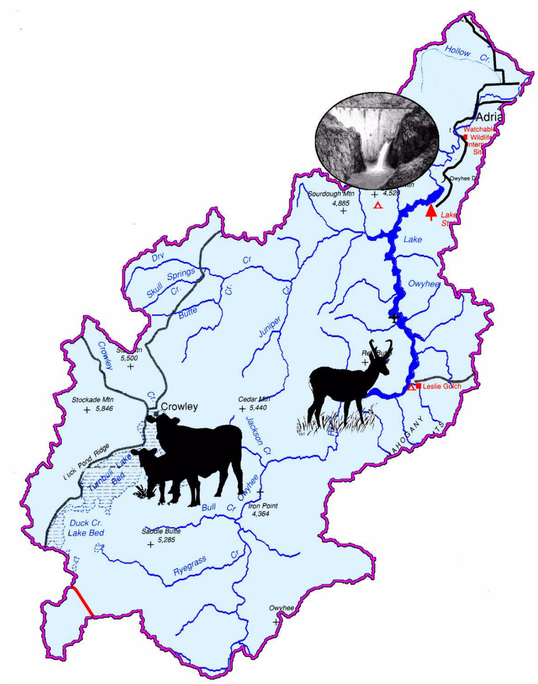


Lower Owyhee Watershed Assessment

II. Background

Contents

II. Background

A. The lower Owyhee subbasin

1 Location

The lower Owyhee subbasin is located in the southeastern corner of Oregon (Figure 2.1) in Malheur county. It covers 1,268,900 acres[64] (1,983 square miles), larger than the state of Delaware.

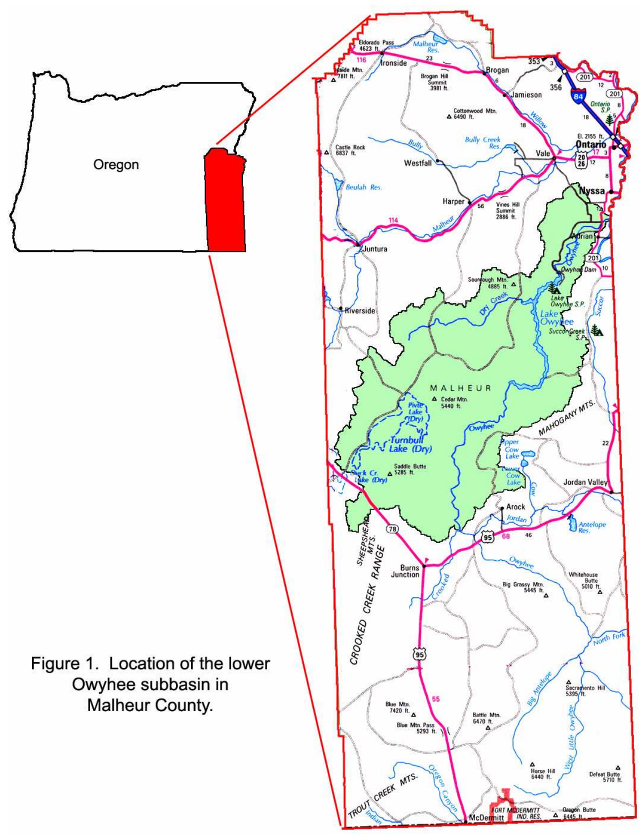


Figure 1. Location of the lower Owyhee subbasin in Malheur County.

2 What is the lower Owyhee subbasin?

The lower Owyhee subbasin is a geographic region designated by the United States Geological Survey (USGS). The United States is divided into geographic units called hydrologic units based on drainage areas of rivers. The largest units, given first order hydrologic unit codes (HUC), are drained by a major river or series of rivers. These regions are further subdivided into areas drained by a river system. These areas in turn are split into smaller units.[98]

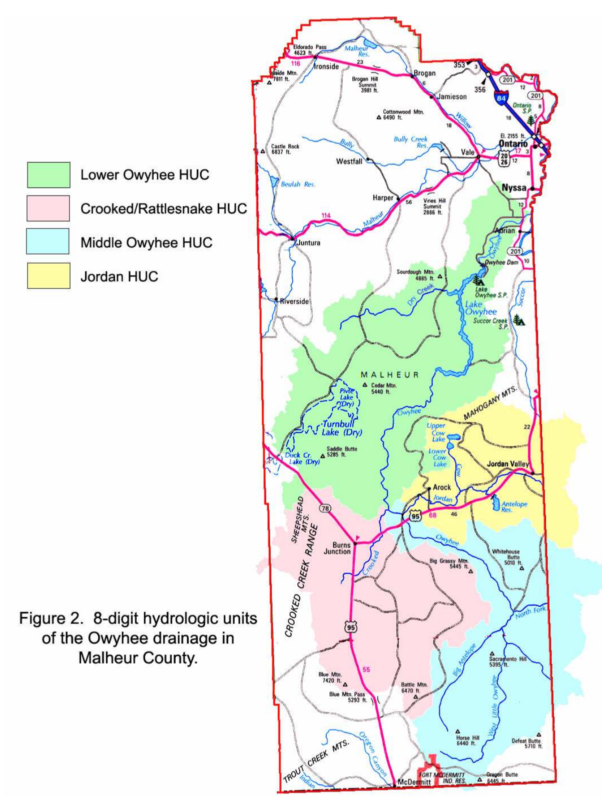


Figure 2. 8-digit hydrologic units of the Owyhee drainage in Malheur County.

The lower Owyhee subbasin is a 4th order or 8-digit hydrologic unit. It is part of the Columbia River, Snake River, and Owyhee River drainages. Within the Owyhee River drainage, there are several tributary rivers which have been designated as 4th order HUCs. Immediately south (upstream) of the lower Owyhee subbasin, the drainage areas of Crooked Creek and Rattlesnake Creek form one HUC, Jordan Creek drains another HUC, and the middle fork of the Owyhee River drains a third HUC (Figure 2.2). Upstream from the middle fork are three additional 4th order HUCs. The lower Owyhee subbasin includes everything downstream from these HUCs that drains into the Owyhee River. The lower Owyhee subbasin also includes land that does not drain into the Owyhee river, but has the potential to become part of the drainage over a geological time scale. This region is the Paiute, Turnbull, and Duck Creek playa lake beds.

Part of the reason for dividing the United States into small units based on some natural feature is the interest by government agencies at all levels to have some way to monitor, inventory, assess and manage resources.[69] The use of HUCs or watersheds was developed because water is a major resource and concern. It is also fairly easy to delineate the boundaries of most watersheds. However, the area within the boundaries of a watershed is not necessarily homogeneous in other ways. For example, the lower Owyhee subbasin includes forested areas on Mahogany Mountain and barren playa lakes, steep pinnacles in Leslie Gulch and leveled irrigated row crop land.

Within a watershed there are not only natural variations but differing impacts from human activities. Ecology is the study of how all the different factors in an area interact. An "ecoregion" includes both abiotic (non-living) and biotic (living) factors. An ecoregion approach to assessing an area recognizes that the different components of a region interact and exist in association with one another.[69] There is a potential to misunderstand how watersheds can be used to structure ecological management.[70]

James Omernik points out the basins are appropriate units for assessing the relative contribution of human activities at specific points on streams or of evaluating the relative contribution of point and nonpoint source pollutants.[69] However, determining the capacity and potential of a watershed depends on the characteristics of the ecoregions within it. Each of these is a mosaic of abiotic and biotic factors including climate, geology, soils, land cover including vegetation, human use, wildlife, water chemistry, and topography.[69]

In assessing the lower Owyhee subbasin, the existence of different ecosystems needs to be taken into consideration.

3 Ecoregions within the lower Owyhee subbasin

There is a great difference between the geographic unit designated by the watershed and a region based on some other factor such as geology, land use, or vegetation. An ecoregion description includes multiple factors. There is no one accepted definition of the term ecoregion nor one opinion on how they should be delineated.[69] In general an ecoregion is defined as an area with relative homogeneity of biotic and abiotic components which are distinct from adjacent areas.[69,82] Many of the classification systems for ecoregions give preference to specific factors for separating areas. Below we discuss four approaches to describing ecoregions within the lower Owyhee subbasin.

a. NRCS

A common resource area map is included in the Natural Resources Conservation Service (NRCS) profile of the lower Owyhee subbasin.[64] The NRCS has developed a land classification system as a resource for farming, ranching, forestry, engineering, recreation, land management, conservation programs, and other uses.[66] This classification divides the United States into land resource units, major land resource areas (MLRA), and common resource areas (CRA).[65,66] The major land resource areas

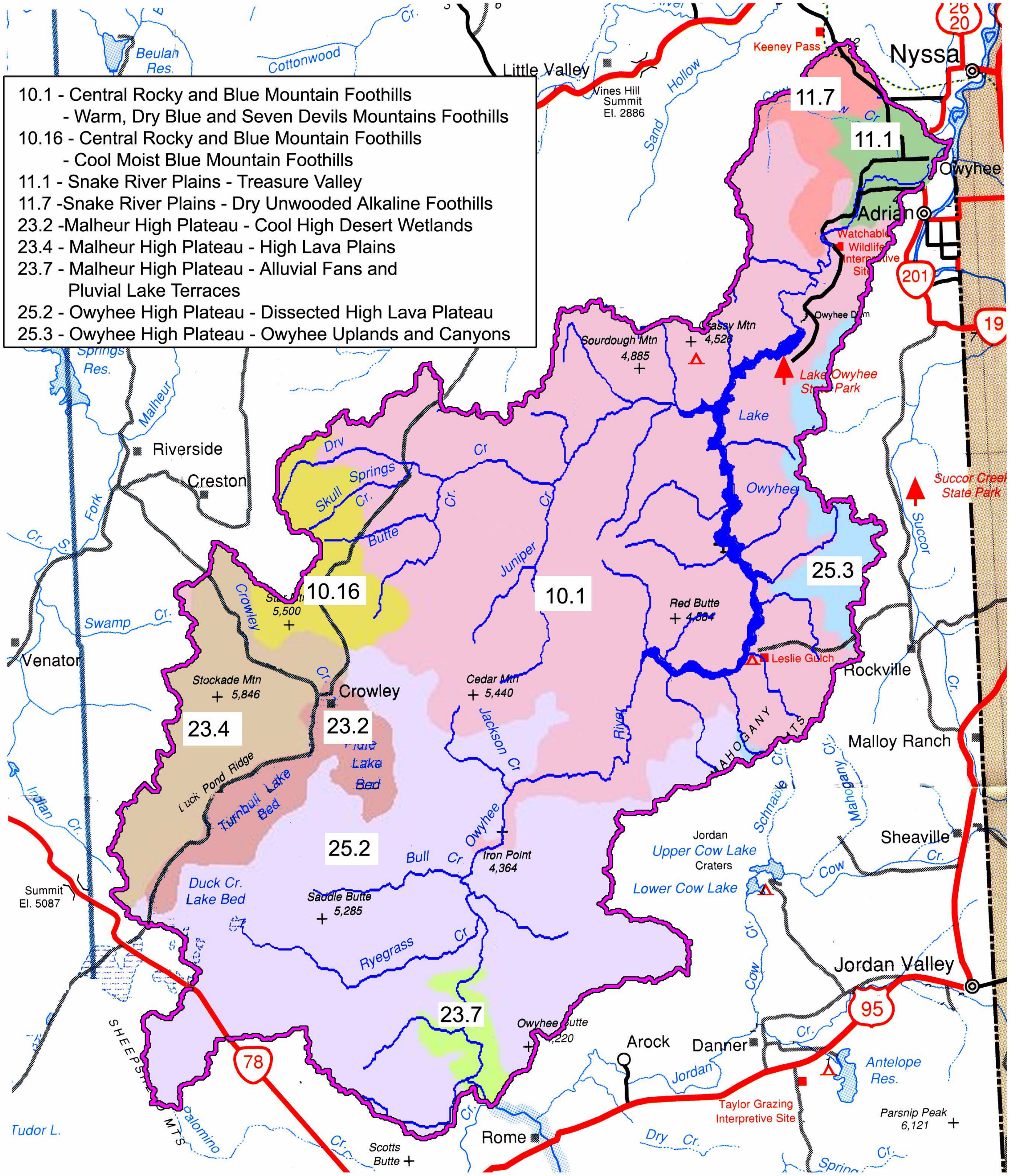


Figure 2.3. Common Resource Areas in the lower Owyhee subbasin.[68] Descriptions in Appendix B.

are one continuous area or several separate areas near each other without consideration of political boundaries. The dominant characteristics which determine an MLRA are location and climate with consideration given to generalized geology, water, soils, biological resources and land use in each area.[65,66] The NRCS has identified 278 major land resource areas in the US[65] and the lower Owyhee subbasin includes parts of four of these areas.[64,66,68]

