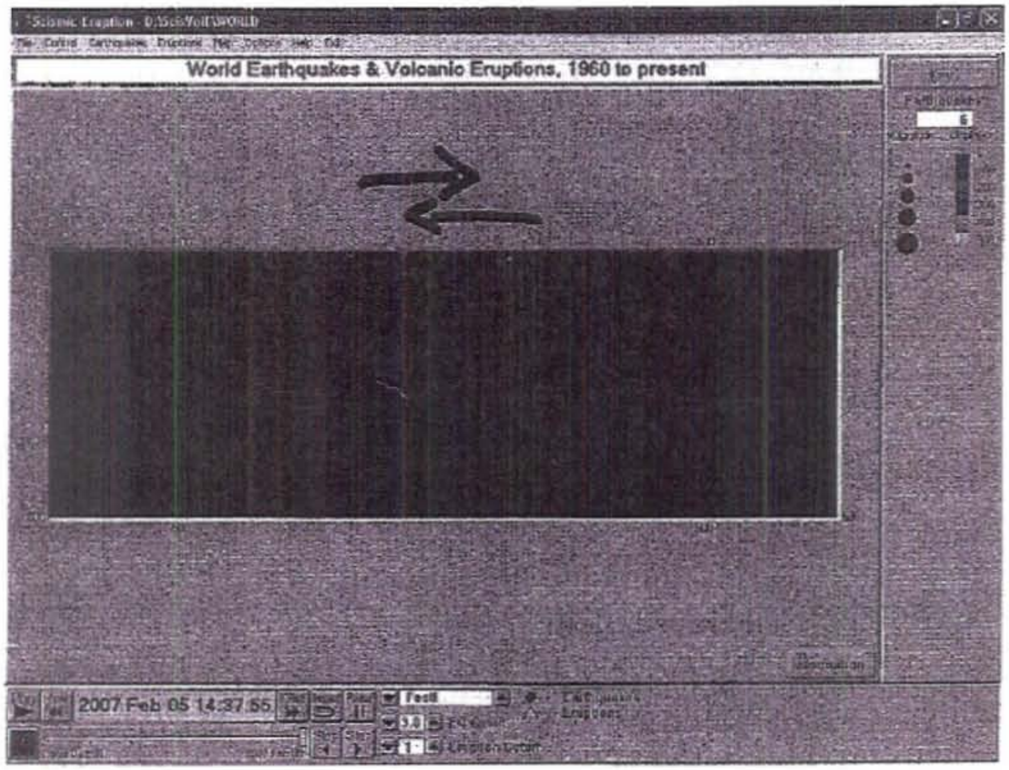
Divergent Boundary. The African Plate and the South American Plate.



Convergent Boundary, Pacific and N. American plate.

