Okanogan Highlands Field Trip 8/6/11
Geology Summary, Dr. Ralph Dawes

Introduction

The Okanogan Highlands hold a special place in the geologic history of the Pacific Northwest. The rocks of the Highlands were among the first to be added to the edge of the ancient continent as North America rifted apart from Pangaea nearly 200 million years ago.

Growing Continent

As North America moved westward, an oceanic plate began subducting beneath it. Resided on this subducting oceanic plate were island arcs made of volcanic rocks, igneous intrusions, sediments, and coral reefs. Rocks from these island arcs, along with pieces of the deeper ocean floor, were scraped off the subducting plate and added to the edge of North America as accreted terranes. Accreted terranes near Chesaw and Beaver Creek go back to the Paleozoic Era, nearly 300 million years old. The accreted terranes in the western Okanogan Highlands are grouped together under the name Quesnellia.

The accretionary process shoved large slabs of accreted terrane on top of other slabs, along thrust faults. It also caused the sedimentary and volcanic rocks to undergo metamorphism, burying and heating the rocks enough to at least slightly recrystallize them.

After accretion, the subducting oceanic plate caused masses of molten rock to rise up and intrude the crust, forming large bodies of granitic rock, including the Mt. Bonaparte Pluton. This happened during the Cretaceous period, between 145 and 65 million years ago. One of these intrusions caused the Buckhorn Mountain precious mineral deposit to form, where fluid from a hot, molten body of granite circulated into and underwent mineralizing reactions with marble and other sedimentary rock of Quesnellia near the edge of the intrusion.

Stretching Crust

During the Eocene Epoch, 55.8-33.9 million years ago, plates in the Pacific Northwest began moving sideways along the edge of the continent, instead of pushing directly in and subducting beneath. The Earth's crust in the region stretched and broke along normal faults. Down-dropped valleys formed between the faults. Two of these Eocene rift valleys formed in the Okanogan Highlands—the Toroda Graben and the Republic Graben.

The changed tectonic plate interactions during the Eocene also caused widespread volcanism across much of the interior of the region, including the Okanogan Highlands. This volcanic outbreak is called the Challis volcanic event, after a town in Idaho where many Eocene volcanic rocks are found. The Toroda and Republic grabens filled with lava flows, volcanic ash, and sediments that rapidly washed down from the steep, active volcanoes. The volcanic activity caused hot fluids rich in dissolved chemicals to circulate in the shallow crust, leading to epithermal gold deposits near Republic and Toroda.

Lakes formed in the Republic and Toroda grabens during the time of Eocene rifting and volcanism, and many of the leaves, flowers, insects, and fish that died and were buried at the bottom of the lakes turned into fossils. The fossils represent diverse upland forests flourishing in a climate that was much more humid and warm on average than it is today, without any snow in the winter.

Also during the Eocene Epoch, along with the two grabens, the deeper crust of the Okanogan Highlands was stretched like taffy, metamorphosed, intruded by granitic magma, and forced upward, while sedimentary and volcanic rocks that were up above, in the shallow crust, slid off to the side along what are called detachment faults. The Okanogan fault, which underlies most of the Okanogan Valley, is a major detachment fault. It borders the Okanogan Metamorphic Core Complex, a zone of rocks that were stretched, intruded, metamorphosed, and uplifted from the depths of the crust.

Flood Basalts and Normal Subduction

During the Miocene Epoch, huge volumes of basaltic lava erupted across the Columbia Basin, forming the Columbia River Basalt, which overlaps parts of the Highlands to the south.

During the Miocene and Pliocene epochs, normal subduction of an oceanic plate was established once again along the nearby edge of North America, forming the modern Cascades volcanic arc.

Ice Ages

Following the Pliocene Epoch, during the Pleistocene Epoch that began about 2.6 million years ago, a cooling global climate led to the growth of a giant ice sheet in the mountains of western Canada. The Cordilleran Ice Sheet flowed across the Okanogan Highlands. Cordilleran glacial ice advanced and melted away several times during the Pleistocene Epoch, most recently reaching a maximum advance onto the northern Columbia Plateau south of the Highlands between 15,000 and 20,000 years ago and then melting away by 10,000 years ago. The giant sheet of moving ice smoothed the Highlands landscape. This contrasts with the North Cascades, where many peaks protruded above the ice and eroded into jagged shapes.