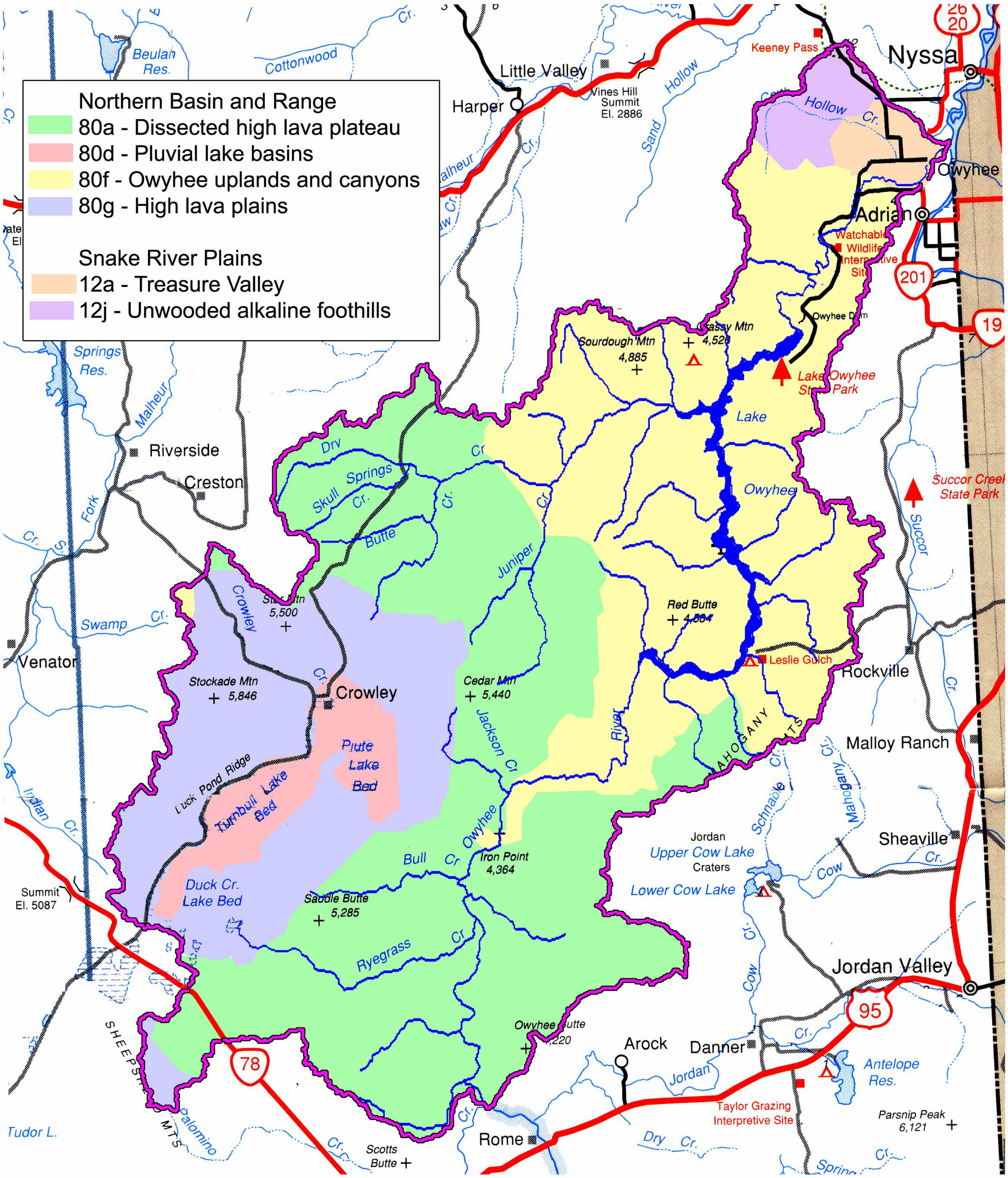


Figure 2.4. Northern basin and range ecoregion subregions and Snake River plains ecoregion subregions in the lower Owyhee subbasin from the Oregon Natural Heritage Plan.[72] Descriptions in Appendix B.

The MLRAs are further broken down into common resource areas. A common resource area "is defined as a geographical area where resource concerns, problems, or treatment needs are similar."[67] They are created by subdividing MLRAs by topography, other landscape features, resource concerns, resource uses and conservation needs.[66] There are parts of nine common resource areas in the lower Owyhee subbasin (Figure 2.3) (Appendix B).[64,68]

b. Oregon Natural Heritage plan

One of the goals of the Oregon Natural Heritage (ORNH) program established by the Oregon legislature was to identify the "full range of Oregon's natural heritage resources."[62] To do this they identified ecoregions that support different terrestrial, wetland and aquatic ecosystems.[62] Part of the purpose of describing the ecoregions is to identify natural areas of exceptional value for conservation. The lower Owyhee subbasin includes two of the ORNH ecoregions and six subregions (Figure 2.4) (Appendix B).[62] These ecoregions are the ones used by the Oregon Department of Fish and Wildlife.

Although the original purpose of the NRCS and ORNH delineations is different, a comparison of the maps of the NRCS common resource areas (Figure 2.3) and the ORNH subregions (Figure 2.4) shows some overlap between the identified distinctive areas.

c. Ecological Provinces of Oregon

Anderson, Borman, and Krueger[6] recognize that much planning and management is done on different scales and that it is important to understand the relative similarity in quality and quantity of resource types on different scales. They define an ecological site as an area with certain soils, climate, topography, and vegetation. These factors influence management decisions.

On a broader scale they define an ecological province as an area in which the difference in vegetation among ecological sites can be related to underlying geology, climate, and the characteristics, configuration, and evolution of rocks and land forms. An ecological province therefore contains a number of ecological sites.

Ecological provinces can be used for considering broader scale responses to management decisions. The ecological province has grouped ecological sites with similar types, quality, and quantity of environmental resources. Ecological provinces are not homogeneous. They have unifying characteristics that impact the local environment. The local environment is created by an interaction among factors including soil, aspect, slope, elevation, moisture, and temperature. The distinguishing feature between ecological provinces is that within a province, vegetation in similar local environments, for example on north-facing slopes, is similar.[6]

Anderson, Borman, and Krueger have described 15 ecological provinces in Oregon. The lower Owyhee subbasin contains parts of four of these provinces (Figure 2.5) (Appendix B).[6]

d. Owyhee Uplands ecoregion

On a different scale, the Bureau of Land Management (BLM) and the Nature Conservancy have described an Owyhee Upland ecoregion which includes all the drainage area of the Owyhee River, all of Malheur County, parts of Harney and Baker Counties, parts of southwestern Idaho, and part of Nevada north of McDermitt. They

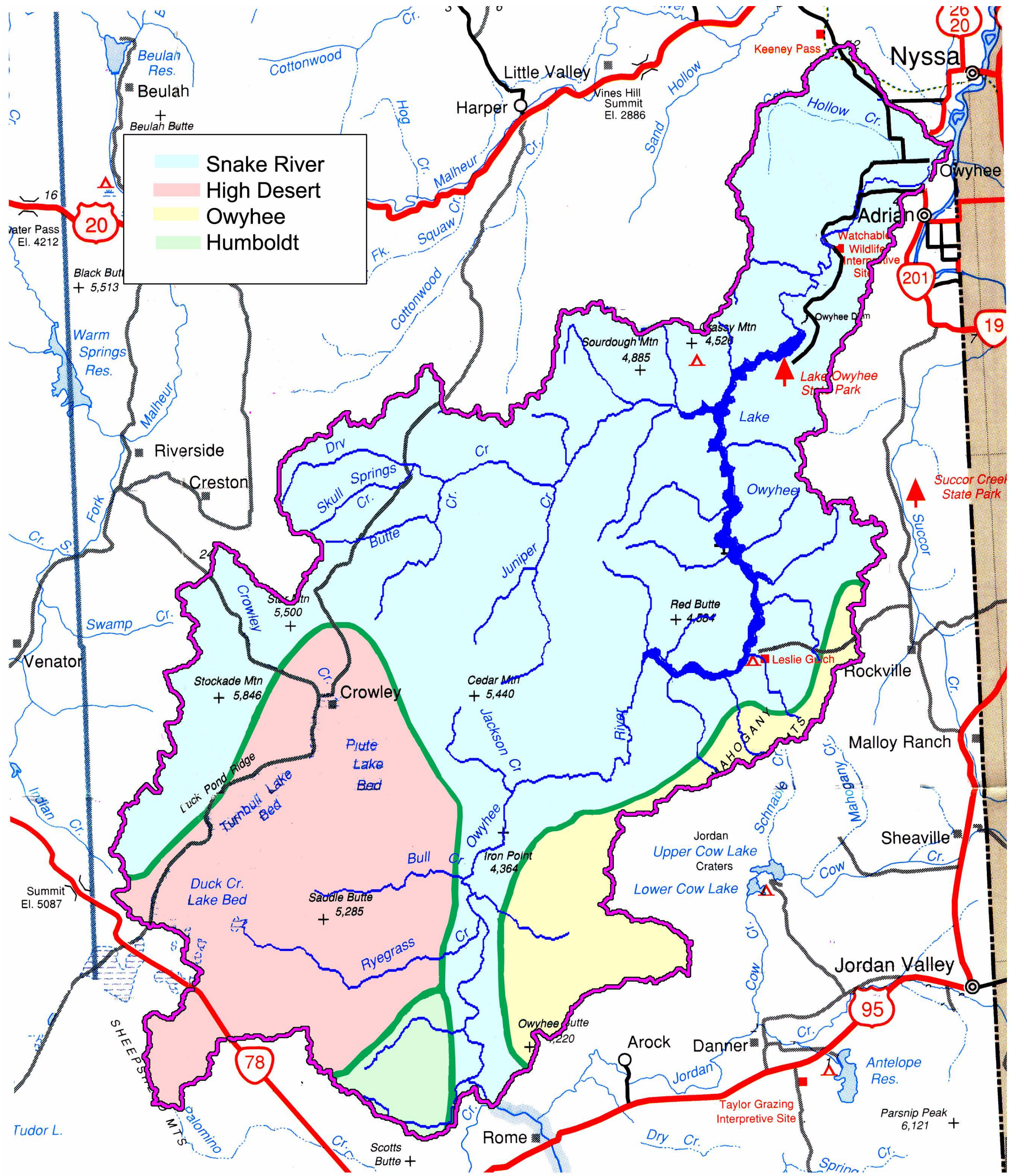


Figure 2.5. Ecological provinces in the lower Owyhee subbasin from Anderson, Borman, and Krueger.[6] Descriptions in Appendix B..

are trying to distinguish the Owyhee Upland ecoregion at the regional and national level of ecoregions from the Great Basin and the Snake River Plain. This is more along the lines of a first order HUC or a land resource unit. The discussion of the characteristics of the Owyhee Upland ecoregion is broad and general.[82]

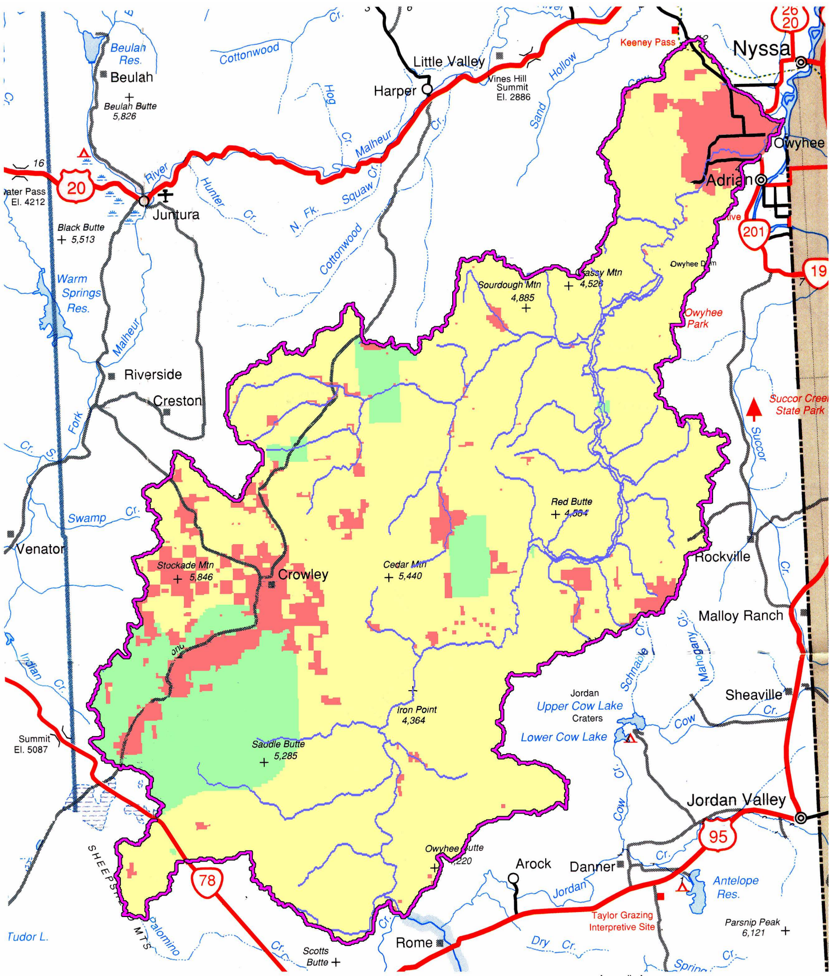


Figure 2.6. Land Ownership in the lower Owyhee subbasin.

