**Overview of Oregon Geology**
**(summarized from Orr and Orr, 1999)**

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(1) alpine glaciation
(a) cascades, wallowas, steens
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(1) 11 kyr, arch. sites in central / eastern OR
(2) sujbdictuion zone earthquakes, coastal seismic cycle
(3) offshore landslides from slope

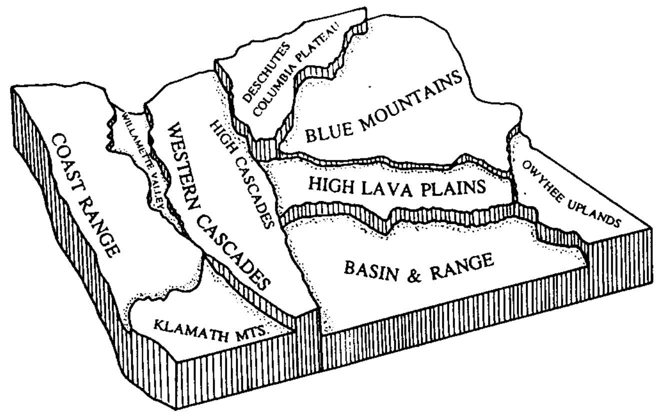
# Introduction

It is difficult to do justice to Oregon's unique and varied geologic past with the broad brush strokes of a summary. As the state experiences a variety of processes from erosion to volcanism and even glaciation, each leaves its unmistakable signature recorded in the rocks and strata.

**Plate Tectonics**

Because of Oregon's position on an active continental margin, tectonic processes have played a profound role in the state. With global or plate tectonics, land masses are riding atop great plates of the earth's crust that are constantly in motion. As they move, the plates can pull apart, collide, or slide past each other. When a plate rifts or breaks up, molten rock pours up as lava from cracks that open in the stretched crust. As the lava cools in a rift zone under the sea, a submarine mountain range or ridge is constructed along the rupture. Currently an extensive and growing system of undersea ridges exists along the floor of the world's oceans. When plates merge and collide, the heavier one dives beneath the overriding slab. Once this occurs, the veneer of sediments atop the descending slab is scraped off and accreted to the upper plate. At the same time, rocks carried down or subducted beneath the overriding plate are melted to be recycled. Some of the melted rock makes its way through the overriding plate to emerge as volcanics. The remaining magma crystalizes beneath the surface forming a foundation to the volcanic chain.

Developed on moving crustal plates, volcanic island archipelagos are typically involved in accretionary tectonics. Carried on an oceanic plate, the island chain will eventually collide with a landmass on an oncoming plate where it is attached or accreted to the edge to become part of the mainland. As part of the accretion process, plate fragments making contact with the mainland rotate to obtain a "fit". The contact point between two colliding plates is often marked by a long trough or trench. Between this trench and the island chain a shallow forearc basin may develop. Behind the archipelago, a backarc basin may subside between the volcanic chain and the mainland. Parallel to the




archipelago, both of these troughs derive volcanics from the island chain, although the backarc basin receives sediments from erosion of the adjacent mainland as well.

Each moving tectonic plate has a leading and trailing edge. Along the leading edge, where collision and subduction are taking place, there are large-scale earthquakes and widespread volcanic activity. The leading edge, with its active continental margin, contrasts sharply with the passive margin of the trailing edge. Along passive margins of continents earthquakes and volcanic activity are subdued to nonexistant. Here the main geologic processes are erosion and deposition.

Much of Oregon's early geologic history concerns plate movements and the accretion of exotic terranes. Situated on the leading edge of the North American plate, Oregon has repeatedly been the site of multiple collisions with smaller continental plates that were swept up and added to North America. It is estimated that two-thirds to three-fourths of the state is composed of rocks and sediments that originated elsewhere in the Pacific basin. Fragments of these terranes make up the geologic collage of Oregon. Throughout these collisions, volcanic events and earthquakes mark the mileposts of changing landscapes, climates, and flora and fauna.

II. Geologic Time Scale (oldest to youngest)

A. Eras

1. Paleozoic (600 - 245 m.y.)
2. Mesozoic (245 - 66 m.y.
3. Cenozoic (66 m.y. - present)

B. Periods

1. Cambrian (600-500 m.y.)
2. Ordovician (500-430 m.y.)
3. Silurian (430 - 400 m.y.)
4. Devonian (400 - 360 m.y.)
5. Mississippian (360-320 m.y.)
6. Pennsylvanian (320-280 m.y.)
7. Permian (280-245 m.y.)
8. Triassic (245-210 m.y.)
9. Jurassic (210 - 140 m.y.)
10. Cretaceous (140 m.y. - 66 m.y.)
11. Paleogene (66 m.y. - 23 m.y.)
12. Neogene (23 m.y. - 1.6 m.y.)
13. Quaternary (1.6 m.y. - present)

C. Epochs (for Cenozoic)

1. Paleocene (66 m.y. - 58 m.y.)
2. Eocene (58 m.y. - 37 m.y.)
3. Oligocene (37 m.y. - 23 m.y.)
4. Miocene (23 - 5.0 m.y.)
5. Pliocene (5-1.6 m.y.)
6. Pleistocene (1.6 m.y. - 10 k.y.)
7. Holocene (<10 k.y.)

III. Blue Mountains

A. boundaries

1. east: snake river, north by WA state line
2. west: Ochoco Mountains (low relief)
3. east: Wallowa Mtns (glaciated summits)

B. Physiography

1. Wallowas- up to 9000 ft, rugged
2. Ochoco, Aldrich, and Strawberry mtns in southern part of province
   a. strawberry mtns south of John Day

C. Geologic Overview

1. Paleogeography
   a. late Mesozoic shoreline - E. WA and ID
2. Bedrock
   a. Pz-Triassic-Jurassic terranes
      (1) metamorphics, volcanics, and sedimentary rocks
   b. fault-bounded exotic terranes
   c. Eocene-Oligocene volcanics / sedimentary rocks
   d. Miocene CRB's - cap on many sequences
   e. Wallowa glaciation - Pleistocene

D. Bedrock Geology / Stratigraphy

1. terms
   a. terrane - exotic lithotectonic assemblages that are fault bounded
      (1) distinctive rock and fossil assemblages
      (2) paleomag data suggest northward tectonic transport from tropical latitudes for some of the terranes
   b. accretionary island blocks from Mesozoic
2. Recognized terranes from southeast to northwest (Tr-Jurassic in age)
   a. Grindstone terrane - shallow ocean backarc basin
      (1) melange complex
   b. Wallowa-Olds Ferry volcanic island complex
      (1) volcanic island arc complex
      (2) Triassic limestone - Martin's Bridge LS
      (3) Tr - Seven Devils Volcanic Group
         (a) similar to Wrangellia terrane of Alaska
         (b) model implies tectonic translation along subduction zone
   c. Izee terrane - forearc-trench complex
   d. Baker terrane - deep ocean floor
      (1) ophiolite
         (a) polished - fractured
         (b) serpentinite
   e. The story
      (1) accretion from east to west in eastern Oregon, collapse of Mesozoic convergent zone complex
      (2) Mesozoic accretion ended by early K, punctuated by intrusive activity (see below)

3. Cretaceous Period

a. entire collision zone intruded by K-J granites, granodiorites
   (1) Wallowa batholith
   (2) Blue Mtn batholith
b. late Cretaceous - shallow marine environment over much of 2/3's of OR

4. Cenozoic Era
   a. Paleocene-Eocene
      (1) Cascades and Coast Range not in existence yet
      (2) general lack of Paleocene strata suggests exposure of land surface above sea level with erosion / unconformity
      (3) Eocene (55-38 my)
         (a) Clarno Fm (volcaniclastics / lava flows)
            i) tuffaceous sediments
            ii) lava flows
            iii) lahars /diamictite
            iv) lacustrine-fluvial
            v) paleosols
            vi) forearc deposits of Challis Arc?
               a) Challis Arc - e. WA and ID
      (4) Oligocene (38-25 my)
         (a) John Day Fm (volcaniclastics and lava flows)
            i) ignimbrites
            ii) volcaniclastics
            iii) fluvial-lacustrine
      (5) Miocene
         (a) CRB's (17-12 my)
            i) over 40 separate flows recorded in columbia basin
            ii) >400 cu. mi. of lavas
            iii) filled low spots of Blue Mtns region

         (b) CRB's capped by late Miocene Mascall and Rattlesnake fm's
            i) silicic volc. / ignimbrites
            ii) ashflow tuff
               a) glass shards
      (6) Pleistocene
         (a) Wallowa's and higher el. areas of Blue Mtns glaciated
            i) moraines, u-shape valleys, etc.
            ii) late 20's - last small glacier melted in Wallowa's, today small ice patches but no active glaciers

E. Structure / Tectonics
   1. Blue Mtn Province
      a. ne-sw structural orientation, differs from regional N-S mtn grain of most of Oregon
         (1) Blue Mtns anticline
   2. Lineaments
      a. Klamath-Blue Mtn lineament (SW to NE trend)
      b. Olympic-Wallowa Lineament (OWL) - SE to NW trend from Wallowas to Olympics in WA

(1) basement boundary / deep crustal structure?

3. Tertiary - fault-bounded rotation of Blue Mtns region
   a. 65 degrees clockwise rotation (dextral shear along convergent boundary)

F. Mining - Blue Mtns Region
   1. Gold
      a. BM - has produced about 75% of all Gold in state
      b. gold belt - John Day to Snake River
      c. Lode Gold vs. Placer Gold
         (1) gold-metal veins
         (2) K-J batholith margins
            (a) shattered wall rocks
            (b) gold-qtz veins
         (3) Placer gold
            (a) panning / sluicing
            (b) heavy native mineral deposit in alluvium
            (c) dry climate in eastern OR required water drained from ditches
               i) ditches now used for water resources in some areas
         (4) Gold mining - late 1800's - early 1900's

   2. Other mining
      a. silver / with gold association
      b. copper mineralization along faults in e. Oregon Tr terranes
         (1) peak years 1910-1920
      c. Mercury from cinnabar, assoc. with volcanic plugs in Clarno Fm
      d. thundereggs
         (1) agate-filled geodes
            (a) gas bubble cavity in viscous lavas
            (b) chamber filled with secondary agateor opal
         (2) best associated with John Day Fm

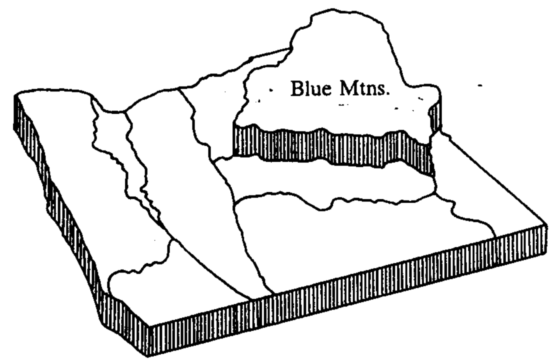
   3. Hydrothermal -limited but occurs locally

G. Other Stuff
   1. Wallowa Mtns in OR extend east across Snake to Seven Devils Mtns in ID
      a. Snake River - gorge 1000 ft deeper than Grand Canyon
         (1) stream piracy, capture of upper snake at Oxbow, aided by lake idaho?
      b. glaciated- horns, cirques, U-shape valleys, morraines
         (1) "3 separate phases of glaciation"

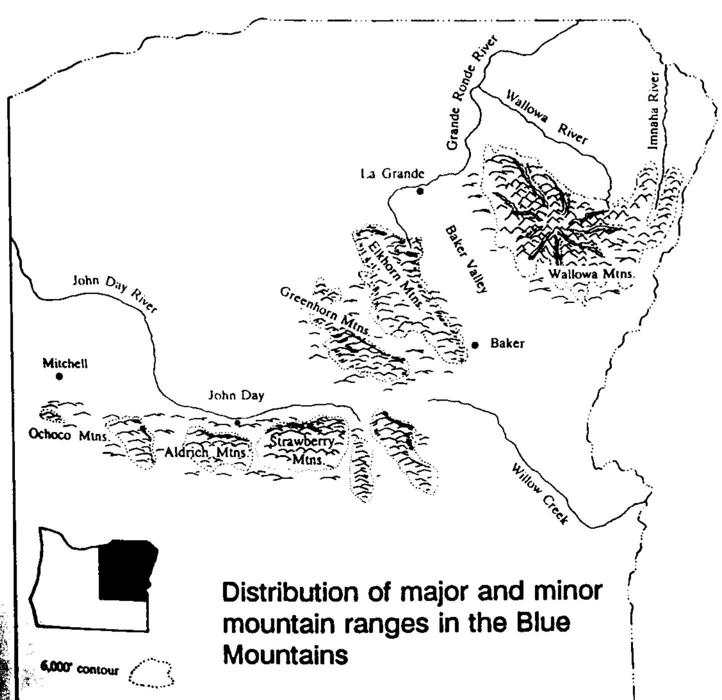
# Blue Mountains

### Physiography

The Blue Mountains physiographic province in northeast Oregon is defined on the east by the Snake River Canyon, on the south at Ontario in Malheur County, on the north by the Washington State line, and to the west by an irregular line running near Pendleton, Prineville, Burns, and back to Ontario. Topography of the Blue Mountains intensifies eastward beginning with the low hills of the Ochoco Mountains in Wheeler County and rising to glaciated summits of the Wallowa Mountains in Wallowa County. The western portion of the province is part of a wide uplifted plateau, while the eastern section contains a striking array of ice sculpted mountain peaks, deep canyons, and broad valleys.




The multiple origins of the Blue Mountains are evident in the topography. It is not a cohesive mountain range but a cluster of smaller ranges of various orientations and relief. To the northeast are the Wallowa Mountains; the Elkhorn and Greenhorn mountains are centrally located; and the Ochoco, Aldrich, and Strawberry mountains are in the southern part of the province. The highest peaks of the province are the Wallowas, an immense oval-shaped range 60 miles long and 30 miles wide. Within the Eagle Cap Wilderness, the most rugged portion of the Wallowas, nine peaks rise over 9,000 feet and seven others over 8,000 feet. A number of broad valleys as Grande Ronde Valley, Baker Valley, Virtue Flat, Sumpter Valley, Lost Valley, and Bonita Valley lie between the mountain ranges.

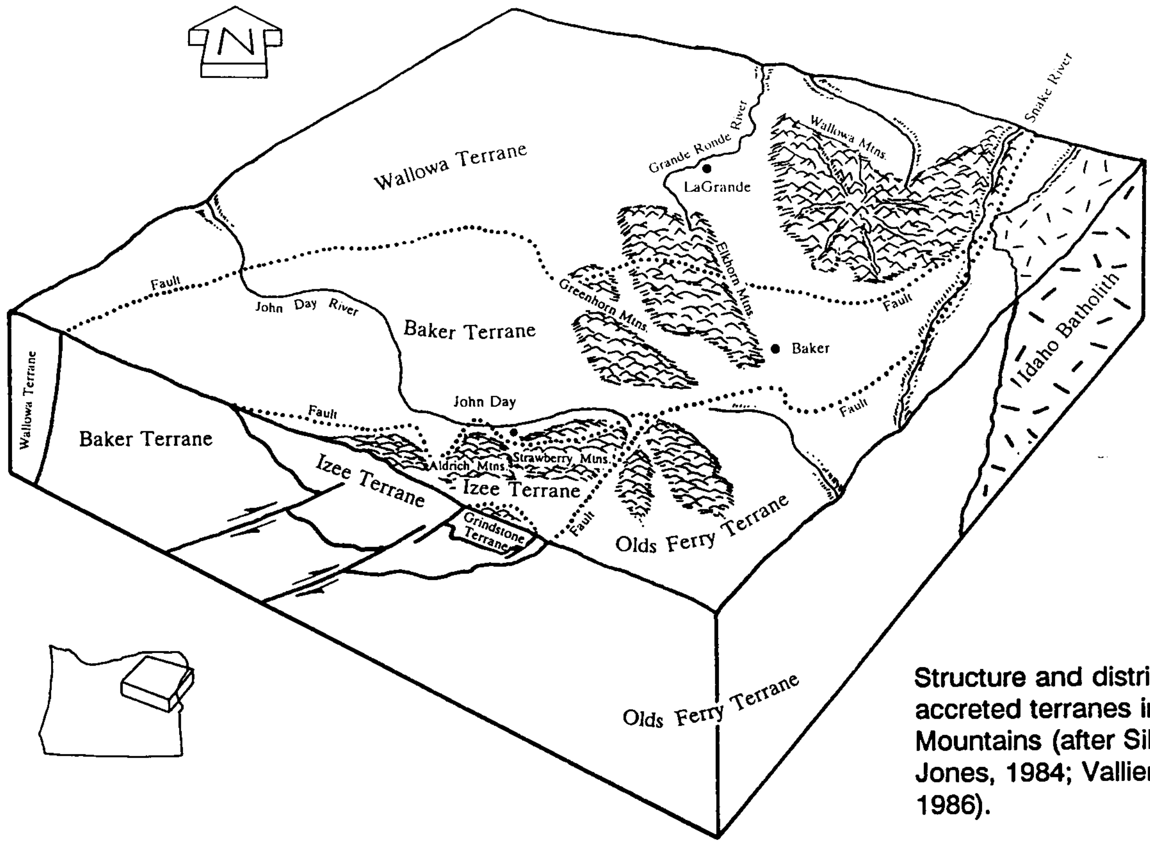



Distribution of major and minor mountain ranges in the Blue Mountains

Several extensive watersheds drain the Blue Mountains. The Grande Ronde, Imnaha, Wallowa, and John Day are the longest rivers. Of these, the John Day River, one of the most lengthy in Oregon, cuts across the province in a northwesterly direction before making a sharp turn toward the north near Clarno, entering the Columbia River close to Rufus in Sherman County. The John Day runs 280 miles from its headwaters in the Blue Mountains.

