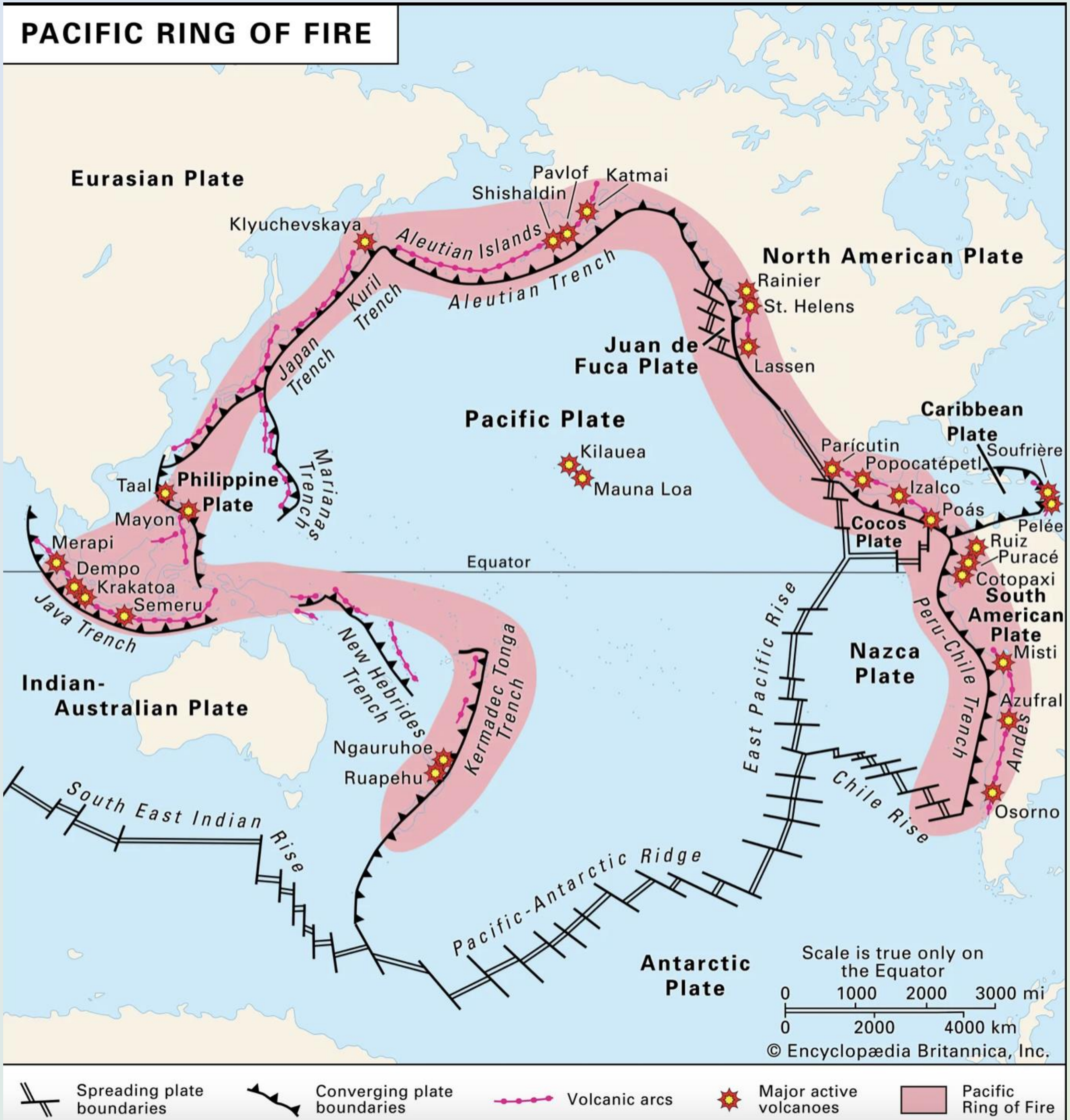

U3A Geology
The Cascades

Introduction

- Cascade Range → 1,300Km chain of volcanoes in North America, extending from Canada through Washington State, Oregon into northern California
- the volcanoes result from the subduction of the Juan de Fuca and Gorda tectonic plates beneath the North American plate
- the Cascades contain 13 major volcanoes and approximately 2,900 other volcanic features including cinder cones, shield volcanoes
- the Cascade Range is composed of numerous small, short-lived volcanoes that have built a platform of lava and volcanic debris
- much of the volcanic debris is composed of lahar deposits

Geological setting

- The Cascades volcanoes form part of the NE section of the Ring of Fire that circles the Pacific Ocean
- the volcanism results from subduction of oceanic tectonic plates
- as the oceanic slab sinks deep into the Earth's mantle beneath the continental plate, high temperatures and pressures allow water locked up in solid minerals to escape
- water vapour rises up into the pliable mantle causing some partial melting, generating magma that reaches the Earth's surface
- Cascade volcanoes erupt directly above where the Juan de Fuca plate reaches ~80Km below the surface