Federal State Private

e. *Discussion*

It is apparent from all of the above approaches to describing ecoregions within the lower Owyhee subbasin that there is tremendous variability within the subbasin.

Within each component of this assessment the complexity of the factors which affect that component will determine what combination of ecological factors needs to be taken into consideration rather than using a predetermined scheme.

4 Ownership of land

Within the lower Owyhee subbasin 79% of the land is federal, 11½% is state land, and 9½% is private (Figure 2.6). BLM manages most of the federal land. The majority of the private land is located on the irrigated lands along the Owyhee River below the Owyhee Dam and in the internally drained subbasin south of Crowley in the southwest corner of the lower Owyhee subbasin.

The corridor along the Owyhee River from the south end of the lower Owyhee subbasin to where the river enters Lake Owyhee is designated as a wild and scenic river. On the federal land, there are a series of wilderness study areas along both sides of the Owyhee River corridor. BLM wilderness study areas constitute 30% of the lower Owyhee subbasin (Figure 2.7).[16] A number of these wilderness study areas have been recommended as suitable for wilderness designation by the BLM (Figure 2.8).

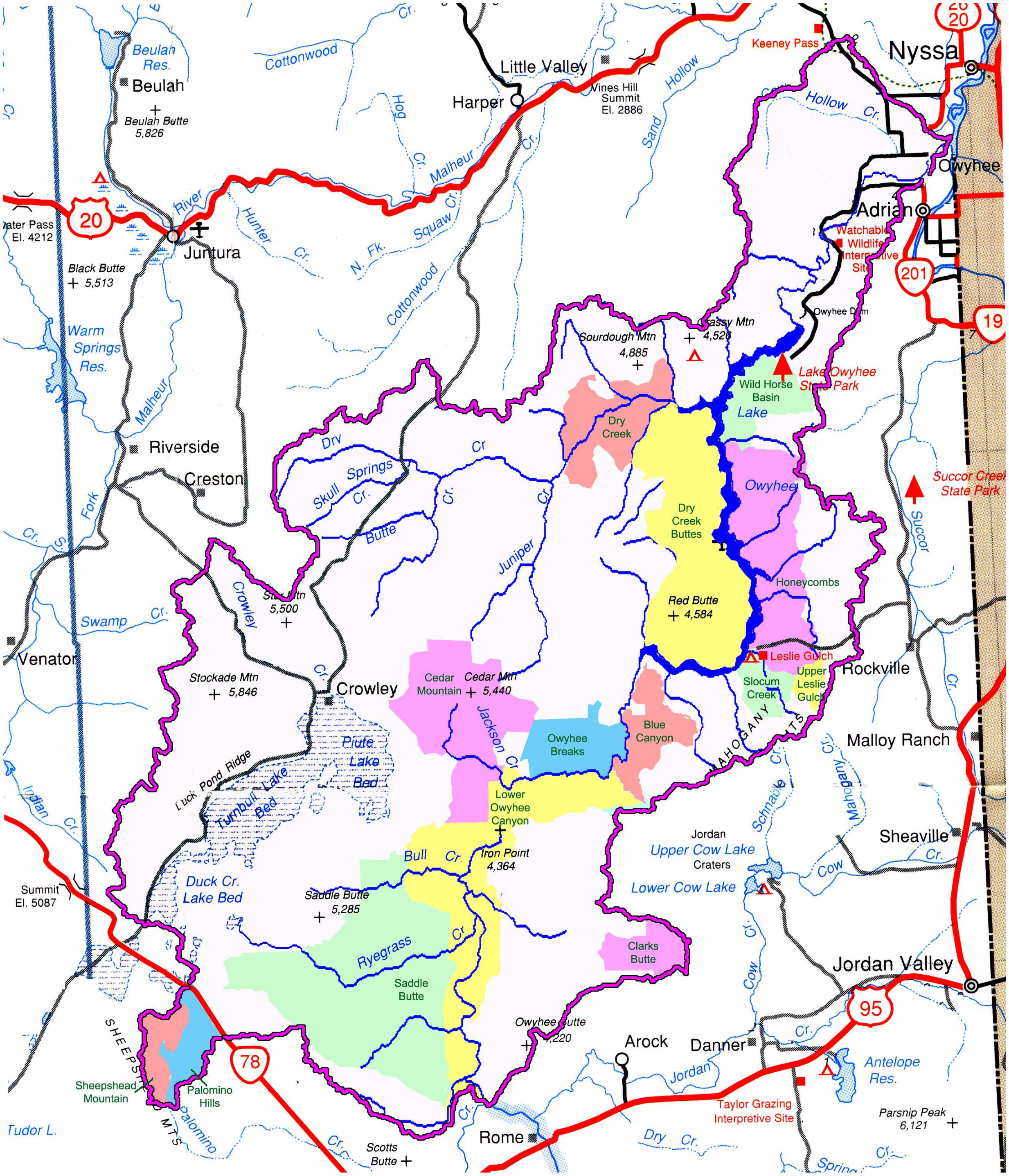


Figure 2.7. Bureau of Land Management wilderness study areas.[16]
BLM names

There is one national historic district in the lower Owyhee subbasin. The Birch Creek Ranch Historic Rural Landscape is on federal land at the junction of the Owyhee River with Birch Creek. There are 4,540 acres including 12 buildings and 7 structures.[61]

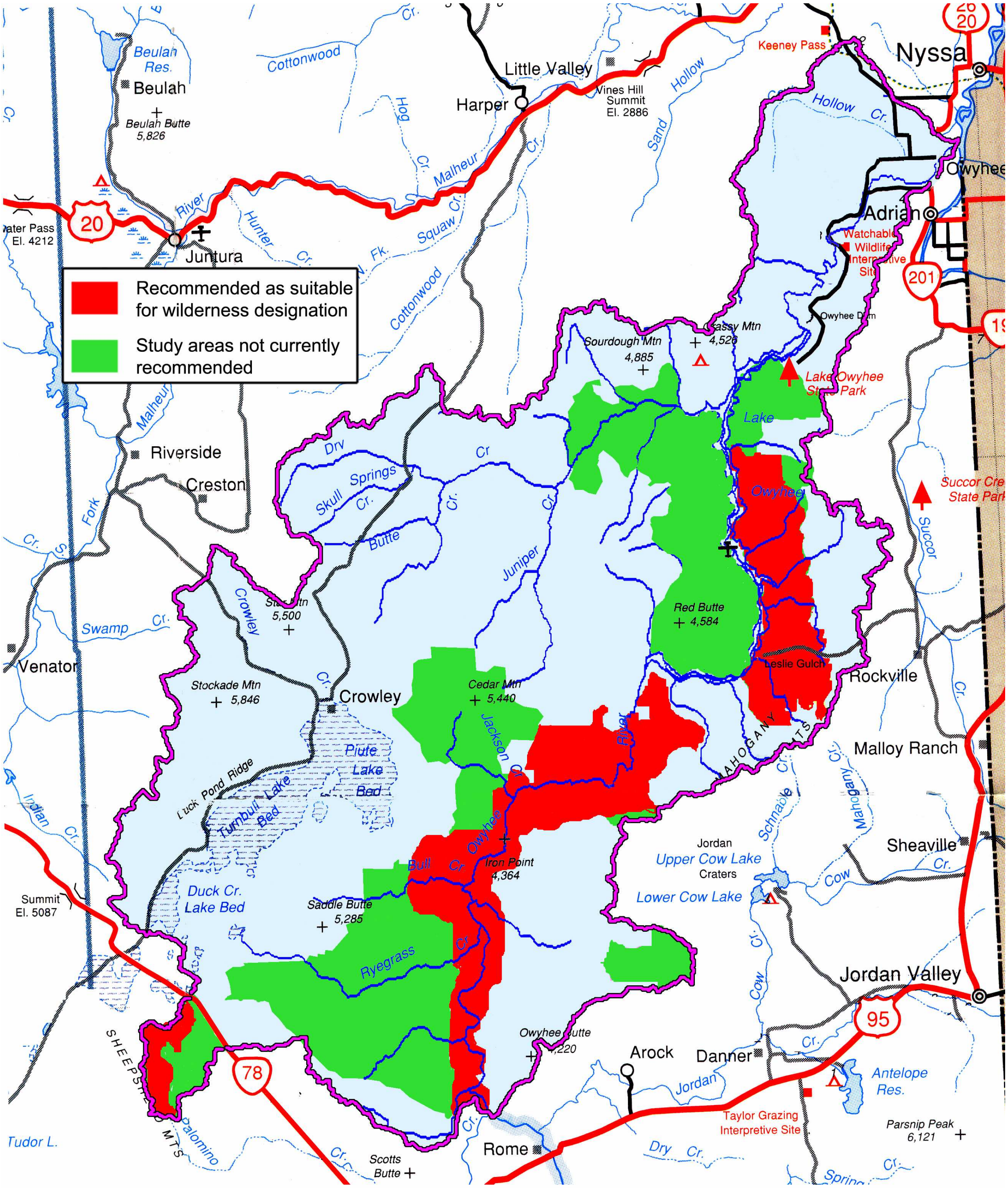


Figure 8. Bureau of Land Management wilderness study areas recommended as suitable for wilderness designation by the BLM.[16]

5 Population

The US census doesn't use hydrologic units as the basis for the data which it analyses. The data is tabulated both by census tract and by zip code. For the lower Owyhee subbasin the zip codes more accurately reflect the area than census tract. The

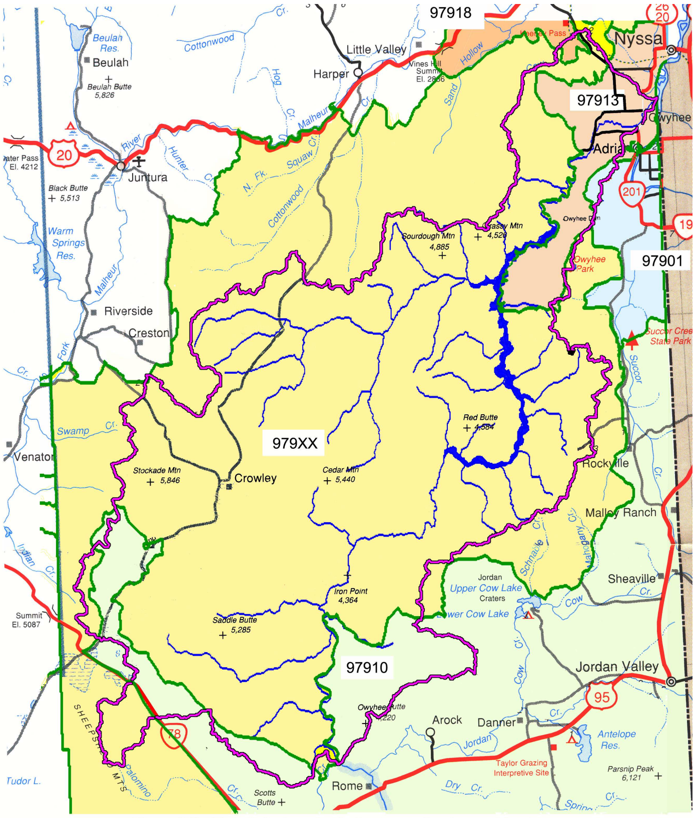


Figure 2.9. Five digit zipcodes in the lower Owyhee subbasin used for US Census data.[Appendix A]

lower Owyhee subbasin contains parts of five different zip codes: 97901 (Adrian), 97910 (Jordan Valley), 97913 (Nyssa), 97918 (Vale), and 979XX (Figure 2.9).

