A Geologic History of the Methow Valley

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One could start a geologic history of the Methow Valley with the story of plate tectonics, because much of the drama written in the rocks is inscribed there due to the forces of moving plates. 200 million years ago (mya) most of what is now northern Washington existed as several large islands, each one a scrap of continent, lying somewhere out in the Pacific Ocean. One after the other they were pushed up against the existing continent and became a part of it.

This cartoonish map illustrates how the earth's crust is broken up into 12 major plates, which are in slow but constant motion. The continents tend to be on different plates than the oceans.

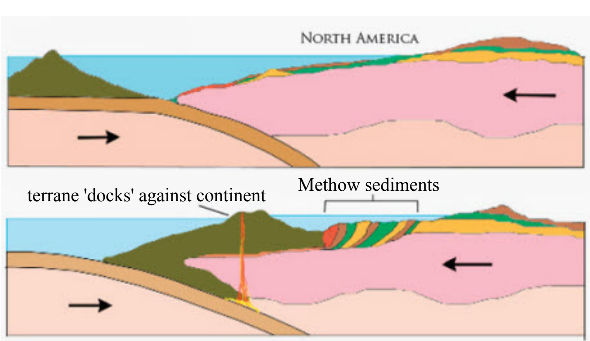
The earth has at its center a metallic core, thought to be 85% iron, although no one has been there to check, and 5% nickel. The core is about the size of the moon. Surrounding the core is the mantle, a thick shell of dark green and black rocks called peridotite that comprise the largest part of our planet. Peridotite is an iron-manganese silicate, which means it is composed of iron, manganese, oxygen and silicon. Any rock with iron will be heavier that those without iron, and will be drawn downward by gravity.

A thin outer skin called the crust covers the peridotite of the mantle nearly everywhere. Oceanic crust is composed mostly of the rock gabbro, which like peridotite is relatively dense. Continental crusts—and therefore the continents—are made of less dense rocks that literally float on the denser rock below. Continents can be thought of as rafts floating on the much more dense gabbro of the oceanic crust and the peridotite of the mantle.

The earth's solid crust that covers the mantle—known as the lithosphere—is a mosaic of about 12 plates, joined at seams. Plates are constantly moving, driven by heat from the nearly-molten mantle. Oceanic plates are pushed apart from each other by upwellings of molten rock at long ridges at the center of the Atlantic and the Pacific; they move apart at a rate of 2-3 inches per year.

Because plates are being pushed apart in the middle of the Atlantic and the Pacific, they are pushed into one another elsewhere. When two oceanic plates collide, one sinks—usually the one farthest from where it formed, because that plate will be the colder and denser of the two. A deep oceanic trench will develop where the sinking plate turns down to start its long dive into the earth's mantle.

Oceanic crust that is forced against continents sinks beneath the continent, heating up from the extreme pressure, and taking on water in the process. 50 miles inland from the ocean-continent boundary magma (liquid rock) and steam typically erupt to form a chain of volcanoes. This is the reason there are five active volcanoes in the Washington Cascades, and that there is a 'Ring of Fire' (that is, a chain of volcanoes) all the way around the Pacific Ocean.



Top: the oceanic plate on the left, sinks under a continental plate. The oceanic plate has a 'terrane' or microcontinent embedded in it. Bottom: the terrane is pushed onto the larger continent, deforming the sediments between the two.

Sometimes there are fragments of continental crust embedded as islands in subducting (sinking) oceanic crust; these are known as terranes, or microcontinents. When they arrive at the edge of a true continent, they are too light to sink with the ocean crust beneath the larger continent; rather they are jammed onto the existing coastline. There is plenty of heat and pressure involved, and they are welded onto the coast and become an integral part of the continent.

Over the millions of years it takes for a microcontinent to approach and reach a larger continent, sediment will be eroding off of both landmasses and accumulating in the sea between them. Over time this sediment will be cemented together into sedimentary rock. As the two landmasses are pushed together, the sedimentary rock that has accumulated between them will be deformed and crushed. This often results in this sedimentary rock, which is inevitably laid down horizontally, but is often forced into upturned positions by plate tectonics. Much of the sedimentary rock in the Methow was laid down in a shallow sea, and then forced into various upturned positions between two colliding masses of continental rock.

Our understanding of plate tectonics and how dynamic the earth is is only about 40 years old.

The subduction of oceanic trenches averages about 2-3" per year. Although that is much slower than a snail's pace, it is fast by geologic standards. This can add up more than 32 miles of ocean floor every million years, and 320 miles in ten million years. Ten million years doesn't amount to much in geological time.

For 800 million years the west coast of North America lay in eastern Washington, in the area of Spokane. 200 million years ago (mya) the Atlantic Ocean first appeared as a split in the supercontinent Pangaea (in fact the Atlantic is still growing at a rate of 3" per year). Since that time the Americas have been pushed westward against the Pacific Ocean plate, which in turn is subducting under the American continents. So the Pacific shrinks precisely as the Atlantic grows.

The geologic history of the Methow proceeds neatly from east to west, largely because the land mass of our bioregion, Cascadia, and much of the state of Washington, has been cobbled together from east to west. The first event written in the rocks of the Methow is along the roadside south of Carlton and in our Sawtooth Mountains. These are 300 million year old (myo) metamorphic rocks known as gneiss. Metamorphic means "changed form," so these rocks must have been something different in the past. They were in fact sedimentary rocks previously, laid down in a marine environment, then buried in the earth and partially melted into the form they take today. The sedimentary rock would have started as loose sediment, eroded from some archaic continent that existed perhaps 600 million years ago. Thus in our first rock outcrops we are faced with a vast depth of time and the astonishing cycling of the very face of the earth's crust. 600 mya is before the first life began to colonize dry land, while by 300 mya amphibians had become the dominant animals. Reptiles were just beginning to appear, while among the plants conifers were just emerging.

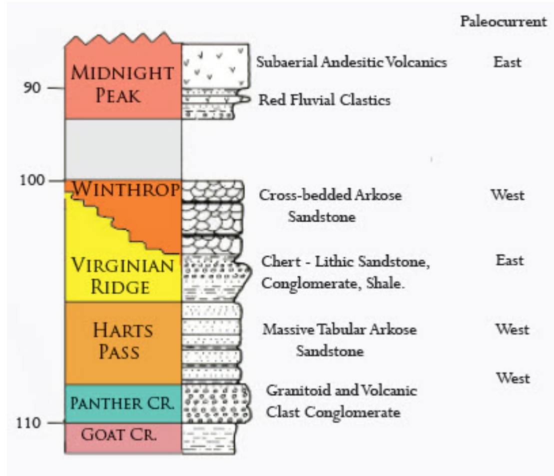
As the ocean floor slipped into the trench at the edge of the continent, island micro-continents (consisting of continental rock, which is literally lighter, or less dense, than ocean crust) embedded in the oceanic crust collided with western North America one after the other.

The first major addition was the Quesnellia terrane (also known as Intermountain Terrane and the Okanogan Highlands), which joined North America about 180 mya. It now forms the highland region between the Columbia and Okanogan Rivers. The original rocks of Quesnellia appear to have been metamorphosed sedimentary rocks, which points to a previous long tectonic cycle. Much later, after 'docking' (the term used by geologists), the terrane was engulfed in an upwelling of granite magma; this was the origin of Tiffany Mountain and other granitic mountains on the eastern border of the Methow and in the Okanogan Valley.

