SCIENCE OLYMPIAD

Exploring the World of Science

Geologic Mapping

Content Intro

Division C, 2024

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1. Introduction

- This document was partially created based on draft rules, and so may not be completely up to date. Please refer to the official Science Olympiad 2024 Rules Manuals as well as rules clarifications and FAQs (all available via the national website soinc.org) for the finalized event topics and rules of competition.
- Every year there are several hundred Science Olympiad tournaments hosted nationwide, which means several hundred Geologic Mapping event supervisors and several hundred interpretations of the content covered in the event rules. While this document aims to provide an overview of all the fundamentals of the event topics, remember that the rules manual (including clarifications and FAQs) is the official source, and the topics covered here are ultimately an interpretation of the rules.
- Like any Science Olympiad event, the topics covered in Geologic Mapping can become quite deep and expansive, especially at higher levels of competition. Writing a textbook in a few weeks is not exactly feasible, so this document deliberately tries to focus on the most fundamental parts of the event (which is not necessarily the same thing as the easiest parts), with the goal that after the reader familiarizes themselves with these topics they will be in a better position to deepen their knowledge.
- In general, this document assumes a familiarity with middle school-level earth sciences, so as to not spend too much time on prerequisites that many readers will already be familiar with – however, some sections may assume more or less, if it benefits the structure.

2. Structural Geology

2.1 Basic Stratigraphy

Consider Image 1, which shows what is called a block diagram, depicting a set of overlain rock layers (i.e. beds, strata). Each stratum here is a type of sedimentary rock, formed through consolidation of loose sediment over time. In a simple scenario such as this, the layers at the bottom are older than the ones above them, since new sediment is deposited on top of existing bedding. (The details are covered further in Section 3)

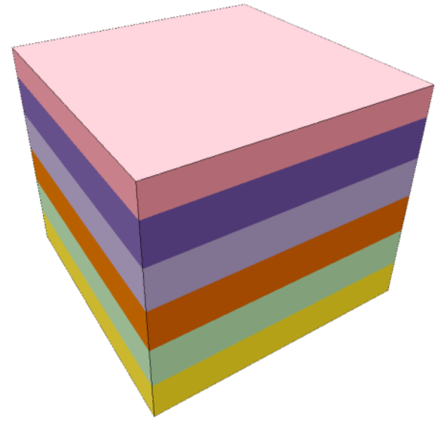

Image 1

2.2 Deformation

Most bedding does not simply lay undisturbed indefinitely – it is typically acted upon by geologic forces (e.g. movement of tectonic plates, or localized igneous events) or erosion between the time it formed and the time we observe it. For example, Image 2 shows an example of tilted bedding. Tilting is usually caused by either compressive or shear forces, most prominently as a result of the collision between two tectonic plates. However, the key point from a structural geology perspective is in how we measure the bedding's attitude (orientation of tilting).