Since none of the zip codes is exclusively in the subbasin, it is difficult to accurately estimate how they represent the area. Zip code 979XX represents the majority of the land area as well as much of the remaining area of Malheur County south to the border with Nevada. However, in the entire zip code there were only 105 residents in 2000.[95] The NRCS, using the percentage of area of each segment in the lower Owyhee subbasin, estimates that there are 4,187 people living in the subbasin.[64]

Combining the information from the 979XX and 97910 zip codes to approximate the upland area and the information from the 97901 and 97913 zip codes to approximate the area below the dam, there are some characteristics which seem to set the upland area apart from Malheur County as a whole. The median age in the upland area is 41 years old as compared to 34 years old for the county. The average family size is smaller, 2.9 people per family as compared to 3.28 for the county.[95] This may be partially accounted for by the fact that a greater percentage of the population is over 65 (Figure 2.10). There are also two and a half times as many vacant houses in the uplands. And, although there is no greater percentage of families with incomes below the poverty level, a greater percentage of the individuals are below the poverty level when compared to county wide percentages. In general the area below the dam differs less from the county wide averages (Figure 2.10).[95]

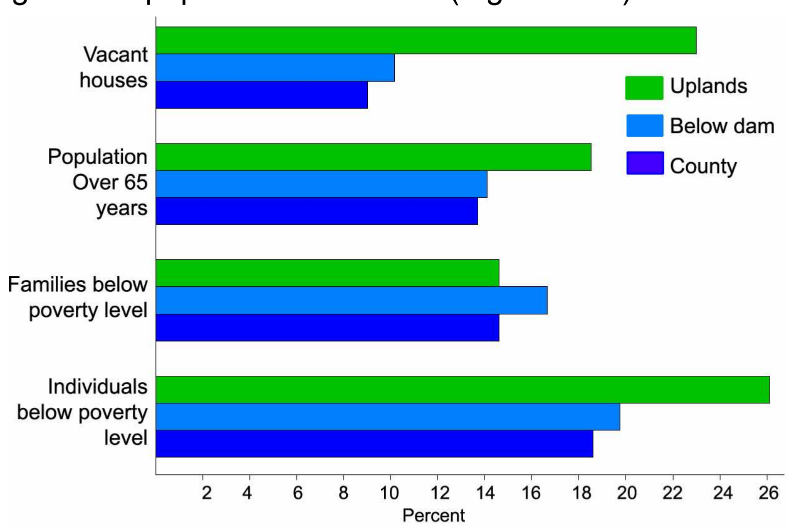


Figure 2.10. Comparison of selected socio-economic factors between the uplands (zip codes 979XX and 97910) and the below dam (zip codes 97901 and 97913) sections of the lower Owyhee subbasin.[95]

B. Climate

1 Historical data

The earliest recorded weather data from near the lower Owyhee subbasin is US army data from Vale, Oregon to the north of the lower Owyhee subbasin. Temperature and precipitation there were measured for nine years from December 1891 to December 1900. A nine year period of weather data is probably too short to be considered to be representative.

Weather records from regions around the lower Owyhee subbasin are available starting in 1922 for Parma, Idaho,[107] in 1928 for Vale[109] and Adrian,[102] in 1931 for Danner[104] and Warm Springs,[110] in 1943 for the Malheur Experiment Station,[105] in 1948 for Beulah Reservoir[103] and Owyhee Dam,[106] and in 1950 for Rome.[108]

2 Precipitation

A research group at Oregon State University have developed a model, PRISM, for using meteorological data to extrapolate to the areas between the data points. The map in Figure 2.11 shows the approximate annual rainfall across the lower Owyhee subbasin developed using PRISM.[64]

Cristopher Daly, one of the developers of the PRISM model, explains that except for the most densely populated regions of developed countries, meteorological stations will be so sparse that they are spaced further apart than the scales at which elevation, large topographic features and cold air drainage are most important. "This means that climate patterns caused by these factors will likely be incorrectly located, inaccurately represented, or not represented at all, if interpolated with simple methods . . . While PRISM explicitly accounts for more spatial climate factors than other methods, it also requires more effort, expertise, and supporting data sets to take advantage of its full capability."[24]

The PRISM model takes meteorological data from the different stations and transforms the data to account for elevation, climate changes due to topography, and cold air drainage. Cristopher Daly, however, cautions that there are general relationships, such as temperature predictably dropping with elevation, which do not apply on a local scale, for example in temperature inversions when temperature increases rather than decreases with elevation. The relationship of elevation to precipitation is more complex although generally precipitation increases with elevation.[24] Other factors which affect climate include slope and aspect, riparian zones, and land use/landcover. These are not accounted for in PRISM or other statistically interpolated data sets. Slope and aspect may play a role in determining local precipitation and near-surface temperatures.[24]

Since there are no known points between the data points used in the interpolations, there is no satisfactory method for estimating error. Error can also be introduced by errors in the original measuring equipment.[24]

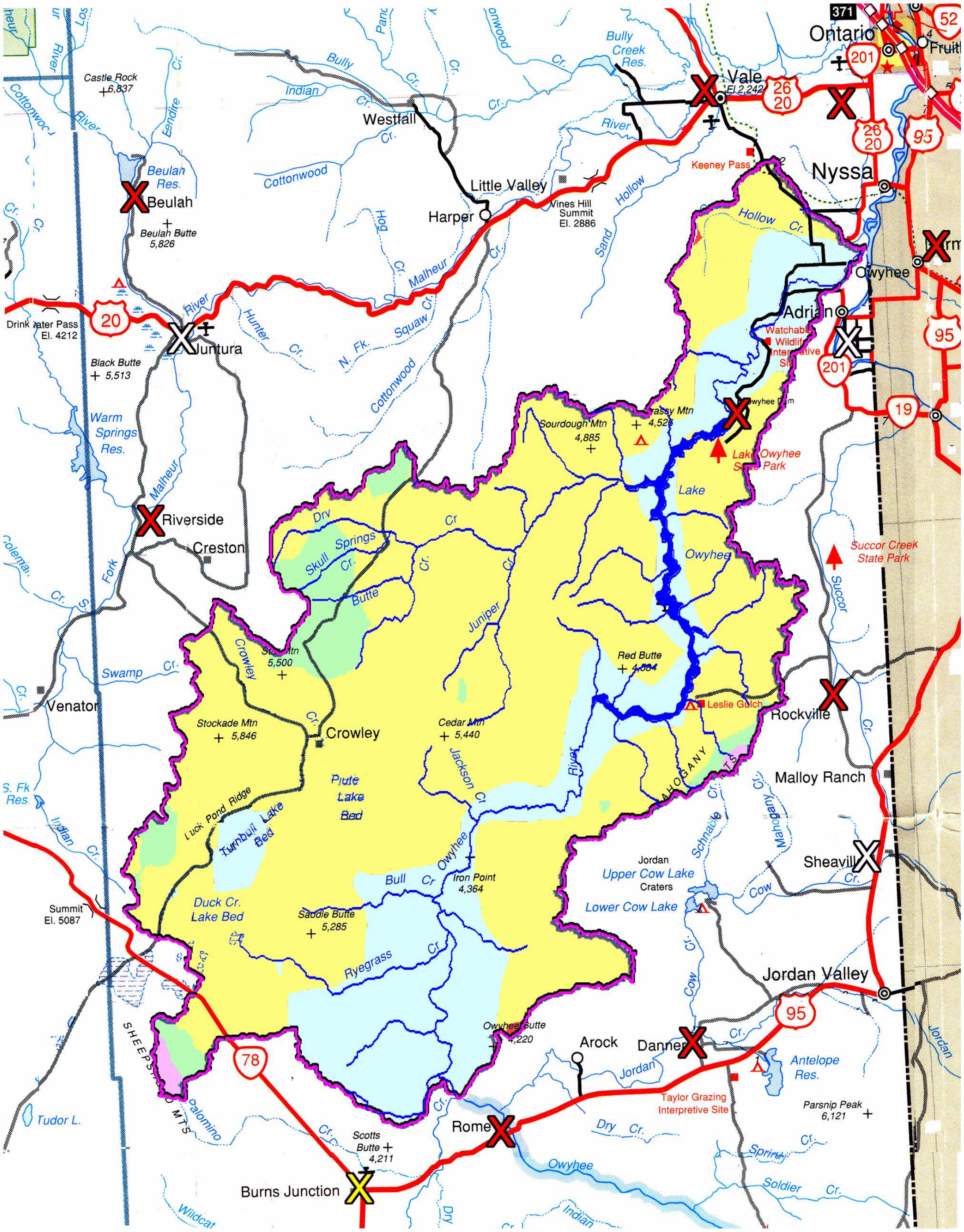


Figure 2.11. Annual precipitation in the lower Owyhee subbasin from PRISM modeling.[64]

Less than 9"
9" - 13"
13" - 17"
17" - 21"

X Current recording stations with over 30 years data

X Discontinued stations with over 30 years data - probably used in the modelling

X Discontinued stations with less than 30 years data

Cristopher Daly concludes "Users are encouraged to think critically when evaluating a spatial climate data set for their needs. None are perfect, but many are useful for a variety of regions and applications, if their limitations and assumptions are understood and respected."[24] The limitations of the annual precipitation map (Figure 2.11) are that it uses data from sparsely located meteorological stations. Local aspects that might affect climate in one locale are not reflected. Since the map is only the most general representation of rainfall patterns, rainfall at a specific point within the area may differ.

From the map of average annual precipitation (Figure 2.11), most of the area of the lower Owyhee subbasin averages less than 13 inches of rain per year. Small areas in the Sheepshead Mountains, Mahogany Mountain, near Duck Butte, and north of Star Mountain receive average annual precipitation between 13 an 21 inches of rain.

Only an area which generally receives less than 10 inches of precipitation a year is defined by some sources as a desert.[25,65] Other sources define a desert as only areas receiving less than 12 inches of precipitation a year.[94] Many ecologists studying ecosystems classify an area receiving less than 10 inches of precipitation as an "arid" deserts, whereas those areas receiving 10 to 20 inches are classified as "semi-arid deserts. [45,63]

Within a desert there is a random spatial variation in rainfall with differences occurring not only on a regional scale but also on scales of 350 feet to half a mile. Here the direction and speed of wind, the degree of slope, and the angle of the rainfall are important in hilly regions.[63] The random variation in where rain falls is greater for summer thunderstorms than for general winter storms. Daily rainfall may be localized to areas 1½ to 5 miles across with rain falling on a patch or strip of land. This variability can "hardly be ignored in ecological modeling in arid zones."[63]

3 Meteorological stations

Owyhee Dam is the only meteorological station within the lower Owyhee subbasin (Figure 2.11). There are other stations around the perimeter of the subbasin. The station at Rome, Oregon is slightly south of the southern boundary of the subbasin and upstream along the Owyhee River. The station at Danner is at a higher elevation on the plateau to the east of Rome. The Malheur Experiment Station (MES) station is to the north of the lower Owyhee subbasin within the Owyhee Irrigation District. These four stations have been chosen as fairly representative of the main climates in the lower Owyhee subbasin even though three of them are outside the boundaries of the subbasin.

4 Temperature

The average maximum temperatures at the four meteorological stations mentioned above closely track each other (Figure 2.12). Average temperatures begin to rise from January to February, peak during July, and fall between August and January. Danner, at a higher elevation, has average maximum temperatures that are slightly lower than the other three stations except during the fall. Only Danner doesn't average over 90^{0}F in July reaching only 89.3 degrees on average.[104,105,106,108]

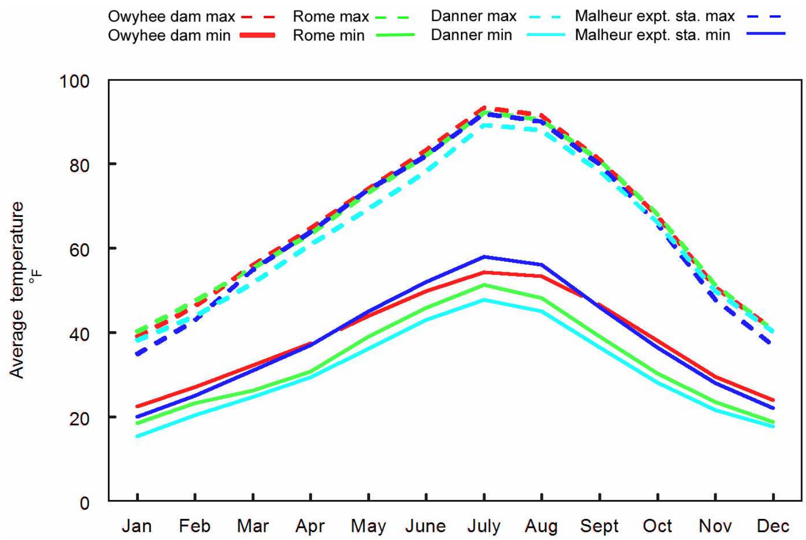


Figure 2.12. Average maximum and minimum temperatures at four weather stations around the lower Owyhee subbasin.