### Geologic Overview

The Blue Mountains are geologically one of the most fascinating areas in Oregon. The unique aspect of the province is its patchwork origin of separate massive prefabricated pieces of the earth's crust. Permian, Triassic, and Jurassic rocks were swept up and accreted to the late Mesozoic shoreline, which at that time lay across eastern Washington and Idaho.



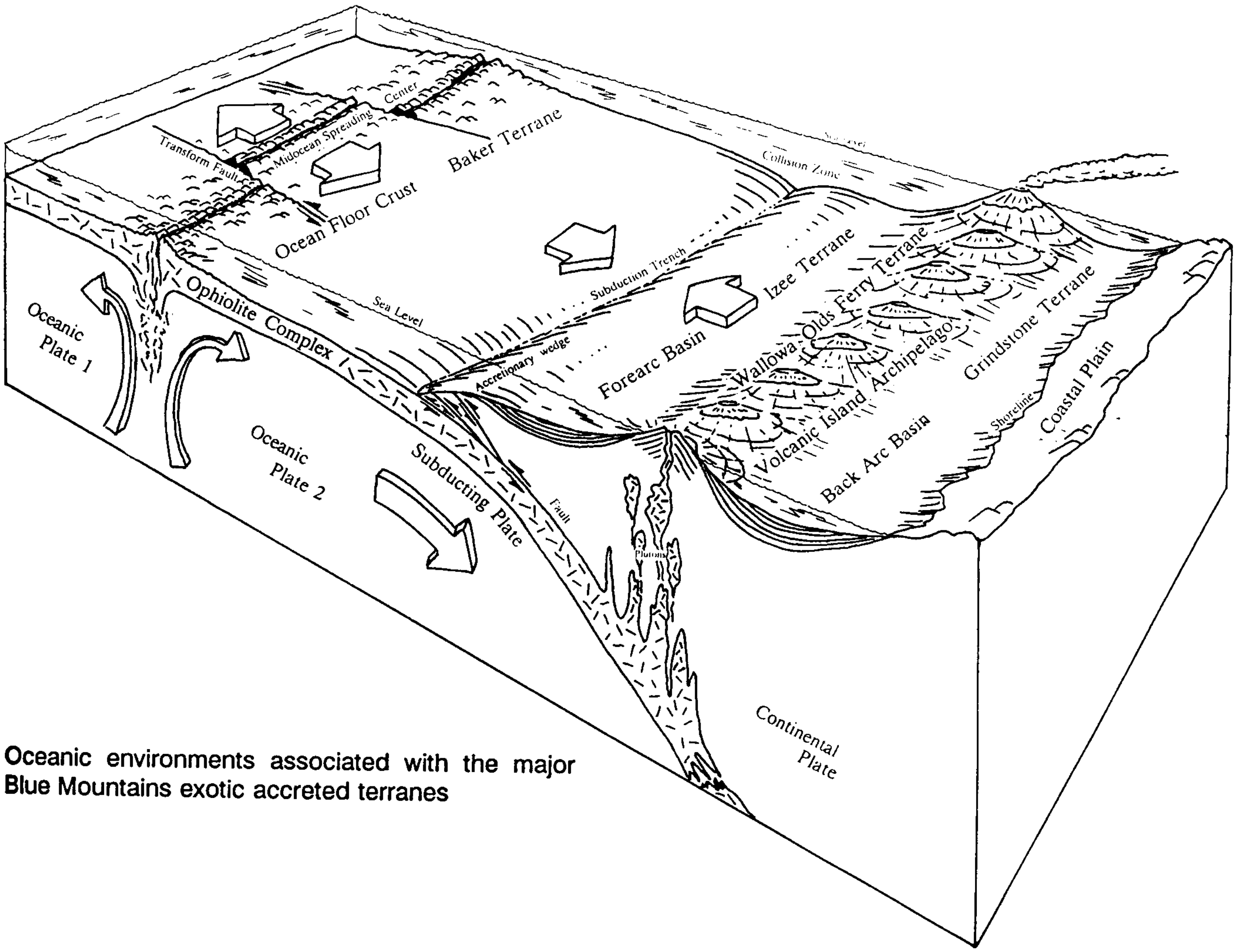

Structure and distribution of exotic accreted terranes in the Blue Mountains (after Silberling and Jones, 1984; Vallier and Brooks, 1986).

and limestones have been dated at late Triassic to middle Jurassic. Significantly, the Olds Ferry terrane includes volcanics that invaded the formations almost as rapidly as they formed, suggesting the marginal ocean island archipelago was in very close proximity to the volcanic source vents. In contrast to other Blue Mountain terranes, Olds Ferry terrane rocks show only minimal folding, which probably took place near the end of the Jurassic.

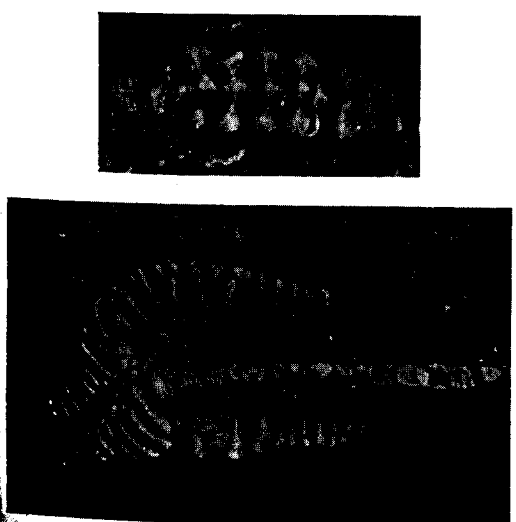
The Izee terrane, directly to the west of the Olds Ferry terrane, is separated by a fault which runs between the two. This terrane is exposed in what is called the John Day inlier, an erosional window cut through younger rocks revealing the older strata below. Composed of a number of formations, the Izee terrane represents the environment of a shallow marine forearc basin between a volcanic island archipelago and the oceanic subduction trench. Fossils are abundant in this twelve mile thick forearc basin sequence in which the limestones, mudstones, silts and sandstones, have been subdivided into distinct marine environments.

Folding of the Izee terrane began during the late Jurassic and gradually intensified due to compressional, thrusting events. With the intrusion of lower Cretaceous granites, rocks of the Izee terrane have experienced several episodes of folding and refolding. The resultant picture of folds within folds has greatly complicated the interpretation of the John Day inlier.

Imbedded in the western edge of the Izee block, but quite distinct from it, is the Grindstone terrane. The smallest of all northeastern Oregon terranes, the Grindstone is limited to a narrow area of eastern Crook County called the Berger Ranch where a mere 200 foot thickness of Devonian limestones, cherts, and argillites represent Oregon's oldest rocks. Corals and fishtooth-like microfossil remains called conodonts from these beds have been dated as lower Devonian, 380 million years old. In the same vicinity, the Mississippian Coffee Creek and Pennsylvanian Spotted Ridge formations include over 2,500 feet of limestones, mudstones, sandstones, and cherts. A shallow-water tropical invertebrate fauna of corals and brachiopods are found in the Coffee Creek Limestone, but the overlying, lower Pennsylvanian Spotted Ridge nonmarine sandstones once supported coastal plain ferns and fern-like foilage similar to those found in the late Paleozoic coals of the central and eastern United States. Nine hundred feet of fossiliferous Permian age Coyote Butte limestones, cherts, and sandstones are the uppermost formation of the Grindstone terrane, although isolated blocks of radiolarian-bearing cherts in the vicinity are as young as lower Triassic. Because of poor exposures and the difficulty of tracing the rock




Oceanic environments associated with the major Blue Mountains exotic accreted terranes



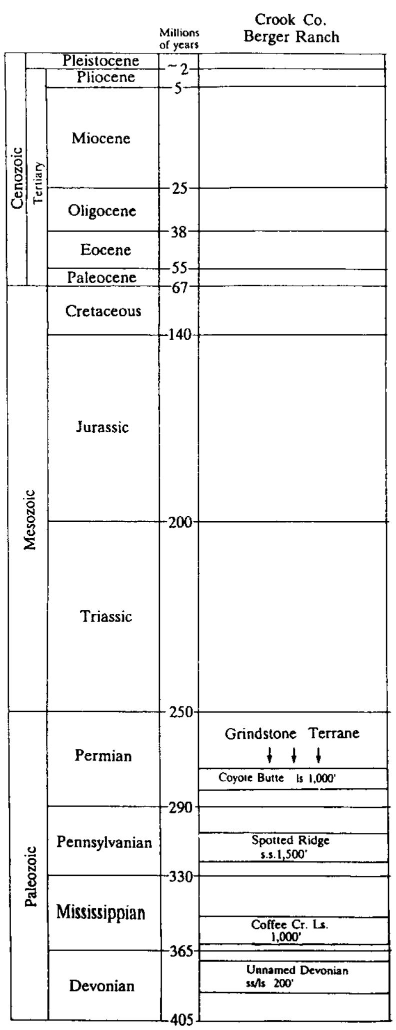
ooth-like microfossils, conodonts from the ian limestone in the central Oregon Grindstone ane, are less than 1/32 inch in length (courtesy of Savage)

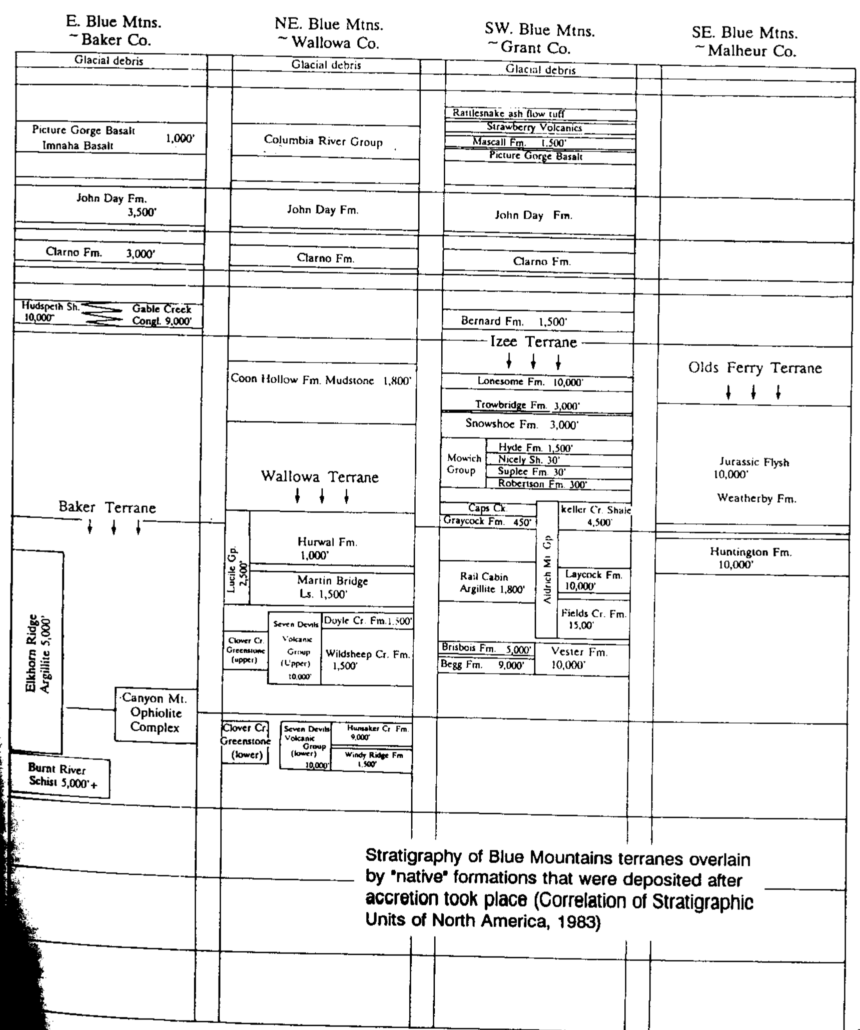
units, it is impossible at present to associate details of this suite of ancient rocks to the rest of the rocks in the Blue Mountains. Clues to the origin of the Grindstone terrane are evident in the similarity of rocks and fossils of the Coyote Butte Formation to the Bilk Creek exotic terrane north of Winnemucca, Nevada.

The diversity of formations in the Grindstone terrane make up what is called a mixture or melange of rocks. Interpreted as once forming the boundary between two converging crustal blocks, melanges are areas where different geologic environments have been telescoped or jammed together by the colliding plates. As with the Olds Ferry and Wallowa terranes, the Baker and Grindstone terranes have sometimes been combined because of similarities between the melanges in them. The position of the Grindstone on the western side of the Izee terrane seems to support this but, contrasting rocks between the two terrances would argue against it.

of a plate collision at a subduction zone. This complex mixture of rocks has been recognized as an "ophiolite", a term which refers to the abundance of the metamorphic rock serpentine. A derivative of gabbro and perioditite, serpentine is easily broken and sheared by faults when subjected to pressure. "Ophiolite" refers to the similarity of these polished faulted rock surfaces to the texture of snakeskin. The term ophiolite is comprehensive, used to describe thick sections of raised deep sea floor. An ophiolite sequence is a predictable arrangement of deep ocean crust with olivine rich peridotities at the base, followed by gabbro and basalts, and capped by pillow lavas and deep occan shale and cherts. Along with serpentine, the Canyon Mountain ophiolite complex contains argillites, cherts, gabbro, diorite, and volcanic tuffs.

As the weak rocks of the Baker terrane were shoved against the mainland, they were squeezed into what is called an accretionary wedge. In today's oceans these wedges are the sites of severe folding and fault-




Stratigraphy of Blue Mountains terranes overlain by "native" formations that were deposited after accretion took place (Correlation of Stratigraphic Units of North America, 1983)

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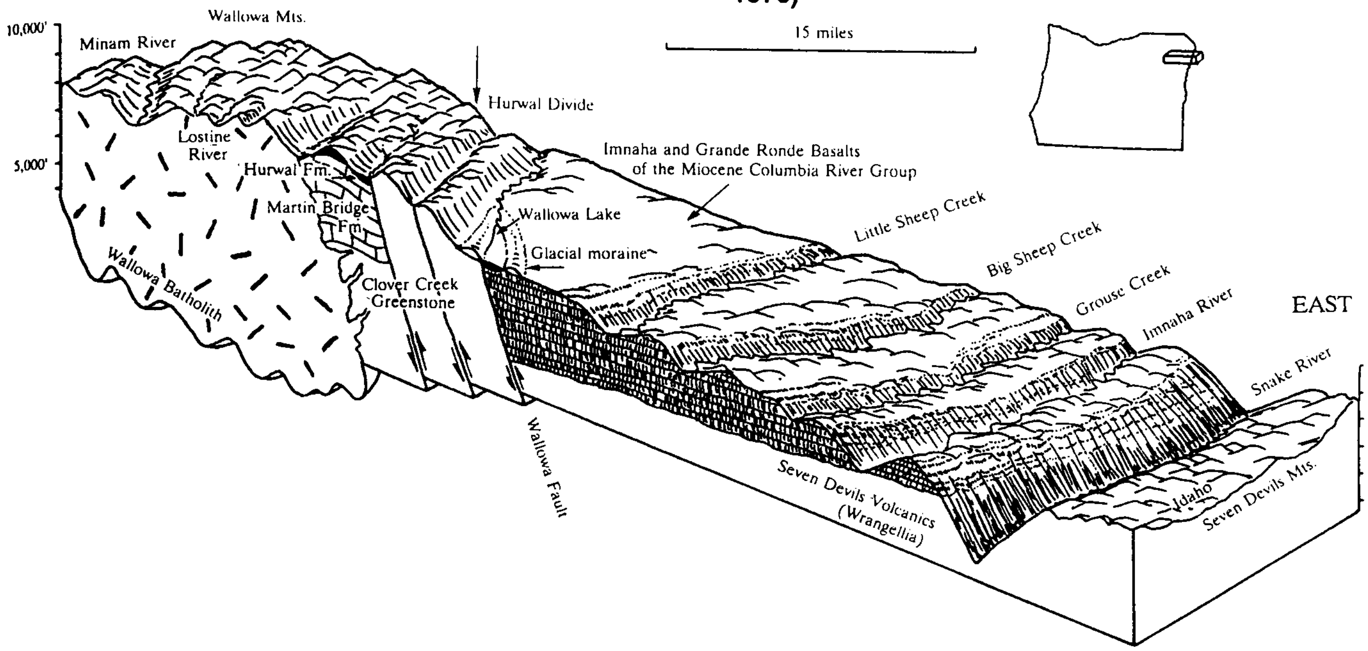
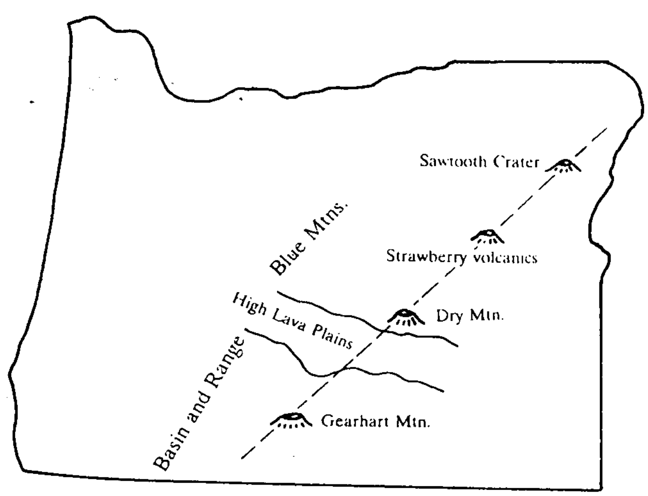
Structure and stratigraphy of the eastern flank of the Wallowa Mountains from the Minam River to the Snake River (after Smith and Allen, 1941; Walker, 1979)




The extent and volume of the Columbia River lavas tend to overshadow important Miocene eruptive provinces that were developing at the same time in the southern Blue Mountains where Sawtooth Crater, Strawberry Volcano, and Dry Mountain evolved as three separate volcanic centers. These centers in turn line up with a fourth volcano of the same age at Gearhart Mountain to the southwest in the Basin and Range province. Lavas from these four volcanic regions were predominantly a stiff, slowly flowing andesite variety that accompanies very explosive eruptions. Vents in the vicinity of Strawberry and Lookout mountains were the most numerous, extruding the thickest and most extensive lavas. Covering a total of 1,500 square miles, the Strawberry volcanics are over 1 mile thick at Ironside Mountain in Malheur County.