PACIFIC RING OF FIRE
Eurasian Plate
Pavlof
Katmai
Shishaldin
Klyuchevskaya
Aleutian Islands
Aleutian Trench
Kuril Trench
Japan Trench
North American Plate
Rainier
St. Helens
Juan de Fuca Plate
Lassen
Pacific Plate
Kilauea
Mauna Loa
Marianas Trench
Philippine Plate
Taal
Mayon
Merapi
Dempo
Krakatoa
Semeru
Java Trench
Equator
Caribbean Plate
Soufrière
Parícutin
Popocatépetl
Izalco
Poás
Cocos Plate
Pelée
Ruiz
Puracé
Cotopaxi
South American Plate
Misti
Azufral
Andes
Osorno
Nazca Plate
Peru-Chile Trench
East Pacific Rise
Chile Rise
Indian-Australian Plate
New Hebrides Trench
Kermadec Tonga Trench
Ngauruhoe
Ruapehu
South East Indian Rise
Pacific-Antarctic Ridge
Antarctic Plate
Scale is true only on the Equator
0 1000 2000 3000 mi
0 2000 4000 km
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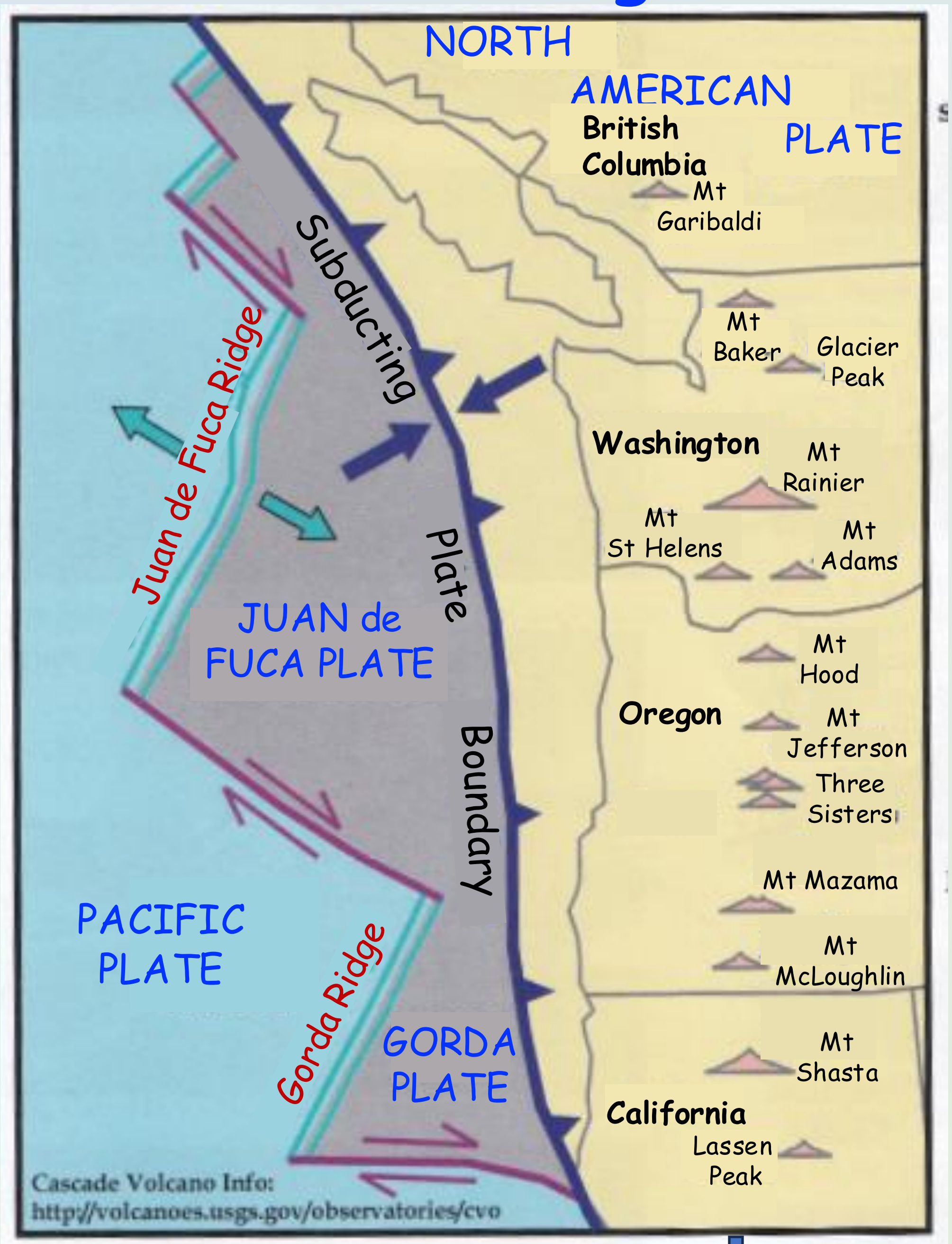
Spreading plate boundaries
Converging plate boundaries
Volcanic arcs
Major active volcanoes
Pacific Ring of Fire

Cascade Range

- Cascade Range → nearly continuous chain of mountains extending from Canada to northern California → part of the American Cordillera
- within the region there is a string of 13 explosive volcanoes
- the tallest mountains of this range are stratovolcanoes that are still active
- the small section of the range in Canada → the Canada Cascades
- there is one major break in the Cascade mountains → Columbia River Gorge with exposed distorted layers of basalt (Columbia River basalts)

Cascade Range



Cascade Range

North Cascades

- The North Cascades encompasses the northern section of the Cascade Range from British Columbia in Canada to NW Washington State
- this region of the Cascade Range is mostly composed of non-volcanic mountains, although it does contain a few stratovolcanoes (e.g. Mts Baker, Garibaldi, Glacier Peak)
- the geological history of the North Cascades is complex and records more than 400 million years of various rocks and terranes that have been scraped off, slammed together and buried
- volcanoes grew and erupted covering the already complex geology with lava and ash

Cascade Range

High Cascades

- The High Cascades make up the rest of the Cascade Range all the way from Mt Rainier, through Oregon to Lassen Peak in northern California
- the mountains in the region have built up from lava and volcanic debris over very many years
- a chain of lava domes, long-lasting volcanoes and cinder cones make up the High Cascades
- sitting on the Pacific Ring of Fire, this region has been volcanically active for several million years