The first non-metamorphic rocks to appear in the Methow is a huge pile of terrestrial sandstone, marine shale and volcanic rock laid down as sediment between 150 and 120 mya known as the Newby Group. This is further divided into the Twisp Formation and the Buck Mountain Formation. The Twisp Formation outcrops regularly from Lookout Mountain, across Poorman Creek to Moccasin Lake and Patterson Lake, and the across the Methow River to Lewis Butte. The Buck Mountain Formation parallels it a few miles to the east, first showing up on McClure Mountain, forming the striking rock outcrops on the Eastside Road just north of Twisp, and extending north through Pearrygin Lake and on to Buck Lake and Buck Mountain. The 120-150 mya time span of these formations bracket the time when the first flowering plants show up in the fossil record; it is also early in the Age of Dinosaurs.

Two striking features of the Newby Group are 1) they account for an expanse of 30 million years, and 2) the total depth of the sediments is 18,500 feet; that's a lot of deposition. Both formations consist of an interlayering of marine sediment, continental sand, volcanic tuff (which is welded volcanic ash), and volcanic breccia (welded angular pieces of volcanic rock). For an enormous period of time this area must have been a shallow sea, with sediment arriving from both the continent and offshore volcanic islands. A few marine fossils have been found in the Twisp Formation, while both marine fossils and terrestrial plant fossils are common in the Buck Mountain Formation.

At the end of the Newby Group deposition something dramatically tectonic happened, because many of the Newby sediments are turned straight up in the air, and portions of the sediments are missing altogether, eroded away by some unknown force. Afterward this drama, a whole new period of sedimentation begins. Three somewhat distinct layers of sediment, going by the names of the Goat Creek, Panther Creek and Hart's Pass Formations, accumulate another 18,000 feet of sediment. Much of this is continental material, sand from eroding granitic rock. But it is interbedded with fine marine shale loaded with marine fossils, so many geologic chapters must have been written over this 10 million year period (120-110 mya).



A diagram of some of the Methow's sedimentary formations.

The Panther Creek Formation is visible on Sweetgrass Butte and Sunrise Mountain, the Goat Creek Formation outcrops on upper Goat Creek, and the Hart's Pass Formation shows up on Tatie Peak in the Hart's pass area, but not at the pass itself, nor on Slate Peak nor Deadhorse Point. These locations record the next distinct layer of sediment to accumulate, Virginia Ridge.

The Virginia Ridge Formation, which was deposited approximately 100-110 mya, is quite extensive in the Methow, outcropping continuously all the way from the high hills west of Moccasin Lake north to beyond Slate Peak. This 10,000 feet thick deposition of sedimentary rock is primarily of marine origin and is loaded with marine fossils. The upper layers contain chert pebbles—chert is a form of quartz that at times forms from the skeletons of diatoms and radiolarians, which when alive are photosynthetic forms of plankton (free-floating microscopic organisms).

On top of the Virginia Ridge Formation, and dating to 100 mya, is 10,000 feet of sediment called the Winthrop Sandstone, containing numerous fossils of flowering plants, ferns and conifers that grew in a semitropical environment. This formation appears mostly on the west side of the valley north of Winthrop, and includes the summit of Lucky Jim Butte and most of Sandy Butte; there is an outcrop on the east side of Boesel Canyon that is rich with fossils. A recent doctoral thesis by Methow native Ian Miller identified 150 plant species in the Winthrop Formation, and supported previous evidence that this terrane originated on the Pacific coast of Baja California. Tectonic forces ripped it off of that land mass and transported it 1500 miles north on the Pacific Plate before delivering it to the coast of the Pacific Northwest. It is not known how many of the other Formations of the Methow are also terranes that originated further south.

Next up is one of the most striking rocks of the Methow Basin, known as the Ventura Member of the Midnight Peak Formation. Ventura rock is sandstone, but it is deep red and purple in color. Such coloration is due to the oxidation of iron in the rock, a reaction that takes place only on land. For the original rock from which the sediment came to be high in iron, it must have been from the ocean crust, but for it to erode on land it must have been push out of the sea and onto the continental margin. Oceanic crust usually sinks under continents, but sometimes if it gets shoved hard enough that it will ride up on to the continental crust. This colorful rock can best be viewed near where the Hart's Pass Road crosses Lost River; it dates to about 90 mya.

Overlying the Ventura rock is an outpouring of volcanic rock from the Midnight Peak formation, which is laid down in strata up to 10,000 feet deep. There is no trouble finding this formation; Goat Wall is made up of it; as is Goat Peak and Robinson Mountain. If it doesn't look volcanic, it is because it has been slightly altered (metamorphosed) in the millions of years it was buried under ground, before erosion from the Methow River and rivers of ice bared it to the light of day. Midnight Peak dates to about 80 mya.

The Methow was shut off from any further marine sediment accumulation when igneous terranes arrived from the west and accreted onto the continent. The first of these west of the Methow is the Black Peak Batholith (a batholith is very large amount of igneous rock that cooled deep underground, where it would tend to form rocks such as granite with large crystals), which is dated at 98 myo, and then the Golden Horn Batholith, at 45 myo. The latter group includes Golden Horn Mountain itself, as well as Liberty Bell and Cutthroat Peak.

The minimum depth for the slow cooling of granitic rock such as that found in the Golden Horn Batholith is thought to be three miles down in the crust. Thus the majestic mountains that protrude today were once buried under immeasurable tons of overlying rock, which has been eroded away by the passage of enormous amounts of time since that rock cooled. This would have been accompanied by uplift of the batholith itself from continual pressure being applied by sinking oceanic crust off to the west.

The Methow Valley itself is a down-dropped block of sedimentary rock that lies between igneous terranes. This type of downward movement of a section of rock is called a *graben*, which is a German word for 'grave.' The Methow Valley is a graben.

There was one more large depositional event in the Methow at what is now Pipestone Canyon about 60 mya, where 2000 feet of boulders, cobbles, sand and silt were deposited in a water environment, but apparently not in an ocean, as the interbedded sandstones contain only land plant fossils. Eight terrestrial plant fossils that would have grown in a semi-tropical environment have been found in Pipestone sediments, including Metasequoia, the 'dawn redwood.' Because the Methow was largely sealed off from the Pacific Ocean and deliveries by the Pacific Plate, it is likely that Pipestone was deposited on site, in the location it currently occupies.

The dawn redwood found in Pipestone grew in North America from the time of the dinosaurs to about 8 mya, when it made its last stand in the swamps of what is now eastern Washington—possibly in the Methow Valley! Although well known as fossils, they were believed to be extinct globally until a small population—just 1200 trees—was located in a steep isolated valley in Hubei Province, south-central China, in 1941. Some seeds were brought to the United States in 1946, and in 1952 Metasequoia produced cones on the North American continent for the first time in eight million years.

The depositional time of Pipestone strata 60 mya was a pivotal one on earth. Evidence is now thought to be conclusive that a large asteroid ten miles across slammed into the earth off the coast of the Yucatan Peninsula 65 mya, causing so much smoke, dust and debris to be ejected into the atmosphere that a 'volcanic winter' ensued. This lead to the collapse of terrestrial ecosystems and the extinction of almost all large animals, including the dinosaurs. During the time that the Pipestone sediments were being deposited the biosphere was still in a state of recovery from this mass extinction, and mammals were in the process of becoming the dominant animals on land.