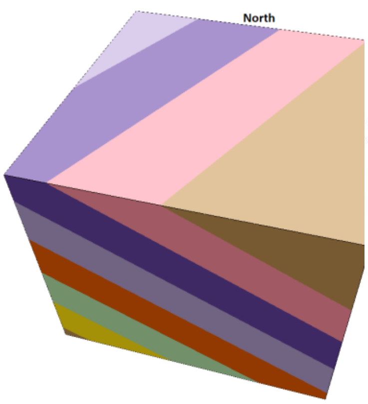

Image 2

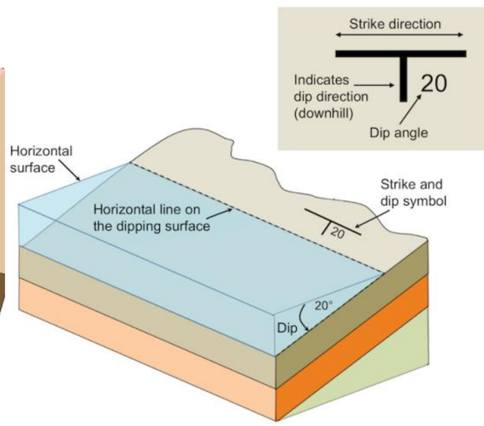

Image 3

Consider Image 3, which illustrates the strike and dip of a tilted stratum. This is the typical pair of measurements used to describe the attitude of strata. The strike is expressed as an azimuth (angle of a compass direction e.g. measured from North), in various ways depending on convention, and the dip is an angle from horizontal down to the plane, in the steepest direction, straight downhill. In general, a stratum or collection of adjacent strata can be thought of as dipping in a certain dip direction, by a certain dip angle. On many geologic maps, the strike and dip symbol may be marked to indicate the attitude of the stratum at a given location. (This is illustrated in more detail in Section 4.2). Understanding and applying measurements of strike and dip is a core skill of Geologic Mapping, and is particularly relevant when interpreting geologic data.

Another common type of deformation is folding. Image 4 shows an example of folded strata, with several elements of the fold labeled. Folds are formed primarily by compressive forces. Notice how the anticline of the fold shows the younger layers outcropping (visible on the surface) toward the hinge, while the syncline shows the older layers outcropping towards the hinge. Observing surface outcroppings (e.g. younger layers in the middle, older layers on the sides) and inferring the subsurface structure from those

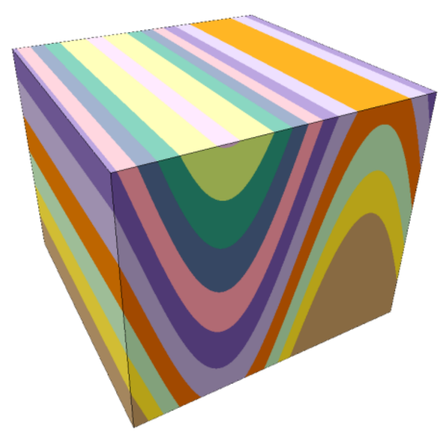

Image 4

observations (e.g. a syncline or related structure) is a key aspect of interpreting geologic maps.

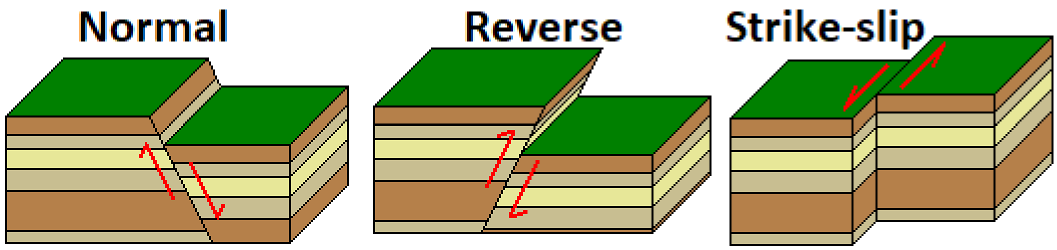

Image 5

The last of the fundamental geologic structures is faults. These can be formed by any type of force – if you examine the three major types of faults in Image 5, you may be able to see how tensile forces tend to cause normal faults, compressive forces tend to cause reverse faults, and shear forces tend to cause strike-slip faults. Note the displacement between the strata across normal and reverse faults.

Of course, real-world deformation structures tend to be less clear-cut than the examples shown earlier. Often, tilted strata are only locally flat, folds tend to be very asymmetrical, and many sequences of multi-directional faults will be formed by the forces at play in a region. As is often the case, analyzing real-world structures will therefore be more difficult than simulated structures, and both types of tasks are likely to come up in competition. Handling real-world situations is covered in some more detail in Section 4.

3. Rock Formation

So far, we have been dealing primarily with sedimentary rocks, and only from a structural perspective. This section will delve a little deeper into the processes that produce the three types of rocks that many readers will be familiar with, as well as their relevance to Geologic Mapping as a whole.

3.1 Igneous

Igneous rocks are those formed by cooling of magma. They do not form layers, and in fact their formation often deforms sedimentary strata. For example, Image 6 is a cross-section which shows an example of an intrusive (solidified within the Earth, rather than outside = extrusive) igneous unit, which has deformed the strata around it. Various types of igneous intrusions and extrusions may be observed in reality, with different environments of formation and effects on the surrounding rock.

