

Plate Tectonics Exercises

Overview:

This exercise examines the ideas of continental drift and of sea-floor spreading that lead to the Theory of Plate Tectonics. Part one concerns the characteristics of plate boundaries, while part two concerns the paleomagnetic evidence for sea-floor spreading.

There are three types of plate boundaries. All three of these types are found either near to or below Vancouver Island. You will be asked to sketch a cross section containing two types of plate boundaries and identify the geological processes occurring at these boundaries.

The discovery of magnetic anomalies on the sea-floor provided the evidence needed to support the idea of continental drift and sea-floor spreading. In part two of the exercise you will examine magnetic profiles for symmetry and then calculate an ocean ridge spreading rate.

Objectives:

On completion of this exercise you should:

1. know the three types of plate boundaries (divergent, convergent, transform) and be able to describe the relative motions and geological features of each;
2. understand how geomagnetic reversals provide evidence for sea-floor spreading.

Readings:

Magnetic anomalies and Sea-floor spreading, Marshak sec. 3.3 and 3.6

Plate tectonics and plate boundaries, Marshak sec. 4.2, 4.3, 4.4 and 4.5

Reference: The exercise on sea-floor spreading was adapted from the following paper. Shea, J.H., 1988: *Understanding magnetic anomalies and their significance*, Jour. of Geological Education, V. 36, p. 298-305.

Part 1, Plate Boundaries:

Introduction:

Examine Figure 9.1 on the next page. This map summarizes the type of plate margins and the geological processes going on underneath your feet.

The Juan de Fuca Ridge is a divergent plate margin where oceanic crust is produced. Hot magma rises to the surface to produce an igneous rock known as basalt. Mt. Benson is composed of the same type of rock, although Mt. Benson was formed as part of a submarine plateau not a mid ocean ridge. As the rock cools it acquires the current Earth magnetic signature. When this new rock cools, it becomes denser and sinks making room for more rock to be formed above it.

Closer to the coast, the Juan de Fuca plate is subducting beneath the North American plate. This is a convergent plate boundary where crustal material is being consumed.

Water, which is released from the descending plate migrates into the adjacent mantle and leads to melting of mantle material. The resulting magma rises to the surface. The feature associated with this process is the linear chains of volcanoes called the Cascadia volcanic belt. This belt stretches from near to the Garibaldi area of BC to northern California, and includes volcanoes such as Mt. Shasta, Mt. St. Helens, Mt. Rainier, Mt. Baker and Mt. Garibaldi.

North and south of this region the oceanic crust of the Pacific plate is not subducting, instead it is moving laterally relative to the North American plate along the San Andreas and Queen Charlotte transform faults.

Assignment:

Procedure:

Figure 9.1 shows a plan view of the geological processes occurring beneath Vancouver Island. Your assignment is to sketch and label a cross section of the plates and how they are moving relative to each other. The location of the section you are asked to sketch is marked by the line A-A' on figure 9.1.

The figures in Chapter 4 of Marshak should help you to visualize what is occurring.

Show the relative motions of the plates, the locations of any volcanic activity and its source of magma, and indicate where you think earthquakes might occur.