The average minimum temperatures rise and fall in a similar manner at the four stations (Figure 2.12). Although the average minimum temperatures from the different stations parallel each other, they show a difference roughly corresponding to their elevations. The average minimum temperature in every month is lowest at Danner, at the highest elevation, followed by Rome at a slightly lower elevation. Factors other than elevation are affecting the average minimum temperatures at the Owyhee Dam and MES since MES has lower temperatures than at Owyhee Dam except during the late spring and summer months.[104,105,106,108]

Average monthly maximum temperatures over 90^0F are considered to be hot. There is another way of looking at how hot the area gets. On average, how many days each month does the temperature reach 90^0F? Figure 2.13 shows the average number of days each month when the maximum temperatures are 90^0 or greater. In every month from June to September, Owyhee Dam has the most days above 90^0, followed by Rome, MES, and Danner with the fewest days over 90^0.[104,105,106,108]

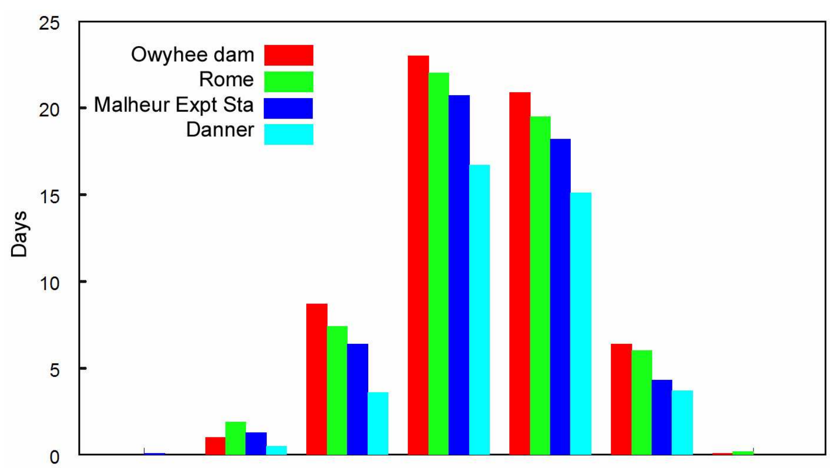


Figure 2.13. Average number of days each month with maximum temperatures greater than or equal to 90 °F.

Although all four of the meteorological stations show average minimum temperatures below 32^0F from November to February, how many days on average each month does the minimum temperature fall to 32^0 or lower? In every month, the Owyhee Dam site averaged the fewest days with minimum temperatures below 32^0 (Figure 2.14). Except for December and January when all of the stations had similar numbers, Danner had the most days that fell below 32^0F, followed by Rome and MES. The greatest difference in the number of freezing nights was in the fall and spring months: September, October, March, April, and May.[104,105,106,108] These are the months when the difference in low temperatures is most likely to affect the growth of vegetation in a different fashion at the different elevations.

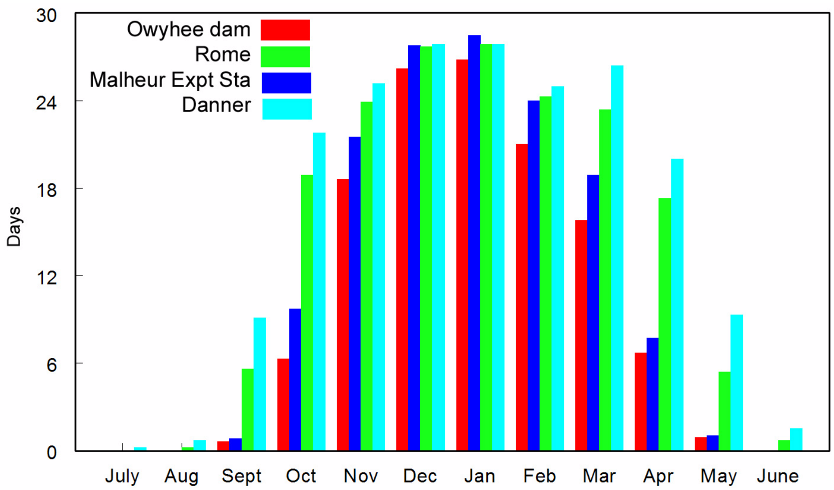


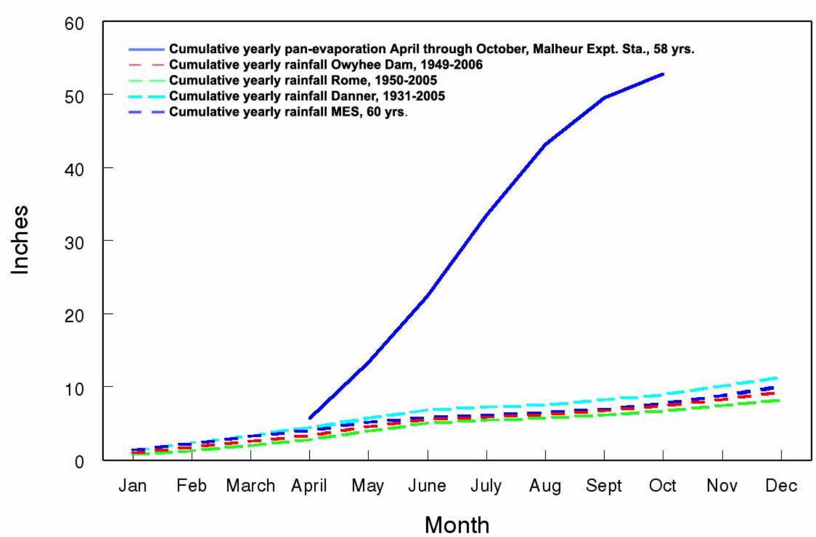
Figure 2.14. Average number of days each month with minimum temperatures less than or equal to 32 °F.

Because the temperatures in the winter in the lower Owyhee subbasin drop as low as they do, the area is also classified as a cold-winter desert.[45,101] The lower Owyhee subbasin is a semi-arid, cold-winter desert.

5 Potential evaporation.

One other way to define a desert is a region where the potential evaporation is significantly larger than the precipitation.[45,63,101] The Malheur Experiment Station measures the pan-evaporation, the amount of water which evaporates from a flat pan, from April to October. When the cumulative amount of pan-evaporation at MES is compared to the cumulative amount of precipitation at the different meteorological stations (Figure 2.15), it is apparent that the evaporative potential far exceeds the cumulative rainfall.[28,104,106,108] By October it is about five to six times as great.

Figure 15. Cumulative rainfall at four meterological stations in the lower Owyhee subbasin and cumulative pan-evaporation at Malheur Experiment Station.



The deficiency of rainfall received relative to the potential evaporative water loss tends to create a landscape with sparse vegetation.[45] Life in these regions is limited by the constant struggle to obtain water. The availability of water controls much of the ecosystem.[63,101] When annual water gained by precipitation is far less than annual water lost by evaporation, there are few permanent surface water streams that originate in a region.[25] Perennial surface water streams in the lower Owyhee subbasin largely originate elsewhere.

C. Vegetation

The vegetative distributions in the lower Owyhee subbasin are shaped by the geology, soils, and the low quantities and infrequent nature of water availability. The primary plant community is steppe vegetation dominated by sagebrush scrub and perennial bunchgrass.[87] Other plant communities are those consisting of playa vegetation, sagebrush on lava beds and the high elevation community containing mountain big sagebrush scrub and both mahogany and juniper woodlands. Depending upon soil depth and elevation, different subspecies of sagebrush (*Artemisia tridentada*) flourish.[6,87] Paleobotanical research reflects an environment which has supported *Artemisia* steppe / desert scrub communities for the last 8000 years.[87]

Willows, sedges, rushes, cottonwood trees and other riparian vegetation are found along perennial streams and some intermittent streams.

Throughout a desert environment, there is high spatial variability of plants. Vegetation can differ significantly between patches; patches in close proximity to one another may contain different species compositions.[87] Not all the vegetation is native. Cheat grass has spread over much of the rangeland and other invasive "weed" species are also altering the vegetative communities. The vegetation in the lower Owyhee subbasin is covered in more detail in the rangeland section below.

D. Wildlife

There is limited access to perennial water in the lower Owyhee subbasin due to steep canyon walls along much of the Owyhee River. Just like the vegetative distributions, the animal distributions are shaped by the low quantities and infrequent nature of water availability. The species present are similar to those found in surrounding regions. Large mammals of the Owyhee uplands today include pronghorn, mule deer, white-tailed deer, elk, feral horses and cougar. Bighorn sheep have been reintroduced to the rugged canyons. Wild horses are abundant. Some small animals are cottontails, jackrabbits, badgers, rattlesnakes, gopher snakes, chipmunks, sagebrush voles and coyotes. Birds like sage grouse, hawks, chukars, and migratory ducks and geese are fairly common.[82,92] Wildlife in the lower Owyhee subbasin is discussed in more detail in the wildlife section below.

E. Geology

The geological history of the lower Owyhee subbasin describes how the rock formations got to be where and what they are today. The rocks found within the lower Owyhee River subbasin can be the source for ores and minerals sought by rock hounds. The bedrock has also weathered to form the soils found within the subbasin. An overview of the chemical composition of rocks within the whole Owyhee River drainage explains the source of minerals such as uranium and mercury which, if they naturally occur within a rock, can be leached to the streams as the rock weathers. Once in the streams, these become part of the mineral load the river is carrying when it enters the subbasin.

The discussion will show that the rocks in the lower Owyhee subbasin were formed relatively recently from a geological perspective. The soils discussion will show that for the Owyhee Uplands the recent geological origin has resulted in soils that are very shallow.

1 Basic Geology

Geology is the study of the rocks that are found within a region, what the rocks are made of and how the rocks got to be where they are today. Geology explains scenic vistas like Leslie Gulch (Figure 2.16), the source of precious metals, and the source of sediments within the watershed.

Figure 2.16. Intricate rock formations in volcanic tuff in Leslie Gulch.

a. Minerals and rock formations

The term **mineral** is used for naturally occurring, solid compounds with a specific crystalline structure. Minerals can be found in their pure form, like a quartz crystal or gold vein, but more frequently minerals are mixed together to form rocks.

Rocks are named on the basis of texture, mineral composition and formation process. Common rocks are basalt and sandstone. Two sandstones may have the same basic mineral composition and similar texture, but they will often vary in the quantities of trace elements.

"The geologic record is made up of many different kinds of rock layers, some thick, some thin, some widespread, and some extending only a few feet. It is impossible and unnecessary to understand completely the relationships among all individual layers. Instead, geologists mentally gather layered rocks together into manageable units that are called formations. A formation may be a single thick layer or, more commonly, a group of individual layers with more or less consistent characteristics which are recognizable throughout a wide area."[49:3] For example, the lava flows from one volcano or the sediments accumulated in one lake bed may be called a **formation** as they have a similar source, composition, and age. Rock formations are given proper names such as “Jordan Craters Basalt”.

b. Rock classes

Geologists classify rocks into three major groups based on how the rocks are formed on the earth.

Igneous rocks are those formed by the cooling of magma. Basalt and granite are both igneous rocks as they are formed from magma: basalt by cooling on the surface of the earth or under the ocean in a lava flow and granite cooling more slowly within a mountain.

Sedimentary rocks are those formed by the accumulation of sediment in layers. Sediment most frequently accumulates on the bottom of the ocean, but it can also accumulate in lake beds or be layered ash.

Metamorphic rocks are those formed by placing existing rocks or sediments under extreme pressure and heat, usually deep within the earth's mantle.

Most of the rocks found within the lower Owyhee River subbasin are igneous or sedimentary rocks.

c. Weathering of rocks

Weathering is the process by which rocks are turned into smaller rocks and eventually sediment.

Physical weathering is the breaking of rock by natural forces such as frost wedging (water in cracks freezing and expanding), exfoliation (outer slabs detaching like onion peels), or wind breaking particles off of a rock. The amount of physical weathering depends upon weather conditions and the action of wind and water.

Chemical weathering is when a rock is altered or dissolved by chemical reactions such as the oxidation (rusting) of iron or dissolution of rock from acid produced by fungi. The rate of chemical weathering is determined by heat and humidity, which makes it rapid in the tropics.

In deserts the most common form of weathering is physical weathering. Chemical weathering affects unstable minerals such as halite (common table salt) which dissolves easily in water. By understanding the forms weathering takes as well as the original bedrock it, is possible to predict the effects of natural weathering processes on a region's rock features.

2 Rocks common in the lower Owyhee subbasin

A variety of igneous rocks are found in the lower Owyhee subbasin because of the active volcanism in the recent past. **Basalt** is a common rock of lava flows. It is generally black or dark-grey. Basalt pours out of cracks (vents) in the earth, so the final form looks like the syrup you pour on a pancake, it forms fairly level sheets of rock. Within the sheet the lava can crystallize into hexagonal columns (Figure 2.17).[9] The dark colors in basalt come from high concentrations of iron and magnesium. **Rhyolite** is the same composition as granite but it cools on the surface; it is composed almost entirely of silica.[77] In a pure form rhyolite will be a white rock, however it often has small mineral inclusions of iron or magnesium that turn the color reddish brown.