Cascade Range

Western Cascades

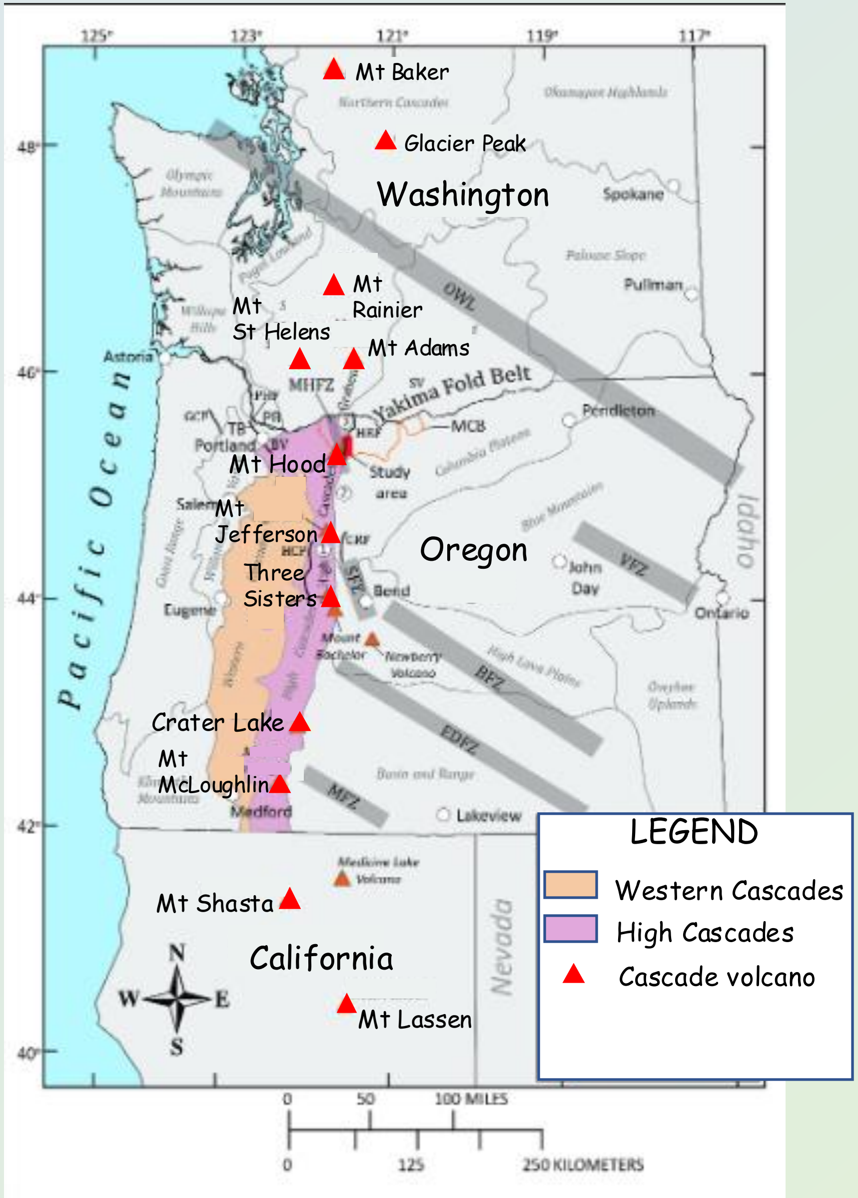
- The Western Cascades in Oregon encompasses volcanic rocks as old as 45myr
- the region is deeply eroded in contrast to High Cascades
- the distinction arises for two reasons:

  (1) broad uplift of Western Cascades after 8myr created steep rivers → enhanced erosional downcutting

  (2) volcanism was focused along axis of High Cascades, filling the canyons and building up the spine of the range
- Western Cascades sub-province has only experienced small volcanoes in past 4myr → spared canyon infilling allowing stream erosion

Western Cascades

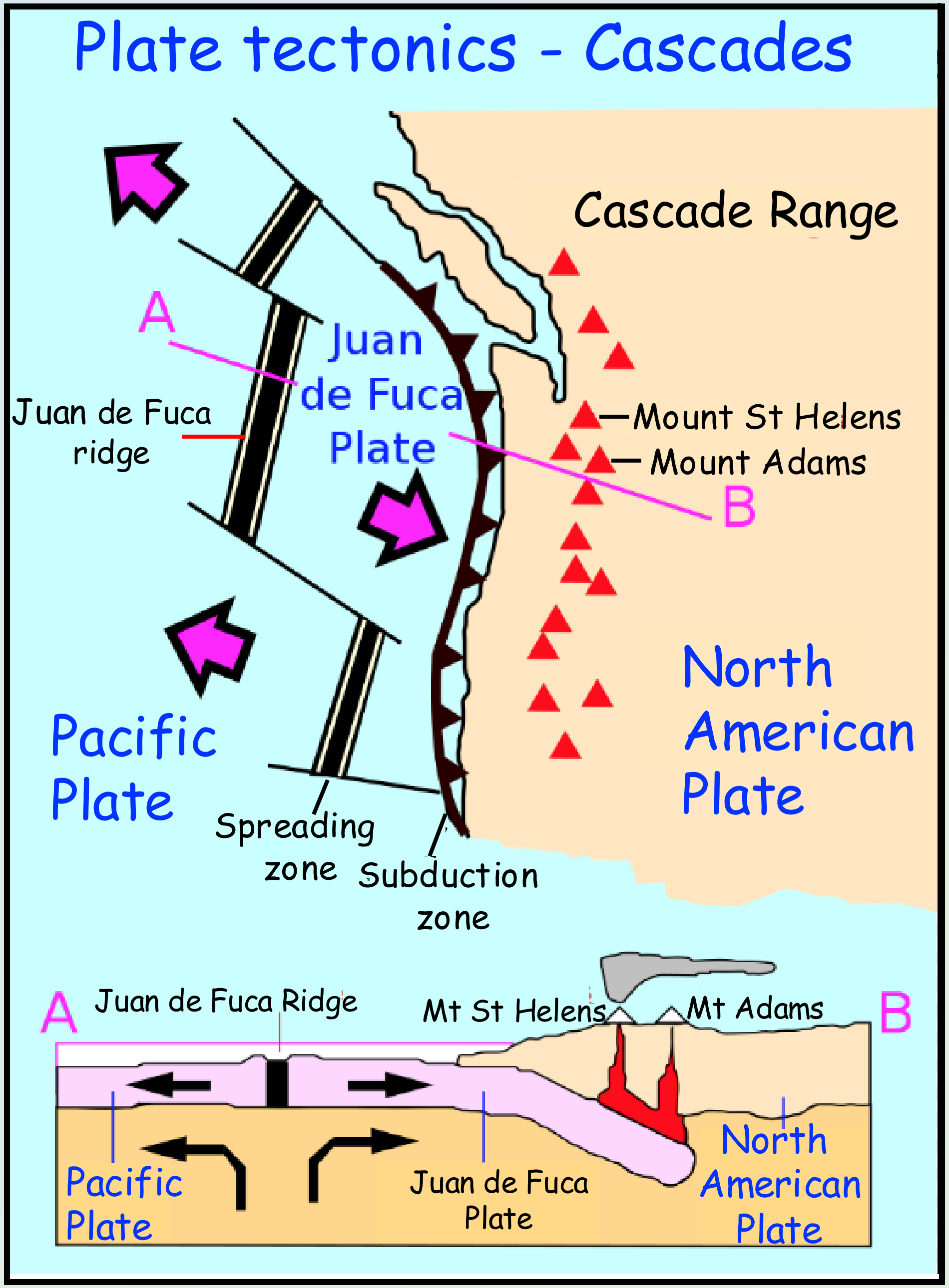
- Contains many extinct shield volcanoes, cinder cones and lava flows
- geologically active ~45-17Ma
- volcanic activity shifted to the east in the Miocene and Pliocene ~7-5Ma