By late middle Miocene time, the Oregon oceanic shoreline had retreated far to the west near the present day coast. Ash from late Miocene and Pliocene volcanoes in the Cascades fell over an increasingly cooler temperate landscape where streams and rivers intensively eroded the older sediments. Volcanism at this time in the Blue Mountains was limited to small eruptions of lava along the southern and western margins of the province as local lavas mixed with showers of ash from emerging Cascade volcanoes to the west. Sediments and lava flows from these events were deposited directly atop the Columbia River basalts. Of these, the Mascall Formation of volcanic tuffs, carried and deposited by streams, preserved a variety of middle Miocene fossils. A rich mammal assemblage of horses, antelope, camels, deer, and oreodons along with predators such as dogs, bears, weasels, and racoon suggest an open woodland or savanah in association with cool, temperate broadleaf plants dominated by angiosperms.




Lineation of Miocene andesitic volcanic centers in eastern Oregon (after Robyn and Hoover, 1982)

IV. Klamath Mountains

A. Physiography

1. Location
   a. Klamaths occupy nw CA and sw OR
   b. Bear Creek valley separates Klamaths from w. Cascades to east
2. Topography
   a. steep slopes, dissected mountains
   b. peak el. to over 7000 ft
      (1) Mt Ashland = 7530 ft, highest point
   c. narrow coastal plain, steep headlands
3. Drainages
   a. Rogue River, heads in w. Cascades (near Crater Lake)
      (1) tribs: Illinois River and Applegate
      (2) meets ocean at Gold Beach

B. Geologic Overview

1. Exotic terranes: Klamaths comprised of accreted exotic terranes (oldest to east, youngest to west)
   a. rock ages: late Paleozoic through Jurassic
   b. oldest rocks in Klamaths = Triassice (but CA side has older rocks that date back to Ordovician (450 my)
2. amalgamated terrane assemblages intruded by Jurassic-Cretaceous granitic magmas
3. Final terrane assemblage rotated 100 degrees clockwise (in association with massive extension to east)
4. Klamath sediments + Idaho batholith sediments drained to forearc (Tyee etc.) during early Tertiary
5. Modern Klamaths uplifted in Miocene (associated with Coast Range uplift), subsequently dissected into present configuration
6. Pleistocene
   a. small, localized alpine glaciers
   b. uplifted terraces along coast
7. Klamaths - associated with metals and secondary mineralization
   a. ophiolite complexes (from seafloor volcanism)
   b. mineralization associated with J-K plutonism

C. Bedrock Geology

1. Nature of accreted exotic terranes
   a. terranes recognized on basis of unique rock and fossil assemblages
   b. convergent tectonic boundary off coast of Oregon during late Pz and Mz
      (1) underthrusting / accretion of fault bounded terranes
         (a) terranes young to west
         (b) thrust faults dip to east
   c. Triassic-Jurassic subduction zone complex
      (1) island arc and seafloor volcanics
      (2) similar assemblage as to that of Blue Mountains
         (a) accreted subduction-seafloor complex
         (b) similar age rocks
         (c) similar J-K intrusive / amalgamation

d. idea: Klamaths and Blue Mtns were part of linear chain
   (1) perhaps: early Teriary-Tertiary Klamaths were displaced westward with 100 degree clockwise rotation
   (2) result: separated terranes from Blue Mtn features
   (3) Klamaths and Blues may be connected in basement, beneath Cascades and Tertiary volcanic cover of central OR
e. terranes organized in NE-SW fault-bounded belts

2. East-West / Oldest to Youngest Klamath Terranes in Oregon
   a. Western Palezoic and Triassic Belt (Triassic age complexes)
      (1) accreted in middle late Jurassic
      (2) rotated to present position in Mz-Tertiary time
      (3) complex of subterranes
         (a) ocean floor - ophiolite complex
            i) high heat / pressure metamorphism
         (b) volcanic arc
      (4) tropical fossil faunas in sedimentary interbeds
   b. Western Klamath terrane ("Western Jurassic Belt") (Jurassic age complexes)
      (1) ophiolite-seafloor spreading complex (in ascending order)
         (a) basal: ultramafic rocks overlain by gabbros (upper mantle)
         (b) sheeted dike complex
         (c) pillow basalts / seafloor lavas (oceanic crust)
         (d) pelagic chert, shale, radiolarian-bearing sed. rks (deep ocean sediments)
         (e) upper ophiolite complex - pillow basalts
            i) subject to hydrothermal circulation during formation on seafloor
            ii) extensive mineralization: gold, silver, platinum, chromite, nickel
         (f) entire complex subject to low-grade metamorphism (serpentinite and greenstone, highly polished / fractured)
      (2) Smith River Subterrane
         (a) Joshephine Ophiolite
            i) 160 my. = middle Jurassic
            ii) seafloor volcanics / upper mantle
            iii) one of largest and most complete ophiolites in world
            iv) extensive massive sulfide deposits and mineralization (comparable to Cypress)
            v) hydrothermal deposits: gold, silver, copper, zinc, cobalt
         (b) Josephine Ophiolite overlain by ss and slatey shale = Galice Fm
            i) Galice = offshore sediments, turbidites
            ii) tectonically scraped off subducting slab

   c. Southwest Oregon Terranes ("Franciscan and Dothan")
      (1) Snow Camp terrane
         (a) Coast Range ophiolite
      (2) Pickett Peak terrane
      (3) Yolla Bolly terrane
      (4) Gold Beach terrane

            - (a) melange
        - (5) Sixes River terrane

3. Mesozoic Plutons (post-amalgamation / intrusion)
    - a. Jurassic-Cretaceous boundary
        - (1) folding / faulting of Klamaths with concomitant intrusion
            - (a) Jurassic Intrusive activity
            - (b) Sierra Nevada activity = mid Cretaceous
        - (2) plutons / intrusives
            - (a) <1 sq mi to > 100 sq mi diameter
        - (3) four plutonic belts (nw strike), organized from SE (oldest) to NW (youngest) (middle Jurassic to Cretaceous)
        - (4) plutons show clockwise rotation

4. Cretaceous sedimentary strata
    - a. Cretaceous transgression covered much of Oregon
    - b. Cretaceous marine rocks preserved in isolated basins of Klamaths and Mitchell area of central Oregon
    - c. Cretaceous strata not widespread in Oregon

5. Tertiary
    - a. limited Tertiary strata found in Klamaths, suggests that it was persistant highland / provenance during this time
    - b. Coastal sed. rocks
        - (1) Lookinglass Fm (turbidites / offshore) ... more to south
        - (2) Tyee Fm (turbidites / offshore)... more to north
            - (a) source: Klamaths / Idaho Batholith

6. Pleistocene
    - a. localized glaciation in Klamaths, not extensive like Wallowas
    - b. marine terraces well-developed in coastal areas

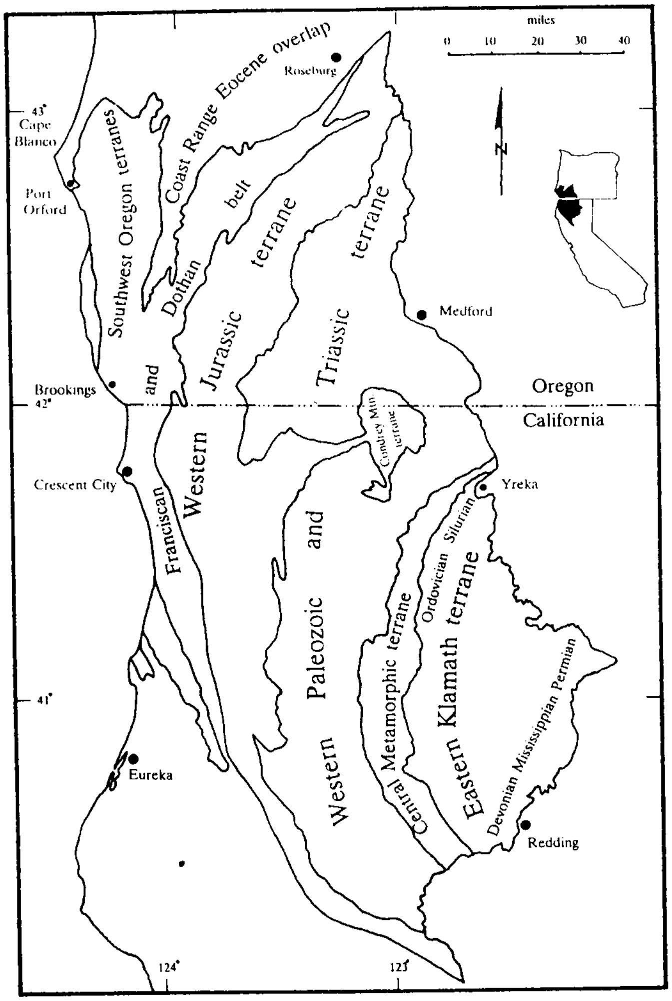
D. Structure
- 1. Klamath-blue mtn lineament (SW to NE)
    - a. gravity trends, crustal thickening
        - (1) interpretation: pre-Tertiary continental crustal margin at depth?

E. Mining and Mineral Industry
- 1. General
    - a. Klamaths are noted mineral district in Oregon
        - (1) gold, silver, copper, nickel, chromite
    - b. primary mineralization associated with ophiolites: seafloor spreading / hydrothermal mineralization
    - c. secondary mineralization associated with plutonic activity / magmatic fluids
        - (1) pluton margins
        - (2) less abundant mineralization compared to Ophiolites
    - d. Josephine ophiolite complex - "Cypress type" massive sulfide deposits (Fe-Cu sulfide deposits)
        - (1) spreading center / faulting (forms framework for circulation)

(2) hydrothermal sulfides, mineral rich seawater infiltration, volcanic fluids

2. Gold (late 1800's early 1900's)
    a. placer deposits
        (1) illinois river
        (2) ditches, flumes, hydraulic mining
    b. underground lode mining
        (1) Jackson and Josephine counties, highest gold produces in state
3. Nickel
    a. forms as residual deposit associated with deep weathering of ophiolite complexes
    b. not as widespread as the gold and sulfide deposits
4. Chromite
    a. chrome ore, mined in 1900's up to 60's

F. Other Geologic oddities
1. Oregon Caves Natn'l Monument
    a. limestone cave system, stalagmites, etc.
    b. metamorphosed triassic limestone, forms part of older Pz-Tr terranes
2. Table Rocks (north of Medform)
    a. Pleistocene lava flows form Mesa in Rogue watershed
    b. lava flow cap rocks reflect inverted topography, similar to salem hills
3. Coastal Features
    a. rocky headlands, offshore stacks, terraces




Distribution of terranes in southwest Oregon and northern California (after Irwin, 1985)

westward by a well-developed riverine system. Draining the Idaho batholith and Klamaths, the rivers deposited the sediments in the forearc basin along the margin of the mountains. Uplift in the Miocene resulted in extensive erosion of the region. The Pleistocene brought only small glaciers to these mountains, while continuing uplift along with rising and falling sea level produced coastal terraces.

In their long history as part of the sea floor as well as during the emplacement of granitic intrusions, Klamath terrane rocks were enriched with a diversity of economic minerals including gold, copper, nickel, and chromite.

**Geology**

Because the Klamath Mountains are made up of composite belts of rocks formerly part of an ocean environment, the concept of displaced accreted terranes is fundamental to understanding geology here. Terranes are separate groups of rocks formed in an open oceani or coastal environment, each group with its owr layered sequence of distinctive rocks and fossils b which it is recognized. These slabs of oceanic rock wer rafted toward North America from the west where the were bent, folded, and broken upon collision. As the were accreted to North America, the succeedin terranes were thrust beneath each other like shingle on a roof with the oldest to the east and the younges to the west. All of the terranes are separated from eac other by fault zones.

During the Paleozoic and Mesozoic more tha 250 million years ago, the Klamaths began as an ocea chain or island archipelago that extended in a north west line down from British Columbia and Washingto into Idaho and California. Assembled very close to th North American West Coast, terranes were accreted t North America in the middle and later Jurassic. I middle Jurassic time, a subduction zone between tw tectonic plates generated a series of volcanoes ato these older, accreted terranes. As the volcanic ar separated from the landmass and migrated westwar away from North America, a backarc basin develope between the older volcanic chain and the eruptiv centers situated above the subduction zone. During th late Jurassic, sills and dikes were intruded into th basin. In the final stage, the arc, basin, and remnants c the older volcanic chain migrated toward North Amer ca where they were accreted and imbricated in thru sheets over each other.

From south to north the provinces tod include the Sierra Nevada in California, the Klamat and Blue Mountains in Oregon, Idaho, and Washin ton, and the Cache Creek area in central Britis Columbia. Terrane rocks of the Klamath province a linked to those of the Sierras of California and t Blue Mountains in northeast Oregon by striking similar fossils and rock layers. Even though the rel tionship between these regions is still not well unde stood, all three form a discontinuous belt of Paleozo and Mesozoic rocks. This 1,000 mile long ancie mountain chain bends in a northeast direction acro the state beneath the Cascades from the Klamaths the Blue Mountains before turning back toward t north in the Blue Mountains to continue into nort western Washington. This kink is thought to ha developed during early Tertiary with rotation a westward displacement of the Klamath and Bl Mountains provinces.

After initial contact of the exotic blocks to t North American continent, the Klamath block w rotated into a final position. It is particularly import to fix the time the terrane was accreted to the m

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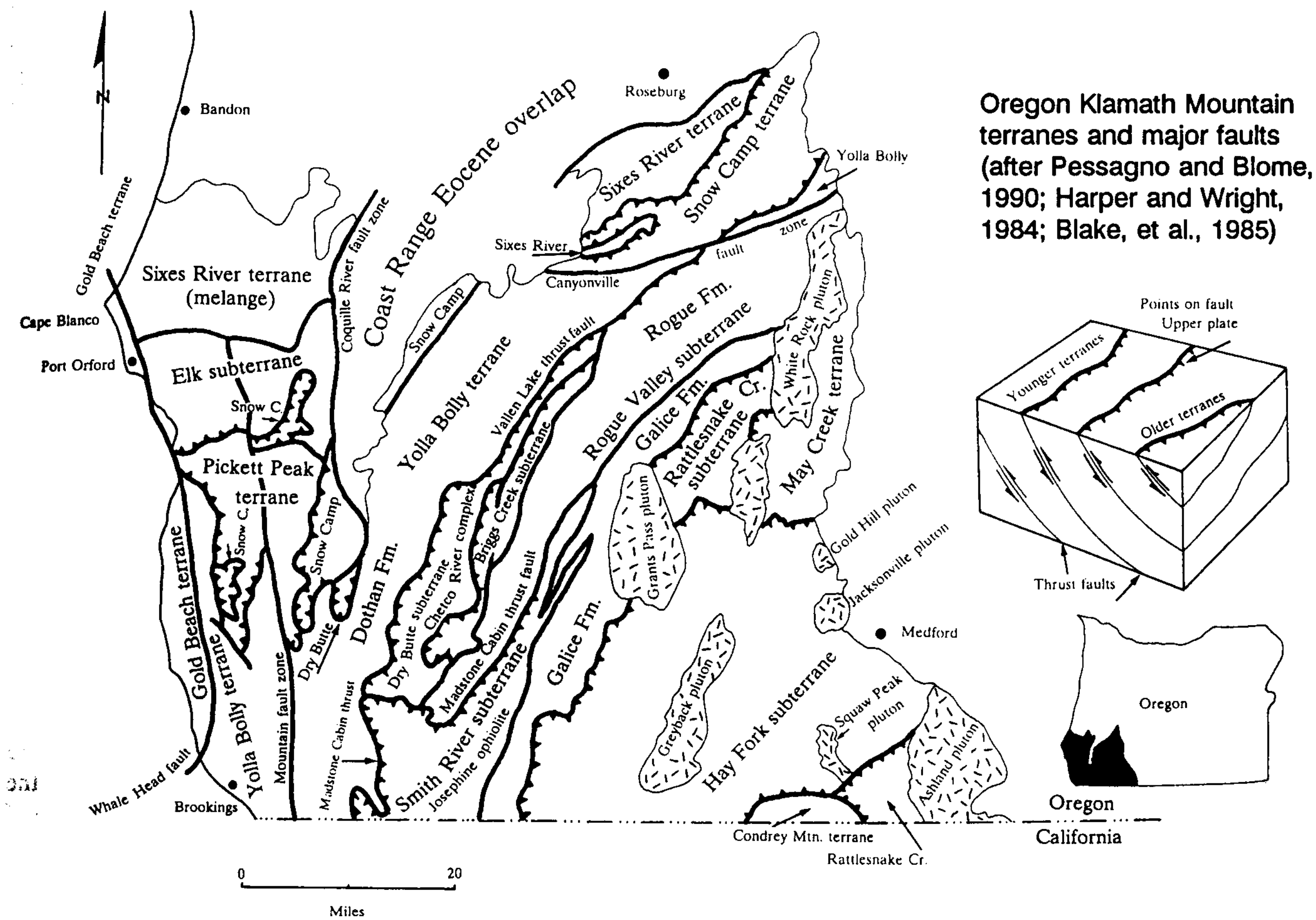