As if 100 million years of marine deposition and mountain uplift, volcanic eruptions and crashing terranes were not enough, nature enlisted another powerful force to continue to redesign the landscape—rivers of ice. The entire Pleistocene Epoch, which lasted from 2.4 million years ago to just 12,000 years ago, was an age of ice. There is some evidence that there not one or two but 20 glacial advances in the Methow and throughout the northern portion of North America in that period, reoccurring on an approximately 100,000 year cycle.

Before the last glacial advance in the Methow, which began here about 18,000 years ago, the Methow Valley would have been easily recognizable, but also somehow very different. Many of the plant species that exist in the Methow today would have been present then, but they would be combined in different plant associations, as they have been scrambled in the interim by major climatic shifts and glacial impacts. The physical topography of the Methow would be familiar but subtly different, as the unimaginable impact the last glacial advance, which sent a mile thick river of ice grinding across the Methow's hills and valleys, would not yet be inscribed upon the land. Perhaps most notably, an entire suite of large mammals that existed in North America 24,000 years ago are absent today, having suddenly gone extinct about 12,000 years ago. Many of these species have left fossil remains in eastern Washington and some would have been members of the Methow's Pleistocene fauna. These rather recently extinct species include mammoths, mastodons, the American lion, giant sloths and giant beavers, and horses (which had also migrated to Asia over the Bering Land Bridge, and returned to North America in the early 1500s with the Spaniards.

In the last glacial advance in North America, which occurred 70,000-14,000 years ago, this continent had considerably more ice (18.5 million square kilometers) than Antarctica had then (13.8 million square kilometers) or now (12.6 million square kilometers). At the maximum extent of the last glacial advance 80 million cubic kilometers of water was frozen in glaciers, lowering sea levels by about 350 feet. The land bridge between Asia and North America, known as Beringia, was 800 miles wide.

18,000 years ago the Methow's alpine glaciers engaged in a major advance from the high mountains toward the valley floor. This was a thousand years before the continental glacier arrived from Canada. These glaciers extended several miles downstream from their source in the cirques of the high mountains, although some never reached the Methow proper. The evidence for this is in the fact that the upper portions of these drainages (e.g. Oval Creek and Libby Creek) are U-shaped— carved by glaciers—but the lower ends are V-shaped—indicating that these sections were carved by running water.

The continental glacier that flowed into the Methow 17,000 BP (before the present) from the north enveloped all but the highest peaks in a river of ice. It of course destroyed all the existing vegetation in the watershed except those few species that persisted on the protruding peaks.

When the climate warmed 14,000 BP, tributary valleys melted first, sending torrents of water toward the Methow Valley proper, which was still plugged with the ice of the continental glacier. Water flowed over the surface and at the edges of this glacier, washing 3000 years of accumulated debris into the crevices along the ice boundary, forming the flat kame terraces on the hillsides of the mid and lower valley (*kame* is a Scottish word meaning 'hill').

Water blocked by the main valley glacier was shunted into side canyons, carving coulees such as Elbow Coulee and Pipestone Canyon. Water impounded by ice walls formed glacial lakes, later draining and leaving broad, elevated benches such as Mills Flat (south of Carlton). Melting glaciers also left a large amount of glacial till (unsorted glacial sediment) in the primary drainages. Till in the Mazama area is as much as 1000 feet deep, while in the Twisp-Winthrop area it is 200 feet deep in some places.

The Methow glacial ice left its last terminal moraine just south of the present position of Twin Lakes, where there are classic kettles—large depressions in the landscape that were filled by enormous blocks of ice. The two Twin Lakes are kettles which were about 14,000 ya filled with ice left stranded as the continental lobe in the Methow melted. The thin strip of sand and gravel separating the two lakes was a crevasse between the two blocks of ice, which filled with debris as the blocks melted. There are hundreds of smaller kettles in the larger moraine complex near Twin Lakes known locally as the 'potholes.'

The large accumulation of glacial till in the Twin Lakes area is a 'recessional moraine,' a ridge of material that formed as the last glacier in the area paused for a time as it melted, depositing additional debris. After this moraine formed, there were apparently no more pauses in the melting, for there is not one more moraine up the length of the valley.

The smooth rounded hills of the Methow—what geologist Julian Barksdale referred to as 'the ice cream cone topography' of the valley—reflect the efficiency of a mile of flowing ice with its cutting tools frozen into its base.

As the western portion of the continental ice sheet melted between 14,000 and 13,000 years ago, dramatic floods of meltwater flowed through central Washington just east of the Methow Valley. These occurred because meltwater from a primary lobe of the continental glacier was blocked from draining for years at a time due to the glacier itself. This blockage formed a lake in the area that is now Missoula, Montana that held as much water as Lake Erie (one of the Great Lakes) does today. When the lake water grew deep enough, it floated the impeding lobe of ice out of the way, and the entire 'Great Lake Missoula' drained out through central Washington in a period of just two weeks. It is thought that as much water as flows in all the rivers of the world coarsed through the middle of the state for those few weeks when the ice dam was removed, resulting in the Missoula Floods (also known as the Spokane Floods and Bretz Floods). It is now thought that this scenario played out repeatedly, with at least 40 separate floods over occurring. While they had minimal effect on the Methow, they did send floodwaters into the lower portion of the valley.

There is one more important aspect of Methow geology, and that is the active volcanoes of the American west. The largest of these is the Yellowstone Supervolcano, which is estimated to have sent 600 cubic miles of ash and debris into the atmosphere 2.4 million years ago, with smaller eruptions 1.2 million years ago and 640,000 years ago. Closer to home, Glacier Peak, which is only 50 miles away, had a major eruption 12,000 years ago, depositing up to a foot of ash in the Methow. This was followed by Mt. Mazama in Oregon, which blew apart approximately 7000 years ago, creating Crater Lake and deposited up to 2" of ash here in the Methow, and an eruption of Mt. St. Helens 3500 years ago that was ten times larger than the 1980 eruption and deposited another 2" of ash in the Methow. White volcanic ash layers are visible in undisturbed Methow soils.