Tectonic setting

- At the Cascade subduction zone, two relatively small fragments of the Pacific plate, the Juan de Fuca plate and the smaller Gorda plate to the south are subducting beneath the North American plate
- the two plates are moving eastward at ~5cm/year
- subduction of these descending slabs generates magma beneath the edge of the continental plate
- subduction also creates weaknesses through which the magma rises to the surface forming Cascade volcanoes from Lassen Peak in northern California to Mt Garibaldi in Canada

Cascades tectonic setting



Cascade volcanism

- The Cascade volcanic arc has been erupting a chain of volcanoes over the past 40Myr
- plutonic rocks of these ancient volcanoes remain and outcrop as large batholiths e.g, Chilliwack batholith
- Cascade volcanism began in the last 5 to 7 million years and is still active modern day
- all of the volcanic eruptions in the continental USA over the past 200 years have been from Cascade volcanoes
- the most recent were Lassen Peak from 1914 to 1921 and a major eruption of Mt St Helens in 1980. Minor eruptions of Mt St Helens occurred from 2004 to 2008

Shield volcanoes

- Shield volcanoes → very broad volcanoes with low angle slopes resulting from eruption of low silica magma → low viscosity
- these volcanoes are relatively quiet but lava fountains may occur with mildly explosive activity producing cinder cones
- can be extremely large building up over time
- most of the High Cascades platform in Oregon → built of overlapping lava flows from shield volcanoes

Mauna Loa, Hawaii

Stratovolcanoes (composite volcanoes)

- Stratovolcanoes are built from alternating layers of lava and pyroclastic debris
- they produce moderately steep slopes protected from erosion by successive layers of lava
- stratovolcanoes have more eruptive styles than any other volcano types
- 12 of the 13 volcanoes in the Cascades are stratovolcanoes
- magmas that produce stratovolcanoes are moderately to highly viscous with intermediate to high silica e.g. Mt St Helens

Stratovolcanoes

Stratovolcano model

Glacier Peak, Washington state, USA

Alternate lava, pyroclastic layering , Crater Lake rim

Cinder cones

- Cinder cones → consist almost entirely of pyroclastic material
- typically small volcanoes <450m high
- generally steep-sided because pyroclastic piles form slopes between 30° and 40°
- no intervening lava flows bind the loose pyroclastics
- cones can form from magmas of any composition as long as they contain enough gas to shower lava into air → creates pyroclastics
- cinder cones also commonly erupt lava flows from a vent

Cinder cones

Lava fountain, Hawaii

Cinder cone. Mt Edziza,

British Columbia, Canada

Lava domes

- Lava domes → mound-shaped protrusions resulting from slow extrusion of viscous lava from a volcano
- the majority of lava domes are of intermediate to acid composition (andesite, dacite, rhyolite)
- common in convergent plate settings, 6% of eruptions on Earth are dome forming
- lava domes grow due to influx of magma into the dome or, by discrete lobes extruded on their surface
- they can reach heights of hundreds of metres and often experience explosive eruptions over time

Lava domes

Lava dome, Chaiten, Chile

Lava dome growing in crater,

Mt St Helens, Washington state

Magma composition

- The four most common magma types, basalt, andesite, dacite and rhyolite are all found in the Cascades
- it is primarily the silica content that determines to which group the particular magma belongs
- silica content not only determines viscosity but also explosive potential
- gas-poor magmas tend to produce effusive eruptions in contrast to gas-rich magmas that are more explosive

Volcanic rock types

Vesicular basalt

Porphyritic andesite

Porphyritic dacite

Porphyritic rhyolite

Pyroclastic materials

- When gas-rich magma rises to the surface where confining pressure is released, it typically explodes into fragments forming pyroclastic material
- most common pyroclastic material is tephra, consisting of solid or semi-solid fragments blown into the air
- tephra can be described on particle size:

diameter	<2mm	volcanic ash
	2-5mm	lapilli
	>5mm	blocks (bombs if in molten or plastic state)

- tephra can also be classified on texture
- if tephra is glassy with high gas content, rapidly escaping gases form vesicles, produces pumice → lightweight frothy glass

Pyroclastic materials

Volcanic bomb, Kilhaueau, Hawaii

Pumice

Volcanic ash

Volcanic rocks in the Cascades

- Basalts → rich in Fe and Mg, dark coloured, low in silica
- the low silica content <54% makes them fluid → able to spread out in thin sheets over large areas
- andesite → most characteristic Cascade lava → comprises most of the stratovolcanoes
- andesite has an intermediate silica content of 54-62%
- more viscous than basalt, it flows shorter distances and piles up to form moderately steep cones
- some Cascade peaks such as Baker, Rainier, Adams and Shasta are constructed almost entirely of andesite