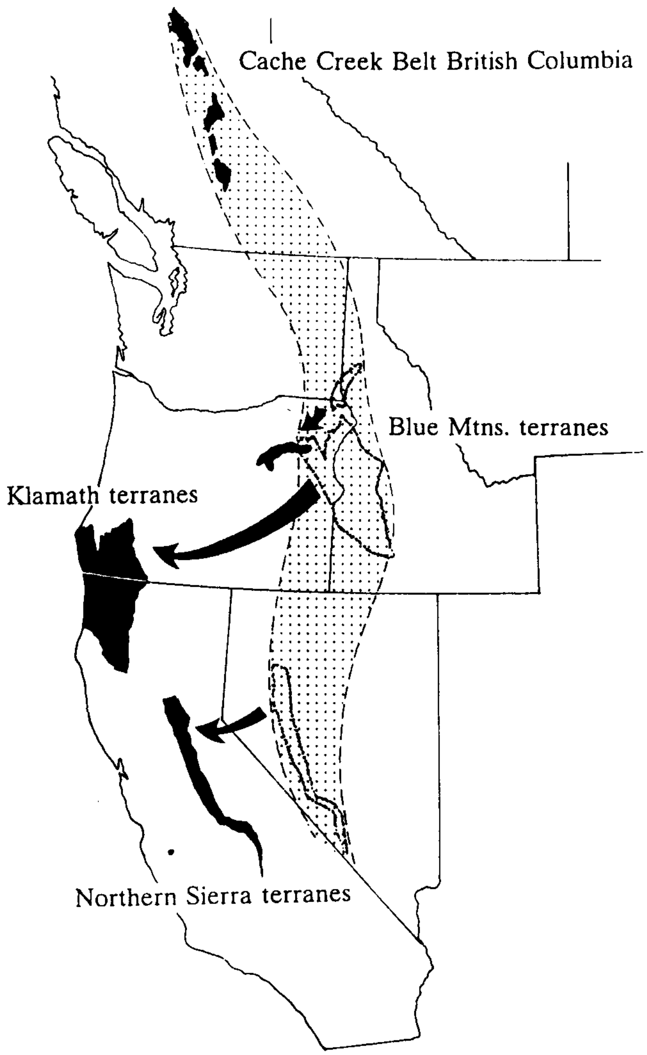

Oregon Klamath Mountain terranes and major faults (after Pessagno and Blome, 1990; Harper and Wright, 1984; Blake, et al., 1985)

continent and when the same terrane was rotated into its present orientation. The timing determines whether the plate rotation occurred when the terrane was still an independent part of an oceanic plate or whether it was moved after it had become welded to the main continent. Present evidence suggests that all Klamath terranes had completed their swinging clockwise motion by the early Cretaceous. This established the early Cretaceous as the time by which the multiple, composite Klamath terranes became joined to the stable North American continent.

### Individual Terranes

After delineating and mapping these terranes, the process of grouping the many isolated pieces together is the next step in reconstructing their origins and history. In the Oregon Klamath province there are seven recognized terranes which are further subdivided into multiple subterranes. Two terranes in the Klamaths of northern California, the Eastern Klamath terrane and the Central Metamorphic terrane, do not extend into Oregon. From east to west, or from the oldest to youngest, Oregon Klamath terranes include the Western Paleozoic and Triassic belt, the Western Klamath terrane, also known as the Western Jurassic belt, the Snow Camp, Pickett Peak, Yolla Bolly, Gold Beach, and Sixes River terranes. The overall grain of the Klamath terranes curves northeast by southwest with the convex side to the northwest.

Among the Klamath Mountain terranes, the Western Paleozoic and Triassic terrane, which is significantly older than subterranes of the Western Klamath belt, was accreted in middle late Jurassic then rotated to its current northwest facing configuration in Mesozoic and Tertiary time. Also known as the Applegate, this terrane has been subdivided into three subterranes. The Rattlesnake Creek subterrane originated as an ocean crust or "ophiolite". The Hayfork subterrane, which represents a volcanic island archipelago, is laminated between the Rattlesnake and May Creek subterranes. The May Creek, which is also ophiolitic, has been heavily distorted and altered by heat and pressure to high grade metamorphic rocks. The Western Paleozoic and Triassic terrane has tropical fossil faunas similar to those found in the Cache Creek terrane in British Columbia and the Baker terrane in the Blue Mountains.




Model for pre-rotation configuration of West Coast tectonic terranes (after Miller, 1987)

Commonly occurring in Klamath terrane rocks, ophiolites are layered rock sequences up to 3 miles in thickness that develop in the deep ocean floors between two spreading tectonic plates. At the bottom of an ophiolitic series, dark-colored ultramafic rocks of peridotite are overlain by gabbros that form the base of the ocean crust. These in turn grade upward into a complex of sheeted dikes without an apparent host rock. Layered over the intruded dikes are pillow basalts which are lavas extruded underwater onto the sea floor. These pillow-shaped blobs of lava are capped by deep sea cherts and pelagic clays with fossils of radiolaria and foraminifera typically found today in the open ocean under thousands of feet of water. Ophiolites are significant as they offer a chance to examine first hand ocean crust as well as upper mantle rocks from mo than three miles below the seafloor.

The upper pillow basalt layers of an ophioli sequence are highly porous, and during the oce spreading process the convection of seawater through the ophiolitic rocks and out near the rid crest contributes to the precipitation of massi sulfide deposits. In this way the upper portion of t ophiolite is richly mineralized with copper, lead, a zinc with smaller amounts of gold, silver and platinu Nickel and chromium ores are primarily associat with the deep periodite layer of the ophiolite sequen Basalts, ultramafics, and gabbros in the Klama ophiolites have been altered to form the low-gra metamorphic rocks, greenstone and serpentine. T word, "ophiolite", meaning snake, refers to the ro serpentine which is completely fractured and broken by faults giving it a smooth surface.

The Western Paleozoic and Triassic belt is to t southeast of the Western Klamath terrane. These t terranes are separated by a fault marking the surfa along which the Western Klamath terrane was push beneath the Western Paleozoic and Triassic terra Studies of the magnetic alignments of mineral cryst in the rocks of the Western Klamath terrane sugg that it has been rotated less than 100 degrees in clockwise direction since its origin in the late Juras to arrive at its present orientation of northeast southwest. Presently the Klamath Mountains are approximate alignment with the Blue Mountains. Bo provinces display extension and clockwise rotati suggesting that the Klamaths may have connected wi the Blue Mountains beneath the Cascades.

The Western Klamath terrane has be subdivided into six subterranes. From east to west, th are the Condrey Mountain subterrane, the Smith Ri subterrane, the Rogue Valley subterrane, the Bri Creek subterrane, and the Dry Butte and Elk subter nes. Two of these, the Condrey Mountain and Sm River subterranes, have been the focus of considera attention because of their geologic environment a economic minerals.

Southwest of Ashland, the Condrey Mount subterrane, 90% of which projects across the bor into California, is an inverted drop-shaped expos formed during the late Jurassic between 146 to 1 million years ago. A hot oceanic slab and cooler oce sediments, brought together by thrusting plates, w altered to the metamorphic rock, schist. Within body of the Condrey Mountain, the schists range fr the low-grade greenschist on the outside, to the mid layer of graphite-rich blackschist, and the core of hi grade blueschist, all of which have been folded w tight crenulations. Intensive erosion of the dome to

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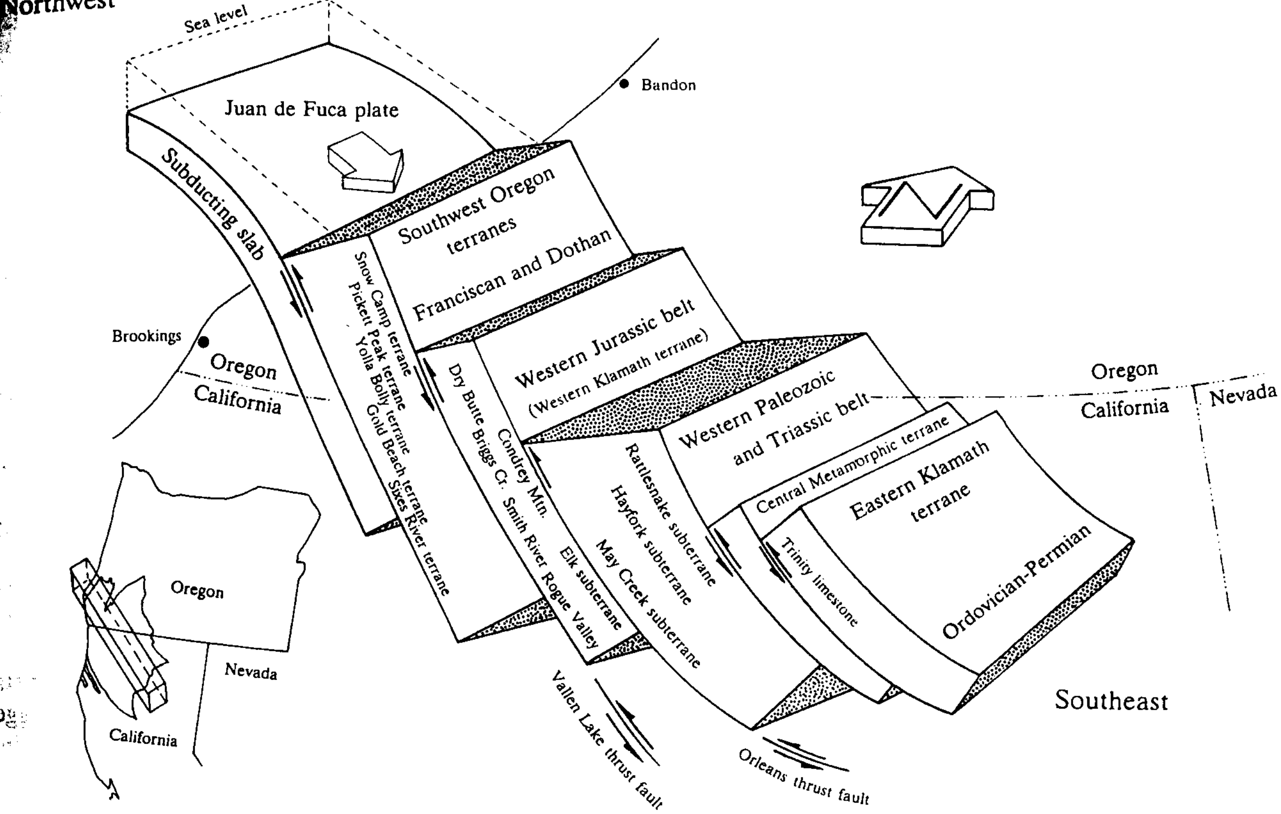
Major tectonic terranes of the Oregon and California Klamath Mountains

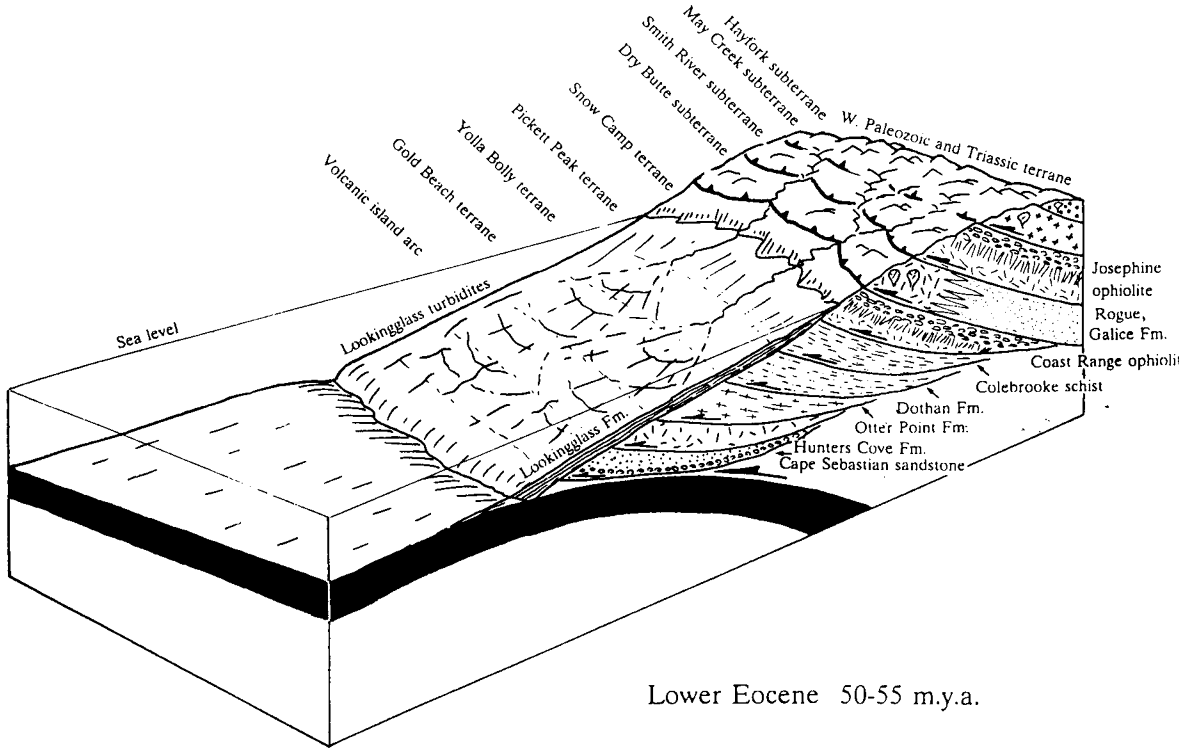



creates a deep window into the blueschists. The advanced metamorphic state of the Condrey Mountain subterrane makes it difficult to correlate with rocks of the Klamaths, although it may be derived from shales of the Galice Formation exposed further west.

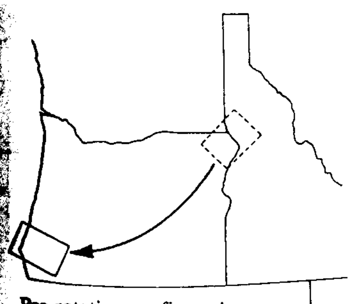
An intriguing aspect of the Condrey Mountain exposure is that it displays a distinct doming believed to have developed in the Neogene. It was probably during the Miocene epoch as the Juan de Fuca plate was actively being subducted beneath the larger North American plate that lateral pressure between the two converging plates caused the bowing or doming, compressing the rocks by as much as 5% and raising them over four miles in elevation. Compression for this doming may have come from a slight change in the subduction direction of the Juan de Fuca plate where the forearc basin, containing the Condrey Mountain dome out in front of the Cascade volcanic arc, was pushed upward. Although the broad uplift of the Klamath Mountains in the later Tertiary was recognized early, the dome configuration was only identified in 1982.

With its mineral wealth, the Smith River is, perhaps, the most important subterrane within the Western Klamath block. Made up of two parts, this subterrane has an underlying, deep ocean crust suite of rocks known as the Josephine ophiolite and a three mile thick overlying sandstone and slatey shale called the Galice Formation. The Josephine ophiolite was originally a slab of ocean floor, approximately 163 million years ago, lying in a spreading backarc basin between the mainland and an active volcanic archipelago to the west. Microfossils from the ophiolite sediments suggest that the terrane developed at a tropical latitude lying well to the south of the present Klamath Mountains. In addition to thick sequences of volcanic flows and ash, the Galice contains turbidites which grade into shale at the top. Structural evidence suggests that softer Galice rocks were literally scraped off the ocean floor and piled against the proto-Klamaths as two crustal slabs collided and slid past each other.