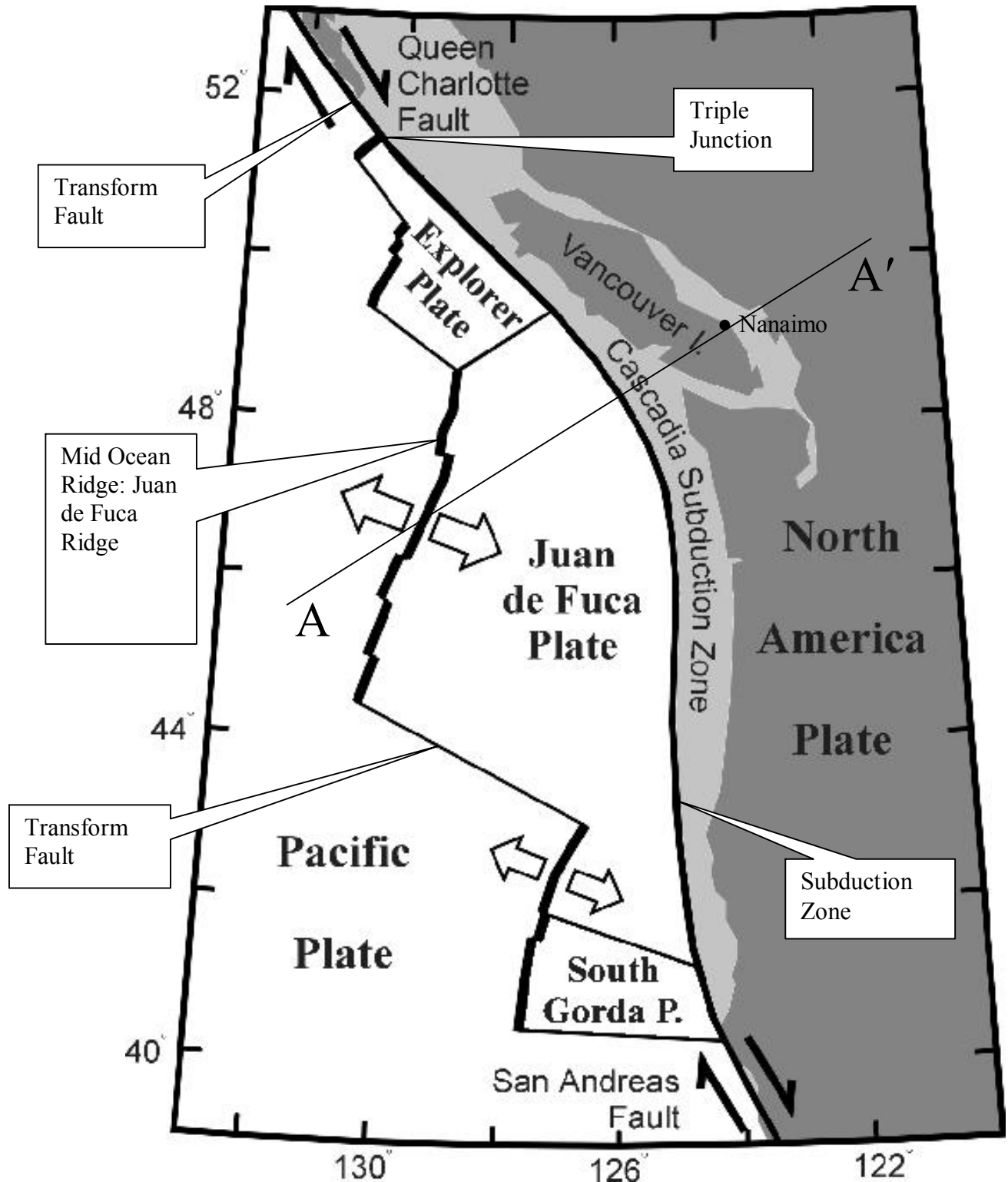


Figure 9.1 Showing local plate boundaries and their relative motions from Geological Survey of Canada Pacific Geoscience Centre, 1999. *Earthquakes and Plate Tectonics in Western Canada*. < <http://www.pgc.nrcan.gc.ca/seismo/eqinfo/eq-westcan.htm> > (July 24, 2002)

Part 2, Sea-floor Spreading:

Introduction:

Understanding the patterns of sea-floor magnetism:

A magnetometer is an instrument that is used to measure very small spatial variations in the intensity of the earth's magnetic field within an area. Magnetometers can be moved around on land (usually by a person on foot), in the air (towed beneath an aircraft) or at sea (towed behind a ship). Studies of magnetic variations are useful in geological mapping and exploration for minerals because they provide general information about variations in rock types (e.g. granite versus basalt), and about the presence of rocks that have significantly more magnetic minerals than other rocks (e.g. iron ores with magnetite).

During WWII, naval ships accompanying supply convoys crossing the Atlantic Ocean towed sensitive magnetometers behind. These magnetometers were looking for submarines (a large metal body capable of deflecting the Earth's magnetic field locally). The operators of the magnetometers found strange patterns of magnetic field reversals as they traversed the Atlantic. In the mid-1950s the U.S. Office of Naval Research undertook a systematic oceanographic survey of an area off the west coast. After much persuasion, they agreed to a request from the Scripps Institute of Oceanography to tow a magnetometer behind the ship. The results of this survey, which, for the first time, included many precisely located parallel survey lines, are shown on Figure 9.2 below - a confusing, but systematic pattern of contrasting strips of positive magnetism (black areas) and negative magnetism (white areas).