Volcanic rocks in the Cascades

- Dacite although less abundant than andesite with silica content of 62-68% also occurs in the Cascades
- usually light coloured, dacite has a low melting point (~850°C) and is viscous when molten
- dacite tends to produce short thick tongues of lava or steep domes
- most of Mt St Helens' voluminous tephra as well as domes growing in craters consist of dacite

Volcanic rocks in the Cascades

- Rhyolite is the fourth type of Cascade lava, it is highly viscous with a silica content of 72% or more
- although normally very light in colour (light grey, beige, pink), rhyolites are sometimes very dark
- the most striking form of rhyolite is obsidian (volcanic glass)
- some Cascade volcanoes have also produced rhyodacite a silicic lava intermediate between dacite and rhyolite
- the largest Holocene outpouring of rhyodacite occurred about 7,700 years ago when Mt Mazama discharged many cubic Km of rhyodacite tephra

Mt Rainier, Washington State

Mt Rainier

- The highest volcano in the Cascade Range elevation 4,393m
- the mountain features deep valleys and 20 known glaciers
- history of volcanism in the vicinity reaches back 36Myr with at least three major volcanic and sedimentary units and, one major intrusive unit that predate the modern volcano
- during the first eruption stage that lasted from about 500,000 to 420,000 years, the volcano erupted both pyroclastic flows and andesite lavas
- beginning about 40,000 years ago, Rainier built up its upper reaches

Mt Rainier

- Rocks of the modern volcano are primarily andesite and dacite that date back 500,000 years
- they show that the volcano's growth took place in several different stages of intense magma production, separated by periods of fewer eruptions
- the most detailed activity comes from the last 11,000 years although Rainier did not produce any substantial lava flows, it did produce >30 tephra deposits
- ten or twelve of these episodes were over the last 2,600 years, the most fully documented eruption occurred 1,000 years ago

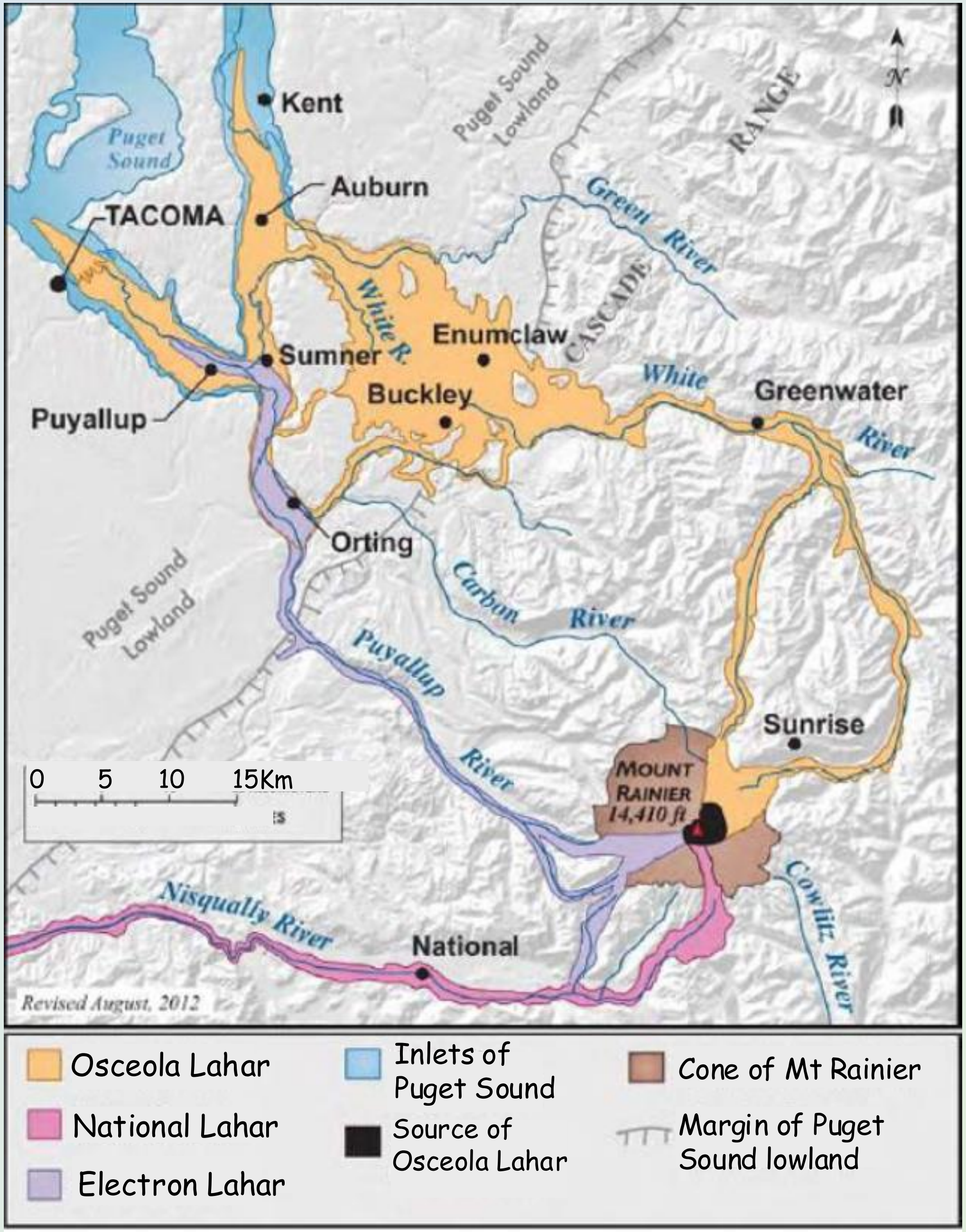
Mt Rainier lahars

- Mt Rainier produced numerous lahars over the last 11,000 years
- lahars may be triggered by eruptions, when hot rock mixes with and melts glacial ice and snow or, by large avalanches that form volcanic debris flows
- an eruption 5,600 years ago caused a large part of E Rainier to collapse resulting in a major lahar (Osceola mudflow) to flow down the White River reaching Puget Sound near Tacoma
- another eruption ~2,600 years ago produced the National lahar that flowed down the Nisqually River to Puget Sound
- ~500 years ago, a large lahar called the Electron mudflow flowed more than 80km down the Puyallup River

