Module 2: Mountains, Climate & Weathering

Climate & Weather

Mountains influence and even create weather. Topographically, mountains are rainmakers. On the west coast of British Columbia, air moves eastward off the Pacific Ocean. As it hits the mountains, it begins to rise. The air then cools as it moves up and over the mountains, resulting in clouds and rain, and as it continues east, there are "rain shadows," dry areas. So the west side of the mountains are wetter than the east, with a kind of a windward/leeward difference. The proper name for this is the **orographic effect**.

You see this all over the world. The same phenomenon happens with the Tibetan Plateau, where it is very dry, being on the leeward or rain shadowed side of the Himalayas and the Kunlun Mountains and the Quilian Mountains in China.

As in circumpolar regions, mountains are experiencing faster rates of climate-change, introducing major implications for humankind and the ecosystems on which we depend. This is due to mountains extending above the surface boundary layer into the free atmosphere and are more directly exposed to major incoming weather systems. Extreme climate change is happening at above 3000 metres, with 90% of data coming from Utah, Colorado and Tibet. Areas already in crisis are the Andes and the Hindu Kush Himalaya.

So with climate change you see increasing mountain exposure to hazards such as storms, landslides, and avalanches. But it's not just increased air temperature that's the issue. Rather, it is the increased humidity coming from warm air holding more water vapour and warming seas and land releasing more water into the atmosphere through evaporation.

Context: So why do we care about weather? Because mountains, and vegetation, and animals will have to adapt in response. Where a mountain was once, say, cold and dry, but is now warmer and more humid, how will the vegetation change? How will natural hazards be different? How will animals and humans adapt? How will our water availability from glaciers and snowpacks change? These are the big questions of mountain sustainability.

When you look at what they are measuring at basecamp of Mount Everest (at 5,013 metres), it is temperature, wind, pressure, and humidity. Soil temperature data are not a standard weather measurement at weather stations but are of increasing interest in terms of climate change. For plants to grow and germinate to full maturity, we need to know what's happening at specific depths in the soil, and that will help determine what will grow on our mountains in the future.

Interesting weather facts and definitions:

Weather is a general term for changes in water vapour phase (rain, snow) and air pressure differences (wind).

Climate is the statistical analysis of long-term weather measurements.

The energy that runs the Earth's weather comes from the sun. Weather is a product of solar energy and water vapour in our atmosphere. Like carbon dioxide, water vapour is a **greenhouse gas**. Greenhouse gases partially trap the energy radiated from the Earth's surface that is warmed by sunlight.

The troposphere is the lowest part of the atmosphere. It is about 14 km thick at the equator and about 8 km thick at the poles. The troposphere contains most of the Earth's oxygen and water vapour. None of the mountains of Earth extend above the troposphere into the stratosphere. Earth's atmosphere is mostly nitrogen (~70%). The majority of aerosols (very small suspended solid particles in the atmosphere) are found below ~3000 m. These include black carbon from incomplete combustion of fossil fuels, wildfires, and sea salt aerosols from the ocean.

Atmospheric pressure is the weight of the air around you. Atmospheric pressure drops as altitude increases. The pressure of the atmosphere at sea level is slightly greater than 100 kPa (kilopascals.) The pressure at the top of mount Everest is about 30 kPa. At the top of the Sea to Sky Gondola the air pressure is approximately 90 kPa. It's a good weather indicator. Low pressure systems involve wind and precipitation; high pressure systems are clear.

Lapse rates are the rate of temperature change as you move upward through the earth's atmosphere. Warm air is buoyant. When warm air rises it cools. In winter this relationship can be reversed, especially in snow covered mountain areas. This is because cold air sinks and pools at the valley bottom. In winter, mountain peaks can be much warmer than the temperature at valley bottom. This is called an **inversion**.

Anabatic winds are warm upslope winds that blow up a mountainside when the mountain surface is warmer than the surrounding air. **Katabatic winds** are cool winds that blow downslope under the force of gravity when the mountain surface is colder than the surrounding air.

