GY 111 Lecture Note Series
Extrusive Igneous Rocks

Lecture Goals
A) Pyro-what? Air fall volcanic rocks
B) Felsic and Intermediate Extrusive Rocks
C) Mafic Extrusive Rocks

Reference: Press et al., 2004, Chapters 5 and 6; Grotzinger et al., 2007, Chapter 4

A) Pyro-what?
The term **pyroclastic** is composed of two parts, both of Greek origin. *Pyro* means “fire”. *Clastic* means particles. Pyroclastic literally means particles produced from fire. Pyroclastic igneous rocks have been erupted “explosively” and are deposited as particulate material (not liquid lava) around the flanks of volcanoes. Please remember that the pyroclastic material first starts of as lava, but as it is blasted into the atmosphere (see image to right), it is fragmented and cools very quickly. Texturally, almost all pyroclastic material is **glassy**. Most pyroclastic igneous rocks are produced by composite volcanoes because their magmas are much more viscous and more likely to be violently erupt As examples, the volcanic eruptions of Mt. Vesuvius in AD 79, Krakatoa in the late 1880’s and Mt St. Helens 100 years later eruption were all pyroclastic.

It is quite easy to get confused with some of the terminology used to describe eruptions from composite volcanoes. The term pyroclastic refers to the material that is produced from these eruptions, but some geologists (yours truly included) often them pyroclastic eruptions. This is not really correct usage of the term. Eruptions that produce vast qualities of pyroclastic material are best called **plinian**. Plinian eruptions blast pyroclastic material from the volcanic vent at supersonic speeds. This material can reach 25 km or more in altitude (higher than the Concorde flies). Exceptionally powerful eruptions (termed **ultraplinian** by some geologists) may reach 75 km. That is almost outer space. The stuff shot out of volcanoes during plinian eruptions is not just pyroclastic rock. Much of it is gas. The most common gases erupted from composite volcanoes include water vapor (H₂O), carbon dioxide (CO₂), hydrogen chloride (HCl), sulfur dioxide (SO₂), nitrogen oxide (N₂O), and argon (Ar). Water is omnipresent in magmas and much of it (at least along convergent plate boundaries) was derived from the subduction of wet oceanic plate. Geologists have calculated that the entire volume of the Earth’s oceans can be recycled at convergent plate boundaries in as little as 200 million years. Argon comes from radioactive decay in the Earth’s interior. There is a lot of this going on; Ar is the 3rd most abundant gas in the Earth’s atmosphere (after nitrogen and oxygen).

There is one other eruption worth mentioning here. When magma encounters groundwater near the Earth’s surface, you can get an explosion of steam and pyroclastic material. These **phreatic** eruptions resemble the puffs from old steam locomotives, but are on a scale 100’s or 1000’s of time larger.
B) Felsic/Intermediate Volcanic Rocks

When pyroclastic material is shot up into the Earth’s atmosphere, it is moving at very high velocity. Almost immediately, the Earth’s gravity starts to pull it back down. The result is a rain of pyroclastic material down wind of the eruption. The further you are away from the eruption, the finer the material is that falls on you (see image to left). The finest material is called volcanic ash and it can be a problem as it tends to plug your lungs if you breathe enough of it. It has also been known to plug up airplane jet engines. If you are closer to the eruption, the pyroclastic material falling down on you can be composed of considerably larger fragments (cm to 10’s of cm in size). It is still composed of glassy material, but we now call it pumice rather than ash (they are, however, exactly the same as far as their geochemistry and textures are concerned). Beds of pumice are given a specific name; tephra. Many geologists intermix the terms tephra and volcanic ash and it’s okay for you to do that in this class. Just remember though; tephras can be composed of very large pumice clasts.

Some of the fragments shot out of volcanoes are large enough to remain molten as they are through the air. Their outer surfaces cool quickly forming a glassy chilled margin (refer to tomorrow’s lecture), but their interiors are still molten. You do not want to be hit by one of these volcanic bombs (see image to right). Bad enough that they might weigh 50 kg or more and be dropping from the sky at 200 km/hr; these gumballs are liquid rock inside (1000 degrees C). Your skull would be caved in and your brain would burst into flame if you were hit by a big enough volcanic bomb. If time permits, I’ll tell you a true story of some geologists who learned first hand what it’s like to be beaned by a bomb. It’s not a pleasant story (see next page for a condensed version).