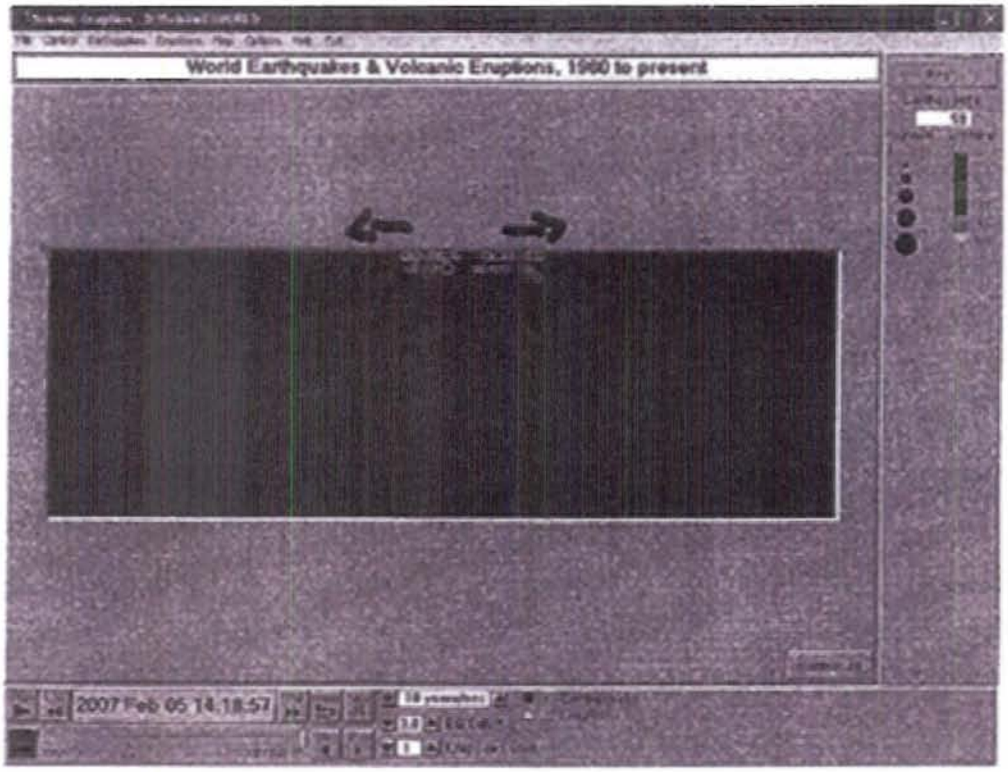


Transform Boundary, N. American and Pacific Plates

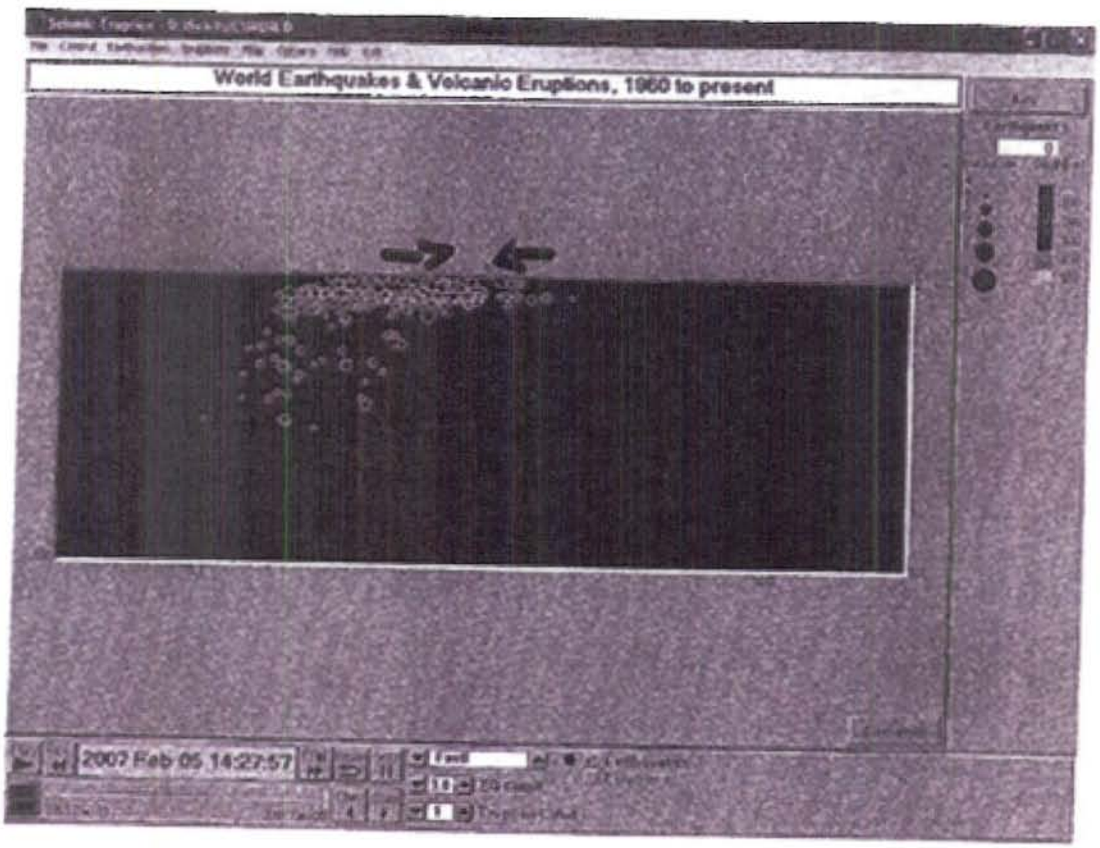


Group 10

Divergent Boundary- African Plate and South American Plate



Convergent Boundary- Pacific Plate and North American Plate



Transform Boundary- Pacific Plate and North American Plate