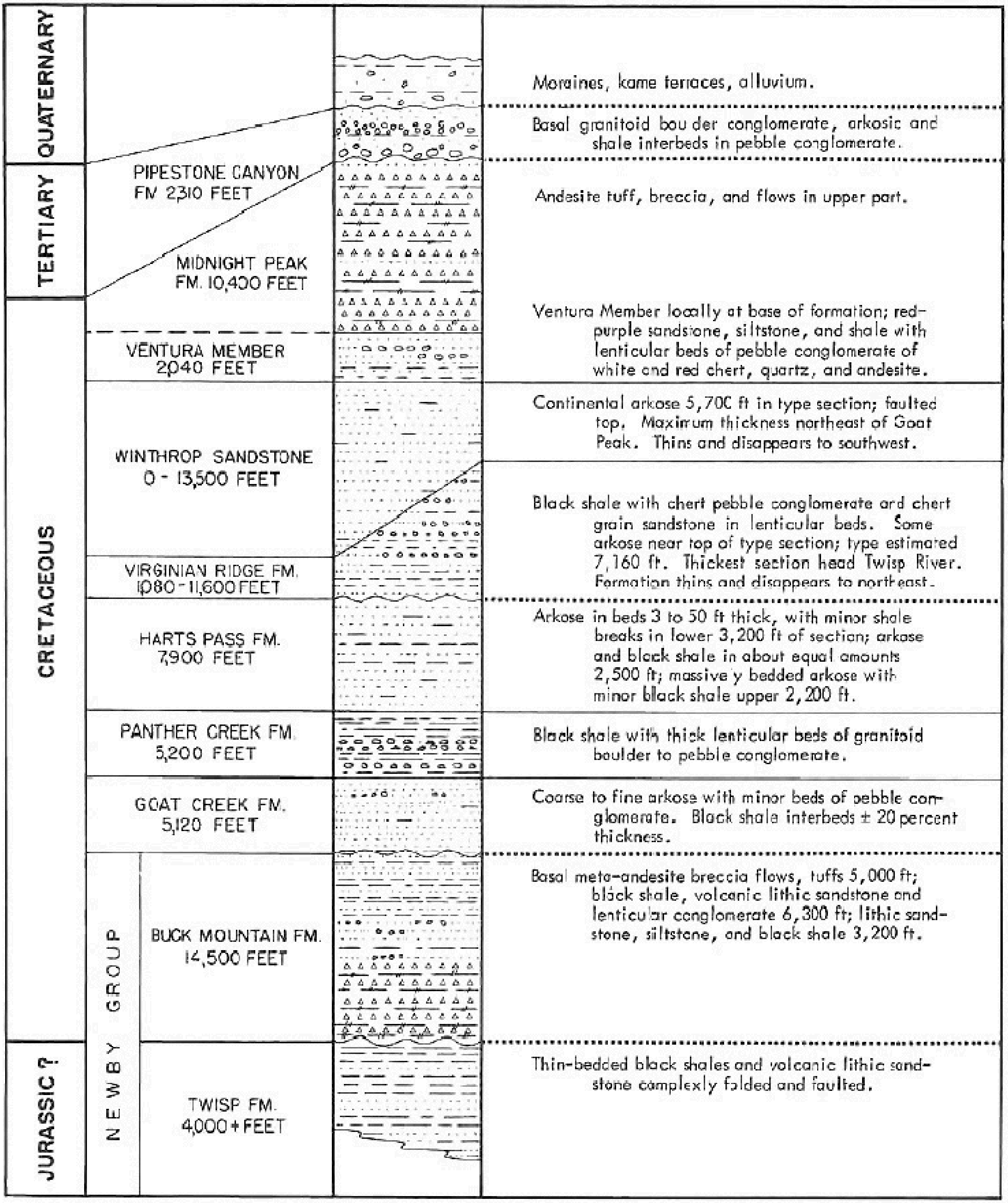
The melting of the ice 14,000 years ago was not the last chapter in the shifting patterns of weather, climate, biology and geology in the Methow. There was a sharp drop in temperature all over the planet between 13,000 and 12,000 years ago known as 'the Younger Dryas,' during which time alpine glaciers advanced. This was followed by a notable warming 10,000 years BP, a sharp cooling 8000 years BP, a very warm period called 'the Hypsithermal' 6000 years BP, a 'Neoglaciation' 5000 years BP, a 'Medieval Climatic Optimum' 1000 years BP, and a 'Little Ice Age' 600 years BP.

The only constant in geology seems to be change.

Geology, Biology and the Methow

Eon	Era	Geologic Period	Timeline Period Began:	Outstanding Events: In Geological History	Outstanding Events: In Biological History
Phanerozoic ('visible life')-0.7 bya to present Proterozoic ('earlier life')- 2.5-0.7 bya- photosynthesis Archean (Gr 'beginning')- 3.7-2.5 bya; bacterial life Hadean (Hades, Gr god of underworld) 4.6-3.7 bya pre-life	CENOZOIC (Gr, new, zoo= animal life)	Quaternary (4th) Recent 0-12 tya Pleistocene 2 mya (Gr almost, cene= new)	bya= billion years ago mya= million years ago tya= thousand years ago BP= before the present 2 mya	200-400 BP (1400-1800 AD)- Little Ice Age; alpine glaciers advance to Methow valley floor 12,000 BP All large glaciers in the Methow have melted 70,000- 12,000 BP Last Ice Age; one lobe of the continental glacier extended nearly as far south as Wenatchee 2 mya- There have been two complete 'Glacial Ages' in the last one billion years, each lasting ten million years or more. The third Glacial Age began 2 mya, and we are still in it. The last Ice Age was only one of many (perhaps twenty) in this latest Glacial Age.	6000 BP- Approximate date that salmon appeared in the Columbia River system in large numbers 11,500 BP- Age of ceremonial Clovis culture spear points found in orchard in East Wenatchee in 1987; Native Americans likely present in the Methow by this date 13,500 BP- Earliest widely accepted date of humans south of Alaska 13,500-10,000 BP- Last Ice Age ends; human numbers increase rapidly across the continent; over 50 genera of large mammals go extinct in North America
		Tertiary (3rd) Pliocene 6 mya (Gr, more; cene = new) Miocene 22 mya (Gr, less) Oligocene 36 mya (Gr, few) Eocene 58 mya (Gr, dawn) Paleocene 65 mya (Gr, old)	65 mya	58 mya- Pipestone sediments laid down, consisting of 2000' of conglomerates, sandstone and shale. Eight fossil land plants have been found in the Pipestone Formation. 65 mya- Approximate date of the arrival of the North Cascades microcontinent	50,000 BP- Approximate date that humans first crossed from Siberia to Alaska 300,000 BP- *Homo sapiens* first appear in fossil record 6 mya- The first hominoids (human ancestors) appear in the fossil record 58 mya- fossils in Pipestone sediment, including the 'Dawn Redwood,' *Metasequoia*, indicate a semi-tropical climate, warm and wet 65 mya- Asteroid slams into earth in the Gulf of Mexico, probably causing the extinction of most dinosaurs
	MESOZOIC	Cretaceous (French, 'chalk')	150 mya	90 mya- The Methow 'graben' (German for 'ditch' or 'grave'), begins to form as strata are folded and the subsides relative to surrounding formations. 150 mya- Oldest non-metamorphosed sediments in the Methow--now called the Twisp Formation--are laid down in a marine environment. These thin-bedded shales are visible on the road cuts just south of Winthrop on both the state highway and the eastside road; they are also visible on Poorman Ck road.	120 mya- The first flowering plants appear in the fossil record 150 mya- The Age of Reptiles (dinosaurs); the first birds come to light
		Jurassic (Jura Mts in France)	210 mya		
		Triassic (3-fold division of rocks in this period)	250 mya	250 mya- All the earth's land masses, previously having joined together into one massive continent known as Pangaea, begin to split apart	220 mya- The first mammals appear in the fossil record 250 mya- Permian Extinction- 90% of all marine life and many terrestrial species perish; cause unknown.
	PALEOZOIC	Permian (Duchess of Permia)	290 mya	300 mya- The Chelan batholith (the Methow's oldest rocks, forming much of the Sawtooth Range) is formed, deep underground, through the metamorphsis of marine sediments. Much later (88 mya), about the time the Methow Valley is forming (subsiding relative to surrounding formations), the Chelan batholith is uplifted.	275 mya- Conifers become the dominant land plant, and remain so until displaced by flowering plants about 100 mya 300 mya- The Age of Amphibians; the first reptiles emerge from the evolutionary cauldron
		Carboniferous (coal deposits)	360 mya		365 mya- Fish are the dominant animal type; the dawn of amphibians
		Devonian (Devon- site in England)	410 mya	380 mya- The earliest coal deposits are laid down as dead organic matter	The vegetation of the early Devonian consisted primarily of small plants, the tallest being only a meter tall. By the end of the Devonian, ferns, horsetails and seed plants had also appeared, producing the first trees and the first forests.
		Silurian (a tribe in Old England)	450 mya	460 mya- The earth's climate stabilizes, a 'Glacial Age' ends, glaciers melt, sea levels rise, inundating continental shelves	450 mya- The colonization of dry land by plants and animals begins 460 mya- Coral reefs first develop in shallow seas
		Ordovician (a tribe in Old England)	500 mya	470 mya- most land masses (excluding NA) joined into a supercontinent, Gondwana, which drifts over the South Pole, inducing a 10 million year Glacial Age.	470 mya- a mass extinction occurs, killing 25% of all marine life; the cause is thought to be a Glacial Age that lowered sea levels
		Cambrian (Cambria- Roman name for Wales)	550 mya	500 mya- The uplifting of the Appalachian Mountains begins 550 mya- The earliest oil and gas fields, which are the organic remains of abundant life, begin to form	550 mya- The first primitive fish appear in the fossil record
		Precambrian	Older than 575 mya	600 mya- The oldest event recorded in the rocks of the Methow was the deposition of mud sand and limy sediment in a marine environment; much later this sediment was metamorphosed into the Chelan batholith.	680 mya- The earliest evidence of animals (creatures in the Kingdom of Animals; the planet previously inhabited by bacteria and other single-celled organisms)
		Birth of the Planet	4,650 mya	3.8 bya- The oldest known rocks on the planet, found in Canada, Greenland and Australia	3.8 bya- The oldest evidence of life appears in rocks 3.8 byo, bacterial in form. Apparently life appeared on the planet relatively soon after it became hypothetically habitable.