One of the largest and most complete ophiolite sequences in the world, the Josephine ophiolite is an assemblage of rocks representing fragments from an ancient ocean crust and upper mantle that are rich in magnesium, iron, and serpentine. The Josephine ophiolite is famous for its massive sulfide deposits which are similar to those on the island of Cyprus in the eastern Mediterranean. Within the Josephine

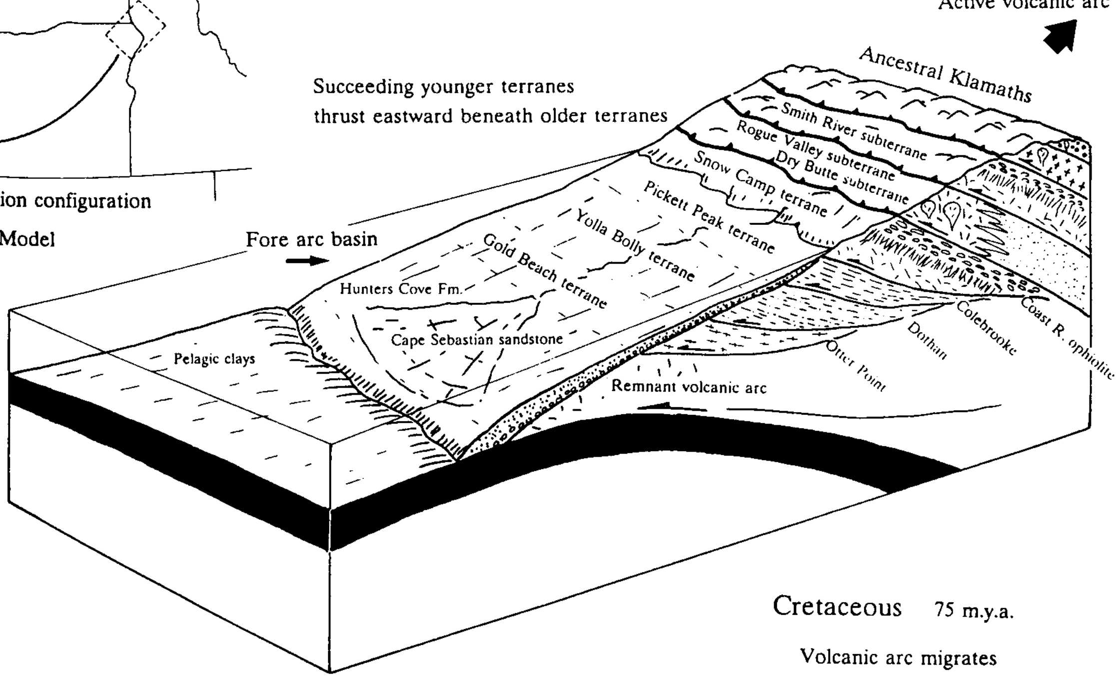



Lower Eocene 50-55 m.y.a.



**Pre** rotation configuration

Model




Cretaceous 75 m.y.a.

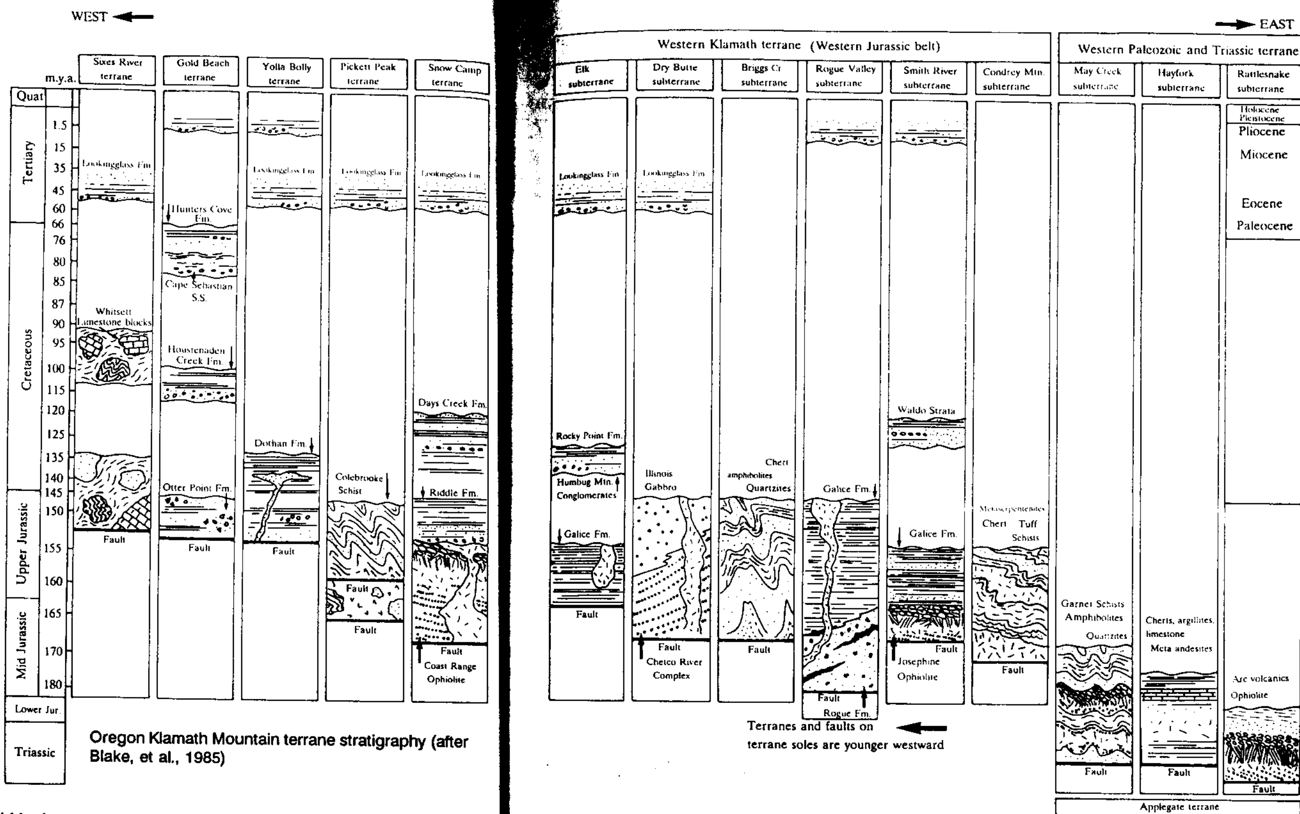
Volcanic arc migrates
back to the east

›etter exposures of a
it is in the Turner-
ict on the southern
ıydrothermal depos-
copper, zinc, and
been interpreted as
eading ridge where
rom submarine hot
:s up to 650 degrees

tant mineral-bearing
the Jurassic Preston
Klamaths. Best ex-
ıe Preston Peak has
·ition over the Jose-
ginally the Preston
o the east and was
›ped volcanic archi-
e Josephine interarc

ey subterrane forms
ust northwest of the
The Rogue Valley
ows and ash of the
›ered by shales and
ırmation. The volc-
:red to greenstone
gold and other base
:ek subterrane, west
. consists of folded
aring amphibolites.
:rrane includes the
‹ of plutonic rocks,
linois River gabbro,
ıave been the roots

st of the main expo-
:n Klamath terrane
:errane is included
Klamath because it
able sandy turbidit-
ıe volcanic flows of
Atop the Galice and within the
: marine gravels of the lower
Mountain Conglomerate and
·n are found.
›unger terranes, the Snow Camp,
lly, Gold Beach, and Sixes River
ıe overlying Western Klamath
'aults of early Cretaceous age.
ne is a disjunct group of rocks
ange ophiolite which has been
Cretaceous Riddle and fossilifer-




Oregon Klamath Mountain terrane stratigraphy (after Blake, et al., 1985)

ous marine Days Creek formations of conglomerates, silts, and sands. The highly folded Colebrooke Schist of late Jurassic age makes up the Pickett Peak terrane. Metamorphosed in early Cretaceous, the Colebrooke is a blueschist that was originally a mixture of tuffs, cherts, and pillow lavas in a deep sea, oceanic setting. The Yolla Bolly terrane of upper Jurassic-lower Cretaceous age has been divided into east and west sections, both of which include the distinctive Dothan Formation. Deriving its sand from continental and volcanic arc sources, the Dothan is composed of oceanic continental slope rocks of turbidite sands and muds with some deep water cherts. The Gold Beach terrane is a "melange" or mixture of upper Jurassic Otter Point Formation silts and sands mixed with lavas, breccias, chert, and even schists. Overlying that terrane, the upper Cretaceous Cape Sebastian sandstone and Hunters Cove siltstone reflect storm wave conditions with turbidite sands and shales. Bounded by a fault, the cohesive block of the Gold Beach terrane may have been moved north out of California in Tertiary time.

The Sixes terrane is exposed just north of Cape Blanco and in a small sheet south of Roseburg. It consists of Jurassic and Cretaceous mudstones, sandstones, and conglomerates chopped up by faults and studded with huge separate blocks of blueschist and the distinctive high-grade metamorphic rock eclogite. Near Roseburg, blocks of the middle Cretaceous Whitsett limestones with corals and deep water shales along

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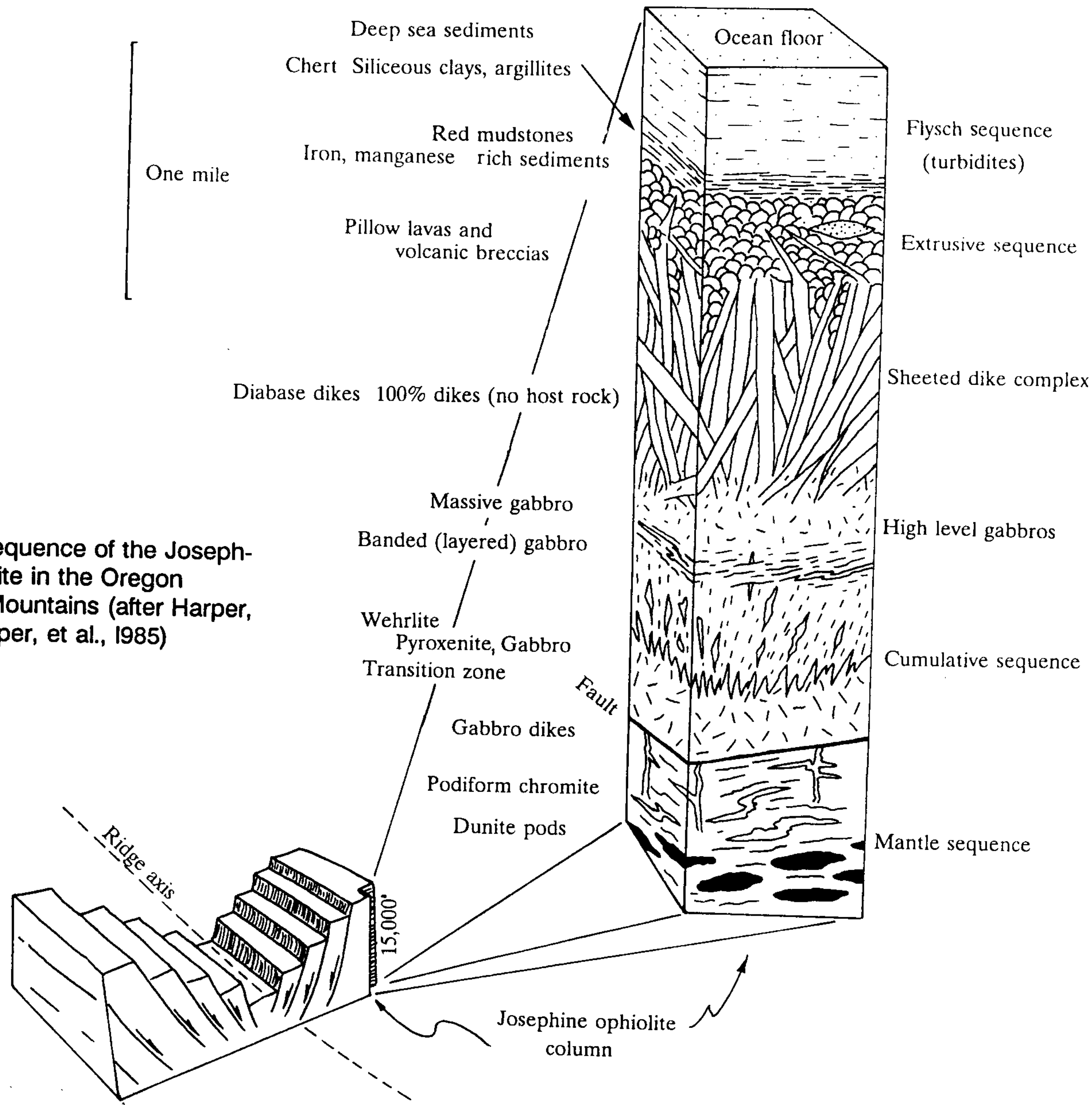
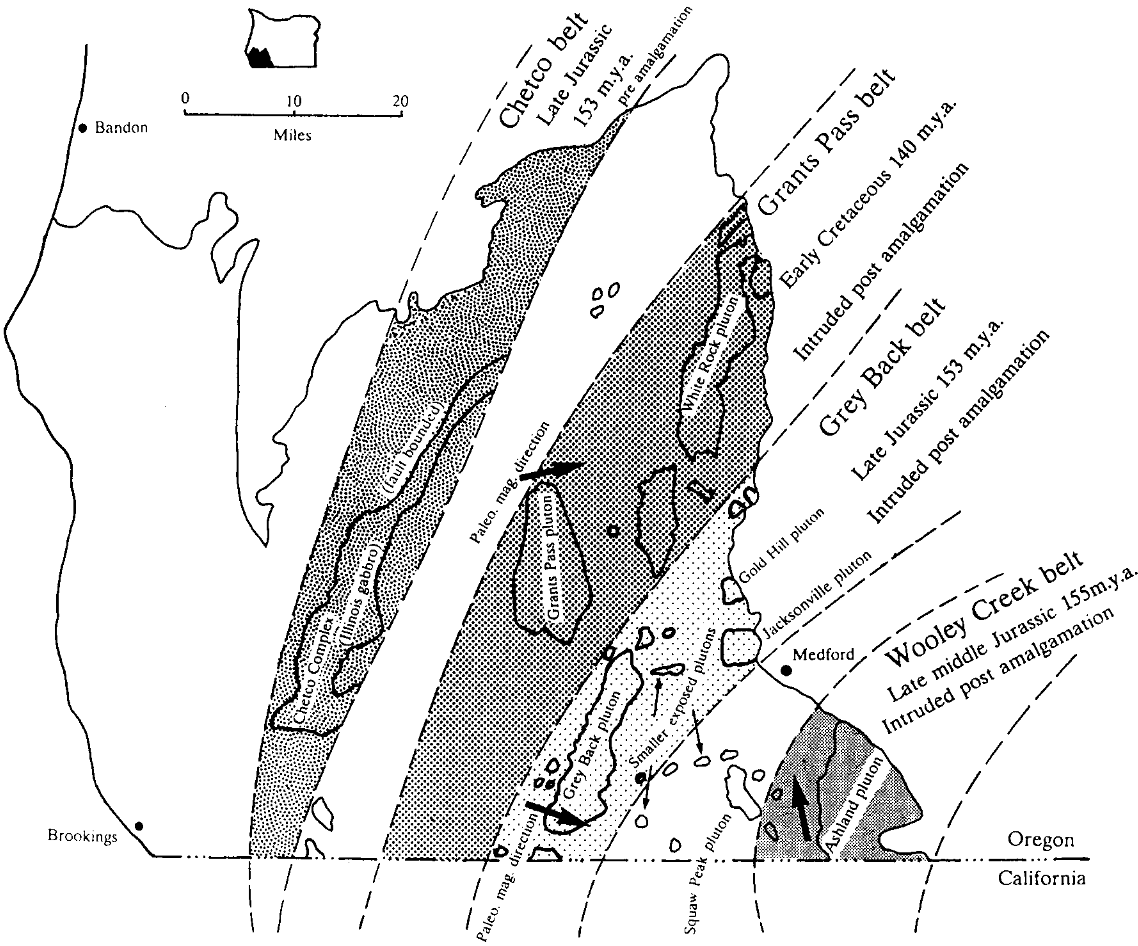



**Vertical sequence of the Josephine ophiolite in the Oregon Klamath Mountains (after Harper, 1984; Harper, et al., 1985)**

to those covering over 100 square miles. Intrusives are situated in four major northeast trending belts with the oldest in the southeast and the youngest in the northwest. The oldest of these, the Wooley Creek belt of late middle Jurassic age at 155 million years ago includes the Ashland plutonic complex of quartz monzonite and granodiorite. About 150 square miles in total size, approximately two-thirds of the Ashland pluton is in Oregon where Mt. Ashland is its major exposure. The Wooley Creek pluton belt intruded the Rattlesnake and Hayfork subterranes of the Western Paleozoic and Triassic belt terrane after the subterranes had been amalgamated.

Northwest of that region, the Greyback belt of late Jurassic age includes the large Greyback pluton as well as the smaller Gold Hill and Jacksonville plutons. This belt, dating back to 153 million years ago intruded the Hayfork, Rattlesnake Creek, and May Creek subterranes of the Western Paleozoic and Triassic belt. Just northwest of the Grayback belt, the Grants Pass early Cretaceous plutonic belt at 140 million years includes the large Grants Pass and White Rocks plutons. Displaying 85 degrees of clockwise rotation, the Grants Pass plutons intruded the Smith River subterrane on the south and the Rattlesnake Creek and Rogue Valley subterranes to the north after amalgam-




Plutonic rocks of the Oregon Klamath Mountai
(after Holtz, 1971; Irwin, 1985)

ation had taken place. The Chetco belt of late Jurassic age at 153 million years ago includes the Illinois River gabbro and is synchronous with the Greyback. In contrast to other intrusive belts in southwest Oregon, the Chetco belt, intruding the Dry Butte subterrane before it was amalgamated, formed the roots of a volcanic island arc.