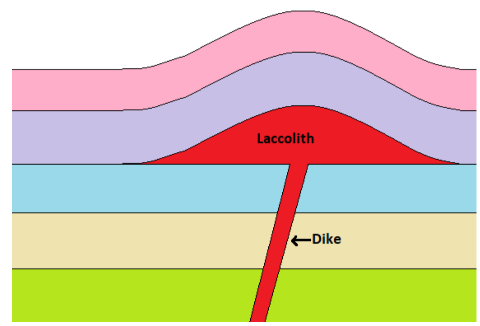

Image 6

A key element of igneous rock formation is fractional crystallization, the process by which magma solidifies into different minerals depending on the melting temperature of its various constituents as some of its composition precipitates into solid rock. This is shown in Image 7, Bowen's reaction series, an ordering of various types of minerals from high melting temperature (solidifies first as magma cools) to low melting temperature (solidifies at later). As a result of these properties, a wide array of geologic conditions and processes correlate to Bowen's reaction series – for example, minerals that precipitate at higher temperatures tend to be less resistant to the chemical weathering of the rather cooler surface temperature. Applying the principles described by the series may often be helpful in interpreting geologic data.

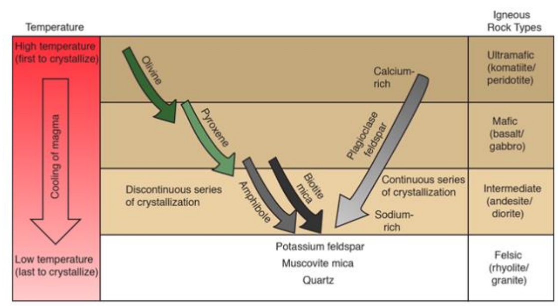

Image 7

3.2 Sedimentary

Sedimentary rocks are formed from compacted sediments. Typically, sediments are deposited or precipitated via water or wind, and become rock-like through immersion in water and mineralization of the spaces in the sediment, forming a cement matrix. Sedimentary rocks are typically classified by a mix of their composition and the size of the sediment grains.

One key aspect of sedimentary rocks as relates to Geologic Mapping is the depositional environments they form in and how that affects their properties – or in reverse, how analysis of sedimentary rocks can reveal information about geologic history. For example, grain size of

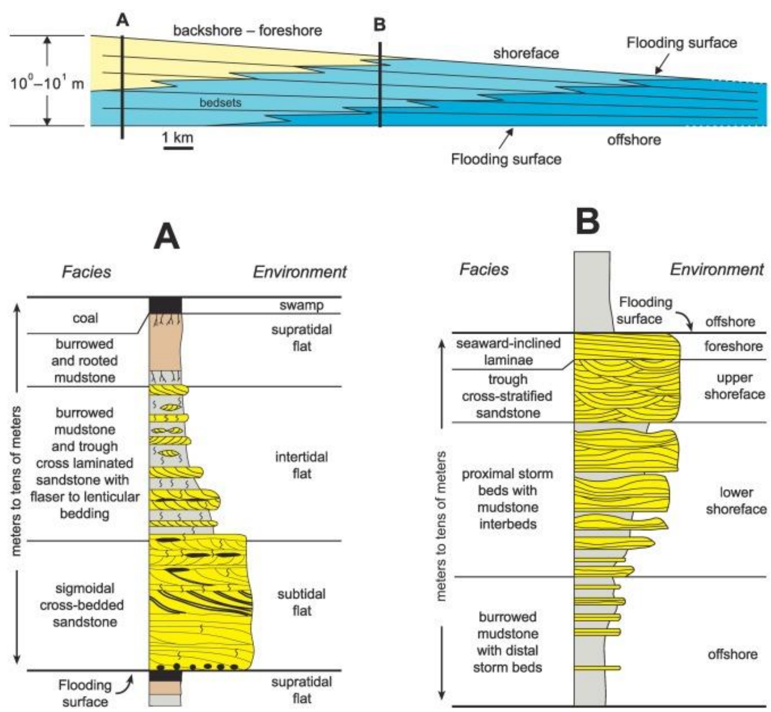

Image 8

deposited sediment often varies by distance from a shoreline, and a change in grain size in rock strata over time or distance can reveal the flooding or receding of water in the area when the sediment was being deposited. Image 8 (previous page) shows a rather in-depth example of how the strata in a given location may change over time and be interpreted to reveal the receding of the water body that produced these strata.