Methow Stratigraphy



Abundance of the Primary Elements in Rocks in Different Systems

Composition of: (Density)	Aluminum 2.7	Calcium 1.5	Iron 7.9	Magesium 1.7	Oxygen .001	Potassium .86	Silicon 2.3	Sulfur 2
The Universe (or solar system)	0.006	0.006	0.1	0.058	1	0.0003	0.05	0.04
The Atmosphere	0	0	0	0	21	0	0	0
The Earth's Crust	8	0.4	5.5	3	46	2.5	28	0.05
The Earth's Mantle	2.2	2.3	6	23	44	0.03	22	trace
The Earth	1.6	1.7	32	15	30	0.016	16	0.6
The Oceans	0	0.04	0	0.1	88	0.04	0.0003	0.1
The Human Body	0.000087	1.4	0.006	0.05	65	0.2	0.002	0.25
Plants	0	0.5	0.01	0.2	45	1	trace to 10	0.1

Physical Characteristics of Minerals and Rocks

Primary Rock Elements: Oxygen Silicon Aluminum Potassium Calcium Magnesium Iron

Primary Rock Minerals: Quartz Feldspar Biotite Amphibole Olivine Pyroxene

High Silica Content → Low Silica Content

Light Color → Dark Color

Light Weight (density) → Heavy (dense)

Low Melt Point (600°F) → High Melt Point (2000°F)

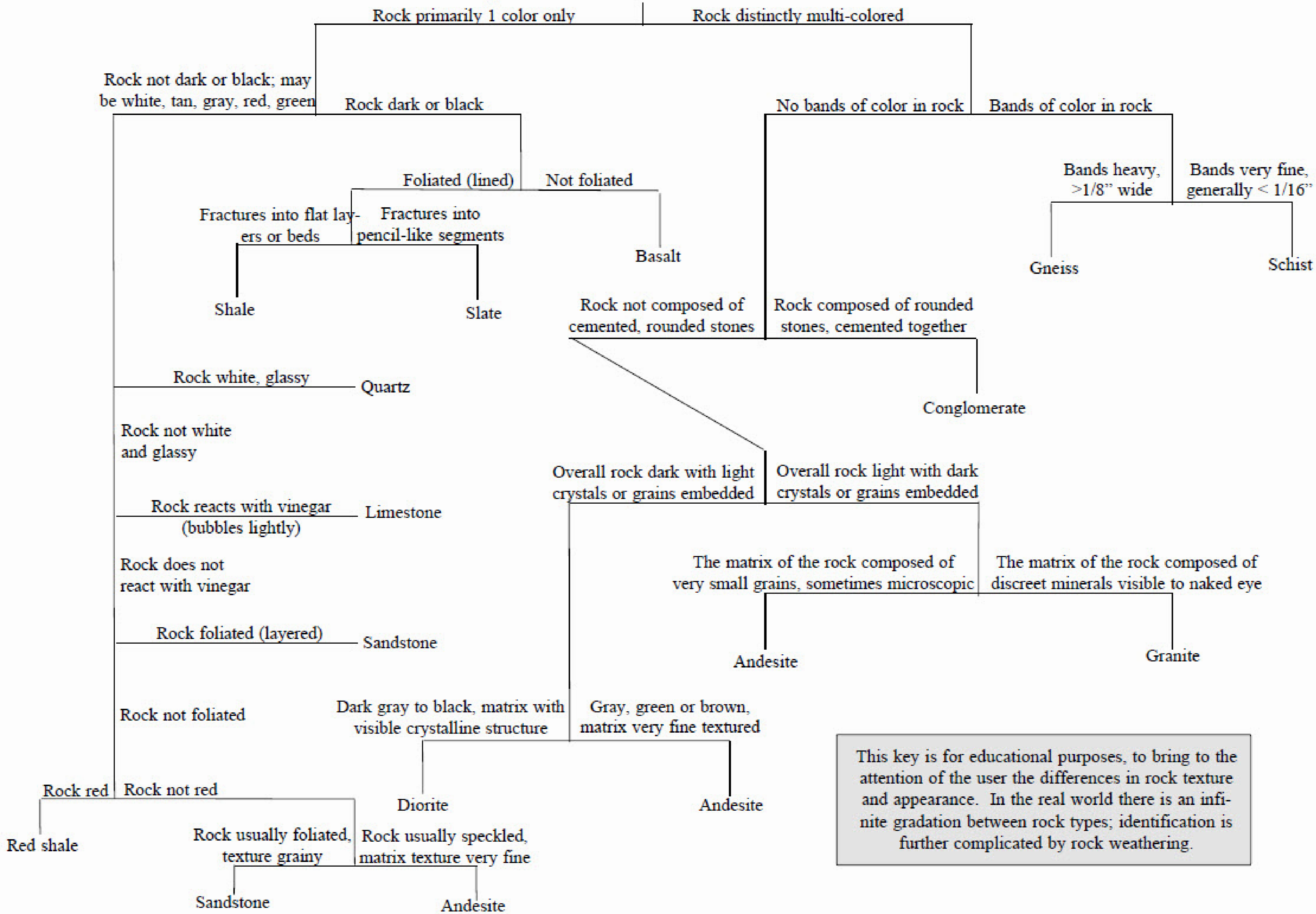
Hard → Soft

Viscous → Fluid

Primary Rocks:

Granite	Diorite		Gabbro	Peridotie
Rhyolite	Dacite	Andesite	Basalt	(no equivalent)
Quartzite	Gneiss	Schist	Shale	(no equivalent)
Sandstone			Shale	(no equivalent)

Key to Methow Rocks



This key is for educational purposes, to bring to the attention of the user the differences in rock texture and appearance. In the real world there is an infinite gradation between rock types; identification is further complicated by rock weathering.