One of the problematic igneous rocks that you will see in the lab is called tuff. Tuffs are pyroclastic, but they are produced from ash that remains hot (but not molten) when it hits the ground. Most tuffs form very close to the volcanic vent. Here, pyroclastic material is rather “gooey” and particles will stick together forming pyroclastic rocks (not pyroclastic sediment). Tuffs come in 3 main “flavors. Welded tuff, as the name implies, is a rock that fuses together through heat (it is the textbook example of a standard tuff). Flow-banded tuffs display horizontal layers and elongated clasts of pumice. The layers were caused by minor flow after air fall is over or through variations in the intensity of the eruption. (The specimen you will see in the lab
was a production of the latter scenario. When the eruption slowed, finer ash rained down on the tuff. When the eruption picked up again, hotter and larger stuff was deposited on the ash etc.). **Crystal tuffs** are tuffs that contain a lot of phenocrysts. They range in colour from white to purple to pink reflecting their mineral content and overall composition (felsic and intermediate). In some situations, crystal tuffs look exactly like rhyolite porphyries. The only way that you can tell the difference is to know how they were erupted (the former is air fall – pyroclastic; the latter is a lava flow – extrusive).

Volcanologists Killed in Blast

An excursion to an active Indonesian volcano turned deadly last month after a group ignored basic safety guidelines. On 27 July a party of seven scientists taking in the sights of Semeru, Java's tallest volcano, went within meters of the crater rim. Just then, the mountain let loose one of more than 500 explosions recorded that week. Flying rocks killed two researchers from the Volcanological Survey of Indonesia and injured four foreign visitors, one seriously.

Despite the danger of their profession, volcanologists have no mandatory, internationally agreed-upon safety precautions. Three incidents in the early 1990s, in which 12 volcanologists died, brought the issue to the fore (Science, 16 April 1993, p. 289). In 1994, a committee of the International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI) urged, among other advice, that meeting-related fieldtrips not visit hazardous areas, that active craters be approached only when absolutely essential, and that everyone wear hardhats and protective clothing.

The fateful visit to Semeru ran counter to most of these guidelines. It was a group visit following an IAVCEI meeting in Bali, although it was not officially sponsored; the volcanologists weren't doing science, only satisfying a "curiosity to observe volcanic events," says Lee Siebert of the Smithsonian Institution in Washington, D.C., who suffered a blow to the head at Semeru. Moreover, no one was wearing a hard hat, because the decision to approach the active crater only "evolved" after a 2-day climb to the summit, Siebert says.

Other volcanologists understand what lured the group so close to Semeru. "They're volcanologists," says Edward Venzke of the Smithsonian, who watched from a safe distance as Semeru erupted every 5 to 30 minutes during a pre-meeting fieldtrip. "It's valuable for us to see things up close sometimes, to get some firsthand experience."

Now I know what you are going to say. Isn’t pyroclastic flow an oxymoron? Flows involve **fluids** (e.g., lava). Pyroclastic means bits of solid. So how can we have pyroclastic flows? The answer has to do with the way some pyroclastic deposits are deposited. If the eruption is shooting stuff straight up, wind blows the pyroclastic material (ash and pumice) laterally. Ash beds and tephras are deposited down wind. But sometimes eruptions do not shoot straight up. Some blasts are lateral (see cartoon below). Ash, pumice and gases are shot sideways out of the volcano and move down the slope in a chaotic fashion. This is exactly the same way that a snow avalanche moves.
down a mountain after a heavy snowfall. The snow “flows” down the mountain, but is capable of ripping up trees, houses and skiers as it moves. If snow can be this destructive, imagine what a lateral pyroclastic “flow” would do. It’s moving at 160 km/hr (or more) and is perhaps 800 degrees C. Ouch. The French called this type of “glowing avalanche” a nuée ardente. These types of flows are quite common and have been known to kill thousands of people at a stroke (e.g., 20,000 to 40,000 people were killed when Mt. Pelée erupted in 1902).

