Chapter 2
Elements of a Science Investigation

In the previous chapters I discussed elements that distinguish science from other forms of thought. In this chapter we go into more detail about how science is practiced and what kinds of considerations must be addressed during a scientific investigation. Figure 2.1, below, is a diagram showing some of the rhetorical components of a science paper. These components and how we can use them to improve students' understanding of science writing will be discussed in this chapter.

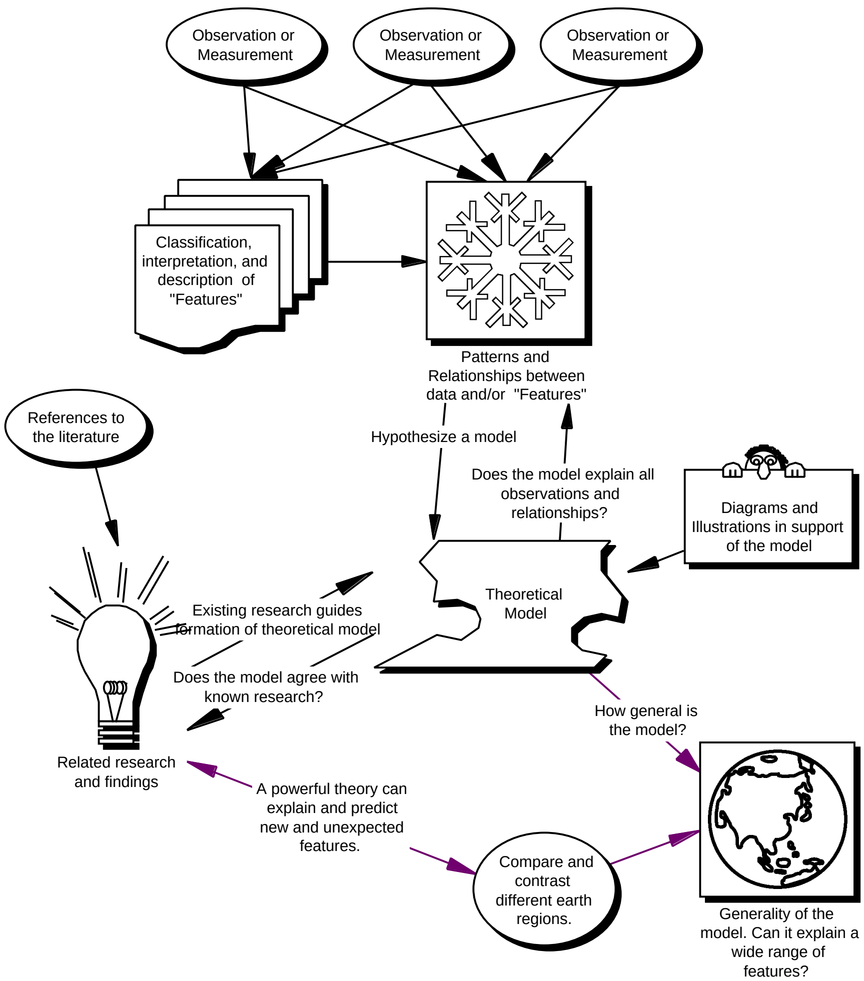

Figure 2.1. Elements of a science paper. The elements in this diagram show critical elements of a science paper, and can be used to more precisely evaluate student writing.

The most critical step in a scientific investigation is figuring out what to investigate. How do scientists figure out what experiment they will do? This is a serious challenge for learners because they first need to understand the prevailing theories and have a lot of general knowledge about what is known and not known in the subject area. It presents the educator with a challenge because we don't want to sacrifice learners inherent interest by loading them with so many facts at the start that interest and energy is gone by the time the investigation begins. This is the same problem that new graduate students face upon entering graduate school and beginning work in their chosen specialty. This dilemma is solved by the graduate student's major professor, who makes suggestions about what kinds of investigations might be of interest, and would advance knowledge. We can also do the same thing with less knowledgeable learners. We create a need to know by suggesting ways to begin the investigation. Then, as learner knowledge and confidence increases he/she should begin to ask more original questions. To help the teacher help the student, chapter 6 in this document develops possible topics for investigation.

Scientific evidence: interpretation or observation?
Once an investigation has begun, learners will begin to take data, or make observations. Hopefully, he/she has some idea of what theory will be tested. If not, this is no problem, but soon the learner will have to separate observations from their interpretations. As you will see, this is not so easily done as we might think. The next two paragraphs are devoted to these reasons.