Methow Biodiversity Project/Methow Naturalist PO Box 175 Winthrop, WA 98862

Demystifying Rocks

Elements

Rocks are made up of minerals, and minerals are made up of elements. Elements, as you may remember are those discrete little building blocks of the universe that fill the scary Periodic Table of Elements. There are 92 naturally occurring elements on earth, but only 8 are major constituents of minerals, and those are aluminum (symbol for which is Al), calcium (Ca), iron (Fe, from the Latin word for iron, ferrum), magnesium (Mg), oxygen (O), potassium (K, from a Latin word for potassium 'kalium'), silicon (Si) and sulfur (S). If you combine these in different proportions you get different minerals and different rocks.

Minerals

Apparently there are over 4500 minerals on earth, but it is our good fortune that we only need to have a passing familiarity with 6 of them: amphibole, biotite (which we are familiar with as 'mica'), feldspar (which comes in two flavors, orthoclase feldspar and plagioclase feldspar), olivine, quartz (also known as silica) and pyroxene.

A mineral consists of one or more elements, chemically combined. To be classified as a true mineral, a substance must be a solid and have a crystalline structure. It must also be naturally occurring, with a defined chemical composition. By comparison, a rock is an aggregate of minerals and does not have a specific chemical composition.

A particularly interesting aspect of minerals and rocks is this short series of facts: **1.** The more silica that is present in a rock (silica is the same thing as quartz, its chemical formula is SiO_2, which stands for 1 atom of silicon and 2 atoms of oxygen) relative to other minerals, the lighter (less dense) the rock will be. **2.** Continental rock—the stuff we stand around on—is made of high silica rock, like granite. Because it is less dense than most other rocks it actually floats on the denser rock below. **3.** Silica has a much lower melting point that most of the other 7 minerals listed above. **4.** If a mass of rock is only partially melted, the silica will melt first and migrate out of the larger mass. **5.** Separating out silica means that minerals and rocks evolve over time; more high silica rocks have appeared over time. **6.** If more high silica rocks have evolved over time, then the continents have evolved over time as well.

Here's our short list of important minerals, all made up of the 8 elements we listed above. I give a chemical formula for each—don't let it frighten you; at some point it's helpful to know. Each mineral has its relative density listed at the end; the comparison is to the density of water. For example the first mineral below, amphibole, has a density of 3.3. That indicates that a given volume of amphibole would be 3.3 times as dense as the same volume of water. This factor is important because denser minerals tend to sink downward in the earth's crust and less dense minerals tend to rise. The denser minerals tend to be darker in color, while the lighter minerals are also lighter in color.

1. Ampibole (Gr, 'ambiguous') (also known as hornblende)—A silicate (which usually means some combination of silicon and oxygen, but not necessarily *silica*, which is $SiO_{2)}$ + iron or magnesium, sometimes with calcium. A general formula is Mg and/or Fe_2SiO_4. Amphibole is chemically similar to olivine, which is listed below. One difference between the two is cleavage; amphibole cleaves in plates close to 180° while olivine cleaves at 90°. Density 3.33

2. Biotite (named after French physicist J. Biot d 1862)—Biotite is familiar to us as mica. It is composed of a sheet silica with iron, magnesium, potassium, and aluminum; the sheets are weakly held together by potassium ions and cleave apart easily. $K(Mg,Fe)_3AlSiO_{10}(OH)_2$. Density 3.1

3. Feldspar ((German, 'field mineral')—An aluminum silcate $AlSi_2O_8$. There's a lot of feldspar out there; it makes up as much as 60% of the earth's crust. Density 2.6. Orthoclase feldspar adds potassium to the formula; plagioclase feldspar adds sodium (Na) or calcium.

4. Olivine (name comes from its typically olive-green color)—A magnesium iron silicate, with the formula Mg and/or Fe_2SiO_4. Density 3.3

5. Quartz (probably from an Old German word for 'hard')—the chemical formula is SiO_2--silica. This is the second most abundant mineral in the earth's continental crust after feldspar. Density 2.6

6. Pyroxene (Gr, 'fire stranger,' in reference to the fact that they show up it crystals embedded in glass or lava because of their high-temperature of solidification)—Calcium, iron, sodium and/or magnesium + SiO_3. Density 3.4

Rocks

There are three main types of rocks, **igneous, sedimentary, and metamorphic**. Each has a different history and tells a different story. Learning to recognize these three rock types can tell you a lot about the environment that you are in.

Igneous- The word igneous means 'born by fire'; igneous rocks are those that have been melted completely (into magma) before solidifying. A useful rule of thumb is that the faster a magma or lava cools, the finer the grain size of the rock will be. Thus volcanic rock, which is exposed to the air or at least close to the surface, is fine-grained. Rocks that cool deep underground, like granite, are made up of large crystals of different minerals, which were able to form because the original molten material cooled very slowly.

There are two types of igneous rocks. Those that cool at or near the surface of the earth are known as **extrusive igneous rocks**, and are generally associated with volcanic activity. Rocks that melt completely and then cool deep underground cool slowly—sometimes over a million years or more—are called **intrusive igneous rocks**. Their long period in a liquid or plastic state allows the molecules of any particular mineral in the rock to migrate to other molecules of the same type. This leads to the formation of distinct crystals of different minerals within the rock. For example, if you look at granite closely, you will see that there are distinct white crystals in the rock structure—quartz—along with pinkish crystals, which are feldspar, and black flecks, which are mica.

Felsic rocks are lighter colored rocks that are rich in light-colored elements such as silicon, oxygen, potassium and sodium. They are also relatively light-weight, with densities less than 3 (3 times the equivalent volume of water). The term "felsic" combines the words "feldspar" and "**si**lica".

Mafic rocks are dark colored rocks that are rich in magnesium and iron; the word 'mafic' is constructed from the ma in magnesium and the fe in ferric (which means iron in Latin). They have a density of more than 3 and tend to feel heavy.

Below are some examples of common intrusive and extrusive igneous rocks. Both groups are arranged in order of decreasing quartz (SiO2, silica dioxide) content and increasing darker, heavier minerals.

The darker, heavier minerals solidify at higher temperatures than those with a greater silica (SiO_2—which is light-colored) content. Thus olivine and pyroxene (see mineral section below) will precipitate out of a cooling magma much earlier than will quartz. The surprising related point is that the first minerals to crystallize in a mass of magma (those that crystallize at high temperature) are most unstable at the earth's surface and are the quickest to weather, because the surface is most different from the conditions under which they were created. On the other hand, the low temperature minerals are much more stable because the conditions at the earth's surface are much more similar to the conditions under which they formed. Therefore dark rocks such as gabbro, basalt and slate will quickly weather to fine, silt-like particles, whereas high-silica rocks such as rhyoliteand granite will weather to relatively large fragments. This is why they world's beaches are covered with sand, and not mud or silt. The fine silt washes away to quiet water, while the larger quartz-feldspar sand resists deportation.