3.3 Metamorphic

Metamorphic rocks are those transformed from other types of rocks by heat and pressure. They can be classified by a combination of their composition and the transformations caused by the amounts of heat and pressure that the base rock is subjected to. Metamorphism is often the result of exposure to deep subsurface environments, although it can also occur locally from igneous intrusions (contact metamorphism). There is more that can be said about metamorphic rocks (of course – there is more that can be said on any of the topics in this document), but such information is well beyond the realm of core fundamentals, as far as relevance to the event goes, hence the brevity of this section.

4. Geologic Data

Part of Geologic Mapping in competition involves reading and interpreting geologic data, performing calculations based on existing data, synthesizing information from multiple data sources to decipher geologic history, and related tasks. While event supervisors can of course vary question difficulty quite a bit, it is often the case that interpretive tasks tend to be among the most difficult, since geologic analysis necessitates a strong grasp of the underlying principles. While practical experience is the most effective way of learning to interpret data, it can often be a daunting aspect of the event, with no clear places to start learning. This section aims to remedy that situation.

4.1 Stratigraphic Analysis

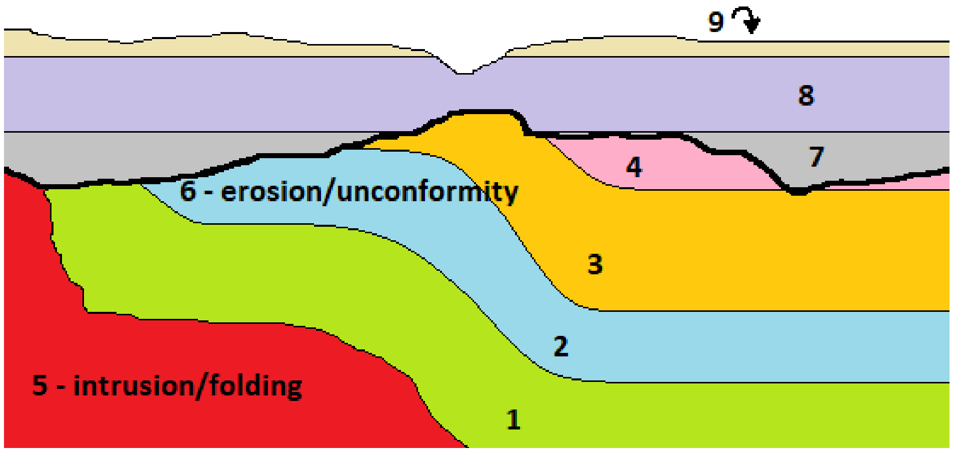

Image 9

Many tasks in Geologic Mapping involve interpreting or constructing stratigraphic data. Consider, for example, the cross-section shown in Image 9. The units and events (faulting, folding, and erosion) in this region have been labeled 1-9 in order of their occurrence. The strata 1-4 were most likely laid in that order, being atop one another in a straightforward way. The igneous intrusion causing the folding of those layers would have come afterward, followed by the erosion and resulting unconformity – which can be dated based on the fact that it has eroded some of the intrusion (and therefore must have occurred, or at least ended, afterward). The same superposition principle can be used to order the remaining strata above the unconformity. While this example is simplified from reality, most tasks in competition will also be simplified from reality – real-world data tends to be murkier, and event supervisors generally try to pick clear-cut examples when using real data.