An experimenter reads a dial on an instrument, measures a voltage on a meter, and puts it into an equation to get the temperature of a thermometer. The temperature is recorded as the temperature of "Santa Barbara" and it is reported in the newspaper. Is this an "observation"? Yes, it could be treated that way. However, it contains many assumptions. Some of the assumptions are: a) the temperature at the thermometer is representative of the temperature of Santa Barbara, b) the equation used to convert voltage to temperature is correct, c) the thermometer is working correctly, etc. The thermometer may be in the sun, or in the shade, or near a body of water. We can see that, in this view, the "observation" is indeed, based on a number of interpretations. All observations embody some degree of interpretation. People who are experts in a particular specialty, through publications and other communications, come to an informal agreement about what assertions constitute science "facts," and what do not, so must be referenced in the literature.

Let's discuss another example. Suppose a geologist picks up a rock in the field and decides she/he wants its age to help constrain a model for the formation of the terrain under study. He/she takes it home and sends it to an analysis laboratory. The analyst processes the rock, loads it into a mass spectrometer to determine the correct isotope ratios, enters these into a formula that computes the date, then sends the date (with its accuracy) back to the geologist. To the geologist, the data and its error consist of "data" which is put on a map and correlated with other data in an attempt to refine the model (make an interpretation of the data). The analyst at the laboratory has a different viewpoint. He/she receives a rock for dating. For him/her, the data is the readings of the peaks in the graph that comes out of the analyzer. The peaks are entered into an equation that produces a date. The interpretation is the date and its error. Going back further, when the mass spectrometer that does the isotope analysis was being developed, the developer designed a vacuum system, an ion emitter to eject the charged particles, magnets to bend the ions, and a sensor to detect them and generate electrical signals. For this developer, the data are the magnetic field level of the bending magnets, ion generator current and voltage, pressure in the vacuum chamber, and signals from the detection device. The interpretations are the signals from the ion detector, which must then be converted into quantities of a particular isotope. Each of these scientists have different definitions of observations and interpretations, and they depend on the context of the science being performed, and the goals of the experiment.

Figure 2.2 shows how scientific knowledge can be classified, and some indications of how observations and interpretations can be distinguished. As the preceding discussion demonstrates, knowledge can be classified on a scale according to how well it is accepted. Even within a single scientific context, there is a shifting of categories as new discoveries are made.

> Can you think of any knowledge that you once considered “fact”, yet reconsidered after gaining new information?

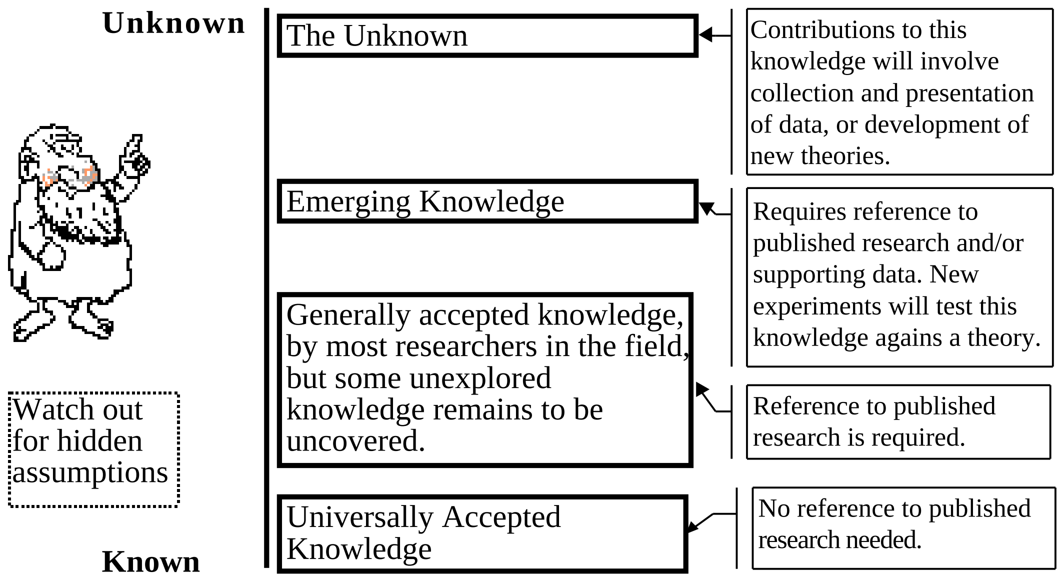

Figure 2.2. Science knowledge structure and the difference between observations and interpretations.