Osceola lahar deposits

Osceola lahar deposit ~8m thick along the White River. The lahar flowed 50km from Mt Rainier to Puget Sound

Major Rainier lahars



Mt St Helens, Washington nState

Mt St Helens

- Until 1980, Mt St Helens looked like a typical volcano of the Cascades, it was unusually symmetrical forming a circle in plan view and reached an elevation of 2,950m
- on May 18th 1980, the volcano erupted catastrophically resulting in a loss of 400m off its height and producing an enormous crater open to the north
- the first eruptive cycle of St Helens began about 300,000 years ago and continued intermittently until 35,000 years ago
- over that period, it scattered pyroclastic material far and wide over the Pacific NW of the USA

Mt St Helens

- Mt St Helens did not produce a significant number of lava flows until sometime late in its history
- until sometime after 2,200 years ago, the volcano consisted of an irregular cluster of dacite domes enclosed by voluminous aprons of pyroclastic debris
- there were countless lahar deposits forming thick valley fills that extended tens of Km from the central dome field
- the US geological survey divided the volcano's history into four major eruption stages, Ape Canyon, Cougar, Swift Creek and Spirit Lake stages

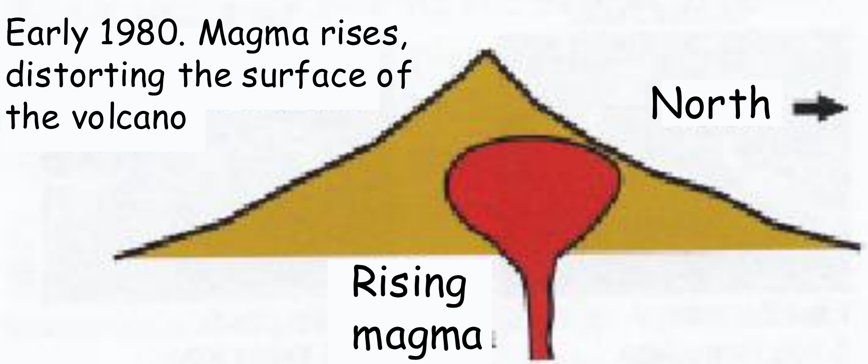
Mt St Helens

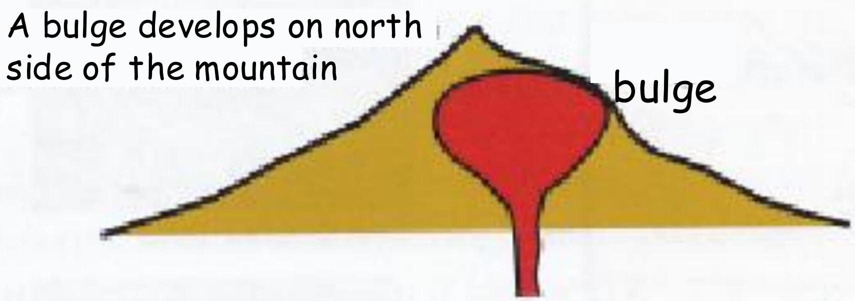
- During the first two stages (Ape Canyon, Cougar) Pleistocene glaciers eroded away most of the St Helens' early deposits
- after a dormant period of ~7,000 years, the Cougar stage began 28,000 years ago initiating a 10,000 year long period of intense volcanism
- the Cougar stage produced the thickest lava flow in St Helens' history with an andesite flow up to 180m thick
- at the end of the Cougar stage ~18,000 years ago, Mt St Helens stood ~1,800 metres high

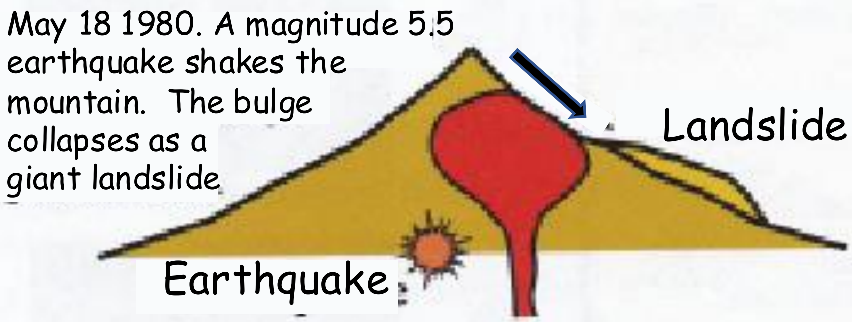
Mt St Helens

- The Swift Creek stage occurred between 16,000 and 12,800 years ago and produced both pumiceous and lithic pyroclastic flows, the latter derived from a growing lava dome at or near the vent
- the Spirit Lake stage was introduced ~3,900 years ago with two eruptive periods that largely replicated earlier eruptive activity
- they produced dacite tephras, silica domes and pyroclastic flows