Extrusive Igneous

1. Rhyolite: Rhyolite is the extrusive chemical equivalent of granite, with 70% SiO_2 (which is very high silica content). It aphanitic (fine-textured) or an aphanitic porphyry (fine matrix with some larger crystals mixed in), and is usually pale, in shades of white, gray, pale green, although it is (unfortunately) sometimes red or brown. It is a very hard rock that break with a conchoidal fracture like glass; in fact obsidian is a glass version (noncrystalline) of rhyolite. An important thing to remember about these extrusive igneous rocks is that the lava viscosity (which can be defined as 'resistance to flow,' or 'gooey-ness') increases dramatically with silica content. Molten rhyolite may be up to 1000 times more viscous than molten basalt—which means rhyolite rarely flows. The name comes from the Greek word for 'flow' (ironically). Density 2.5

2. Dacite: Dacite is intermediate between rhyolite and andesite, and is the volcanic equivalent of granodiorite, with a silica content of about 65%. It is aphanitic or an aphanitic porphyry, often medium gray, sometimes brown or buff. Dacite contains more plagioclase feldspar and less orthoclase feldspar than rhyolite. This rock is common in Romania, which the Romans called Dacia, thus the name. Like rhyolite it is a viscous mineral and will tend to plug volcanic vents rather than flowing, which leads to explosions. Much of Glacier Peak is composed of dacite, as are the lava domes on Mt. St. Helens. Density 2.6

3. Andesite: Andesite is the extrusive chemical equivalent of diorite, with a silica content of about 60%. . It is aphanitic or an aphanitic porphyry, typically gray, green or sometimes reddish brown. It is high in plagioclase feldspar, which is sometimes found as white or gray phenocrysts or as tiny lath-like crystals in the groundmass. This feldspar has a much higher melting point than the background minerals and came up with the magma as a solid--, like marshmallows floating in cocoa. The majority of the rock in big Washington volcanoes is andesite- whereas basalt predominates in the 'High Cascades' (in Oregon). Most of Goat Wall, Goat Peak and Robinson Mt. are composed of slightly altered andesite. The rock is named after the Andes. Density 2.7

4. Basalt: Basalt is the extrusive chemical equivalent of gabbro, with a silica content of 50% SiO_2. It is fine-textured and usually dark, although it can be medium gray, greenish or reddish. In general the individual crystals within basalt are not visible with the naked eye or through a hand lens. Sometimes basalt is peppered with air holes (vesicles), which indicate that the rock congealed near the surface of a lava flow. The name comes from a Latin word meaning 'very hard stone.' With its low silica content, basalt is very fluid, and it flowed out abundantly as the flood basalt of central Washington 16 million years ago—about 100,000 cubic miles of it! Density 2.9

5. Pumice: A very light, airy rock which forms on the surface of a viscous, high-silica lava like rhyolite. It may also form in the air after rhyolite explodes. It is light-colored with abundant tiny vesicles (air holes). Some pumice is so full of air that it will float on water. The name derives from an old Latin word meaning 'to foam.'

6. Tuff: Consolidated volcanic ash. Ashfall can be cemented over decades from dissolved silica, or it can cement itself from its own heat, a 'welded tuff.' Tuff creates the steep angle and smooth outline of stratovolcanoes (the classic steep-sided shape of our PNW volcanoes). The word comes from the Latin *tufa*, meaning 'porous rock.'

7. Obsidian: volcanic, rhyolitic glass (high silica by definition), usually black. Obsidian is lava that cooled very quickly, without organizing into crystalline minerals. It is only found where volcanic activity has occurred in fairly recent times, for it tends to crystallize into fine-grained rock or decompose by taking on water. Named after an Old Roman rock hound, *Obsius*.

Intrusive Igneous

1. Granite: 70% SiO_2. The name derives from 'granular'; and indeed the texture is granular, one of interlocking crystals. Granite has at least 10% visible quartz; in fact quartz crystals (which are SiO_2) will only form above 55% SiO_2 content. It is usually pale overall, although it can be pink to red. Dark minerals are never abundant but their presence gives granites a 'speckled' appearance. Quartz is the white to buff, translucent component; feldspars are salmon to pale gray; and the black flakes are biotite mica, hornblendes and pyoxenes are dark gray. Granite forms by cooling over hundreds of thousands of years. Density 2.7

2. Granodiorite: 65% SiO2. Similar to granite but darker, with more plagioclase than orthoclase feldspar. It usually contains abundant biotite mica and hornblende, giving it a darker appearance than true granite. Mica may be present in well-formed hexagonal crystals, and hornblende may appear as needle-like crystals.

3. Diorite: 60% SiO_2. Diorite is usually speckled, dark but up to 50% light crystals. . It can also be black or bluish-grey, and frequently has a greenish cast. It is composed principally of plagioclase feldspar, biotite, hornblende, and/or pyroxene; it is relatively rare. Density 2.9.

4. Gabbro: The chemical equivalent to basalt, with 50% SiO2. It is coarse-grained and typically a dark salt and pepper appearance. It sometimes shows little contrast in color, making the crystals inconspicuous. It is relatively rare on the earth's surface, the most commonly being found in dikes over 4" wide—with its low silica content and low viscosity it flows into openings with ease. The vast majority of the Earth's surface is underlain by gabbro within the oceanic crust, produced by basalt magmatism at mid-ocean ridges. Named after a town in Italy. Density 3.1

5. Peridotite: Less than 45% SiO2. A dark, ultra-mafic rock, typically green, flecked with black crystals and a greasy looking luster. Weathers into serpentine soils. Peridotite contains a high proportion of the dense green mineral olivine (40% or more; olivine contains iron, so it is a dense mineral), and is too heavy to reach the earth's surface without exceptionally deep and rapid rock movement. Thus peridotite has no volcanic equivalent. Density 3.3

Sedimentary (from the Latin, sedimentum, 'settling')- Sedimentary rocks are most often formed from the breakdown of older rocks. The final particle size from the older rock that is laid down as sediment and then cemented to other particles varies from microscopic to house-size boulders. It is the cementing that turns sediment into sedimentary rock.
There are two other less-common types of sedimentary rock, organic and chemical. Organic sedimentary rock is formed from organic debris—the deposits or remains of once-living organisms (shells, corals, wood, plants, etc). Chemically formed sedimentary rocks consist of interlocking crystals that precipitated from a solution (which is where the old proverb comes from: 'If you're not part of the solution, you are part of the precipitate.').
1. Shale: a fine-grained, clastic (made up of fragments of pre-existing rock) sedimentary rock composed of mud that is a mix of flakes of clay minerals and tiny fragments (silt-sized particles) of other minerals. Shale usually will split or cleave into thin sheets along the lines it was laid down on. The fine components are bound by cement or by simple compaction. Shale tends to be composed of the low-silica, high-dark mineral rocks, which break down more easily into fine components than do high-silica rocks. Density 2.6

2. Sandstone: a rock composed of sand-sized particles cemented together. May be light or dark, depending on the mineral composition. Tends to be composed of high-silica, hard rocks like decomposed granite. Density 2.5

3. Conglomerate: sedimentary rocks composed of at least 50% erosion-rounded stones over 1/8 inch in diameter; most are pebble beaches and river bars turned to stone. There is over 1000' of conglomerate in the Pipestone Formation.