Understanding the theory: the role, and need for background knowledge
The preceding discussion makes it clear that the ability to distinguish between an observation and an interpretation depends on knowledge of the field and the context of the experiment. This understanding comes naturally to the practicing scientist as he/she progresses through various levels of education and accomplishment. However, it is vital for the scientist/educator to appreciate difficulties that are faced by the student who has not had this long apprenticeship. As practicing scientists, we become curious about a particular problem, learn what is already known about it, then begin our investigation (after a sometimes long process of writing a proposal and getting a grant). The process began when our curiosity created a “need to know” the material required for our investigation. This is the way it should start with our students. We might motivate them by appealing to their curiosity, presenting questions that need explaining, and ultimately by making an assignment that requires them to learn specific knowledge in order to be successful.

The investigation into data that support plate tectonics requires that students understand the theory. Fortunately, the theory is composed of relatively simple kinematics that are easily represented in cross section drawings. Students who have difficulty visualizing the animations may need real 3 dimensional models. Clay modeling can be effective.

The Rhetoric of a Science Paper

It is important to find ways how to teach students to write scientifically. Too often we just throw up our hands with the comment "students really don't know how to write anymore; how awful!" My response is that it is our job as educators to teach them. English professors aren't scientists and don't generally teach scientific writing, so if we don't do it, who will? One of the challenges in my Oceanography class is to explain to a student why a paper got a B instead of the hoped for A. The TA or professor can easily tell the difference, but how do we explain it to students? Students tend to go away dissatisfied, even when presented with copies of exemplary "A " graded papers for their review. The methods shown below are our attempt to clarify the elements of a good scientific paper.

Figure 2.1 suggests important elements of science writing. Graduate student Allison Takao and Prof. Greg Kelly have studied student writing in UCSB Oceanography classes and found that the effectiveness of student arguments can be measured by classifying sentences into a relatively small number of rhetorical levels. The research also specifies content links between sentences in these levels. The categories listed below:

1. include an observation, or description of an observation.
2. name or classify an observation in terms of geological features.
3. describe a feature that has been classified
4. describe relationships between classified features
5. describe a model or theory and/or a relationship between model features
6. describe relationships between features or data and a theoretical model

1. Observation: Observations are at the top of figure 2.1, and have already been discussed in detail. They form the foundation building blocks of the scientific argument. If observations have been made by others, references must be made to publications that describe the experimental methods and errors in the observations. In the context of the "Our Dynamic Planet" CD, examples of observations are the maps of quakes, elevation profiles, quake profiles, and the map with data plotted on it. The learner should be aware of the accuracy of the data, and would report it in the "methods" section of the paper. An example the importance of understanding the data is contained in earthquake data. Quake depths for regions in the middle of ocean basins, far from land, often show concentrations at certain depths, making it appear that horizontal faults are occurring. However, this is an artifact of the earthquake location software, which puts quakes at a specific location when the arrival time data (used to locate quakes) are not complete enough to calculate an accurate depth.

2. Classification: Based on the observations, **classifications** are developed. For example, a series of elevation profiles across a particular geological feature will result in its classification as a trench, ridge, mountain, etc. In short, the data have been used to name or classify a feature according to accepted terms. The separation between observations and classifications is somewhat arbitrary. A geologist would argue strongly that he/she has directly observed a mountain range, rather than a linear shape of darker brown or purple color on the horizon. However, in the context of the plate tectonics investigations, the use of several profiles to infer a mountain range is called a "classification". This classification could also be called a "feature". A feature is somewhat more general and could refer equally well to a mountain range, a linear valley, or an arcuate pattern of earthquake epicenters. The “Profile Game” tool of the CD helps learners acquire the skill of using profiles to make these classifications.

3. Describing a feature: Data have been acquired and a “feature” has been identified. It may be long an linear, dipping into the crust, or localized in some way. Its depth, length, and trend could be measured and reported. It is important to describe features quantitatively, rather than in vague terms such as “large”, “small”, “long”, etc.

4. Patterns and relationships: The next level of scientific argumentation involves statements showing relationships between features. An example would be noting that a topographic trench on the seafloor often has volcanoes parallel to it. The search for the understanding of patterns and relationships provides many puzzles that a theory or model must explain. For example, the investigator might look at many trench-like structures and determine whether a parallel row of volcanoes exist in each instance. Most often, the simple pattern will have exceptions and variations. Why is there an exception? What determines the distance between the line of volcanoes and the trench? Maybe the pattern of earthquakes can help solve the puzzle. Are patterns of quakes different in regions where a parallel line of volcanoes is absent? The search for patterns, with the associated compare and contrast of different regions or regimes, is a powerful method for testing theories in most sciences.