### Cretaceous

Covering the tectonically emplaced plutons of the Jurassic period, sands, shales, and conglomerates between 3,000 to 4,000 feet thick were part of a transgressive seaway during the Cretaceous. As the seaway advanced or transgressed toward the east, it became progressively deeper over most of Oregon. Broken fossil shells and hummocky, uneven stratification of both the Cape Sebastian and Hornbrook formations indicate a turbulent stormy ocean. The steady deepening of the sea in Oregon correlated with a similar late Cretaceous world-wide transgression.

Marine sands, shales, and conglomerates of the Hornbrook Formation were deposited in a broad basin located along the northeast corner of the Klam Mountains. The basin probably extended much fart to the northeast where it connected with the Och basin near Mitchell and Suplee as well as to the so where it merged with the Great Valley near Reddi California. The interrelated basinal structure wo have formed a complex forearc basin to the west of later Cretaceous volcanic archipelago. Rare Cretace floras from the Port Orford area include ferns, cyc and ginkgos that grew at higher elevations in the wa moist climate.

### Tertiary

A rapid northwestward withdrawal of ocea waters at the end of the Cretaceous brought southern end of the shoreline up against the north edge of the Klamath Mountains by early Eocene ti Within the beginning of Tertiary time, the Klama lay at the southern tip of the newly formed volca

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Coast Range block, an extensive volcanic archipelago that extended northwest by southeast across eastern Washington and into Idaho. Only a very thin veneer of Tertiary sediments are found in discrete areas of the Klamath Mountains along the coastal margin, from Powers to Agness, along the Rogue River above Illahe, and at Eden Ridge and Bone Mountain. Micaceous sands and silts of the Lookingglass, Flournoy, and Tyee formations were initially carried westward by a well-developed riverine system that drained the Klamaths and the Idaho batholith to east to be deposited in the forearc basin. Accumulations of plant fragments intermixed with marine fossils indicate an interfingering of near-shore and nonmarine sediments. Late Eocene nearshore environments are represented by conglomerates and sands of the Payne Cliffs Formation exposed in a northwest trending belt along the Bear Creek Valley near Ashland. Grading upward into ash, tuffs, and lava flows, the Payne Cliffs also record the earliest volcanic activity of the Western Cascades, and deposition was primarily by an extensive braided river which flowed to the north. This formation is overlain by nonmarine volcanic sediments of the Colestin Formation. With the continued uplift, the shoreline moved northward, and intensive erosion and leveling of the Klamath Mountains took place.

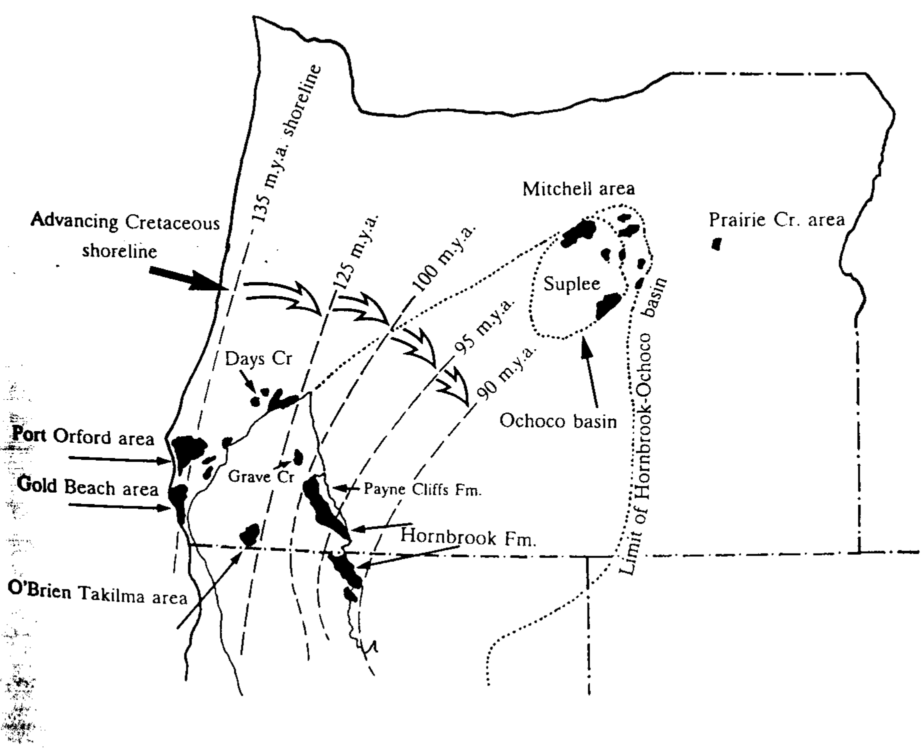
**Pleistocene**

Small glaciers formed in the Oregon Klamaths during the Ice Ages, although this range of mountains didn't have the extensive glacial system of the Blue Mountains, Cascade Range, or of the substantially higher California portion of the Klamaths. Glaciation is most evident in the U-shaped valleys, ampitheater-like cirques, and lakes carved in Chetco Peak near the California border at altitudes between 4,000 to 6,000 feet.

Present in patches along the western edge of the Klamath Mountains province, high marine terraces at different levels are the combined effect of uplift and fluctuating global sea levels during glacial and interglacial periods. Although extensive terraces, for the most part, are missing between Port Orford and the mouth of the Chetco River, south of the Chetco a broad marine terrace is present with an occasional raised sea stack projecting above the plain.

**Structure**

Large-scale lines or lineaments across Oregon and Washington, best seen on aerial photos, are poorly understood. Extending in a northeasterly direction, the Klamath-Blue Mountains lineament runs over 400 miles from the northern boundary of the Klamath Mountains to the northern boundary of the Blue Mountains. The lineament is displayed on gravity maps of Oregon where it reflects a crustal thickening from 20 miles thick northwest of the line to a crust 30 miles thick southeast of the lineament. The meaning of such a zone is unclear, but it may represent a preTertiary continental margin which was oriented north-south




Oregon marine Cretaceous rocks and basins (after Nilsen, 1984; McKnight, 1984)

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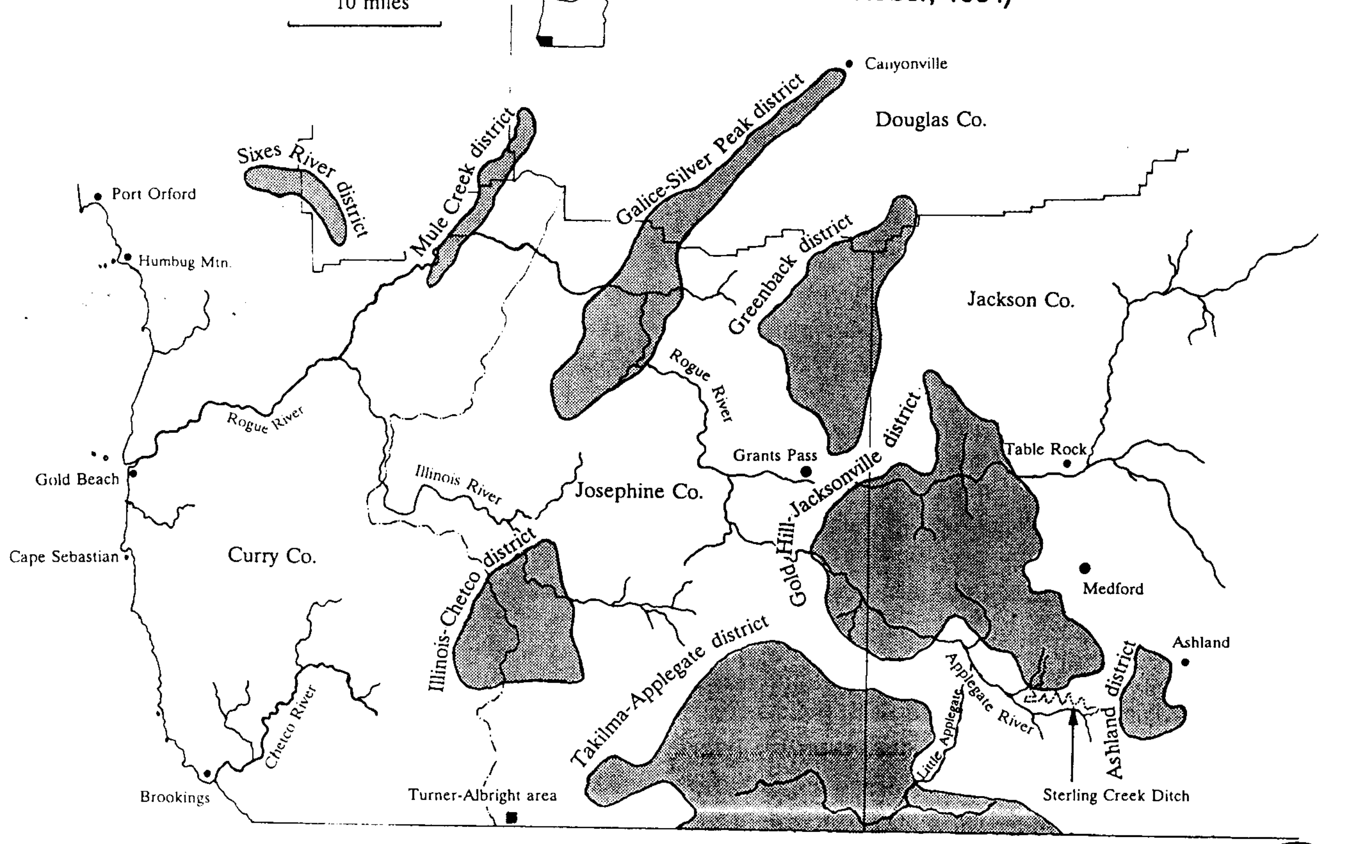
Mining Company had formed, a small copper ore smelter operated intermittently from 1911 to 1917 when 17,000 tons of ore yielded 260,000 pounds of copper, 7,000 pounds of lead, 1,500 troy ounces of gold, and 48,000 troy ounces of silver.

At the northeastern end of the Galice district near Canyonville in Douglas County, gold and silver mineralization in the Silver Peak region had a recorded production of 6,620 tons of ore between 1926 and 1937. Of this, 735,000 pounds were copper, 22,000 troy ounces were silver, and 500 troy ounces were gold. Minerals in the Silver Peak region were uncovered in 1919 on property owned by the Silver Peak mine, and 3,256 tons of ore were shipped out over the next ten years. A Swedish citizen is reported to have located the Gold Bluff mine here, but he was not allowed to claim the $7,000 in gold dust extracted because he was not a United States citizen. The Silver Peak area mainly produced copper, although a total of $216,000 in gold was taken from the mine prior to 1930. New operations here to extract copper, zinc, silver, and gold were begun in 1991. Minerals in the Galice-Silver Peak district are associated with island arc rocks of the Western Jurassic and Yolla Bolly terranes in which massive sulfide deposits occur in fragmented volcanics and sediments of the Rogue and Galice formations.

Rich placers along Jumpoff Joe Creek and the upper Grave creek watershed north of Grants Pass are responsible for most of the gold from the Greenback district, in operation since 1883. Occurring in sediments and volcanics of the Galice and Applegate formations, gold, copper, zinc, pyrite, and chalcopyrite are part of the Smith River and Applegate terranes that are ophiolitic in nature. Placer mining on Grave Creek produced $20,000 in gold, while the rich Columbia placer on Tom East Creek yielded more than $400,000. From September, 1935, to November, 1938, the Rogue River Gold Company operated the largest dredge in the history of Josephine County upstream from Leland in this district. Approximately 115 acres of gravels were worked before dredging ceased in 1939 only when the massive build up of loose gravel made it impossible to reach fresh bedrock. Equipped with sixty-five 7 1/2 cubic-foot buckets, this electrically powered behemoth could handle 5,000 cubic yards in 24 hours.

Mineral districts of the Klamath Mountains (after Ferns and Huber, 1984)

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V. Basin and Range

A. Physiography
1. Basin and Range extends from AZ,CA,NM to UT, NV, ID, OR
2. northern end in south-central Oregon
3. bounded to north by High Lava Plains
4. Topography
a. north-south trending block fault mountains separated by broad basins
b. Valleys and Ranges (from west to east in OR)
(1) Klamath Lake basin
(2) Goose Lake valley
(3) Winter Rim
(4) Summer lake
(5) Chewaucan basin
(6) Abert lake basin
(7) Abert Rim
(8) Warner Valley
(9) Warner Mt
(10) Hart Mtn
(11) Catlow Valley
(12) Steens-Pueblo Mts
(a) steens, highest peak 9600 ft
(13) Alvord basin
(a) most B/R peaks 7000-9000 ft range
c. Owyhee Uplands
(1) forms part of Basin and Range
(2) late Tertiary volcanics dominate, but block faulting not prominent
(3) considered modified variation of Basin and Range
(4) dissected uplands, canyons
(5) Owyhee river flows into Snake

B. Geologic Overview
1. Basin and Range
a. late Tertiary-Quaternary activity
b. high heat flow
c. extensive stretching and thinning of crust
d. block faulting predominates
e. Miocene-Pleistocene volcanic activity
(1) rhyolite-basalt volcanism
f. Pleistocene pluvial lakes
g. localized glaciation on highest peaks (e.g. Steens)

C. Bedrock Geology
1. General
a. older Pz-Mz basement buried by late Cenozoic volcanics
b. Miocene-Pliocene volcanics prevail
c. crust is very thin, high heat flow

2. Extensional Tectonics

a. Miocene-Pliocene (20 to 2-3 m.y.) crustal extension and thinning
    (1) block faulting
    (2) extensional volcanism
    (3) east-west stretching, up to 100% extension
b. changing stress fields
    (1) early extension - extension = NE-SW (NW strike faults)
    (2) later extension - extension = NW-SE (NE strike faults)
        (a) implies clockwise rotation of stretching direction
        (b) dextral shear
c. thinning and faulting of crust = pathways for extrusive volcanic activity
    (1) also pathway for groundwater circulation and geothermal activity
d. mechanism of B/R extension? - hypotheses
    (1) back arc spreading on NAM plate?
    (2) over-riding NAM plate on top of subducted spreading center (Farallon-Pacific)?
    (3) over-riding NAM plate over mantle plume?
e. Basin and Range extensional phases
    (1) Early 20-10 m.y. Late Miocene
        (a) - CRB volcanism, Steens volcanism (fissure eruptions)
        (b) NE-SW extension direction
    (2) Late last 10 m.y. - Plio-Pleistocene
        (a) block faulting
        (b) NW-SE extension direction
        (c) westward volcanic progression across High Lava plains
        (d) associated with 60 degrees of clockwise rotation of much of the state

3. Volcanism and Tectonics
a. Plate Tectonic Reconstruction
    (1) NAM, Kula, Farallon, Pacific
    (2) Kula to North, Farallon to South
        (a) Juan de Fuca - remnant of Farallon
    (3) typical arc volcanism
        (a) above subducting slab, critical depth to melting ~90 miles
        (b) slow subduction rate = steep slab dip
            i) arc to west, closer to trench
        (c) high subduction rate = gentle slab dip
            i) arc to east, farther from trench
    (4) one model for CRB volcanism
        (a) at ~17 m.y., subducting slab became detached at depth, allowed heat to leak to back arc - initiated back arc spreading and CRB volcanism
        (b) extension related to detachment of Farallon plate from Pacific plate, via subducted spreading center along San Andreas
        (c) also created basin and range extension

b. Yellowstone-Newberry tracks
    (1) age progression of basalt-rhyolite volcanism

(2) Yellowstone track: younging from SW to NE
(3) Newberry track (mirror image) younging from SE to NW

4. Mesozoic Geology
   a. Mz rocks very limited exposure in B/R of Oregon
   b. basic idea: basement beneath volcanics likely similar to terranes found in Klamaths / Blue Mtns

5. Cenozoic Geology
   a. Miocene-Pliocene-Pleistocene = abundant volcanics
      (1) 16 m.y. Steens Basalts
         (a) relatively voluminous (3000 ft thick covering 6000 sq. miles)
         (b) basalts and andesitic basalts
      (2) Silicic ash flow tuffs, concomitant with basalts of steens
         (a) ash, tuffs, lavas
         (b) calderas

6. Pleistocene Geology

   a. B/R = pluvial lakes, local alpine glaciation
      (1) pluvial lake Chewaucan
         (a) strand lines
         (b) deltas
   b. Mazama eruption - ash impact down wind to B/R
      (1) mazama 6900 yr ago
         (a) pumice, ash, dust
      (2) volcaniclastic dune fiels surrounding dried lake basins

D. Structural Geology

1. Faulting
   a. early phase
      (1) horsts
      (2) listric normal faulting
   b. fault block moutains
      (1) Hart and Steens most evident
      (2) asymetrical grabens and basins
   c. large-scale regional dextral shear (NW-SE fault swarms)
      (1) OWL
      (2) Vale fault zone
      (3) Brothers fault zone
      (4) Eugene-Denio fault zone
      (5) McLoughline Fault zone

E. Mining and Mineral Industry
1. General
   a. Uranium, Cinabar (hg) have been mined extensively

2. Uranium mining
    a. districts in Lake and malheur counties
    b. geothermal-fault related activity
3. Mercury
    a. very large accumulations
4. Diatomite-Bentonite-Zeolite
    a. freshwater microsopic remains, siliceous (lake critters)

F. Geothermal Activity
1. high heat flow in B/R
2. geothermal waters + fault conduits + high heat flow = geothermal energy
    a. Vale, Lakeview, Alvord Desert

G. Other Stuff
1. Jordan Craters
    a. 4000-9000 yr ago, volc.
    b. craters and basalts, fresh flows
2. Lava Tube Caves


The Great Basin portion of the Basin and Ran
province barely extends into southeast Orego

**Geologic Overview**

The Basin and Range is a tectonically youthful province with an anomalously high heat flow, thin outer crust, and a high regional elevation. The most pronounced structural phenomena effecting the Basin and Range province are the stretching or extension of the crust and the movement of large tectonic blocks. These forces are responsible for giving the basin its characteristic tilted, raised mountains and down-dropped basin structure as well as producing the volcanic activity of the late Tertiary. A complex network of faults and fissures resulted as the enormous crustal blocks were uplifted, tilted, or dropped while the basin was being stretched and distorted. Major faults are marked by spectacular scarps trending northward along the face of the mountain ranges.