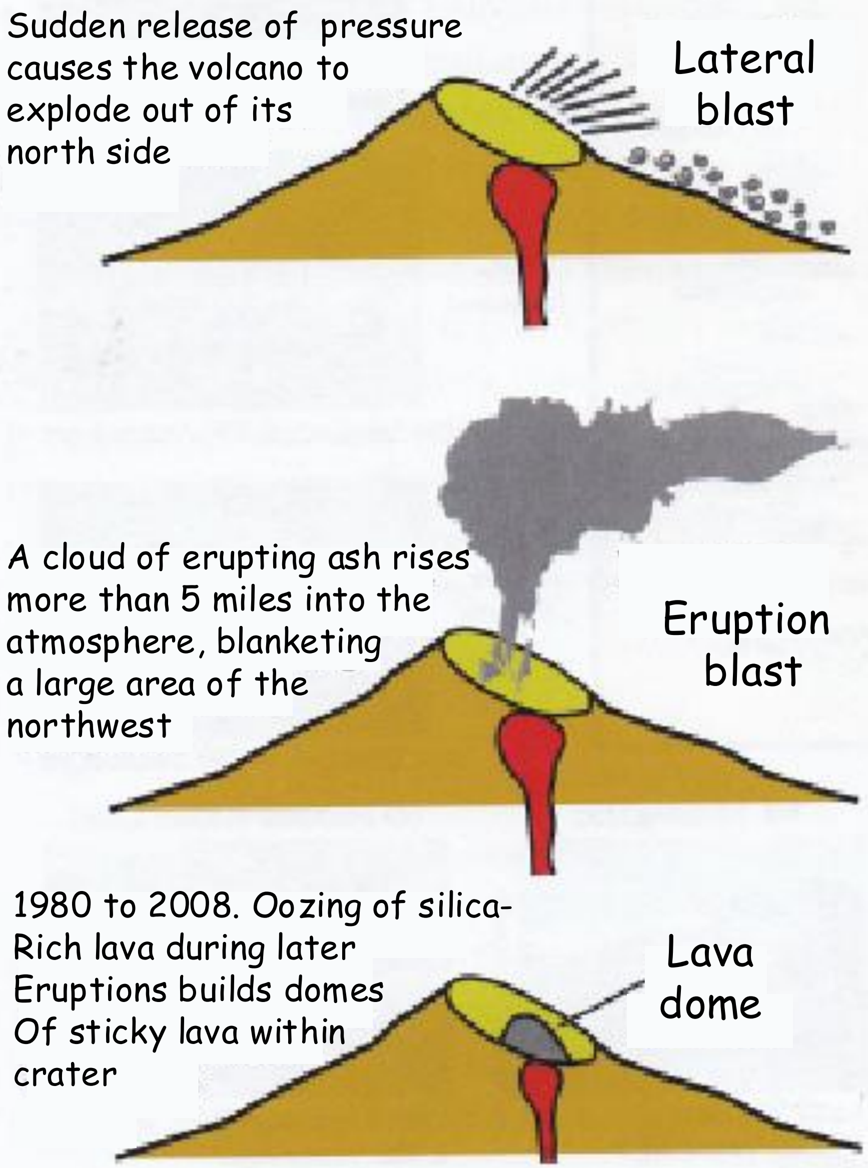
Evolution of Mt St Helens eruption 1980 (Lillie 2015)







Evolution of Mt St Helens eruption 1980 (Lillie 2015)



Mt Hood, Oregon

- Mt Hood is Oregon's highest mountain at 3,245m elevation and is one of the Cascade's most active volcanoes
- most of the present volcano formed since ~500,000 years ago but, beneath these lavas is the Sandy Glacier volcano that dates back to 1.5Ma
- Mt Hood's recent eruptions include two major events, one ~1,500 years ago and one between 1781 and mid 1790s. Minor ones occurred in 1859 and 1865
- today the volcano hosts a number of steam vents
- one distinct feature of Mt Hood is that it contains very few pumice deposits → hallmark of highly explosive eruptions

Mt Hood

Mt Hood

- The peak consists almost entirely of dacite and andesite lava flows
- Mt Hood's lower reaches are blanketed by pyroclastic material mainly ash deposits with large rock inclusions and lahars
- lahars formed when pyroclastic material mixed with melted ice and snow to form fast flowing slurries
- some of the lahars likely formed from avalanches of cold rock lubricated by water

Mt Mazama

- Mt Mazama is a complex Cascade volcano located in Oregon
- most of the mountain collapsed into a caldera following a major eruption ~7,700 years ago forming Crater Lake
- Mt Mazama originally had an elevation of ~3,700m
- Crater Lake is 592m deep and is the deepest freshwater lake in the USA
- Mt Mazama originally formed as a group of overlapping volcanic edifices such as shield volcanoes and volcanic cones

Crater Lake, Oregon

Mt Mazama

- Mt Mazama is underlain by Quaternary High Cascade basalt and mafic andesite to the W and SW
- high-volume rhyodacite flows 600,000 to 700,000 years, underlie Mazama deposits to the S, SE and NE
- by the Holocene, the Mazama volcano was composed of several clustered peaks with Mt Scott the highest, 610m above the surface of Crater Lake
- Mazama has produced 43% rhyodacite, 42% andesite, 15% dacite and <1% basaltic andesite
- all the rhyodacite has erupted in the past 30,000 years of activity

Mazama eruptive history

- The Mazama vicinity formed gradually, its earliest deposits consisting of dacite from up to 1.28Ma
- between 725,000 and 500,000 years ago, rhyodacite was erupted eventually forming a lava dome field 16 x 24Km
- the field featured up to 40 rhyodacite domes and lava flows between 470,000 and 410,000 years ago
- shield volcanoes fed Mazama's expansion with basaltic andesite lava flows that covered large expanses of mountain slopes

Mazama eruptive history

- Roughly 210,000 years ago another flank erupted dacite lava
- the complex remained inactive for ~90,000 years before resuming activity erupting andesite lava from another vent
- the Mazama complex was inactive between 100,000 and 75,000 years ago
- ~75,000 years ago, the volcano erupted effusive andesite flows 300m thick extending at least 7Km from the caldera
- many of the major cone-creating eruptions of Mazama were effusive rather than explosive