5. Describing a model or theory: Ultimately, the goal of research is to find (or test) a model or theory that explains all of the observations. This category includes all sentences that describe a model and describe relationships between “features” of the model. For example, a model of a subduction zone might discuss the topographic trench, volcanoes parallel to the trench, and a descending pattern of quakes as the tectonic plate descends into the earth. A cross section could show how melting at the upper surface of the subducting slab creates molten rock that surfaces as volcanoes, and how the descending pattern of earthquakes is predicted by relative motion between the moving slab and more static plate above it. A clear description of the model makes it easier to point out how the data support or disagree with the model.

6. Relationships between features and a model: In a well-crafted investigation, this section can be the most satisfying one. It is at the highest rhetorical level and can demonstrate student understanding of the investigation. Here the author discusses the relationship between the data and the model. Diagrams and illustrations are used. For example, the model may have the locations of the observed trench and volcanoes explicitly drawn on it (to scale, of course), which explicitly shows the important relationships. The important point is that the model must match with the data. The drawings should clearly show this correspondence. One common mistake that students make is drawing a subduction zone showing the descending slab plunging to the right, while the earthquake data clearly show it descending to the left. Clearly, this student has not thought about how the data and model must agree.

Related research and findings: Here the results of previous research by other investigators is discussed. The author might point out where the new observations expand or provide further support for a particular theory. Other investigators' work must be referenced. The format for these references is discussed later.

The iterative nature of a science investigation: Learners often have the idea that they will take data, interpret it, then write it up and they are done. In science practice, the act of interpreting data most often leads to more questions that can be investigated. We need to make it clear to learners that a good investigation will include serious application of thought, reflection, and refinement of the experiment.

Summary: Several kinds of argumentive statements have been discussed. Support for a theory flows from a recognition of the implied patterns and relationships of features. The features are identified and classified using the observations.

Examples of student writing:

Two examples extracted from student writing in the UCSB Oceanography class are presented for analysis. Neither example is an ideal, but it is interesting to look at the differences and see what we can learn by classifying the sentences according to the rhetorical categories previously listed. Interestingly, the best paper is easiest to classify and the other is more difficult. Before the writing assignments, I ask students in my oceanography class to read each example and vote on the best one. Votes are fairly evenly divided, indicating to me that they have a way to go in understanding science writing.

In the two examples, each sentence has been numbered. I have given my answers at the end of this section, but see if you can classify the sentences according to the rhetorical levels indicated above. The figures have not been included, but it is fairly easy to infer their content based on context.

Paper 1:

Introduction

The area of study is the Kurile trench, identified as a small area on the class CDROM (fig. 1).**(1)** This area corresponds to a plate boundary thought to exist by geologists between the Pacific plate and the Indo-Australian plate (Segar, p62) **(2).** The data collected supports the theory of plate tectonics at a convergent plate boundary.**(3)**

Methods

The data includes topographical profiles created through the ETOP05 elevation dataset which consists of digital elevation data of sea floor and land.**(4)** The sources for this data come from: Ocean Areas—US Naval Oceanographic Office; USA, W. Europe, Japan, Korea, US Defense Mapping Agency; Australia: Bureau of Mineral Resources; New Zealand: Department of Industrial and Scientific Research; US Navy Fleet Numerical Oceanographic Center.**(5)** Gridded data varies in resolution from 5 minutes latitude/longitude to 1 degree.**(6)** Earthquakes are from USGS preliminary determination of epicenters and volcano data are from the Smithsonian Institution Volcano database. **(7)**

Observations

Three profiles taken along the coastal region of the Khamchatka Peninsula display the topographic features of an oceanic trench (see fig. 2 for profile locations).**(8)** Thousands of volcanoes exist parallel to the trench and 200-400 km inland (fig.2).**(9)** The trench lies at 60 degrees N latitude and 160 degrees E longitude and extends for 2,200 km in length along this coast.**(10)** One profile displays the gentle upward slope of the Pacific Ocean Basin which then becomes drastically altered by the sudden drop-off of the trench (fig.3).**(11)** Following the trench, a virtual linear rise occurs as the profile moves northwest and inland.**(12)** A second profile confirmed the presence of the trench 500 km to the south of the first profile, but showed a 400 km long basin located behind the vertical rise of the volcanoes. **(13)** The basin dips 3,000 m below sea level (fig. 4).**(14)** A third profile shows both the existence of the trench another 250 km to the south and the land features described by the first two profiles (fig.5).**(15)**