In the following years similar surveys were done in other areas - with similar results. However, the origin of the patterns remained a mystery until 1963 when a solution was proposed by a Cambridge graduate student (Fred Vine) and his thesis advisor (Drummond Matthews), and (independently) by a Geological Survey of Canada Geologist (Lawrence Morely).

Vine, Matthews and Morely (VMM) suggested that the patterns could be related to the creation of new oceanic crust at a spreading centre, and to the periodic reversals of the earth's magnetic field. The idea is that as new basaltic crust is created its minerals (particularly magnetite) become magnetized in alignment with the existing magnetic field of the earth. Rock formed during a period of normal magnetism will give a positive magnetic anomaly because the rock has the same polarity as the earth's existing magnetic field, while rock formed during a period of reverse magnetism will give a negative magnetic anomaly. The stripes on the ocean floor, it was suggested, represent different ages of oceanic basaltic rock, which have been pushed away to either side of a spreading centre and replaced by younger basaltic rock.

To begin with the VMM hypothesis was largely ignored, firstly because in the early 1960's the idea of sea-floor spreading itself was not well accepted, secondly because the chronology of magnetic-field reversals was not well known, and thirdly because there was not enough sea-floor magnetic data to test the idea. Much more data became available within a few years, and once others had a chance to verify the phenomenon for themselves the hypothesis became widely accepted, and in fact played a crucial role in the general acceptance of continental drift and plate tectonics a few years later.

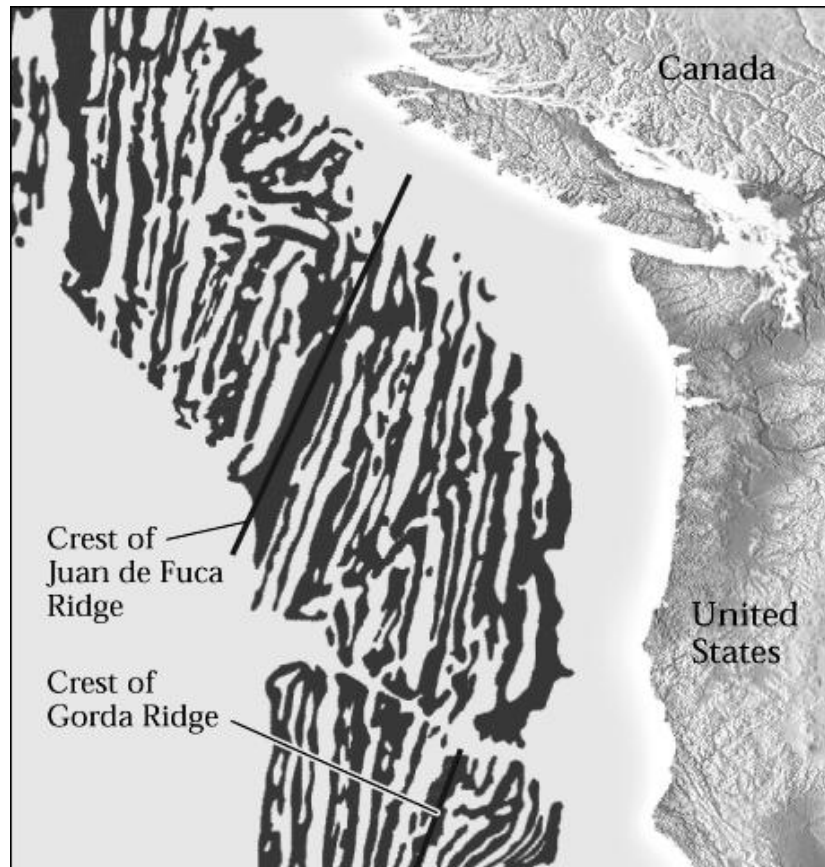


Figure 9.2 Showing systematic pattern of magnetic anomalies of the west coast of North America from Marshak, S. 2001: *Earth, Portrait of a Planet*.