Construction of stratigraphic data (usually from maps, real or simulated) tends to be a little more difficult than interpreting them. The details of a particular situation may be complicated by the interactions between strata of varying attitudes and how they outcrop in uneven terrain. This is covered further in Section 4.3.

4.2 Calculation

Besides general applications of algebra, much of the calculations in Geologic Mapping relate to trigonometry in some way. In order to maintain focus, this section will assume a general understanding of the three primary trigonometric functions, and how they apply to calculations involving triangles. The range of possible problems is fairly broad (an event supervisor could derive quite a few types of questions from the wording of rule 3.c), so this section will cover one of the most common representative problems to help illustrate the principles at play – determining the attitude of a rock bed from multiple surface outcrops, also known as a three point problem.

Consider Image 10 (next page), which shows a flat, tilted purple unit cutting through a mountain, on a 1 km by 1 km map. In order to determine the attitude of the purple unit, we will use the three points A, B, and C, all on the top surface of the unit (of course, the bottom of the unit works just as well, that choice is arbitrary). Three points are sufficient to define a single unique planar surface, so with any three outcrops of the same surface, we can determine the attitude of the unit. There are a few ways to do this, but perhaps the simplest is to consider the line between the highest and lowest altitude outcrops. Consider that if we have a line between two outcrops of a planar unit, this line is a part of the plane. The line between the highest and lowest outcrops descends from the higher to the lower altitude as it “moves” horizontally, which means that at some location along this line, the altitude of the line will be the same as the altitude of the middle-altitude outcrop. If we draw a second line between these two points of the same altitude, that line is by definition the strike, since it is between two points of the same altitude, both on the plan’s surface. To compute the dip, we need to draw a third line which is at a right angle to the second line, i.e. from the second line to the lowest or highest (either works). This third line will be on the plane’s surface and perpendicular to the strike, and the dip angle can be measured trigonometrically from the altitude gap and horizontal distance. Image 11 shows the lines and measurements in question. As you can see, the calculated values are very close to the actual values used to create this simulated map (the only difference being the dip angle was 35 degrees).

Communicating the spatial structure of structural geology problems of this sort can become complicated, but the general principle of constructing geometric relationships using the information provided is core to many of the calculation problems that you may tend to see in Geologic Mapping.