Earthquakes' foci were also plotted along the same path as the middle topographic profile of the Khamchatka coast.**(16)** The plot shows earthquakes occur consistently along this trench (fig.6).**(17)** A cross section of earthquake activity along the middle profile shows a descending pattern of earthquakes to depths of 600 km (fig.7).**(18)**

Interpretations
Areas such as the Kurile Trench along the Khamchatka coast show the characteristic patterns of a continental convergent margin between two plates.**(19)** In this scenario, a plate containing oceanic crust collides with a plate made of continental crust**.(20)** One of the plates descends beneath another, into the earth's asthenosphere (fig.8).**(21)** A topographic trench is formed where one of the plates begins its descent.**(22)** This process is called subduction.**(23)** The sinking plate causes a corresponding pattern of deep earthquakes along its boundary.**(24)** Melting magma along the upper edge of the plate rises to the surface, creating volcanoes.**(25)** Figure 9 shows a cross-section diagram across the middle profile, showing the subduction model and observations of topography, quakes, and volcanoes that occur in agreement with the model.**(26)**

Paper 2

Introduction

I will discuss the motions of the plates and their effecting result on the sea floor and the earth.**(1)** At the center of my discussion will be the Mid-Atlantic Ridge and why it has formed into an S shape.**(2)** It is an underwater mountain range, also known as an oceanic divergent margin**.(3)**

Observations
The Mid-Atlantic Ridge is a very interesting part of our Earth.**(4)** It is an underwater mountain range, also known as an oceanic divergent margin.**(5)** This ridge runs north to south down the center of the Atlantic from the North Pole to Antarctica.**(6)** Many different plates meet at the ridge including the North American, the Eurasian, the South American, and the African Plate.**(7)** The ridge extends at one point as deep as 5,625 m below sea level.**(8)** It stretches east to west from Europe and Africa to the east coast of the Americas, 2,547 km.**(9)** This is evident in Figure 1.**(10)**

An oceanic divergent margin means that the plates, which form the Earth, meet and disperse in opposite directions.**(11)** The resultant gap from these diverging plates is filled up with uprooted, low density magma.**(12)** This process leads to the series of volcanoes which form into a ridge in the gap left by the plates.**(13)** This process is known as sea floor spreading.**(14)** This is also illustrated in Figure 1.**(15)** The aging crust then sinks steadily down, while the mountains in the ridge slowly move outward while new ones fill in their place.**(16)** The mountains move in the direction of the plate.**(17)** This part of the process, combined with narrowness of the Atlantic and the shape of the continents, leads to the S shape formed by the ridge.**(18)**

Interpretations
My study shows the Mid-Atlantic Ridge is an oceanic divergent margin that is formed in an S shape due to many different factors including ocean size, plate motion, volcanic activity, and sea floor spreading.**(19)** This is proven by the data gathered from the map program and is reinforced by the area's topography, which includes volcanoes and earthquakes.**(20).**

Try it yourself!

Choose the numbers of the sentences for each paper that (keep them separate) :

1. include an observation, or description of an observation.

2. name or classify an observation in terms of geological features.

3. describe a feature that has been classified

4. describe relationships between classified features

5. describe a model or theory and/or a relationship between model features

6. describe relationships between features or data and a theoretical model

A sentence may fit into more than one category. My answers are shown at the top of the next page. Feel free to disagree with me. This classification is not an exact science, but I hope you get the idea.

This classification scheme does not consider links between the sentences. The links are critical and have been examined by Takao and Kelly. Generally, writing that contains sentences that fit a variety of categories receive higher grades than those that do not. Logical links between sentences are also important, but are not included in this analysis. Notice that paper #2 (hopefully you also rate it the worst) has a lot of sentences under 6 (description of the model) and few under observations and classifications. This means that the student did not really conduct an investigation, but repeated material from the book, while paper #1 described a lot of data and had 3 sentences describing a relationship between features and one that described the relationship between the model and observed features. It could have been better by connecting the model with the observations in more depth.