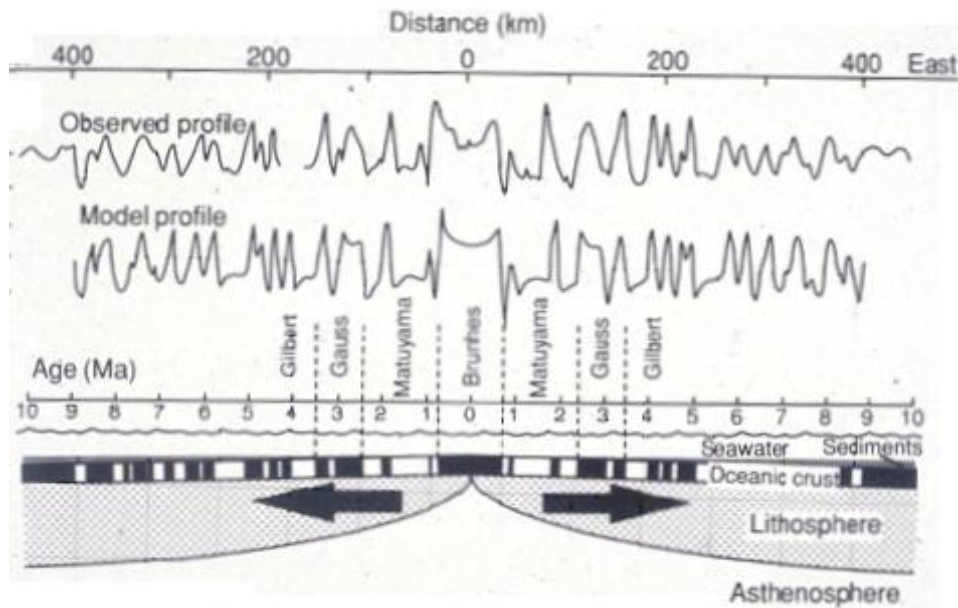


Figure 9.3 Showing sea-floor magnetic anomalies from the Eltanin-19 traverse.

A confirmation of the Vine-Matthews-Morley hypothesis was made in 1966, when W. Pitman analyzed several profiles of sea-floor magnetization across the Pacific-Antarctic Ridge, and

found that one of the profiles, the Eltanin-19 profile, Figure 9.3, showed remarkable symmetry, exactly as implied by the hypothesis.

In this exercise you will make a number of predictions based on the VMM hypothesis, and then use some magnetic data to test them. Some useful predictions are as follows (although you might be able to think of others):

- since the spreading at a ridge is symmetrical on either side of the ridge axis, the pattern of positive and negative magnetism should also be symmetrical,
- magnetic profiles at various points along a ridge, and at different ridges around the world, should be generally comparable,
- the positive and negative magnetic features should correlate with the known chronology of magnetic-field reversals, and
- the corresponding rates of spreading (as determined from the magnetic chronology) should be consistent with typical oceanic-ridge spreading rates (i.e. a few cm/year)

Assignment:

1) Symmetry across the ridge

Profiles of the magnetic patterns on the east and west sides of the Pacific-Antarctic ridge at 51.6° S are shown on Figures 9.4 and 9.5.

Compare the profiles - peak for peak and valley for valley. A good way to do this is to trace the profile onto a separate sheet of paper and place it upside-down on the other profile (axis to axis), and then hold the sheets up to the light. It is best to choose the east side profile (Figure 9.5) to trace.

Compare the profile you traced to the profile from the other side.

Is a reasonable degree of bi-axial symmetry in these patterns? In other words, do you think that the patterns show the same general shape on opposite sides of the ridge?