Glacial streamlining in the Highlands occurred so recently that the landscape is still largely as the glacier left it and glacial drift is strewn across much of the Highlands. Drift includes till (a mixture of coarse to fine rock debris and clay emplaced directly from the glacier), outwash (layered sand and gravel deposited by melt water flowing vigorously from the glacier), and erratics (isolated boulders from elsewhere that were moved by the glacier and dropped onto the landscape when the glacier melted).

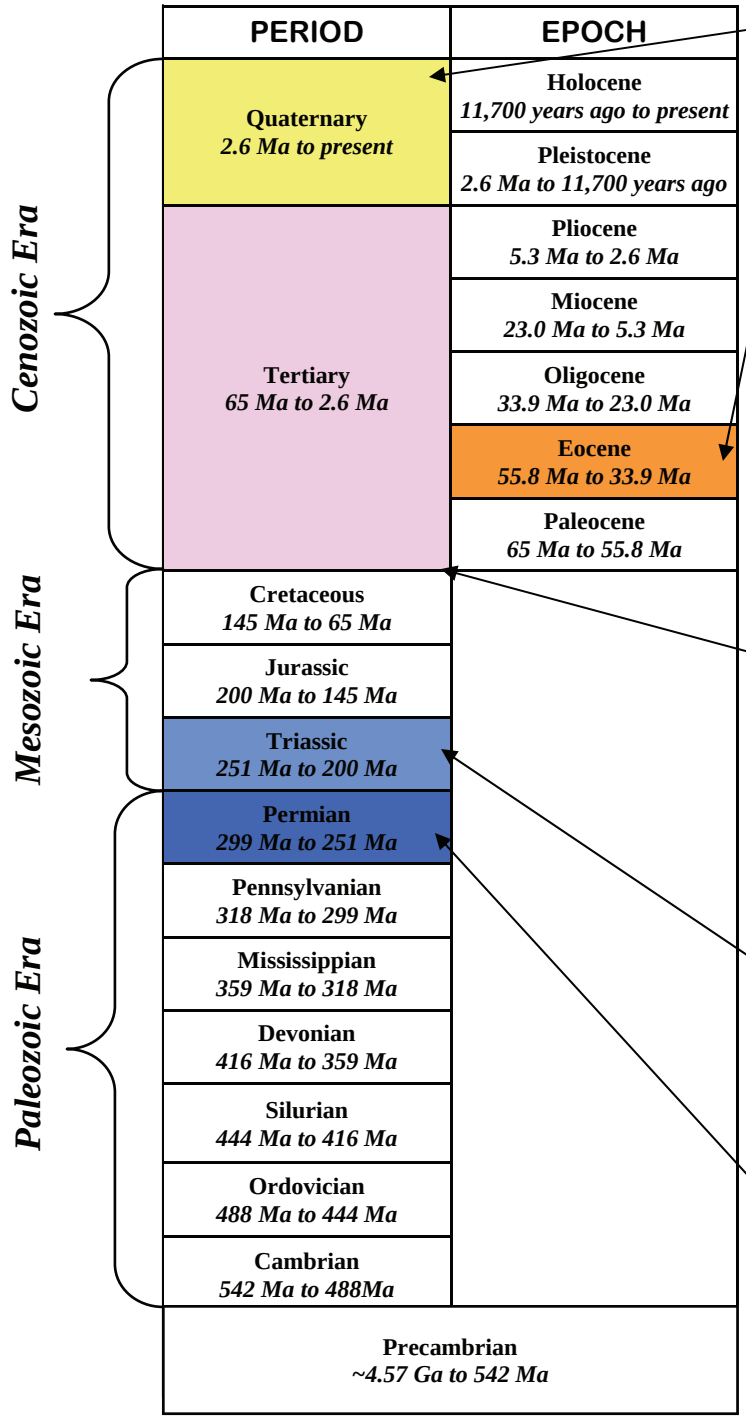
The Okanogan Highlands Today

At the end of the Pleistocene Epoch, as the last ice of the Cordilleran Ice Sheet stagnated and melted from the Highlands, and climates around the globe rapidly grew warmer, many large species of mammals, including mastodons and wooly mammoths, became extinct. Colonizing species of plants and animals moved in and occupied the deglaciated Okanogan Highlands. Humans soon followed.