Alpenglow is the red tinge mountain regions have at sunrise or sunset. The sun's rays at sunrise or sunset travel through much more of the atmosphere than during the daytime. The more distance sun light travels through the lower portion of the atmosphere the more of the short wavelengths of light (blue light) gets scattered by aerosols in the atmosphere. The remaining longer wavelengths of light are predominantly red, which gives the rosy colour to mountains.

Activity: Measuring the weather

What you will need: Outdoor thermometer, anemometer, soil thermometer, compass, sling psychrometer, Relative Humidity Chart.

How to measure wind direction? – observation of vegetation, flagging, wet finger, compass.

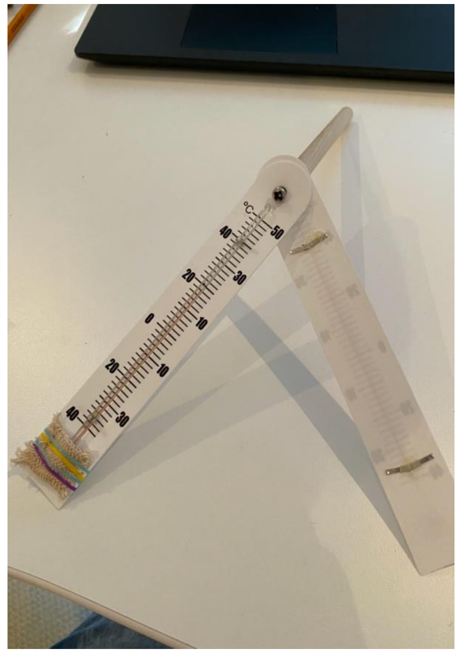
How to measure wind speed and temp? - anemometer and thermometer.

How to measure soil temperature? - soil thermometer. Measure 5 cm below ground. Measure the surface temperature. Then measure the air temperature 2 metres above. Soil temp is important because warmer temperatures accelerate chemical weathering on mountains and determine what vegetation will grow. If our mountains grow warmer with climate change, what changes in plants will we see? What changes will happen for microorganisms so small we can't even see them with the naked eye?

How to measure relative humidity (RH)? – sling psychrometer. Dip sock at end of wet-bulb thermometer in water. Whirl sling psychrometer in air until you get a wet-bulb thermometer reading (approximately 5 minutes.) The spinning causes moisture in the sock to evaporate and has a cooling effect on the bulb. The difference between the wet and dry bulb temperatures help you find Relative Humidity. e.g. If the dry bulb measures 25C and the wet bulb measures 18C, then you have a wet bulb difference of 7C. Find the dry bulb measurement on the left of the chart and read across to the right, you have a Relative Humidity of roughly 50%.
This cooling process, the evaporation of the water on the wet bulb thermometer, tells us how much water vapour is in the air today. As a result of the spinning, the sock at the end of the wet bulb thermometer undergoes a rapid cooling effect at a faster rate. Saturated water vapour would be 100% RH; No water vapour at all in the air would be 0% RH. Evaporation is faster when humidity is low, and as RH increases, the evaporation rate decreases.

SEA TO SKY GONDOLA
ADVENTURE BY NATURE

Relative Humidity																
Dry bulb temp	Difference between wet and dry bulb temp															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
0	81	64	46	29	13											
2	84	68	52	37	22	7										
4	85	71	57	43	29	16										
6	86	73	60	48	35	24	11									
8	87	75	63	51	40	29	19	8								
10	88	77	66	55	44	34	24	15	6							
12	89	78	68	58	48	39	29	21	12							
14	90	79	70	60	51	42	34	26	18	10						
16	90	81	71	63	54	46	38	30	23	15	8					
18	91	82	73	65	57	49	41	34	27	20	14	7				
20	91	83	74	66	59	51	44	37	31	24	18	12	6			
22	92	83	76	68	61	54	47	40	34	28	22	17	11	5		
24	92	84	77	69	62	56	49	43	37	31	26	20	15	10	5	
26	92	85	78	71	64	58	51	46	40	34	29	24	19	14	10	5