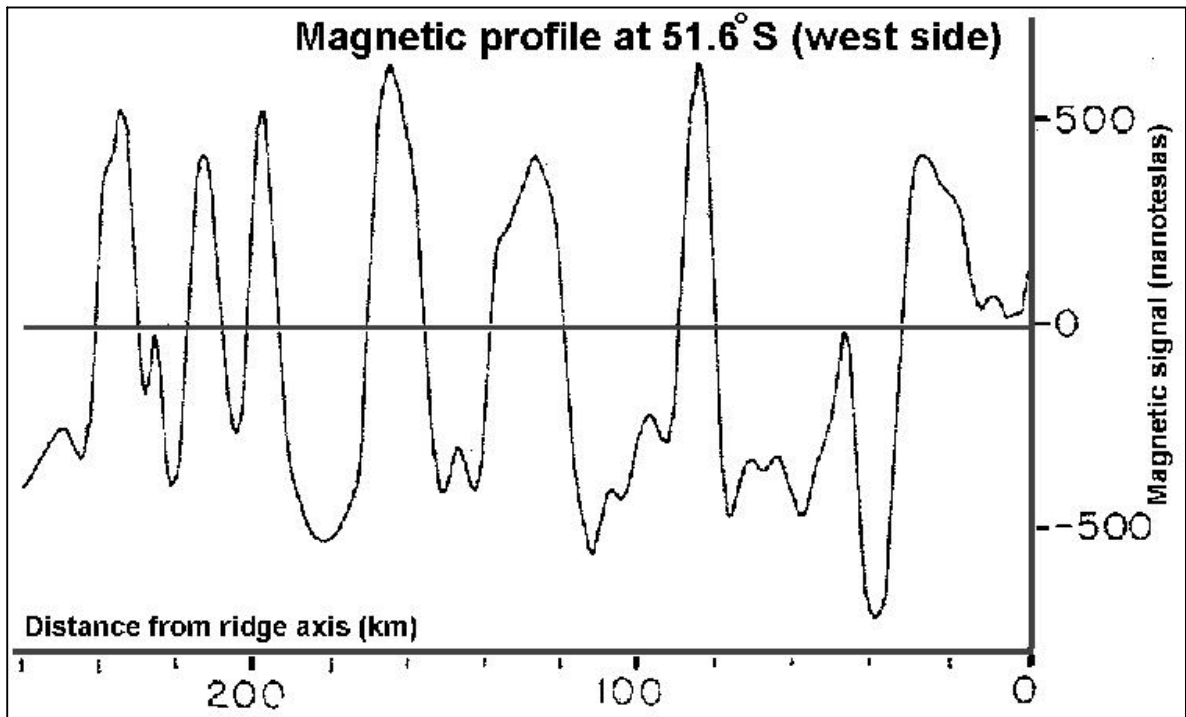
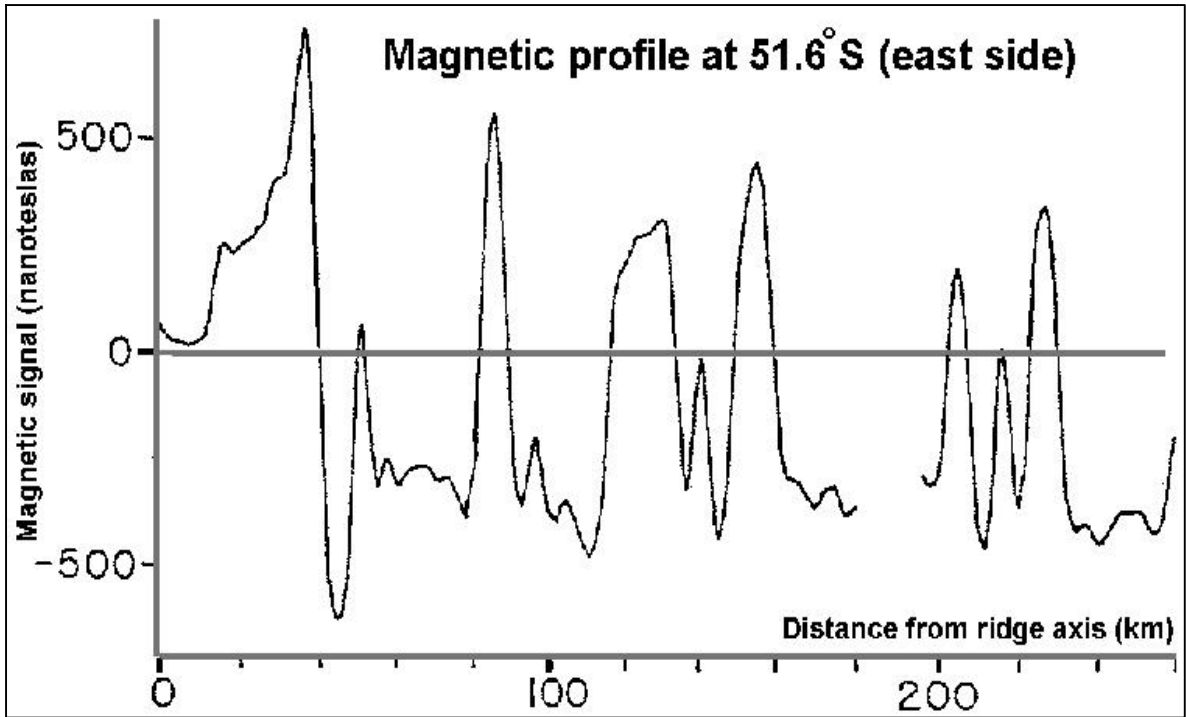