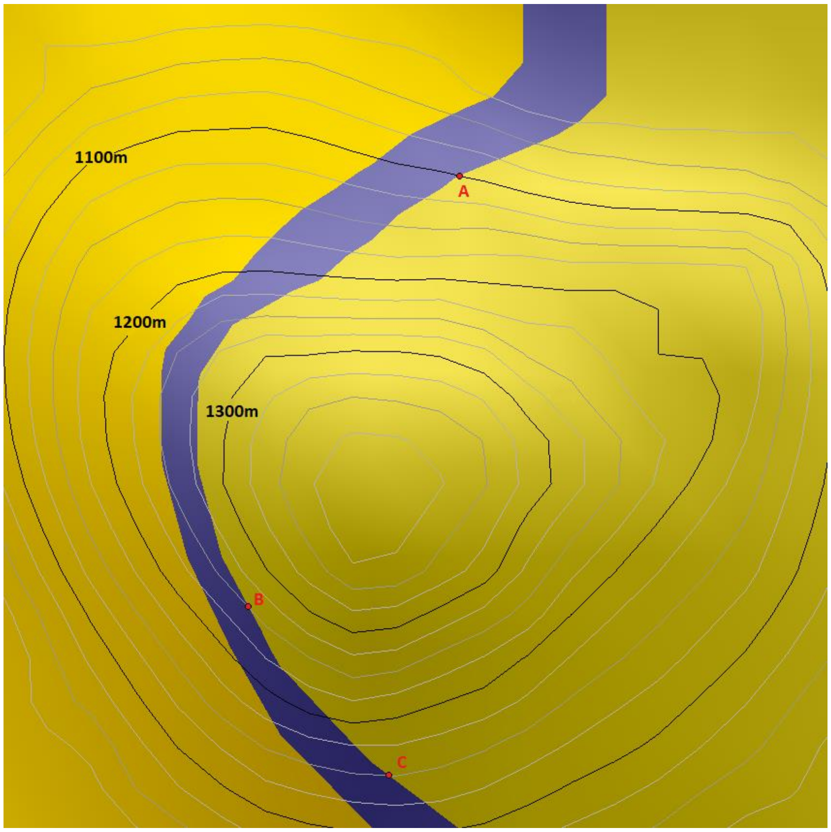

Image 10

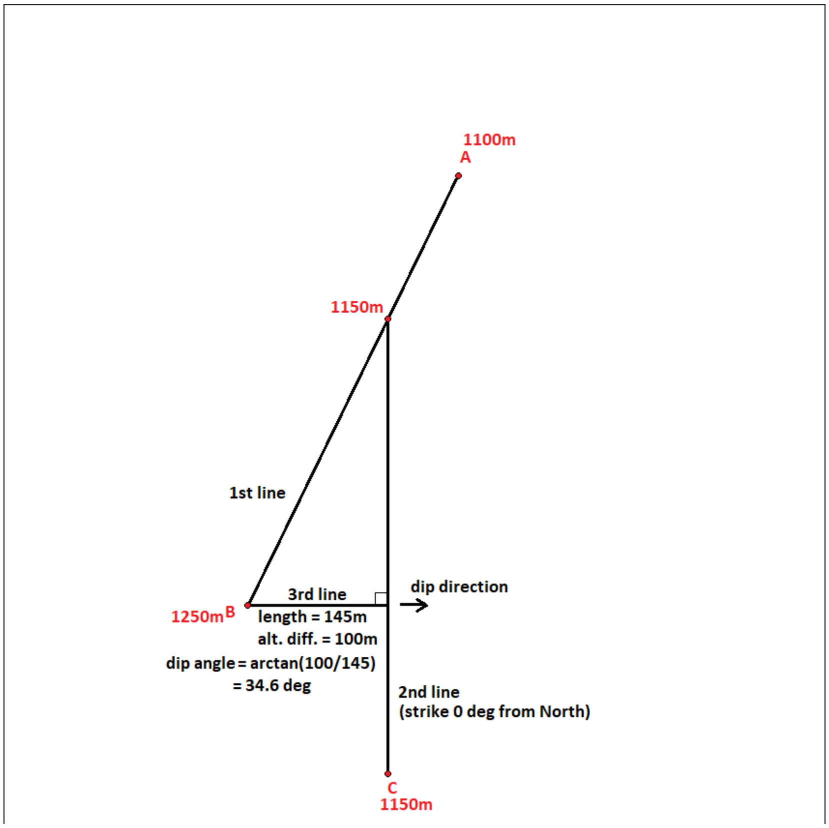

Image 11

4.3 Topographic and Geologic Maps

Map interpretation tends to be a challenging aspect of Geologic Mapping, since it combines many other skills and can be particularly unapproachable. This section shows examples of both real and simulated maps.