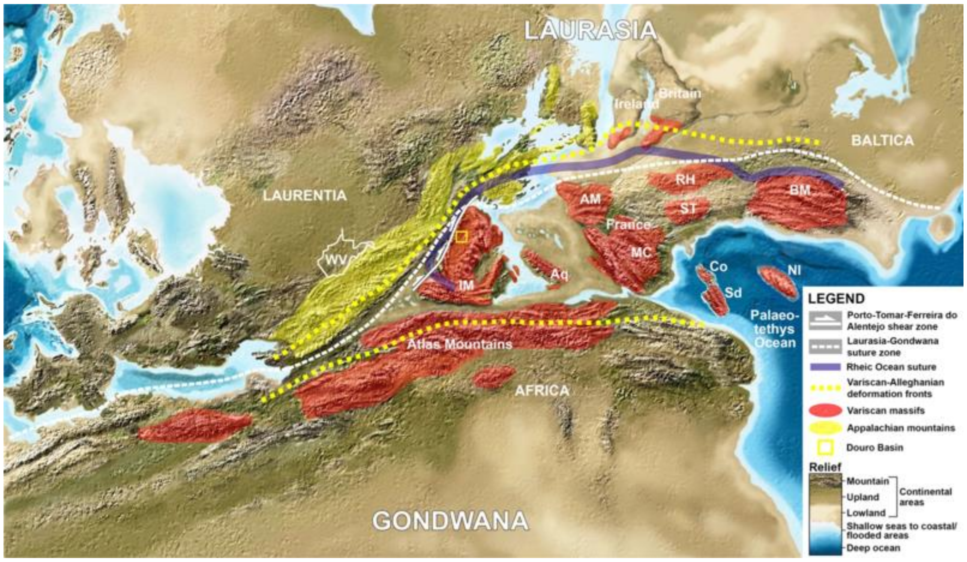
Relative Humidity Chart and sling psychrometer for use in calculating relative humidity.
Photo by Martha Warren.

Laying Mountains Low: Weathering, Erosion, Transportation

As we have seen above, mountains can create weather. Weather also changes mountains.

It is sometimes said that "what goes up, must come down": this is no less the case with mountains. When large masses of rock are accumulated at or pushed to high elevations, they are immediately exposed to a wide range of destructive forces, which will – over tens to hundreds of millions of years – work to transform mountains, first into hills, and eventually to lowlands.

As an example – the Appalachian Mountains (eastern North America), Scottish Highlands and other ranges were formed when several continental masses collided to form the 'super-continent' of Pangea, between 350 and 300 million years ago. At this time, these mountains – few of which are now taller than 1000 m – would have been comparable in size to today's Himalayas, the highest of which are over 8000 m in elevation. Now, we are just seeing remnants of the deep 'roots' of those mountain ranges.



https://en.wikipedia.org/wiki/File:Pangea_mountains.webp

A great many natural processes and forces combine to lay mountains low. Arguably the most important influence is the range of meteorological (weather) conditions: mountains are exposed to stronger winds, higher precipitation, and wide ranges of temperature. Another important factor is gravity: raising something up gives it 'potential energy': if it is (or bits of it are) freed from whatever was previously keeping it in place, gravity will tend to move it to lower levels.

These processes work at a range of scales, from the microscopic to the truly enormous. The two main stages involve firstly the disaggregation or destruction of the rock itself, and then the transport of the resultant particles. This happens in a variety of ways.

Weathering

Rocks are 'picked apart' by a combination of processes known as 'weathering'. In general, weathering transforms solid rock into smaller pieces, called regolith, down through smaller and smaller particles: it may even dissolve a rock completely, so that it becomes part of a liquid. Weathering may take the following forms:

Physical weathering: mechanical stresses imposed on and within rock-units;

- freeze-thaw cycles of water / ice cause cracking, deepening, and widening cracks in rock by expansion and contraction: water finds its way into crevices, and – when it freezes – expands, forcing the crack wider, and flexing it again when it melts
- extreme temperatures may also drive expansion (hot) / contraction (cold)
- hydraulic fracturing – the varied impacts and forces of flowing water
- abrasion – disaggregation by direct impact from particles (from boulders to fine sand) carried by wind or water (arguably a form of erosion, rather than weathering)

Chemical weathering: reactions between the rock's constituent minerals and external agents;