Rocks and Ages
Okanogan Highlands Field Trip, August 6, 2011

Geologic Time Scale

Ma = millions of years Ga = billions of years



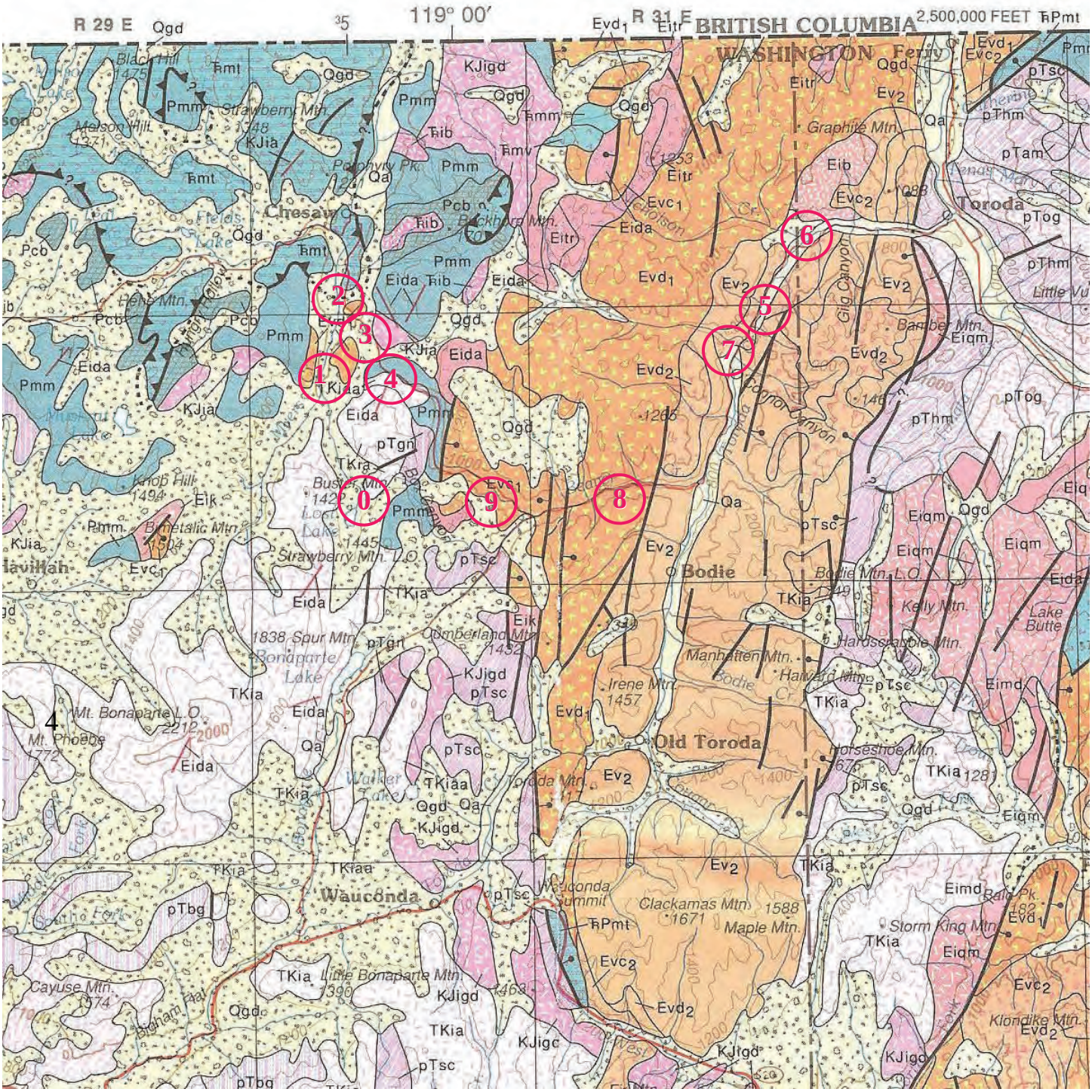
Rock Units

Rock unit names (abbreviations) as shown on map

Qgd	Till, outwash, and glacial lake deposits
Eida	Dacite and andesite intrusions (plugs and dikes)
Evc_1	Volcaniclastic rocks, chiefly tuffaceous sandstone, siltstone, and conglomerate – O'Brien Creek Formation
Evd_1	Dacite and andesite flows (gray, brown, green, or purple) – Sanpoil Volcanics
Ev_2	Epithermally altered volcanic rocks – Klondike Mountain Formation
Evd_2	Black dacite and andesite flows – Klondike Mountain Formation
Eib	Gabbro and diorite
TKiaa	Pegmatite dikes within Mt. Bonaparte pluton
TKia	Granite and granodiorite – Mt. Bonaparte pluton
pTgn	Gneiss, contains some pegmatite dikes, age not well-defined but older than Tertiary
TRmt	Metamorphosed ocean floor sedimentary and volcanic rocks – Kobau Formation, near Chesaw
TRib	Metamorphosed gabbro, diorite, and basalt
Pcb	Marble (metamorphosed limestone) – Spectacle Formation and Anarchist Group
Pmm	Metamorphosed ocean floor sedimentary rocks (argillite, phyllite, quartzite, sandstone, conglomerate) – Spectacle Formation and Anarchist Group