Figure 2.17. Basalt columns in the Owyhee watershed

Rhyolite doesn't flow as easily as basalt so it moves more like molasses. Often rhyolite is associated with explosive volcanism, like the building of cinder cones. When rhyolite forms lava flows it moves so slowly that the surface cools and then breaks into chunks that get moved within the flow so the surface is not as flat as a basalt lava flow.

Within the Owyhee uplands some of the volcanic activity was bimodal, indicating that both rhyolite and basalt erupted from the same volcanic vent at different times of activity. There are also many rocks that have a composition between that of basalt and rhyolite due to mixing of the two types of magma. The most recent volcanism at Jordan Craters provides a nice example of bimodal volcanism because both aspects of the volcanic activity are visible. The cinder and spatter cones are composed of rhyolite. First the cinder cone (Coffeepot Crater) and spatter cones formed on a hill (Figure 2.18). Then basalt lava flows broke through one wall of the cinder cone, flowing downhill, leaving the earlier phase of explosive rhyolite exposed.[11,75,79]

Figure 2.18. Coffeepot Crater at Jordan Craters.

Molten lava pushes to the surface through already existing rocks. Cracks in rocks often provide a route for the lava. After lava stops flowing on the surface, the lava still within the cracks will cool. These vertical pathways for lava are called **dikes**.[26] Sometimes the lava in cracks will never reach the surface, but it may form a dike underground that is later exposed by erosion. One example of a dike in the Owyhee uplands is Three Fingers Rock. When the Three Fingers caldera stopped its activity, this is the rock that cooled and plugged the vent.[74] Other impressive dikes of basalt are visible along the road through Leslie Gulch (Figure 2.19).

Figure 2.19. Basalt dike in Leslie Gulch.

Tuff is the term applied to all rocks formed from volcanic ash. When gasses and steam escaping from a volcanic vent come in contact with lava they can blow the lava apart. If these particles are as small as sand or silt they are called ash. This ash can then be moved long distances as flows or may become airborne.[93] When the ash flowing out of a volcanic vent stays very hot it will cool on the surface of the land, becoming a **welded tuff** (Figures 1.3 and 2.16). The heat of the ash particles was sufficient for them to stick, or weld, to each other.[93] Tuffs and welded tuffs are described on the basis of the type of igneous rock from which they are formed. Therefore a rhyolitic tuff is one that has the same minerals found in rhyolite but is in ash form.

Faulting is the process where pieces of the earth's surface change position in relationship to one another. This can be caused by large scale processes such as the movement of tectonic plates on the earth's surface and local processes like the emptying of magma chambers below the ground resulting in an area subsequently dropping. Faults are the lines along which we can see the movement that has occurred. When faulting causes vertical movement of the earth, multiple parallel fault lines can cause areas to rise into mountains while beside them basins are formed. The dropping piece of land that forms the basin is also called a **graben.**[39] The Snake River plain is a graben between the Owyhee uplands and the central mountains of Idaho.

Sedimentary deposits important within the Owyhee uplands are primarily lacustrine and alluvial deposits. **Lacustrine** sediments are those deposited within a lake. Generally lake sediments are fine grained because they come from material carried by the water. The type of minerals within lake deposits depends upon the rocks eroding around the lake. As the Owyhee uplands had active volcanism the sediments should be derived from those raw materials. In addition ash within the air will settle on the top of lakes and slowly reach the bottom. It is within ash or fine silt deposits of lakes that fish and leaf fossils are often found. Prominent lacustrine deposits in the lower Owyhee subbasin occur north of Rome along the Owyhee River at Chalk Basin, the playa lakes, and the lower Treasure Valley. **Alluvial** sediments are those deposited by running water, generally rivers. Rivers move gravel in their beds and carry small particles in suspension, making them look dirty. The gravel is left in old river courses as the river moves and smaller particles are deposited on flood plains or on lake bottoms where rivers enter lakes.[2] Like lake deposits, the rock materials found in alluvium are derived from other rocks in the area. But in many cases these deposits will contain larger chunks, namely gravel and boulders.

a. Weathering of common rocks

Ash tuffs are soft rocks easily sculpted by wind and water (Figure 2.16).[11] Basalt lava flows are significantly harder but can be broken down more easily than rhyolitic lava which is mainly silica. Rocks exposed in the Owyhee uplands are susceptible to weathering. It can be expected that soils and water will contain minerals common in the rocks, especially those found in volcanic ash or basalt because these rocks are more easily broken down.

b. Mineral and rock deposits with economic or scientific value

i. Gold

Gold has been found across the western US. Gold fever and boom to bust cities form part of the early history of Oregon, but there continue to be many claims to this day. In 1988 there were 10 active mines in Oregon and 36 exploration sites recorded by the Oregon Department of Geology and Mineral Industries.[29] Most gold originates in volcanic rocks, but the history of the landscape determines where it can be found.

Gold occurs in many types of geological deposits.[8,37] Gold veins are generally in metamorphic rocks where the gold has accumulated in conjunction with quartz following the intense heating of the rock. Placer gold is found in alluvial sediments where gold has eroded out of the rock it was originally in and settled out of the running water along with other heavy metals. Thirdly, gold can be concentrated by chemical interactions at hot springs around volcanically active areas.[78] This concentrated gold may be located in veins or disseminated. "The term 'disseminated' is now commonly applied to gold deposits in which very fine-grained gold is dispersed though a relatively large volume of rock."[8:11] It is the disseminated type of gold deposits that are most common in Malheur County, as exemplified by Grassy Mountain in the lower Owyhee subbasin.[29,73]

ii. Fossils

"Fossils are the mineralized or otherwise preserved remains or traces (such as footprints) of animals, plants, and other organisms."[31] "Fossilization is actually a rare occurrence because most components of formerly-living things tend to decompose relatively quickly following death. In order for an organism to be fossilized, the remains normally need to be covered by sediment as soon as possible."[31] Fossilized remains of plants and animals can tell us about the type of environments that existed in the past and the changes they have undergone.[11] Petrified wood is commonly found in the lower Owyhee subbasin.

iii. Thundereggs

"A thunderegg is a type of rock similar to a geode but formed in a rhyolitic lava flow and found only in areas of volcanic activity. Thundereggs are rough spheres, most about as big as a baseball. They look uninteresting on the outside, but slicing them in half may reveal highly attractive patterns and colors valuable in jewelry."[91] The thunderegg starts as a cavity in the rock where over time the passage of geothermal water allows for the deposition of minerals as crystals.[34] "The size of the crystals, including their form and shade of color, vary – making each geode unique. Some are clear as quartz crystals, and others have rich purple amethyst crystals. Still others can have agate, chalcedony, or jasper crystals. There is no way of telling what the inside of a geode holds until it is cut open or broken apart."[34]

c. Bentonite

Bentonite is a naturally occurring clay that is mined commercially. Bentonite is used in various ways including as a mud lubricant in oil and gas drilling projects and as an absorvant.[12,40] The production of bentonite requires the deposition of ash in a lake environment followed by heating from hydrothermal activity. These conditions have produced bentonite in the lower Owyhee watershed.

d. Zeolite

Zeolites are rocks with porous structures. "Natural zeolites form where volcanic rocks and ash layers react with alkaline groundwater."[113] Zeolites are used as cat litter, as a concrete additive, in water purification, in agriculture as a source of potassium, in laundry detergent, and for heat absorption in solar thermal collectors. The use of the zeolite is frequently based on the trace chemicals it contains; there are 48 naturally occurring types of zeolite.[113]

e. Mercury

Mercury is a commercially valuable metal that is used in batteries, paints and electrical devices.[112] Mercury deposits are formed at shallow depths and at temperatures of 50°C to 200°C. Mercury generally fills in pores and fissures where it was carried by heated water. Mercury is often found in association with gold and silver.[112] "The major producer, and only operating mercury mine, in the United States in 1984 was at McDermitt, Nevada. The ore is in . . . volcanic ash and lake beds, and is 70 percent cinnabar [mercury sulfide] and 30 percent corderoite [mercury sulfide chloride]. Grade is about 4 kg of mercury per ton of ore,"[112:146] or 0.4%. Between 1976 and 1983 the McDermitt mine produced mercury accounting for 46 percent of the US consumption.[112]

"Elevated concentrations of mercury in surface water can be derived from many sources, including natural processes and anthropogenic losses. Natural processes include volcanic and atmospheric deposition, degassing, and surface runoff and erosion of mercuric soils. Anthropogenic sources include mercury mining and processing, energy related activities, legacy pesticide application, chloro-alkali operations and small emissions from other industrial processes."[1:1] Geothermal activity can contribute to the concentration of mercury, so it is often found in regions of current activity or in rocks which developed under geothermal conditions. "While mercury most frequently occurs as deposits in rock fractures and veins, it may also be found in low concentrations in other geological formations. In the Owyhee River area, mercury is commonly found as an anomaly, present in 12 of 23 random outcrop rock-chip samples."[1:4]

3 History, as geology tells it

Geologists look at the placement of rock formations on the earth's surface to discover in what order events happened. For layered rocks they start with the principle of **stratigraphy**, that newer layers accumulate on top of older layers of rocks. This means that in a canyon like that cut by the Owyhee River the rocks at the bottom of the canyon are the oldest and those closest to the rim are the newest.

The geological record can be patchy as the creation of rocks is often followed by periods of erosion or relative inactivity. This can be seen when a group of tilted rocks get covered by new flat deposits (Figure 2.20). Past erosional surfaces can also be flat and hard to identify. Geologists call the gaps of time caused by erosional events **unconformities**.

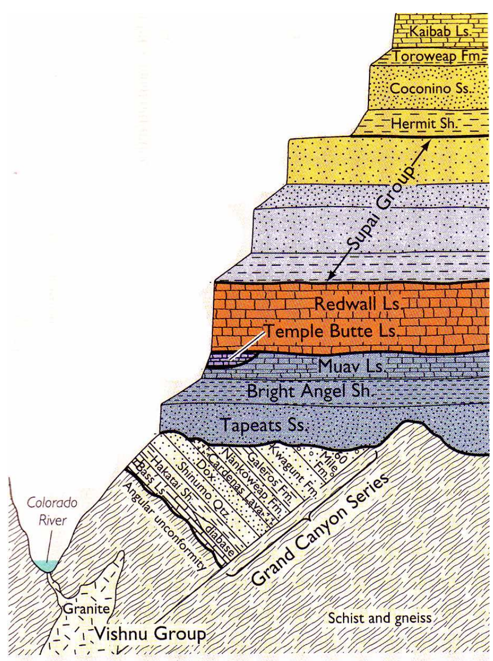


Figure 2.20. Geological series of the Grand Canyon is broken by erosional events (unconformities) seen as darker black lines. **(Adapted from 114:198)**

Things on the earth's surface don't always stay in the same place. **Faults** move pieces of the earth's crust past each other or up and down. The well known San Andreas fault in California is one where the two pieces of the crust are moving past each other. Faults where the crust moves up and down often form mountains and valleys, like death valley which has dropped below sea level while the mountains on both sides have moved upwards. Geologists use the rock formations moved by faults to help date when the faults were active.

a. Geological time scale

To compare historical events like the formation of the Grand Canyon or the Owyhee Canyon and the building of the Rocky Mountains or the Owyhee Mountains, geologists have developed their own time scale. They divide time into very large periods, **eons**, then **eras**, **periods** and the smallest subdivisions, the **epochs**.[97] These divisions are marked by major changes in the earth's environment or animal extinctions.[99] In Figure 2.21 you can see that the die off of the dinosaurs at 65 million years ago marks the end of the Cretaceous period and the Mesozoic era. All mammals are thought to have evolved in the last 65 million years, during the Tertiary and Quaternary periods. The Quaternary period, 1.8 million years ago through the present includes the entire history of modern humans.

