Lecture Goals:
A) The Proterozoic time frame
B) Paleogeography
C) Tectonics 1 (Wopmay Orogeny)


A) Time frame
Last time we discussed the Archean and Hadean Eons. The Hadean Eon represents the period of time without a rock record on this planet. The Archean is recorded through rocks of granulite and greenstone associations. The next eon, and the subject of this week’s material is the **Proterozoic** (2.5 GA to 550 MA). Unlike the Hadean and Archean, a lot of major developments in Earth history started in this eon (which incidentally, covers more than 40% of all geological time), including the first eukaryotic life and the first “modern-type” plate tectonics. Like the Archean, the Proterozoic is divided up into early, middle and late division, except this time, we use the terms **Paleo** (old), **Meso** (middle) and **Neo** (new):

<table>
<thead>
<tr>
<th>Division</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neoproterozoic</td>
<td>900 MA to 550 MA</td>
</tr>
<tr>
<td>Mesoproterozoic</td>
<td>1.6 GA to 900 MA</td>
</tr>
<tr>
<td>Paleoproterozoic</td>
<td>2.5 GA to 1.6 GA</td>
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B) Paleogeography
As we discussed during the lectures on the Archean, continents of the early Earth were small and numerous. With time they combined together to form larger masses shields, provinces, platforms and cratons. A large “**super continent**” consisting of what is today North American and Europe may have formed early in the Proterozoic (although this is not entirely certain), and an even larger mass of continental rocks amassed in the late Neoproterozoic (see adjacent image). The formation of super continents has occurred several times in the Earth’s history and it is traditional to name them. The last major grouping of continental landmasses which occurred during the late Paleozoic resulted in **Pangaea. Laurentia** (North
America and Europe) and **Gondwana** (Africa, Antarctica, India, Australia and South America) also formed during the Paleozoic. The large super continent that formed in the later part of the late Meso-NeoProterozoic (C. 1.0 GA) was called **Rodinia**. A quick check of the diagram below will show that the configuration of continental masses was very different then compared to today. Most of the continents were in the southern hemisphere and continents that are today very far apart were then close neighbors. For example, Australia and Antarctica both lay just to the southwest of North America (you could walk from one continent to the next) and most of South America lay to the east. There was at this time no Pacific Ocean.

There is a significant sedimentary rock record for the Proterozoic and through it, we can conclude that many of the geographic features found in the world today were also present long ago. They include continental shelf areas (some were wide, some were thin like today), **epeiric** or **epicontinental seas** and mountains. Epeiric seas are areas of continents that are flooded by seawater. The best example we have today is Hudson’s Bay in Canada, but in the past, much larger areas of the continents were covered in shallow seas. Some were best classified as epeiric seaways as they extended across continents from one ocean to another. You will hear about the Cretaceous Epeiric Seaway when we get to the Mesozoic later in this course.

Through the sedimentary record, we can also resolve parts of the Earth’s paleoclimate. In the Paleozoic, changes in the distribution and characteristics of fossils can really help us to do this, but the limited fossil record before 550 MA prevents their use in the Proterozoic. Luckily for us, some sedimentary rocks can be used as Paleoclimate indicators.

**C) Tectonics 1: Coronation Geosyncline**

The first of the orogens that we will talk about today is called the **Wopmay Orogen**. It represents a period of mountain building about 2.1 to 1.8 Ga in the western portion of the Slave Province. This
particular event has special significance to me. It was the first major term paper I had to write when I was a student and I remember to this day how impressed I was by the literature that was available on this area. It would be classic even if it wasn’t the oldest “true plate tectonic” event. I should qualify this because many textbooks (and many geologists in general) talk about Plate Tectonics like it has always been occurring, but there is no evidence that I am aware of that supports this belief. That is, until 1.8 Ga.\(^1\)

The western portion of the Slave Province is depicted below. Notice that there are several north-south trending belts of sedimentary and igneous rocks (This is the Coronation Geosyncline).

There are also two wedge-shaped belts of sedimentary rock that trend at an angle to the N-S belts. All of these rocks represent an episode of crustal spreading associated with plate divergence (e.g., this was a divergent plate boundary during the Paleoproterozoic). The Coronation Geosyncline was the result of tension and crustal rifting. We will discuss the belts of rock separately, but before we start, let’s consider mud cracks (yes I realize that this sounds like a major shift in subject material – it is, but not as much as you might at first think). Mud cracks form due to shrinkage when wet mud dries out. Here is a cartoon of what happens:

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\(^1\) In 1989, several researchers reported that they had found evidence of modern style plate tectonics in rocks 2.5 billion years old in a region of what is today India. The report can be found in the March 10th 1989 edition of *Science* magazine. The researchers claim that two pieces of continental crust crunched together from the east and west, squeezing up a band of seafloor between them. If correct, this is an earlier event than the Wopmay Orogeny as described in these weblecture notes.
In a way, the mud is being exposed to tension (as the water molecules dry out, the shrinking mud is “pulled apart”). Have you ever noticed that mud cracks usually have a hexagonal shape to them? They may not have 6 sides, but they usually do display 3 sides like this:

![Hexagonal Crack Diagram](image)