Figure 9.4 Showing magnetic profile on the west side of the Pacific-Antarctic ridge.

Figure 9.5 Showing magnetic profile on the east side of the Pacific-Antarctic ridge.

2) Correlation along the ridge

A magnetic profile on the same ridge at 47.7° S (approx. 450 km from the other profile) is shown on Figure 9.6. Compare this with that of Figures 9.4 and 9.5. Pick out up to 8 well-defined positive and negative peaks that you can correlate on both figures, and label these a, b, c, d etc. on Figures 9.5 and 9.6.

For each of these peaks measure the distance from the ridge, and then record the information in the first two columns of table 9.1, calculate the ratio of the 47.7 profile distance over the 51.6 profile distance, and write that in column 3.

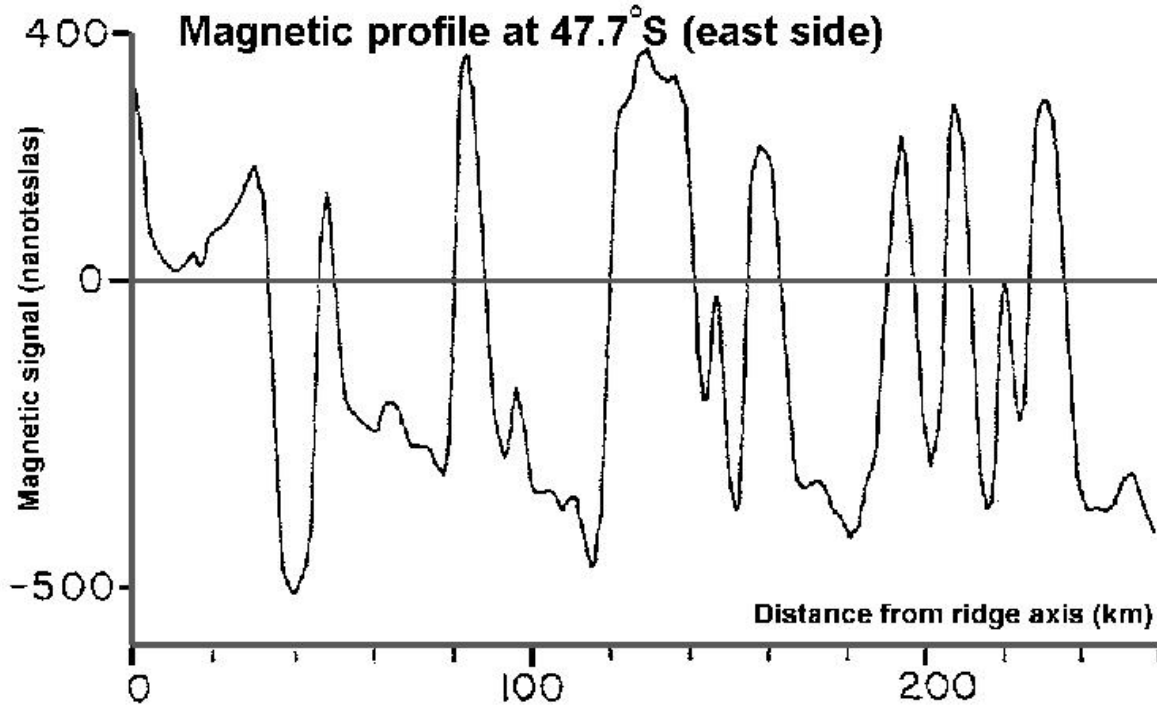


Figure 9.6 Showing magnetic profile on the east side of the Pacific-Antarctic ridge.