Geologic Map for
Okanogan Highlands Field Trip, August 6, 2011

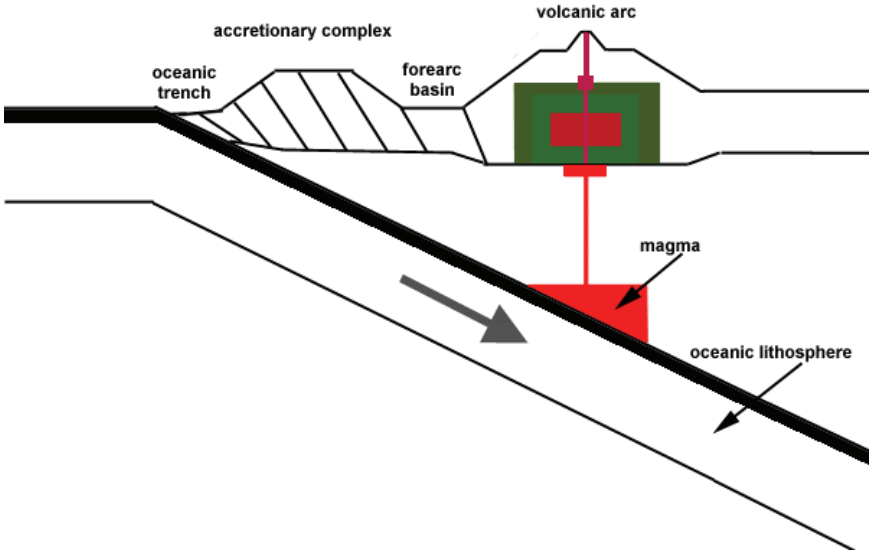
North is to the top. The map spans about 22 miles west to east (left to right).
Black lines with triangular teeth denote thrust faults, teeth are on up-thrust side.
Black lines with attached dots denote normal faults, dot on down-dropped side.
See Rocks and Ages (page 2) for explanation of selected rock units on the map.
Approximate field-trip stops denoted by circled red numbers.



Copied and enlarged from Stoffel *et al.*, 1991, Geologic Map of Washington - Northeast Quadrant, Washington Division of Geology and Earth Resources Geologic Map QM-39, original scale 1:250,000.

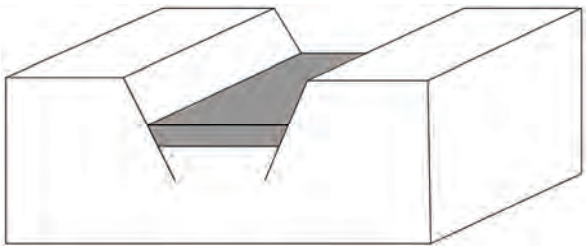
Major tectonic events that formed the Okanogan Highlands

1. Subduction of an oceanic plate beneath the edge of North America resulted in compression, thrust faulting, terrane accretion, igneous intrusion, metamorphism and volcanism.

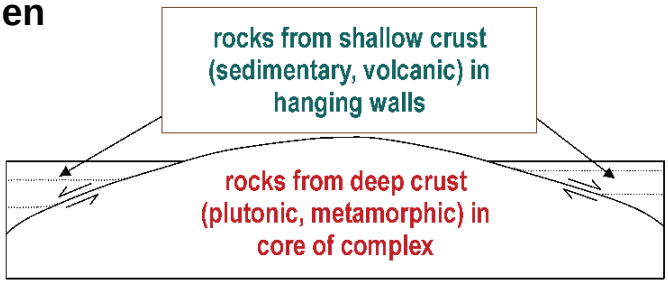


Schematic cross-section of subduction zone

2. During the Eocene Epoch when normal subduction stopped, stretching of the Earth's crust formed grabens and metamorphic core complexes.



Cut-away view of a graben



Simplified cross-section of a metamorphic core complex