This is the all-important “ternary fracture pattern”. It is important because we see continents do the same when they are rifted due to tension. The Red Sea – East African Rift shows a similar pattern to this. Here is what we think happens. When a continent first starts to rift, it bulges and then breaks into 3 rift zones arranged at roughly 120 degree angles (remember the scale here; this is not a mud crack. The rifts here are thousands of metres deep):

![Rift Zones Diagram](image)

The cracks do not stay empty, in fact, they are rapidly filled by a sequence of sedimentary rocks and igneous rocks. Here is an idealized section along one of the arms of the rifts:

![Idealized Rift Section](image)
Notice that the fill is wedge shaped (it thickens toward the centre of the ternary rift pattern). The central area is where the bottom drops out most and tension is the greatest. So it is also this area that is subject to the most faulting (normal faults due to tension) and to the emplacement of igneous dikes and sills. The sedimentary rocks that fill in the rift start off relatively coarse (breccia and conglomerate), but eventually pass upward into marine deposits (this is the typical geosynclinal fill pattern; see sketch on the bottom of the previous page). The important thing to note is that there were different depositional environments established during this phase of sedimentation (shelf, slope and abyssal plain).

These are the same sedimentary patterns that you see up in the Coronation Geosyncline (I told you that mud cracks were not entirely off topic), as well as in continental rift areas of all ages throughout Phanerozoic time. Now you know why the Coronation Geosyncline and the Wopmay Orogen is so important. They indicate that continents were rifting in the same way as today 2.1 to 1.8 billion years ago.

You are probably asking yourself about now (at least you should be) what happens to the ternary rifts as the tension continues? Well they continue to pull apart and some of the rifts may extend to join up with other ternary rift zones elsewhere (see the diagram on the bottom of the page from http://mac01.eps.pitt.edu/harbbook/c_iv/chapter_4b.htm, and the two large sketches on the next pages).

If this happens, the rifting may now be focused along 2 of the 3 arms and in these cases, you may actually pull the continent completely apart. Basalts may flood up into the rift thereby forming oceanic crust. This is what is happening today in the central portion of the Atlantic Ocean along the Mid-Atlantic Ridge. In other words, as rifting continues, 2 of the 3 arms may split open as new ocean basins. As the continental fragments spread
Note: Rifting is now concentrated in 2 arms of each triple junction (eventual ocean flooding)

1. Propagating rift

2. Tension

3. Passive Continental Margin Sediments

Mid-oceanic Ridge (New crust) New Ocean

"Failed" Arms (Aulacogens)
Stages in the evolution of a rift

1. **Initial rifting** (alluvial sedimentation)
   - A: River sediments
   - B: Coarse gravel (alluvial)
   - Normal faults
   - Thinning toward rift center

2. **Continued rifting** (initial flooding by seawater)
   - A: Farites change
   - Shallow marine Limestone & sandstone
   - Deep marine shale

3. **Continued rifting** (first intrusion by dikes)
   - Pillow basalts
   - Basalt dikes

4. **Continued rifting** (new oceanic crust forming)
   - Mid-oceanic ridge (new oceanic crust)
   - Othertside of rift
apart (we are now in true continental spreading mode), the rifts move away from the source of the rifting (the heat and/or convection). The third arm may continue to subside for a while but eventually, it dies. These **failed arms** go by the official name of **aulacogens** and most are given proper names. The northern one in the Slave Province is called the **Bathurst Aulacogen**; the southern one is called the **Athapuscow Aulacogen**.

The north-south trending belt of rocks in the Slave Province has several rock types that are absent from the aulacogens that flank it, and some feel that for a while, there was a north-south trending ocean in this area. But that is not all.

The most important of these unique rocks in the N-S belt are felsic igneous rocks (granites etc). They occur along the western edge of the belt and have been interpreted as continental rocks. That they are along the other side of the ridge is important. It has been suggested that they are the remains of a continent (Australia?) that pushed to the east after the rifting occurred. The ocean that opened during the Paleooproterozoic seems to have closed back up again. This is not all that unusual. If you had me in GY 111, we have already discussed the cycle of closing and opening that formed the Appalachian Mountains and the Atlantic Ocean (actually here it is opening and closing). The first person to discuss this cyclicity was J Tuzo Wilson (we have talked about him before), and as a reward for his fine work, we refer to these opening-closing patterns as **Wilson Cycles**.

By the way, the rocks of the Coronation Geosyncline and a lot of the country rocks that surround it (e.g., the adjacent aulacogens) have been extensively metamorphosed. Consider yourself lucky that we don’t deal with this process all that much in GY 112. It can be a real pain in the butt.

**Important terms/concepts from today’s lecture**

(Google any terms that you are not familiar with)

- Proterozoic (Neo, Meso and Paleo)
- Super continent
- Laurentia
- Rodinia
- Epeiric (epicontinental) seaways
- Gondwana
- Pangaea
- Wompay Orogeny
- Mud crack
- Ternary fracture pattern
- Coronation Geosyncline
- Failed Arm (aulacogen)
- Bathurst Aulacogen
- Athapuscow Aulacogen
- Wilson Cycle