Cenozoic volcanic activity in this provi began in the Miocene and continued into the Plei cene resulting in basalts, tuffs, and tuffaceous s ments totalling nearly 10,000 feet in thickness. As crust thinned and cracks appeared, magma from be broke through to cover the area. Basalts and ash w extruded from a broad shield volcano in the regio Steens Mountain. Following this a number of la calderas in the southeastern part of the state w

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responsible for thick ash and stream-deposited sediments in the basin and Owyhee uplands.

During the Pliocene and Pleistocene increased rainfall was responsible for large lakes filling the basins. These lakes have since dried up or diminished considerably because of more arid conditions prevailing today. The colder climate of the Pleistocene also brought about a build-up of ice masses atop Steens Mountain. Relatively recent volcanism has created some unique topography at the lava fields of Diamond Craters, Saddle Butte, and Jordan Craters.

**Geology**

If Oregon has a foundation block upon which the rest of the state was constructed, it is buried under the Basin and Range province. In the Blue Mountains and Klamaths, the movement, amalgamation, and eventual accretion of late Paleozoic and Mesozoic exotic terranes to North America can be readily demonstrated. By contrast, the volcanic veneer of the Basin and Range region obscures its preCenozoic history, and older rocks here could predate the accretion of terranes of the Blue Mountains and Klamath provinces. However, recent geophysical work on the northern Basin and Range suggests that the crust is even thinner than previously thought. This means that the Miocene volcanics may, in fact, represent the basement or oldest rocks of the province.

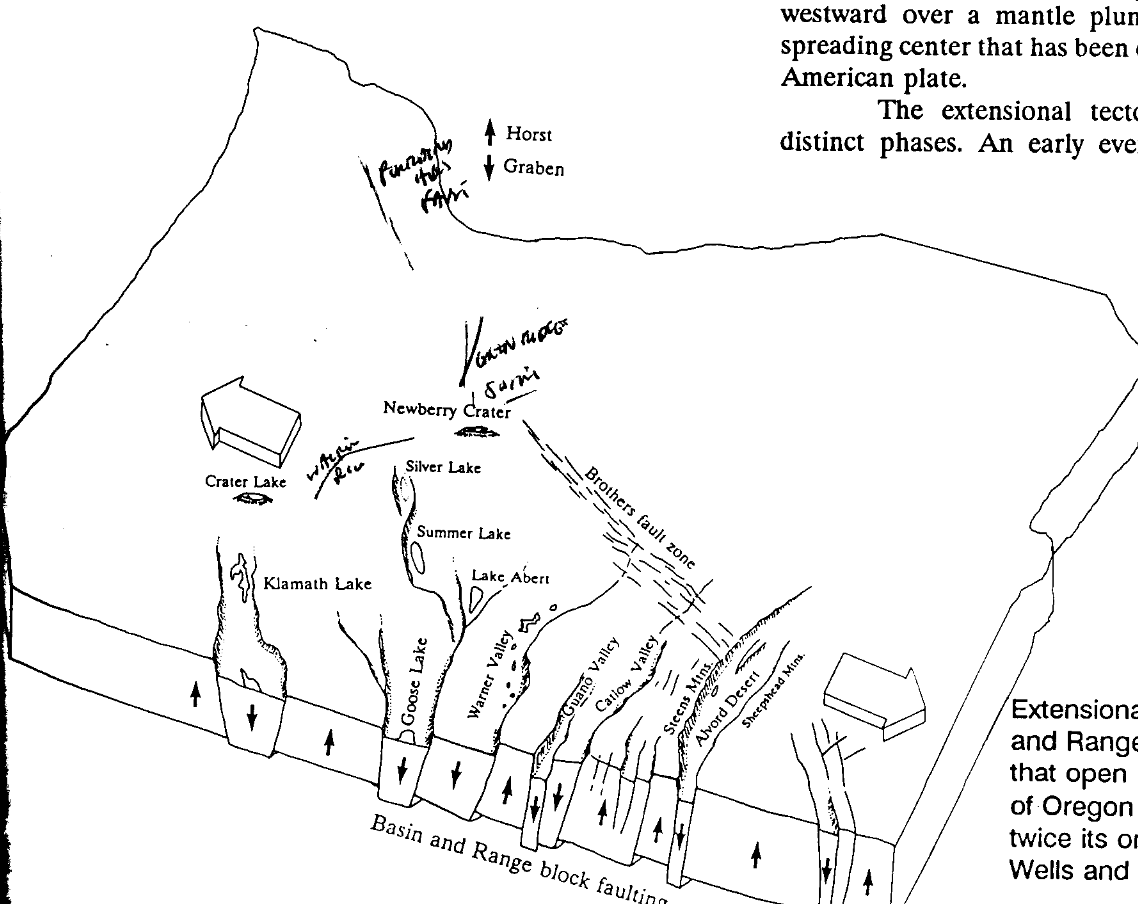
**Extensional Tectonics**

Beginning in the Miocene and extending into the Pliocene, the forces of crustal stretching and the movement of tectonic plates triggered faulting, extensive volcanism, and the development of the basin and fault block mountain topography characteristic of this province. The most profound effect of tectonics in the Basin and Range is an east-west stretching, extensional phenomena that has expanded this province by as much as 100%

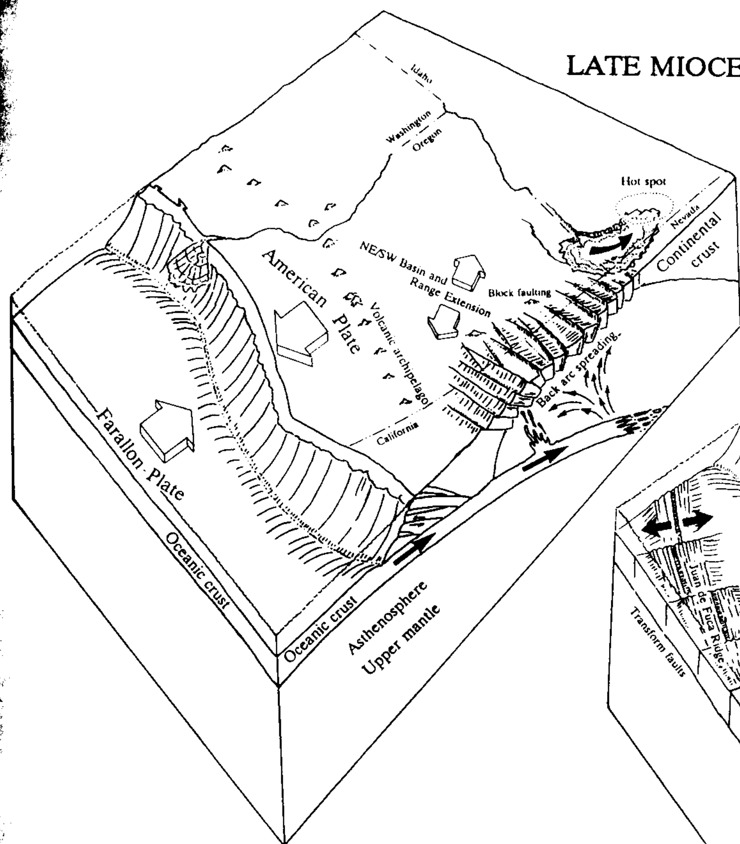
One interesting aspect of the extension in this province has been the clockwise shift in the stretching direction from northeast-southwest to a more northwest-southeast orientation. When the crust of the basin was pulled and drawn apart, it grew thinner like a piece of taffy being stretched. With additional tension, the thin, semi-brittle crust began to fail producing faults which provided a route for magma in the lower crust to escape to the surface as widespread lava flows and volcanoes. The thinning also brought the water table into contact with the hot crustal rocks below so that Nevada and southern Oregon today have scattered thermal springs and explosion craters or maars situated above ancient and modern faults.

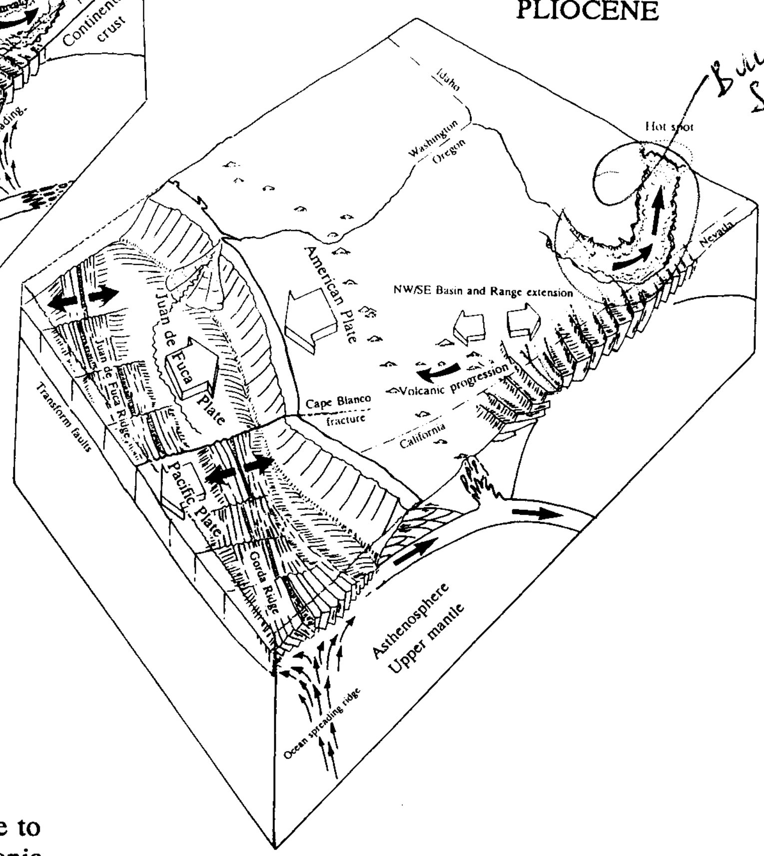
Forces responsible for the stretching of the Basin and Range are still not well-understood. It is possible the basin may be above a spreading backarc that is near the western margin of North America. Alternately, the basin may represent a plate moving westward over a mantle plume or even an oceanic spreading center that has been overridden by the North American plate.

The extensional tectonics occurred in two distinct phases. An early event between 20 and 10




Extensional tectonics in the Basin and Range yield steep-walled valleys that open northward. This portion of Oregon may have stretched to twice its original width (after Wells and Heller, 1988).




Stages in the extensional stretching of the northern Basin and Range as well as movement of the North American plate westward over the Yellowstone hot spot. In this model the subducting slab steepens sending the volcanic front back to the west. Simultaneously the direction of extension in the basin shifts clockwise from northeast-southwest to a more southeast-northwest orientation (after Zoback, Anderson, and Thompson, 1981).

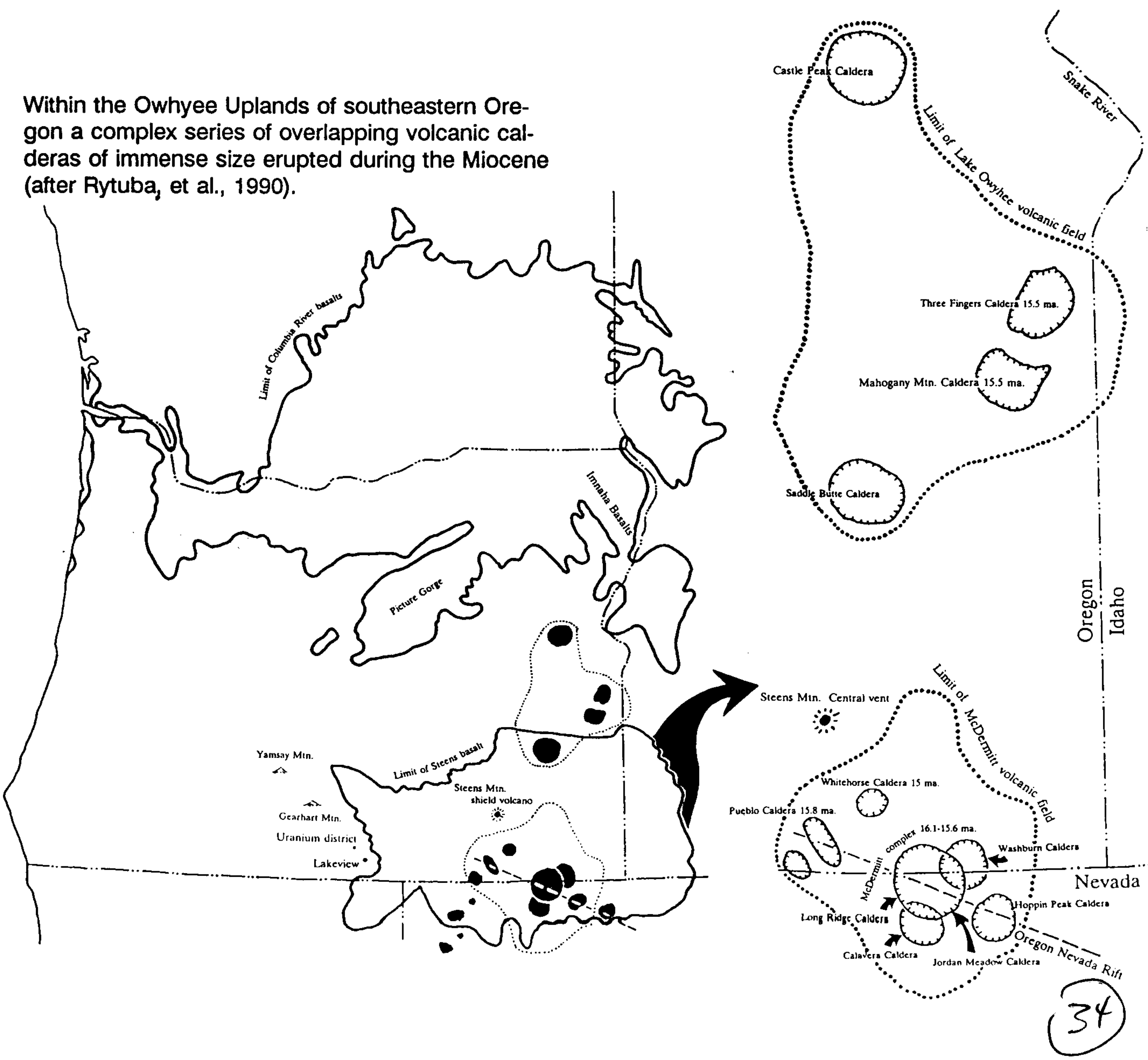
ago, the Farallon slab rose from a very steep angle to a relatively shallow position transferring volcanic activity in the Columbia Plateau and Basin and Range from west to east. About 30 million years ago, during the Oligocene, with decelerating convergence, the slab began to steepen. Then at 17 million years ago the subducting slab was detached and heat broke through at the rupture to initiate backarc spreading and issue as the Steens Mountain and Columbia River lavas. For the past 5 million years extensional spreading forces have intensified to create crustal thinning faults, and volcanism in the Basin and Range.

The most striking aspect of the Basin and Range volcanic activity is that eruptions of silica-rich rhyolitic lavas are progressively younger in a line running northwest across the province. In the eastern margin of the area during the late Miocene, volcanic activity migrated rapidly westward at a rate of 1 1/2 inches per year. However, the volcanic progression slowed to approximately 1/2 inch per year in the western section where volcanism is younger. While this migration of volcanic centers resembles a "hot spot", both the trend and direction are inconsistent with the steady westward movement of the North American plate during the last 10 million years of geologic time. It seems probable that after the subducting Farallon slab became detached, collision slowed considerably to steepen the slab and drive a volcanic wave gradually back to the west.

A similar pattern of volcanic progression extends from Steens Mountain in the southwest all the way across Idaho, through the Snake River downwarp, southcentral Oregon just before major block faulting in the Basin and Range began. In contrast to other volcanoes of this province, Gearhart lacks the typical bimodal history where volcanoes initially erupt basaltic lavas to be followed later by rhyolites. The eruption of the Gearhart volcano began with basalt and ended with a veneer of andesitic lavas. Just north of Gearhart, the prominent volcanic peak, Yamsay Mountain, is significant because it erupted during the Pliocene coinciding with extensional stretching of the Basin and Range. Unlike the Gearhart eruption, Yamsay has a history of bimodal volcanism beginning with a low shield cone of basaltic then rhyolitic lavas. Near the end of its eruptive history, small amounts of basalts again extruded from its flanks. This kind of bimodal volcanic activity may have been due to crustal extension.