Peak	Distance at 51.6° S (km)	Distance at 47.7° S (km)	ratio	Date of magnetic event	Spreading rate (cm/y)	Spreading rate (cm/y)
a						
b						
c						
d						
e						
f						

Table 9.1

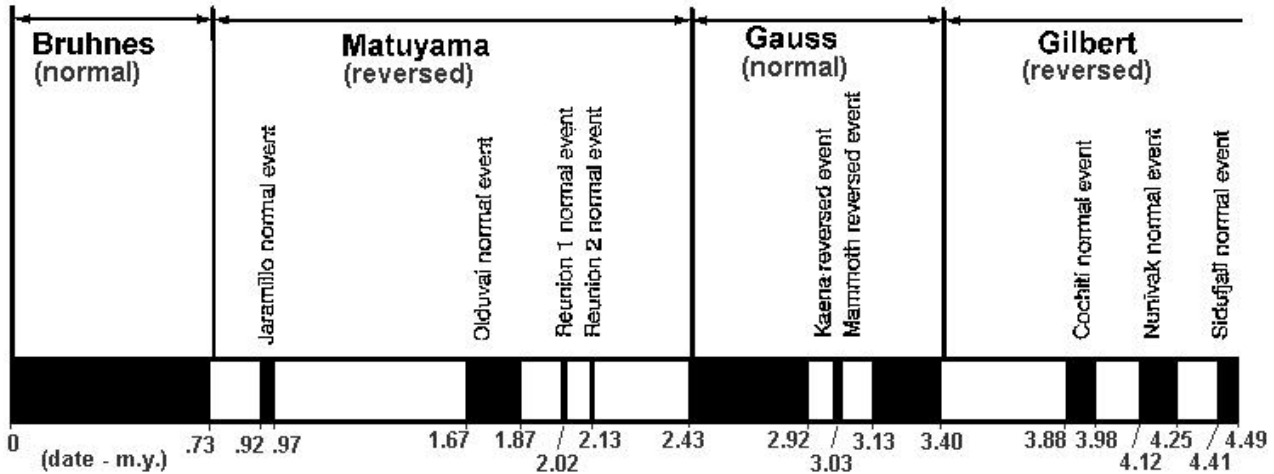
What does the ratio information tell you about the relative rate of spreading at these two points on the ridge?

3) Correlation with the magnetic time-scale

The magnetic reversal time scale for the past 4.5 m.y., which is primarily derived from careful work carried out on rocks of the continental crust, is shown on Figure 9.7. Try to correlate some of the peaks that you selected on Figures 9.5 and 9.6 with the various events described on this time scale, and record the dates of the features in the fourth column of the table above.

Are you satisfied that the magnetic features seen over the Pacific-Antarctic ridge correlate with the known chronology of magnetic field reversals?

Chronology of magnetic field reversals for past 4.5 m.y.



Spreading Rates

Now estimate the spreading rates. Divide the distances (km) by the number of years, and then convert those numbers to cm/year (multiply by 100,000), and put those numbers into column 5. Determine the average rates at the two locations.

Average rate at 51.6 S _____ cm/y

Average rate at 47.7 S _____ cm/y

Are these reasonable rates for a spreading ridge? _____

Your fingernails grow at about 10 cm/y.

Figure 9.7 Showing magnetic reversal time scale.

Are you satisfied that Vine, Matthews and Morely were correct in their interpretation of the sea-floor magnetic patterns? Explain.

If you are satisfied, then you have confirmed the VMM hypothesis. That does not mean that it has been proven to be correct, but if it can pass several such tests, then it can be upgraded from a hypothesis to a theory.

In fact, the VMM hypothesis regarding interpretation of sea-floor magnetic anomalies has been part of the comprehensive theory of Plate Tectonics since the late 1960's.