- when minerals in rocks are unstable in the chemical conditions to which they are exposed (temperature, pressure, moisture, acidity, etc.) they may react and break down
- this is particularly true for volcanic rocks, in which the mineral crystals cooled rapidly, without time to take chemical forms more suited to stability at surface conditions
- as the more vulnerable minerals break down through reaction with atmospheric gases and water-borne chemicals, they leave the less vulnerable (more stable) particles behind, leaving them more vulnerable to disaggregation from the parent rock
- some rocks are made largely of minerals which dissolve in water: for example, limestone is composed very largely of calcium carbonate
- accelerated by moisture and warmer temperatures

Biological weathering: the activities of living organisms;

- burrowing
- root action
- bio-chemical weathering (eg by lichens)

Biological weathering by roots and lichens. Sea to Sky Gondola.
Photo by Martha Warren.

We can also think of the direct effects of human activities – mining is a good example.

Once regolith particles – bits of the original rock – have been detached or disaggregated from their parent rock, they are liable to be moved. In mountain settings, this happens mainly under the influence of gravity, ice, and water (and just possibly wind).

When a piece of rock stays in one place, this shows that the combination of the gravitational force on that mass of rock, the slope of the ground, and the frictional roughness of both the surface and the rock are in balance. If the slope should get steeper, or the frictional 'sticking power' reduces, then the rock will tend to move downhill. It is possible that the slope could get steeper, if it is being worn away by weathering, or an erosional force such as flowing water or ice. It is also possible for the friction between rock and surface to be reduced: most often this happens by adding water, from rainfall or snowmelt.

It's useful to distinguish between the steady processes of weathering and disaggregation which generate quite small particles of regolith, and those – rarer – situations in which very large volumes of rock and/or of accumulated unconsolidated regolith may suddenly detach and move down-slope, in potentially highly hazardous events. The latter will be covered in Module 4 Natural Hazards.

Transportation of regolith by gravity

Relatively small particles and volumes of regolith may accumulate close to their source – perhaps just falling a short way down-slope under gravity – or may be transported great distances by water (including ice) and/or wind, undergoing further transformation as it travels.

Along the feet of many steep slopes, particularly in areas which have quite dry climates, and experience variation between temperatures above and below freezing during part of the year, it is common to see large accumulations of angular regolith, which – having disaggregated from the parent rock (primarily by freeze-thaw) – then falls down the slope to join the growing pile. These accumulations are known as talus or scree. Similar processes on different types of rock may lead to the accumulation of gravels, sand or finer particles.

Most of the time, these talus or scree slopes find a natural configuration of internal organization and slope which permits them to be quite stable: they may even support the growth of vegetation, the roots of which help to anchor the loose, unconsolidated material. In general, a vegetated – particularly a forested – slope will be more stable than one without vegetation: this is partly because the roots bind the material together more cohesively, and partly because the vegetation canopy reduces and spreads-out the direct effects of rainfall and surface flows.

However, sometimes this balance or equilibrium is disrupted, and the slope may slide or flow. Most often this is through the reduction of friction by adding water from heavy rainfall or rapid snowmelt. It is also possible that these events may be provoked by shaking (during an earthquake), or even by animals (including humans!) walking across the slope and dislodging important 'anchors.' It follows from the point above that removing the vegetation – again, particularly trees – from a slope will increase its vulnerability to erosion and 'mass-wasting'.

Transportation of regolith by water

Water is an extremely important agent for the transportation of regolith. Mountain landscapes – particularly those on the windward sides of ranges – experience high rainfall and snowfall (not least by their upward deflection of weather systems into cooler air, prompting condensation of water vapour, and thus enhancing precipitation). Frequent replenishment of water from rainfall keeps many small, energetic streams flowing. As they do so, they carve deeper valleys, in turn encouraging gravitational movement of regolith into these same watercourses. The erosional power of these streams is particularly strong during major rainstorms and rapid snowmelt. As they flow through steep, rugged terrain, these fast-running mountain streams transport the regolith itself e.g. Berg Lake Trail 2020:

https://www.cbc.ca/news/canada/british-columbia/berg-lake-trail-mount-robson-provincial-park-flooding-1.6097648

https://www.therockymountaingoat.com/2021/07/dozens-evacuated-by-air-after-berg-lake-flash-flood/

https://www.therockymountaingoat.com/2021/10/kinney-lake-trail-closes-for-maintenance-damage-assessment-continues/

This journey is often quite violent, resulting in further attrition of the regolith, from larger, more angular to smaller, more rounded particles. The abrasive action of these particles helps to excavate the stream valleys even further, making them deeper and steeper, and so encouraging the whole process to intensify.