Occasionally, thick deposits of volcanic ash, tephra, pumice and fragments of the volcanoes themselves may be blasted laterally during a particularly violent eruption. This gives rise to a rock composed of variously sized particles (some are up to several metres in size). The rock is called ignimbrite and I have seen some in New Zealand and New Mexico that are 3 or 4 m thick. I can’t image the forces responsible for these pyroclastic flows, but I bet they would scare (and burn) the pants off of you.

Another type of flow occurs when ash and water get together, possibly long after an eruption has ended. Large composite volcanoes may be high enough to exceed the snow line, even in tropical areas. They may even have glaciers on them. A lot of hot ash falling on the snow and ice may start to melt it producing a lot of water and mud (ash is fine enough to be considered mud – refer to the sedimentary rock portion of GY 111 for more information about “mud”). The volcanic ash and water pour down the slope of the volcano as a volcanic mud flow. They are officially known as lahars and they can be deadly. They move fast (160 km/hr) and chaotically. You might think that they sound like nuée ardents, but the main difference is that they are not directly produced by a volcanic eruption (they are not pyroclastic flows). Lahars may occur days or weeks after a plinian eruption has ended. When Mt. Unzen erupted in Japan in 1991-93 the combination of vast quantities of ash and rain produced intense lahars as pictured to the right. The moral of the story is:

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\text{Ash} + \text{water} = \text{lahar} + \text{dead and destruction}
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We have concentrated on pyroclastic felsic/intermediate products because in many ways, they are the most spectacular, but don’t forget that composite volcanoes can also produce lava. Rhyolite and andesite are the extrusive igneous rocks that are produced by, respectively, felsic and intermediate composite volcanoes. Obsidian is formed from either volcano if cooling of lava is instantaneous.
C) Mafic extrusive rocks
Fortunately for use, we have more or less already covered this subject in earlier lectures and the introductory lab lecture for the igneous rocks. The major rock types that is produced when mafic lava is erupted at the surface of the Earth is Basalt. This rock is usually aphanetic or porphyritic in texture and contains minerals like olivine, Ca-plagioclase and pyroxene. If Mafic lava cools quickly to instantaneously, you get scoria. There are a couple of other extrusive mafic rocks that we need to introduce, particularly the one that results from molten basalt coming in contact with seawater (e.g., at a divergent plate boundary). We would predict very rapid\instantaneous cooling (we’d be correct). We would also predict that the rapidly cooled lava would have a glassy texture (we’d be correct again). But there is more to the story than just this. Only the outer surface of the lava chills to glass. The interior remains molten. You end up with a rock that is soft and squishy in the middle as long as it is still hot (a bit like a Peppermint Patty mint). When it completely solidifies, the rock has a glassy “chilled margin” and an aphanetic interior. Most importantly, it has a unique shape called a pillow (see picture to left). As the pressure continues to fill the pillows, they crack open, more lava makes contact with sea water and the process repeats itself for as long as the eruption continues. The rock that forms is called pillow basalt for reasons that should be blatantly obvious. Pillow basalts are very important because the pillow morphology is preserved for a long time after the end of the eruption. We find pillow basalts 2 billion years old. The significance is that 2 billion years before, at that location, lava was erupting into water. This is one of the ways that geologists locate former oceans.

While we are on the topic of basalt, let me introduce the vesicular variety. Vesicular basalts are basalts that contain a lot of air bubbles. Some look like Swiss cheese, some look more like froth.
The latter rocks are identical to scoria, but lack the glassy texture. We reserve the term vesicular basalt for those rocks with an aphanetic texture and far fewer bubbles. You might see one in the igneous rock collection.

**Important terms/concepts from today’s lecture**  
*Google any terms that you are not familiar with*

- pyroclastic
- ash (beds)
- air fall
- tephra
- glassy
- volcanic ash (ash)
- Tuff (crystal, flow-banded, welded)
- volcanic bombs
- Plinian eruption
- Ultraplinian eruption
- Phreatic eruption
- nuée ardente
- ignimbrite
- lahar
- Dike
- Sill
- Chilled margin
- Scoria
- Vesicular basalt
- Pillow basalt