**Pleistocene**

Continental ice sheets advancing southward during the Pleistocene accompanied increased precipitation and valley glaciers in the mountains. Rainfall and mountain runoff filled depressions in southcentral Oregon, creating large pluvial lakes across the region. Pluvial lakes are dependant on rainfall, expanding or decreasing dramatically with changing climatic conditions. At the peak of the moist Pleistocene environment vast areas of Oregon were covered by freshwater lakes, whereas today, during an interglacial warm phase, lakes cover less than one percent of the state. During this period nine fair-sized pluvial lakes existed in the Basin and Range province of Oregon. The largest of these in the western section of the province was Lake Modoc covering 1,096 square miles, followed by Lake Chewaucan at 461 square miles in the central region, Lake Coleman, now Warner Lakes, spread over




Within the Owyhee Uplands of southeastern Oregon a complex series of overlapping volcanic calderas of immense size erupted during the Miocene (after Rytuba, et al., 1990).

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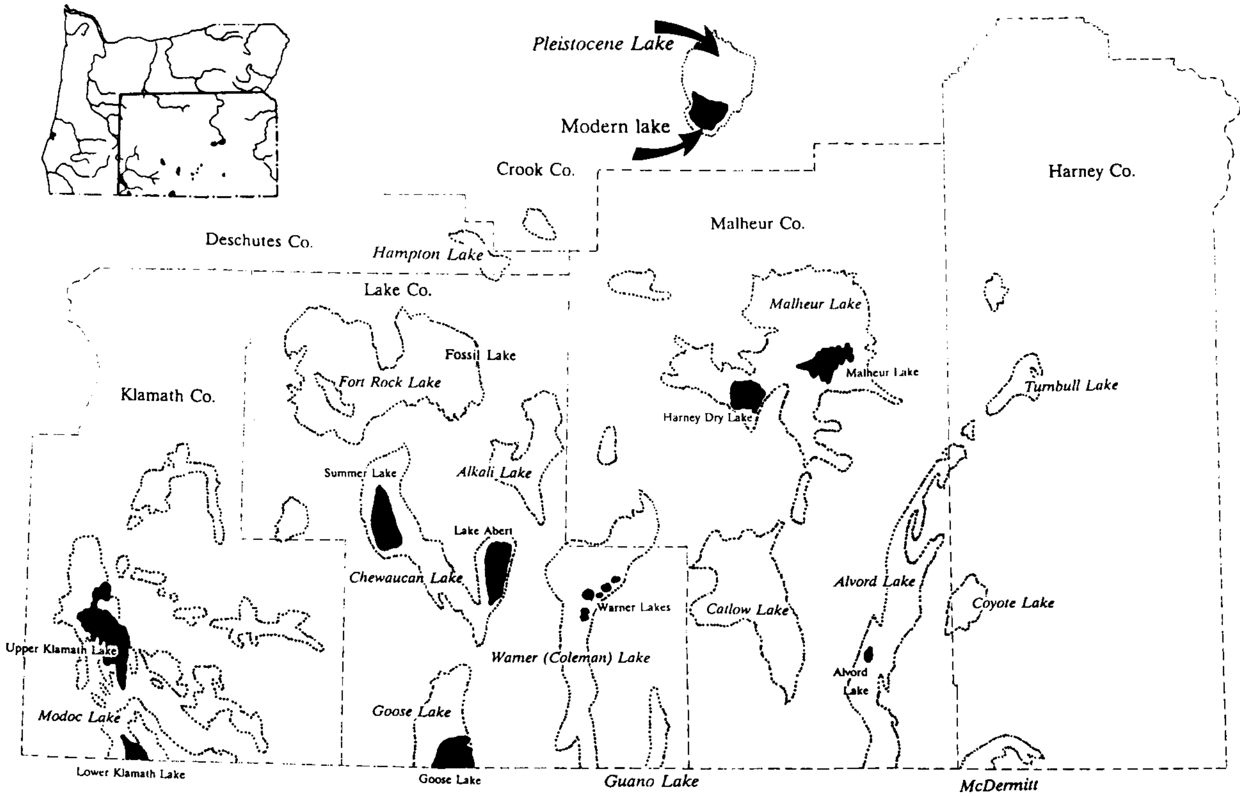
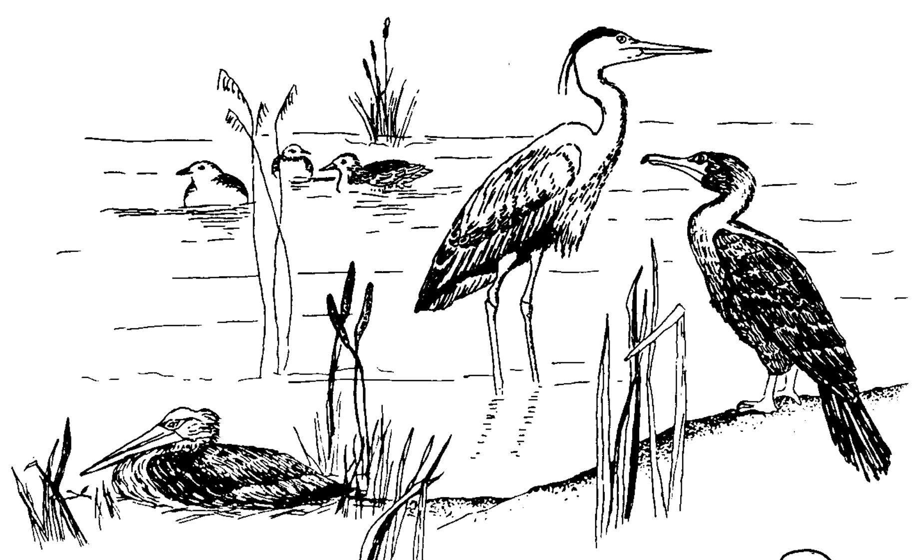



The small playas and pluvial lakes that dot southeast Oregon today are all that remain of much larger bodies of water here during the Ice Ages (after Allison, 1982).

masses. The highest part of Steens Mountain has been more thoroughly dissected by erosion, much of it glacial, than other scarps in southeastern Oregon. This is due to steeper gradients and the greater precipitation that accompanies higher altitudes. Glaciation on the western slope of the Steens sculpted lake basins and cut deep U-shaped valleys. The symmetrically curved Kiger Gorge, the canyon of Little Blitzen River, Big Indian Creek, Little Indian Creek, Wildhorse Creek, and Little Wildhorse Creek were all gouged out by valley glaciers which filled the streambeds. Fish Lake occupies a shallow depression where Fish Creek was dammed by a glacial moraine. Other lakes, such as Wildhorse Lake, occupy glacially cut, saucer-shaped valleys.

Ducks, pelicans, herons, and cormorants used Fossil Lake as a stop-over during the Plesitocene.



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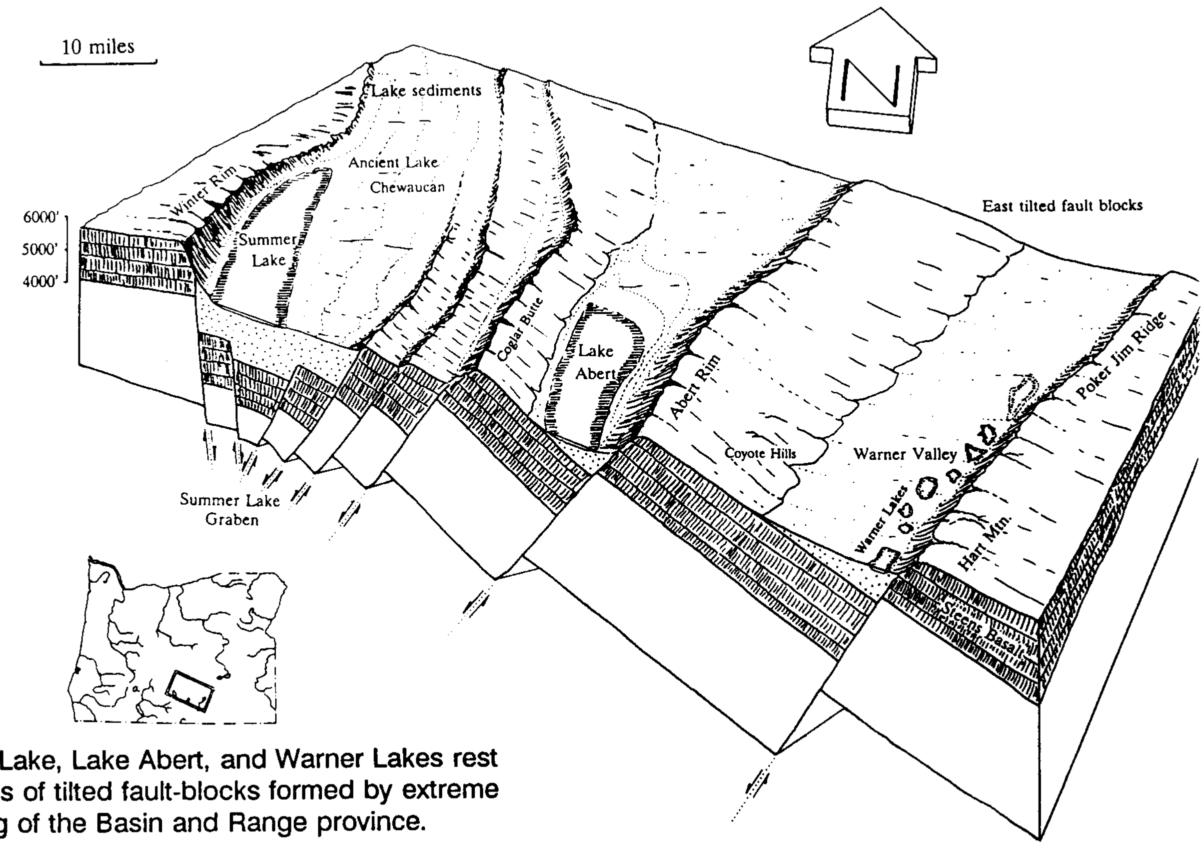
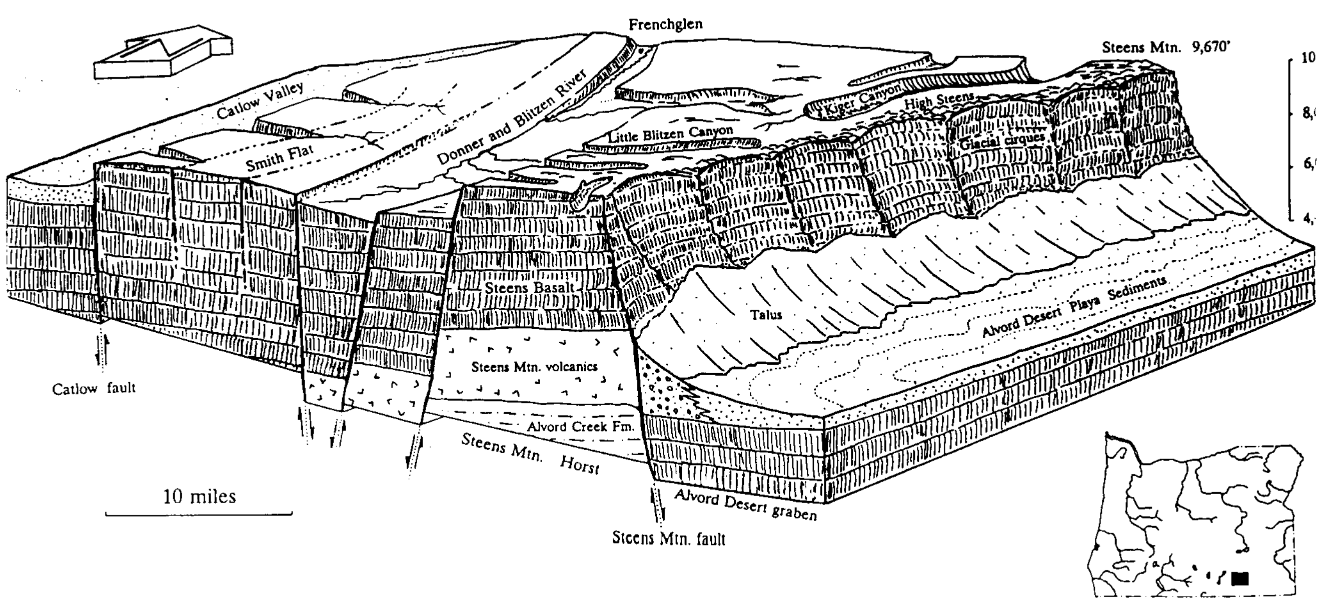



Summer Lake, Lake Abert, and Warner Lakes rest in a series of tilted fault-blocks formed by extreme stretching of the Basin and Range province.

Steens Mountains is an up-thrown fault-block that has been heavily glaciated on its top and sides by Pleistocene ice masses.

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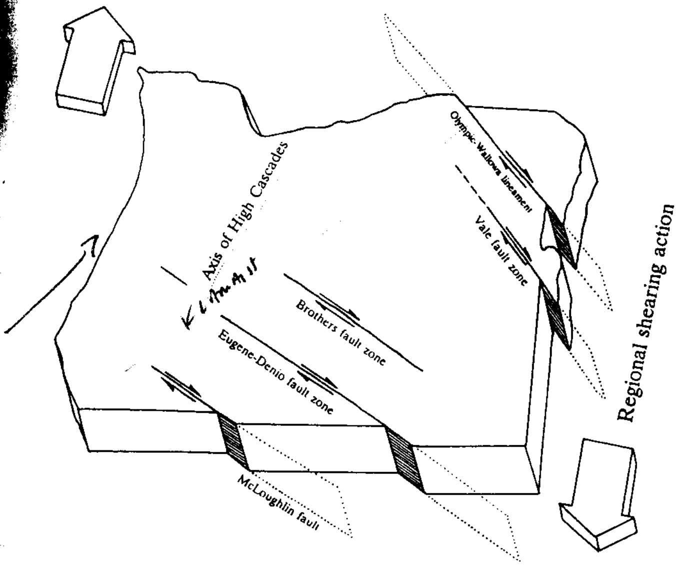


Caught between large-scale moving crustal masses, Oregon is being sheared by extensive faults running northwest to southeast across the state.

Poker Jim Ridge has an 1,800 foot precipitous scarp. Steens Mountain is a large horst where the block has been fractured into several pieces. The northern most portion tilted to the west as it rose giving that side the very gentle slope of Smith Flat. Extending for over 60 miles in a north-south direction, the steep east escarpment displays successive layers of Steens basalt in cross-section.

The southern and eastern margins of Oregon are cut by faults that run hundreds of miles across several physiographic provinces. These large-scale cracks, termed strike-slip faults, move laterally and are parallel to the southeast by northwest Olympic-Wallowa lineament. From south to north they are the McLoughlin fault, the Eugene-Denio fault, the Brothers fault, and the Vale fault. The faults are actually complex fault zones of smaller overlapping faults, but the trends are remarkably parallel. Faulting is most severe to the south and minimal to negligable along the short Vale fracture which runs northwest through the Owyhee Uplands. These fault systems relate to a shearing action where central and eastern Oregon are caught between two large-scale moving blocks. Action along the blocks is similar to movement of the San Andreas fault in California with the eastern block moving south and the western block moving north.

## Mining and Mineral Industry

### Uranium

Although deposits of lithium, antimony, gold, mercury, copper, and uranium have been known for several years in the Great Basin of Oregon, only uranium and cinnabar, or mercury, have been mined extensively. The Lakeview district in the southcentral part of the state as well as the McDermitt district in southern Malheur County have produced small amounts of uranium. Nearly 400,000 pounds of uranium have been recovered from two deposits in volcanic rocks just northwest of Lakeview. Most of the material was from the White King Mine, with smaller amounts from the Lucky Lass Mine where shipments in 1955, shortly after discovery, were the first uranium ores marketed from Oregon. A mill processing 210 tons per day was constructed at Lakeview in 1958, operating until 1965 when closure resulted after several years of only minimal production. Located in the McDermitt caldera, the Aurora and Bretz uranium prospects are the largest in total output of any yet found in Tertiary volcanic rocks of the United States. This potentially economic source of uranium ore, found as uraninite and coffinite, is associated with rhyolitic rocks and lake sediments. Once the thick, flat-lying lavas, covered by tuffaceous lake sediments, had been broken up by faulting, hot waters, containing minerals, followed fissures and cracks to deposit uranium and mercury in veins.

### Mercury

Within the McDermitt caldera complex, the Opalite Mining district, which includes the McDermitt Mine, the Bretz Mine, and the Opalite Mine have had a total output of 270,000 flasks of mercury, the richest supply of mercury in the western hemisphere. Mercury exploitation in the Opalite district began in 1917 with the discovery of cinnabar by William Bretz who had prospected in this region for a number of years. By 1925 tunnels had been driven 80 feet below the ore body and the cinnabar brought to the surface where it was processed in a large rotary furnace completed here in 1926. Over the years production was sporatic, stimulated in 1940 by the rising price of quicksilver prior to and during World War II when large amounts of mercury were used as ballast in submarines. The opening of several new pits signalled renewed mining as late as 1957 when the ore was sent to Salt Lake City for processing.

Very small deposits of cinnabar, copper, and gold along the eastern edge of the Steens and Pueblo mountains are largely unproductive.