When you look at a mountain or hillside, the gullies and valleys you can see have all been formed almost entirely by this process, so helping – bit by bit – to make the uplands lower. It is also worth noting that the regolith transported downhill / downstream by these processes will contribute to the formation of new (sedimentary) rocks on the floodplains of rivers and in the ocean.

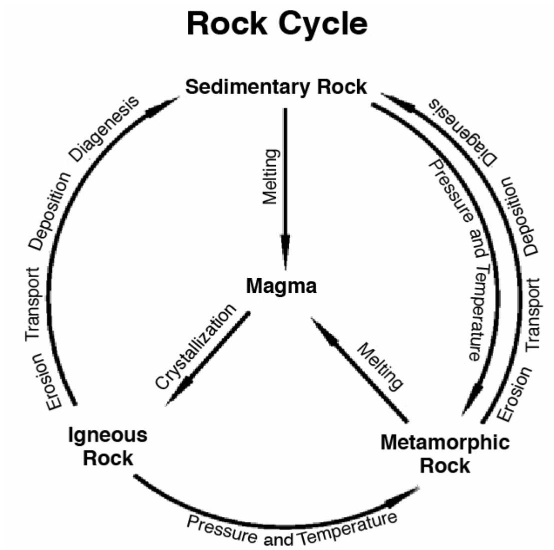
Transportation of regolith by ice

In high mountains, where snow has accumulated and persisted year after year without completely melting, glaciers, icefields and ice caps may be found. Mountain ice of these types is under extreme threat as a result of rising temperatures in the atmosphere and ocean. Recent studies (Bevington Menounos, 2022) have suggested that the entirety of glacial ice in western Canada could melt before 2100.

Glaciers represent immensely powerful agents of erosion and transportation. Formed initially as patches of snow which do not melt through successive summers, they begin to flow downhill under their own weight. As they do so, a complex range of processes works to weaken, disaggregate and move enormous volumes of rock along their paths.

As large volumes of ice, they act as 'cold sinks', lowering the range of temperatures in the air around them: this in turn means that freeze / thaw weathering is more likely through longer periods of the (otherwise) warmer months. Where ice freezes onto rock, the latter – potentially of very large sizes – may be 'plucked' from their origins and moved by the ice, potentially for long distances. The rocks within the ice scrape and 'bulldoze' the surface as the glacier moves, further abrading and eroding the landscape (and the regolith itself, which tends to take on a rounded shape). This excavating action carves deep U-shaped valleys with steep sides – down which yet more regolith is able more easily to fall, under gravity. Also under and in front of the ice, meltwater streams flow, doing the same kind of work as those generated by rainfall and snowmelt, as described above.

Where more snow melts from a glacier each year than it receives, its end or 'snout' will retreat uphill. As it does so, large volumes of regolith previously deposited from the ice may remain perched along the sides of its valley, often precariously (particularly when the retreat is rapid.) These accumulations are unlikely to be stable and may suddenly give way and move rapidly down-slope – particularly with the addition of water and/or seismic shaking. Glaciers and examined in more depth in Module 3 Glaciers, Snow and Water.



https://commons.wikimedia.org/wiki/File:Rock_cycle.gif

To summarize, what we are seeing is the rock cycle at work: mass wasting and the redistribution of regolith under gravity, with erosion being the redistribution of regolith by flowing media, namely: water (fluvial erosion); ice (glacial erosion); and wind (aeolian erosion.)

The particles on Highline Trail, for example, are redistributed to the bottom of the trail.

Regolith on Highline Trail, Sea to Sky Gondola, Squamish, British Columbia.
Photo by Martha Warren

The regolith from the summit at Sea to Sky Gondola is redistributed to the bottom of Átl'ka7tsem/*Howe Sound*. There is a constant movement in mountains, where some mountains are rising, some are becoming smaller, weathering and eroding. Some mountains in the Himalayas are still rising at 1 cm a year due to crustal uplift.