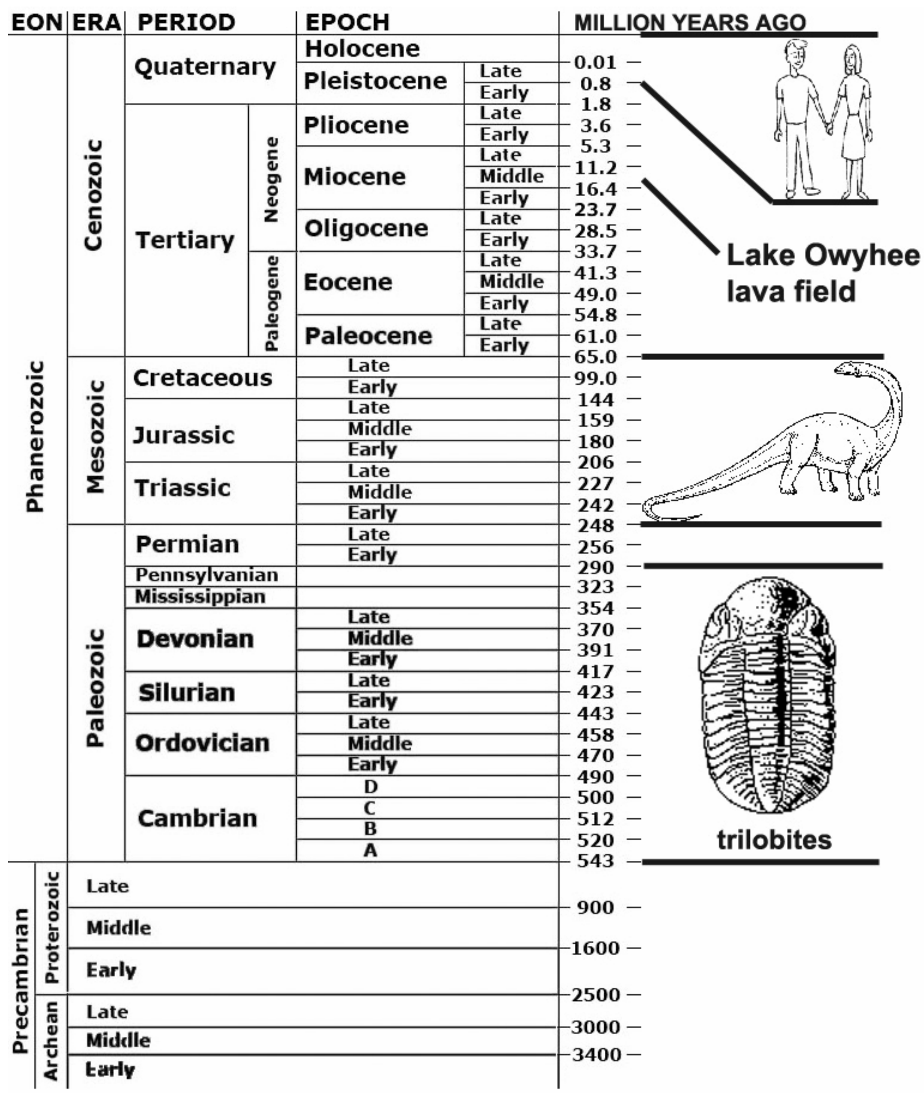


Figure 2.21. Geologic time scale.
(Adapted from 97)

After documenting major change in climate and fossils within the rocks, geologists date the divisions using radioactive decay of naturally occurring minerals within the rocks. Radiocarbon, or C^{14}, is often used to date charcoal from human fires because the rate of radioactive decay is predictable. For example, this is how we know that Native Americans killed mastodon in New Mexico 12,000 years ago. Other radioactive elements also decay at predictable rates but much more slowly so they can be used to date the formation of rocks. The radioactive elements used to date rock formations are potassium 40, rubidium 87, thorium 232, uranium 235 and uranium 238.[38,99]

Based on radioactive mineral data, the Owyhee uplands are very young on the geological time scale. After the dinosaurs died out 65 million years ago it was another 48 million years until the Steens and Sheepshead mountains were formed. This was followed only 15 million years ago by activity in the Lake Owyhee volcanic field.

4 Location of the Owyhee uplands in regional geology

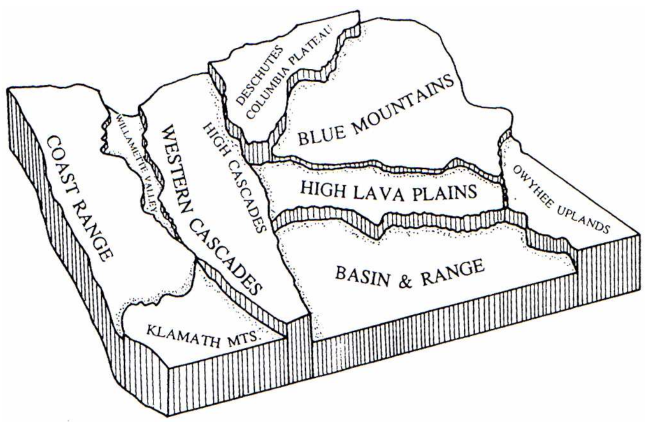


Figure 2.22. Geological areas of Oregon.
(Adapted from 74:1)

Eastern Oregon as we see it today began forming 20 to 25 million years ago. The region began extending east to west. Faulting like that of the Great Basin extended into Oregon. The stretching and cracking of the crust also provided a way for lava to reach the surface. The faulting was accompanied by volcanic eruptions on the Columbia River plateau, in the Steens Mountains, at Glass Mountain, and in the Strawberry Mountains.[11,74] This volcanism formed the High Lava Plains in central Oregon and the Columbia Plateau in northern Oregon (Figure 2.22).[96] In southeastern Oregon the Steens Mountain volcano sent basalt and ash into Idaho on the east, Lakeview County on the west, and up to Saddle Butte in the North (Figure 2.23).[74]

The Steens Mountain volcano was followed in Malheur County by the formation of a large number of calderas, also shown in Figure 2.23. These calderas were responsible for thick ash deposits such as those in Leslie Gulch (Figure 2.24).

North-south faulting with east-west expansion continued across southern Oregon, after the caldera eruptions, forming the basins of the Alvord desert and Warner Valley and ridges like the Steens Mountains (Figure 2.25).[96] Hot spring groups formed in north-south lines running along faults where groundwater could more easily flow down to the hot magma and back up to the earth's surface.

During the Pliocene large lakes formed in the basins because of higher rainfall. Alluvial sediments accumulated in the lake basins and along the stream courses feeding the lakes.[96] One of the largest lakes, Lake Idaho, occupied the area we now call the Treasure Valley. Lake Idaho (also known as Lake Payette) was very deep and covered areas into the northernmost reaches of the Owyhee uplands. It was only after Lake Idaho drained that the Owyhee River eroded its current path into southeastern Oregon. So the canyon lands we see today around the Owyhee River began forming between six and two million years ago.[47]

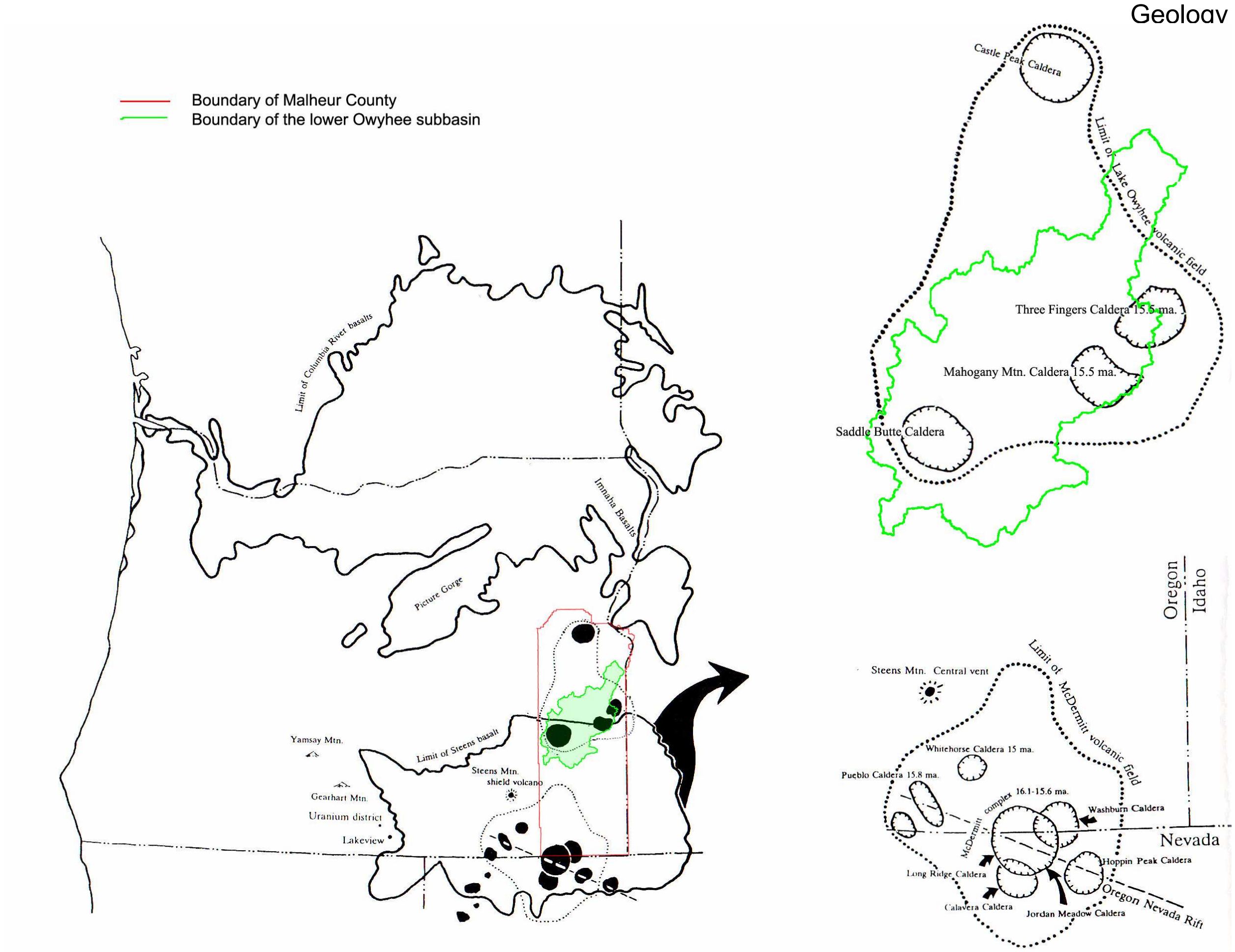


Figure 2.23. The Lake Owyhee and McDermitt volcanic fields are located in the Owyhee uplands of southeastern Oregon and northwestern Nevada.
(Compiled from 74:83 and 121:641)

Meanwhile in the western Snake River Plain, the crust was thinning and dropping. The exact process that accounted for the dropping of what we now call the Treasure Valley is debated, but involved graben faulting as well as possible formation of a rift.[55] "A well drilled by El Paso Natural Gas Co., 10 miles south of Vale, penetrated about 4,500 feet of Pliocene sedimentary rocks and lavas before encountering rocks considered to be ... older"[96:82] Drilling in other parts of the western Snake River plain has passed through basalt flows and sediments to depths of 2 to 3.4 kilometers.[55] This suggests a history where volcanism from the Owyhee River region and Bruneau area filled the Snake River Plain with new sediments and then the area began subsiding under the weight of it all.[47,55]

Volcanism, lakes, and faulting all played important roles in shaping the Owyhee uplands. The specific events that have affected the watershed are discussed below.

a. How did all the volcanism begin?

The Snake River plain is a huge, wide arc of croplands and arid unirrigated plains running from the Oregon-Idaho border to central Idaho where the valley continues to the Yellowstone National Park. The Treasure Valley western end of this valley. It is commonly considered that the movement of the Yellowstone "hot spot" caused the