4. Limestone: Organic or chemical sedimentary rocks with over 50% calcite ($CaCO_3$)- will effervesce with vinegar. Usually light, white to gray.

5. Chert: a microcrystalline form of precipitated quartz, resembling porcelain. The main source is precipitation from sea water solution, initially from diatoms, a microscopic, hard-shelled algae. While most seashells are made of calcite (limestone), there is also a large group of one-celled organisms that make a shell of silica, and these are them main source of chert.

Metamorphic Rocks (from the Greek words meta, 'change', morph, 'form')- Metamorphic rocks begin as either igneous or sedimentary rocks that have then undergone a combination of heat and pressure that changes their form. Metamorphic rocks have been heated to the point where they become plastic, but they are not completely melted. They often have the appearance of having been stretched, with lines of different minerals running through the rock.

1. Slate: metamorphosed shale, and like shale it is very fine-grained and usually dark in color. Slate is composed mainly of clay minerals or micas depending upon the degree of metamorphism to which it has been subjected. The original clay minerals in shale alter to micas with increasing levels of heat and pressure. Slate can also contain abundant quartz and small amounts of feldspar, calcite, pyrite, hematite and other minerals. It may have a satiny luster. Foliation in slate is caused by the parallel orientation of platy minerals in the rock such as microscopic grains of clay minerals and mica during metamorphism. Thus the foliation is *not* along sedimentary lines but is related to heat and pressure. These parallel mineral grain alignments give the rock an ability to break smoothly along planes of foliation. Slate sometimes fractures into slender 'pencils.' Density 2.8

2. Phyllite: A type of foliated metamorphic rock primarily composed of quartz and mica; the rock represents a gradation in the degree of metamorphism between slate and mica schist. Minute crystals of graphite or chlorite impart a silky, sometimes golden sheen to the surfaces of cleavage. Phyllite often pale or dark green. From a Greek word meaning 'leaf,' referring to the cleavage planes.

3. Schist A rock with a texture consisting of fine layers of different minerals, often with layers of shiny black mica. The word schist derives from a Greek word meaning 'to split,' but schist often does not split easily, in spite of the derivation of the name. Most schists have been derived from clays and muds which have passed through a series of metamorphic processes involving the production of shales, slates and phyllites as intermediate steps.

4. Gneiss: consists of foliated or banded light and dark minerals, intermediate between schist and granite in appearance and metamorphism. The parent rocks can be shale or granite. For the rock to be gneiss rather than schist, flaky minerals must be outweighed by fatter grains overall. The minimum depth for gneiss formation is 6 miles. Gneiss is a fairly hard rock, giving rise to the geologist's dictum, 'Gneiss bands don't make punk rock.' The etymology of the word "gneiss" is disputed. Some sources say it comes from the Middle High German verb *gneist*, to spark; so called because the rock glitters. Density 2.8

5. Quartzite: Metamorphosed arksose (feldspar- and quartz-rich) sandstone. Pure quartzite is white or gray, but it often occur in various shades of pink and red due to varying amounts of iron oxide (Fe_2O_3).

6. Migmatite: A rock at the frontier between igneous and metamorphic rocks. Migmatite is the same material as gneiss, but brought closer to melting by regional metamorphism so that the veins and layers of minerals became warped and swirled. Migmatites are composed of a new material crystallized from incipient melting, and old material that resisted melting. The word is derived from a Greek word *migma*, meaning 'mixture.'

Glossary

Aphanitic- fine grained
amphibole (Gr, 'ambiguous')- SiO_4 + iron or magnesium
Arenite- sandstone composed mostly of quartz, with less than 15% fine matrix
Argillite- is a fine-grained sedimentary rock composed predominantly of hardened (by heat or compacting) clay particles. Argillaceous rocks are basically lithified muds and oozes. Another name for poorly lithified argillites is *mudstone*. These rocks, although variable in composition, are typically high in aluminium and silica with variable orthoclase feldspar.
Arkose- sandstone with a high percentage of feldspar and some quartz; it has a chemical composition similar to granite; which is often the parent rock.
Biotite- $K(Mg,Fe)_3AlSiO_{10}(OH)_2$
Breccia- a rock composed of broken fragments of minerals or rock cemented together by a fine-grained matrix. A breccia may have a variety of different origins, as indicated by the named types including sedimentary breccia, tectonic breccia, igneous breccia, impact breccia and hydrothermal breccia. From a Latin word for 'breakage.'
Clastic- rocks are composed of fragments, or clasts, of pre-existing rock.
Clay- a hydrated aluminium silicate, $Al_2Si_2O_5(OH)_4$ from feldspars
Dolomite- $CaMg(CO_3)_2$
Feldspar (German, 'field mineral')- $AlSi_3O_8$, usually more abundant than quartz in granite, white to creamy pink, softer than quartz, can barely scratch with a pocket knife.
Granitoid- at least 1:5 quartz to feldspar ratio
Graywacke- fine to coarse particles in a clay matrix + some pressure and heat
Hornblende- an amphibole, a calcium- iron- magnesium silicate (like pyroxene but with a hydroxyl- OH).
Lapilli is a size classification term for tephra, which is material that falls out of the air during a volcanic eruption or during some meteorite impacts. Lapilli (singular: lapillus) means "little stones" in Latin. By definition lapilli range from 2 mm to 64 mm in diameter.
Lithic sandstone- sandstones with a significant (>5%) component of lithic fragments, though quartz and feldspar are usually present as well, along with some clayey matrix.
Mafic- Fe + Mg; mafic minerals: olivine, pyroxene, amphibole, biotite
Migmatite- intimate interpenetration of gneiss and granite
Mineral- a naturally occurring compound of two or more elements with definite chemical composition and distinctive properties.
Mudstone- like shale but lacks flakiness and cleavage
Olivine- (Mg and/or $Fe)_2$ + SiO_4
Orthoclase- potassium aluminum silicate, $KAlSi_3O_8$, usually pink or cream
Pegmatite- very coarse granite, usually from a dike, the result of high water content, low viscosity, high mobility of certain light elements while cooling.
Phaneritic- coarse grained
Phenocryst- any relatively large visible crystal surrounded by much smaller crystals in igneous rock
Plagioclase- sodium or calcium aluminum silicate, NaAl or CaAl-Si_3O_8
Porphyritic- an igneous rock having large isolated crystals surrounded by fine crystals
Pyroxene- calcium- magnesium- iron- silicate
Serpentine- a magnesium silicate, associated with gabbro. Asbestos is a fibrous serpentine
Tectonic- (from the Greek 'to build')- pertaining to the pressures that change the earth's crust
Travertine- (tufa or sinter) an accumulation of $CaCO_3$ from hot springs and karst areas
Wacke-a name for a poorly sorted sandstone, a mixture of grains of sand, silt and clay size. Graywacke is a specific type of wacke. Wacke contains quartz, like other sandstones, but it also has more delicate minerals and small fragments of rock (lithics).
Xenolith- a rock fragment of country rock incorporated into igneous rock