My answers:

Rhetorical categories	**Paper #1**	**Paper #2**
1. Observations	1. -8-9-11-12-13-15-16-18-	-10-
2. Classify Observations	2. -8-	-none-
3. Describe feature	3. -10-14-	-8-9-
5. Relationship between features	4. -9-13-17-	-none-
6. Describe model	5. -19-20-21-22-23-24-	-3-5-6-7-11-12-13-14-15-16-17-18-19-
7. Relationship between observed and model features	6. -26-	-20-

Implementation Considerations

Setting the scope of the investigation

During my first attempts at using the CD, I asked students to pick a problem related to plate tectonics, from the entire earth, gather data to support an interpretation according to plate tectonic theory, and write up their findings. Students quickly got stuck because I had asked them to make too large a leap. The range of possible studies of the entire earth was just too great. Students were much more successful when I first asked them to study a small area that was pre-selected to contain a classic plate boundary type, and write a one page paper. The one page paper was quickly graded and returned so they could revise and expand it into a larger paper on an expanded topic. I choose a different small area each time I teach the class, to avoid students copying papers written by students in previous quarters.

Motivating and reassuring students (anxiety)

Students can quickly generate a lot of anxiety about open ended assignments. Tobias, in “Overcoming Math Anxiety” (see: http://www.mathanxiety.net/) notes that a problem that requires exploration and thought before a solution is reached often creates such anxiety in students that they become paralyzed and unable to engage in activities that lead them to a solution. Students need to know that science does not have easy answers. I make the analogy to a detective who is trying to solve a crime. Evidence is carefully gathered without an idea of who committed the crime. During this exploration process, the detective begins to eliminate potential suspects and finally the guilty party becomes apparent (at least in TV crime shows). Science is a process that sometimes takes time and an investment of energy. I let students know that they can work toward a solution by studying the theory of plate tectonics until they understand it, then working with the earth data to see if there is a relationship between the theory and the data. Given some time and effort, clarity will emerge.

I have also assured them that students in past courses have successfully completed the assignment. Another technique is to offer some possibilities of the kinds of studies that they might try. A small set of “questions that provide clues” has also been effective at getting some students started.

Supporting activities:
The following table shows activities, with associated goals, that I use to help students write a successful science paper about plate tectonics:

Topic	Activity	Learning Goals
Observations and Interpretations (week 1)	1. Make a map of a portion of the nearby beach and write a description of the area mapped. 2. In-lab class and group discussion about observations and interpretations.	How to describe observations and to separate observations from interpretations
Small area description (week 2)	1. Identify earth features 2. Use CD to make a map of earth's plates and determine plate boundary types 3. Profile game 4. Write 1 page paper on small area (due next week).	Generate interest in earth features, familiarize with the CD, characteristics of plate boundaries, begin thinking about the major science paper and get feedback on it.
Science paper (1800 words) (week 3)	1. Class and small group discussion of possible topics for investigation 2. Each student makes a plan for an investigation 3. Preliminary data access	Solve remaining problems using the CD, focus student on their investigation, give student confidence that he/she can complete the investigation.

Materials (see lab manual at http://oceanography.geol.ucsb.edu/ for all materials)**.** A scoring rubrik for the final paper is included at the end of chapter 3.

Small Group Feedback for Beach Description:

Author's Name: ___________ Reviewer's Name:___________

Suggested review procedure, for each paper:

1) Decide whose turn it is to get reviewed, then distribute the copies of the paper to the group members. Read the author's paper. While reading it, make notes under the correct categories on the form below.
2) When you are completed, discuss each category with the group.
3) Give your filled out feedback form to the author for future reference.

Rate each question with this scale:

0 = needs improvement; 1 = acceptable; 2 = exceptional

1. MAP - technical:

Item under discussion	***Rating***
Distance scale and North direction clearly indicated	
Line indicating location of elevation profile is shown	
Features appear to be in reasonable location and at reasonable scale	

2. Map – clarity:

Map is easy to understand, important features are clearly labeled.	

3. Map – comprehensive:

Map describes the most important features, such as cliffs, sand, ocean	
Map has a reasonable level of detail. Author has included all important features	

4. Elevation profile:

Elevation profile corresponds to the line on the map	
Heights are labeled and elevations appear reasonable	
Figure clearly shows location of important features shown on the map	

5. Discussion:

Includes a description of the "setting", or larger locale of the area being described	
Discussion includes method of determining distances, and an estimate of the accuracy	
Describes important features shown on the map	

6. Classification: Discuss whether the author "classified" as well as observed. What does it mean to classify an object or observation? Identify one sentence in that classifies.

7. Overall: Discuss whether the paragraph was well written. Any other strengths and weaknesses?