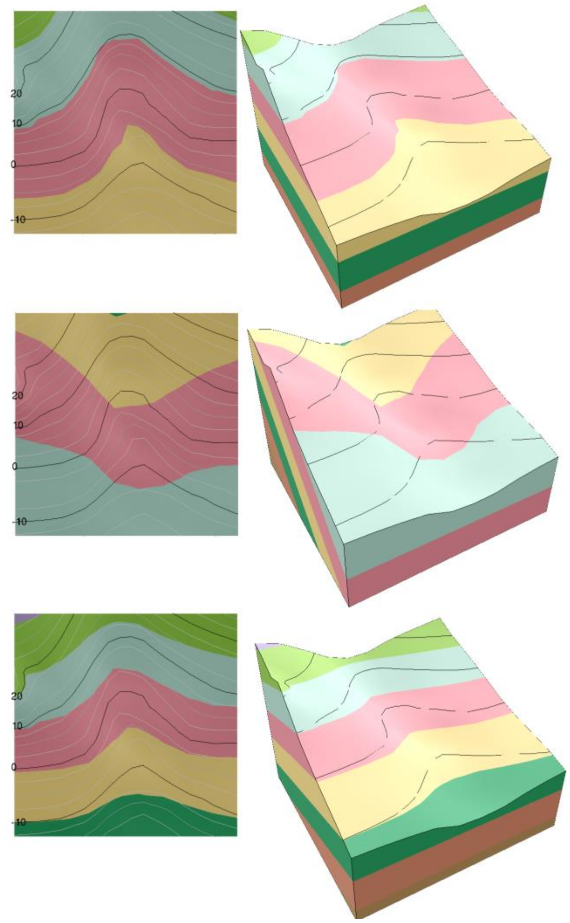

Image 12

Image 12 (next page) shows a few scenarios involving the topography of a river or stream flowing southward, and three illustrative possibilities for tilted strata in the region. You may be able to observe how the topography and geology interact in these situations (or not, as this is already moderately difficult material – however, it makes for a useful example of stratigraphic interpretation). Constructing a cross-section from a surface map and associated data is a common interpretive task.

Image 13 shows an excerpt of a real-world geologic map (specifically – Heron Reservoir, 2017, Aby and Timmons). As you can see, it's rather more complex than the simulated examples so far, including:

- Real-world topography shown by light gray contour lines
- Several exposed sedimentary strata from the Cretaceous period in shades of green (units beginning with "K")
- A river valley exposing some older layers vs. the rest of the surface
- Recent sediment deposits (units beginning with "Q" for Quaternary)
- A large number of faults running roughly north to south (which with careful analysis you might be able to determine are being formed primarily by tensile forces)
- Various surface features, including several roads, and the outline of the reservoir in the northeast

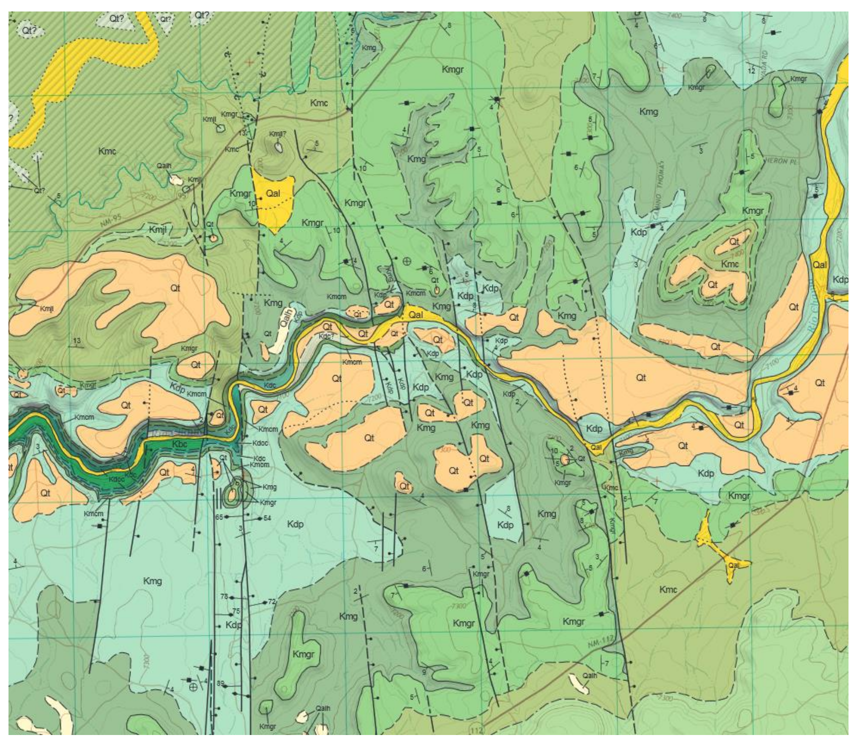

Image 13

The full map also includes a correlation chart (which shows the time periods of all of the geologic units), descriptions of every unit, a cross-section, and other relevant information. Real-world maps can be intimidating, and while it is true that difficult problems in competition often involve them, surmounting the intimidation factor is the biggest barrier to effective map interpretation.