Mazama eruptive history

- Explosive eruptions ~70,000 years ago created silicic lavas that formed thick pyroclastic deposits
- from 50,000 to 40,000 years ago, Mazama vents erupted andesite lava flows and created dacite lava domes that often collapsed producing pyroclastic flows
- ~40,000 years ago, the volcano underwent a shift to solely rhyodacite lava with a silica content of 70%
- between 30,000 and 25,000 years ago, rhyodacite eruptions yielded pumiceous tephra and lava flows

Mazama eruptive history

- Between 100 and 200 years before the climatic eruption, a thick block of dark lava with a volume of 1Km^3 was produced from a rhyodacite flow
- this was preceded by explosive eruptions of rhyodacite containing pumice and ash
- the pyroclastic material was carried by winds several hundred Km into northern and eastern Washington State, Oregon and western Nevada

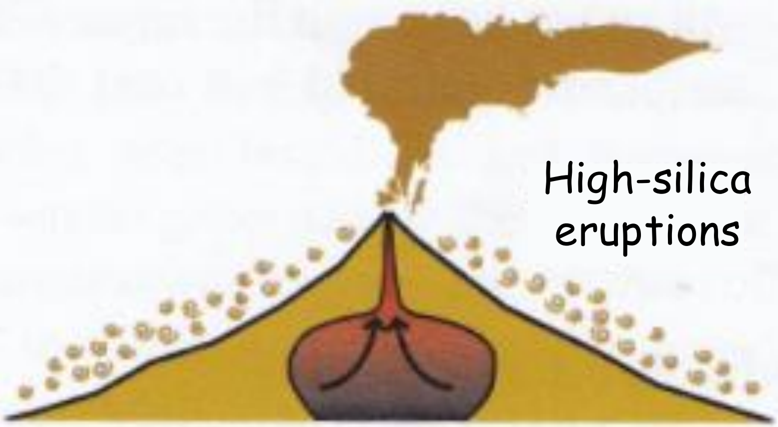
Mt Mazama climatic eruption

- Mazama eruption dated 7,627±150 years, fallout continued for 3 years although the eruption only lasted a few days
- eruptive activity leading to Mazama's collapse, proceeded in two phases
- during first phase → vent produced 48km high ash column into stratosphere, pumice deposits reached depths of 6m adjacent to Mazama, still attaining depths of 30cm 110km to NE
- after the climatic eruption, Mazama's peak was completely destroyed and replaced by a depression with depth of 1,200m
- the total eruptive volume estimated at 176km^3 of pumice, ignimbrite and tephra

Volcanic history of Mt Mazama eruption (Lillie 2015)

Mt Mazama was a composite volcano 3,000 to 3,700m in elevation. Its magma chamber was filled with heavy (low-silica) magma in its lower part and lighter (high-silica) magma above

Paul Rockwood painting



During the initial stages of its climatic eruption the upper part of the magma chamber poured out ash, pumice and rhyolite lava flows

Paul Rockwood painting

Volcanic history of Mt Mazama eruption (Lillie 2015)

Collapse caldera

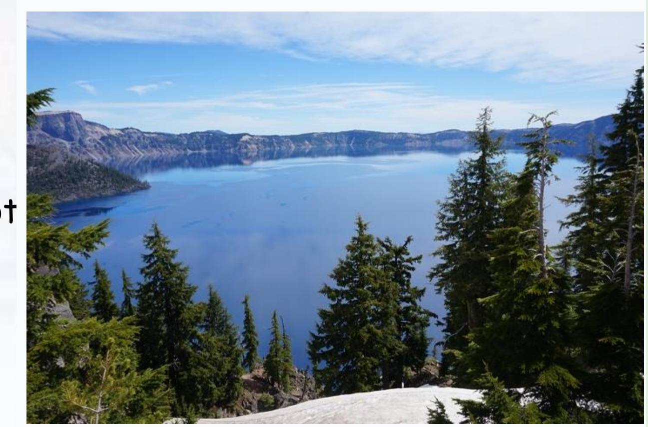
So much magma erupted that the upper part of the mountain collapsed into the void, forming the caldera

Low-silica eruptions

Later eruptions of low-silica magmas partially filled the caldera with basalt lava flows and Cinder cones, including Wizard Island

Crater lake

The coating of volcanic materials sealed the bot tom of the caldera. Over a few centuries rain and snowmelt partially filled the hole with the waters of crater lake. At 592m, Crater Lake is the deepest lake in the US and 7th in the world



Wizard Island

- Between 7,700 and 7,200 years ago, cinders and andesite lava flows formed the Wizard Island volcanic cone

Mt Mazama eruptives

Pumice layers near Crater Lake

Rhyodacite, Crater Lake

Lassen Peak

- Lassen Peak stands within a large collapse caldera that lies in turn within a much larger caldera
- the larger caldera opened about 800,000 years ago when a volcano called Maidu sank into an emptying magma chamber during an eruption
- then Tehama, a much smaller successor to Maidu sank into the second caldera
- Tehama first erupted ~450,000 years ago and continued in intervals until sinking into its caldera 350,000 years ago
- Lassen later rose in the caldera as Tehama destroyed itself

Lassen Peak, California

Lassen Peak

- Most large volcanoes grow in a series of eruptions from a central vent
- Lassen is an enormously oversized volcanic dome that rose fully grown from the Earth
- the rock is dacite and lies close to the rhyolite composition
- Lassen is one of the largest of its type and one of the few to erupt after it stopped growing
- it erupted four ash flows from its north flank about 1,000 years ago, 3 debris avalanches 350 years ago a basalt flow in 1850 and a steam eruption in 1854

Lassen Peak

- In May 1914, Lassen suddenly blew an enormous cloud of steam with volcanic ash
- in May 1915 lava finally reached the surface → after a few days viscous lavas began to overflow crater → created flow 300m long
- tongue of flow was black → consisted mostly of obsidian
- another flow oozed over NE crater wall, poured downslope into deep snowfield → formed lahar → flowed 30km down Lost Creek valley
- two days later a big explosion left Lassen with a gaping crater on NE flank

May 1915 eruptions of Lassen Peak