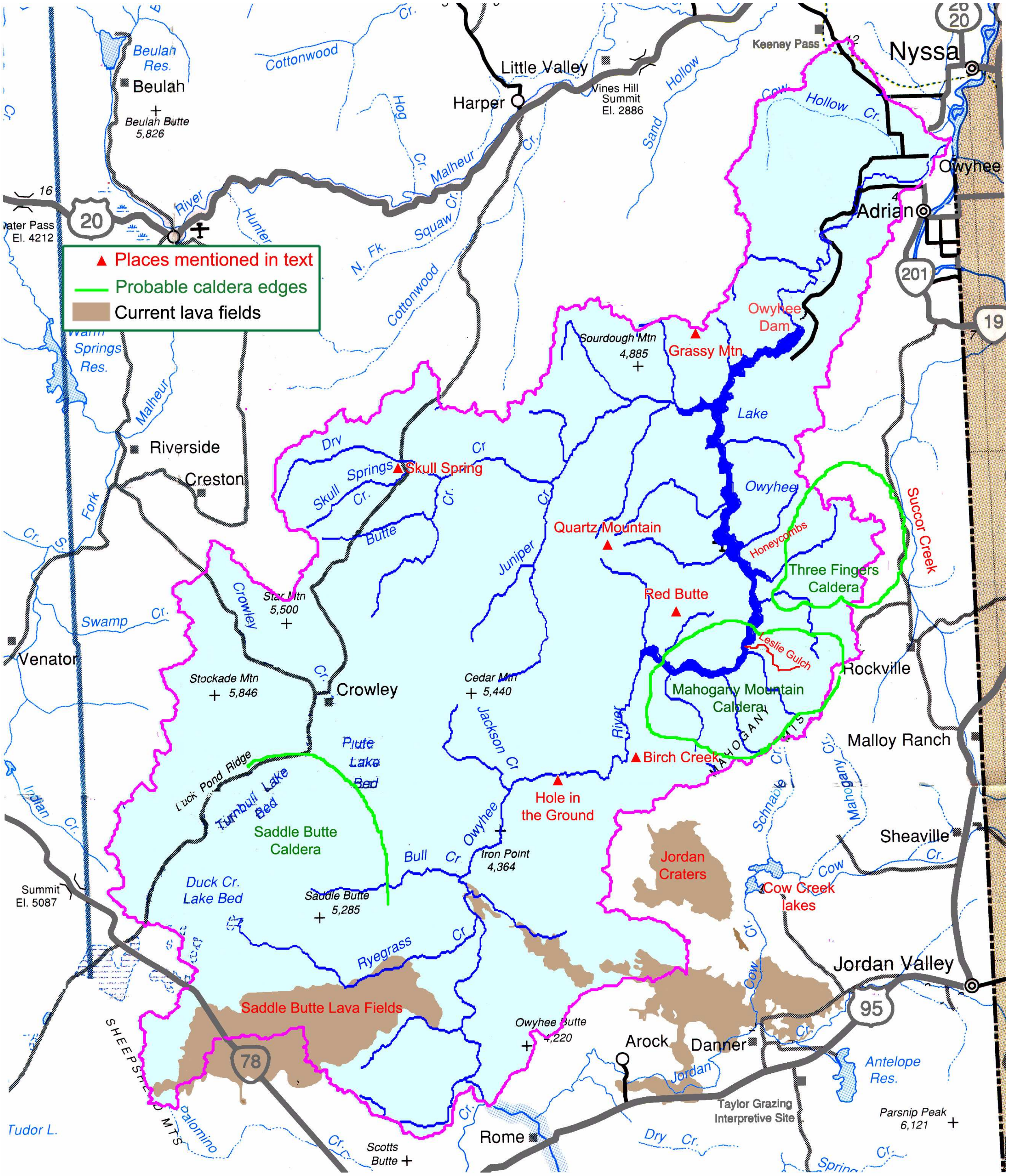


Figure 2.24. Locations of geological phenomena in the lower Owyhee subbasin. Places mentioned in the text are labeled in red.

creation of the west to east extension of the wide Snake River Plain. Hot spots are deep, hot locations on the earth that always produce volcanoes as the crust moves across them, like the Hawaiian islands. The Yellowstone hot spot was responsible for the valley created in central and eastern Idaho, but the hot spot missed the Treasure Valley. The Yellowstone hot spot actually followed a straight course out of somewhere

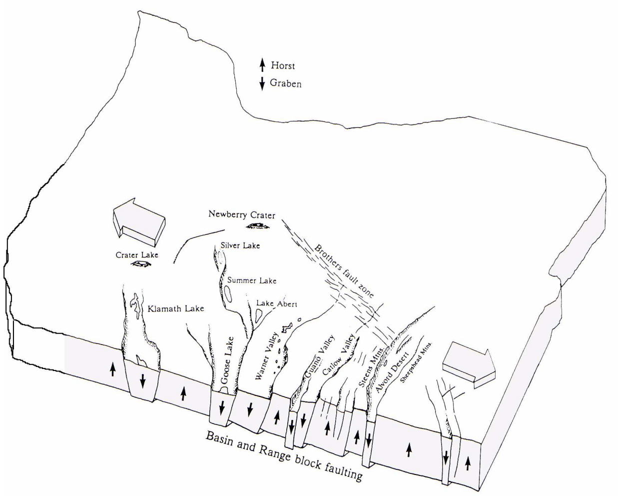


Figure 2.25. Faulting of the Great Basin extended into southern Oregon and stretched the earth's crust creating large valleys and the Steens Mountains.
(Adapted from 74:81)

in southeastern Oregon or southwestern Idaho (Figure 2.26). The fertile Treasure Valley was formed by faulting followed by alluvial sediments being deposited from Lake Idaho and from the water which drained across the Snake River plain after Lake Bonneville in Utah burst.[5,47]

Geologists debate how the Yellowstone hot spot began in southeastern Oregon or southwestern Idaho. Some credit the volcanism to a slab of the earth's crust that broke off as it was being pushed under the North American plate. [11,44,74] It has also been suggested that faulting stretched the crustal sediments in southeastern Oregon thin allowing for an outpouring of lava.[55] And yet others see the volcanism starting with a meteor impact.[3,4,5] Regardless of the cause of volcanism, authors agree that volcanic activity began 17 to 18 million years ago and radiated east and west. Volcanism, starting in the vicinity of the McDermitt caldera follows the Yellowstone hot spot to the east (Figure 2.26).[55] And to the west, volcanic calderas spread from Malheur county west across the High Lava Plains to Newberry crater in central Oregon, a recent caldera eruption (1.7 million years ago).[46,58]

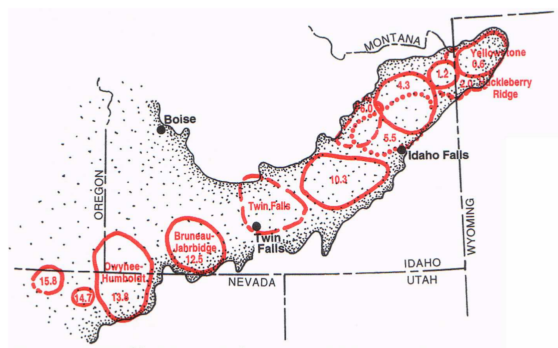


Figure 2.26. Calderas left across Idaho mark the movement of the Yellowstone hot spot from its origin at the Idaho, Oregon, Nevada border to its current location in Wyoming.
(adapted from 5:270)

b. Geological history of the Owyhee uplands

The lava flows and lake sediments found within the lower Owyhee subbasin average 14 to 15 million years old. And yet these changes are relatively recent from a geological perspective. Recall that the dinosaurs died out 65 million years ago.

The Lake Owyhee volcanic field is composed of four caldera volcanoes that were active 14 to 16 million years ago (Figure 2.23). The names given these calderas are Castle Peak, Three Fingers, Mahogany Mountain, and Saddle Butte. These calderas produced rhyolitic lava and ash. This activity as been dated to approximately 15.5 million years ago.[74] The ash from these calderas produced extensive beds of welded tuff exposed today in Succor Creek and Leslie Gulch (Figure 2.24). The activity of the calderas was followed by faulting and some erosion of the ash tuffs into stream courses and basin lakes. Fossils preserved in Succor creek ash and ash derived sediment deposits in a lake environment record Miocene plants and animals.

During the period that the calderas were active, the Owyhee Basalts blanketed more than 1000 square miles. The sources of these basalt flows were dikes that cut through the ash flows near Hole in the Ground around 15 million years ago. These basalts are often overlain by additional ash deposits from the calderas.

While the exact processes that caused volcanism to start and stop on the Owyhee uplands are debated, by 14 million years ago the area's surface was made up almost entirely of volcanic rocks. The next 14 million years are a convoluted sequence of faulting, lake beds filling, formation of sediments, small scale volcanism, and erosion.

The volcanic sediments of the Owyhee uplands have been broken by faulting, but the faults are shorter and more broken up than those in other parts of the Great Basin.[3] So while faulting created many hills and valleys the result is difficult to see and more recent smaller volcanism episodes have filled many of the troughs.[96]

The most recent geological activity dates to the Quaternary period, from 1.8 million years ago up through the present. During this period the surface of the Owyhee plateau has been covered by basalt lava flows. These flows are relatively intact as faulting has transformed the landscape less. The youngest of the lava flows are Jordan Craters (Figure 2.18), 3200 years or younger, and Diamond Craters (Saddle Butte lava field) which dates to approximately 17,000 years ago (Figure 2.24).[18] Jordan Craters is actually part of a larger group of four lava flows that were first described by Russell in 1903.[79] The rest of this lava field is composed of the Rocky Butte flow (30,000 to 90,000 years ago), the Clarks Butte flow (250,000 years ago) and the Three Mile Hill flow (1.9 million years ago).[42] For those familiar with the area, these flows progress from the oldest, Three Mill Hill, just north of Jordan Creek in a northward trend to Jordan Craters. The date of these flows has been estimated by potassium - argon dating, but the relative chronology was apparent in 1903 on the basis of the development of vegetation and soils atop the lava.[42,79]

5 Lower Owyhee subbasin geological features

a. Succor Creek and Owyhee River stratigraphy

While Succor Creek lies outside of the lower Owyhee subbasin, most of the geological studies in the Owyhee uplands have focused on this area and the Owyhee River (Figure 2.24). Since Succor Creek and the Owyhee River have cut canyons, the exposed canyon walls show the sequence in which the rocks were laid down.[13,48,50,53]

In Succor Creek, Lawrence mapped and described the portion between Sage and Camp Kettle creeks which is on the southeast portion of the Owyhee Ridge quad and the southwest portion of the Graveyard Point quad.[52,53] The rocks exposed in Succor creek show that it was part of a south to north trending lake basin in the late Miocene. This lake basin filled with sediments eroded from the volcanic ash and rhyolite to the south.

Kittleman described the formations making up a typical sequence in the eastern portion of the Owyhee region (Figure 2.27).[48,49,50] Starting at the bottom of the sequence, the Succor Creek Formation and Owyhee Basalt are rocks deposited during the caldera activity within the lake Owyhee volcanic field and from basalt vents in the area of Hole in the Ground southwest of the Birch Creek Ranch (Figure 2.24). The Deer Butte Formation is separated from deposits below and above by unconformaties, which can be interpreted as periods of erosion. The Deer Butte Formation has been dated as being from the end of the Miocene using mammal fossils in Idaho.[50] The Deer Butte Formation is a mix of sedimentary material, basalt flows and rocks made of cobbles.[50] The Deer Butte Formation reflects deposition in north trending basins which was controlled by faulting.[21,22] The Grassy Mountain Formation takes its name from basalts and ash layers found on Grassy Mountain that date to the beginning of the Pliocene.[22,50] The formation can be observed as a prominent, former mesa to the west of the Owyhee River. The stratigraphic sequence in Succor Creek ends here, but in other parts of the Owyhee uplands it is topped by younger basalt flows. Younger basalt flows at Cow Creek Lakes are individually 20 to 50 ft thick (Figure 2.24).[50] There are six or eight different flows, the youngest of which are nearly free of vegetation.

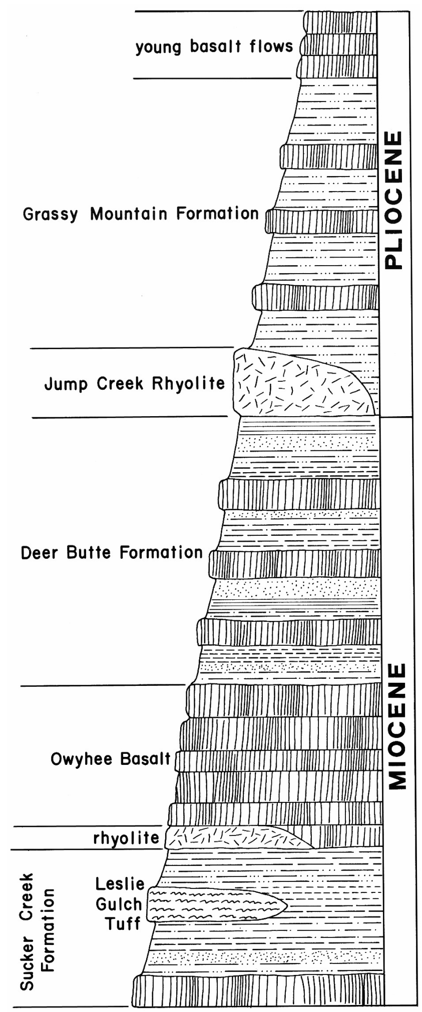


Figure 2.27: Sequence of layered rocks in the eastern Owyhee region, (Adapted from 49: Figure1)

This is the geological work that has been done on the stratigraphy of rocks in the local area, although the research was done outside the boundaries of the lower Owyhee subbasin. Kittleman's basic research around the Owyhee dam shows that the sequence of rock formation exposed in the Owyhee River canyon is identical to the adjacent Succor Creek stratigraphy.[48]

b. Lake Owyhee volcanic field

The Lake Owyhee volcanic field is defined as "all middle Miocene vents that formed following eruption of the Steens Basalt,"[30:12] where the volcanic material has a high silica content, basically rhyolite.

The Lake Owyhee volcanic field is composed of four calderas and a mini-caldera. The calderas are Castle Peak, Three Fingers, Mahogany Mountain, and Saddle Butte and the mini-caldera is the Honeycombs (Figures 2.23 and 2.24). The large volume volcanic eruptions from the calderas are dated between 15 and 15.5 million years ago.[80]

The scale of volcanic activity in the Lake Owyhee volcanic field was tremendous as measured by depth of ash flow and caldera dimensions. The ash flow produced by the Mahogany Mountain caldera is over 1000 feet thick in Leslie Gulch.[11] The scale of these eruptions is also visible along the Owyhee River canyon where much ash is visible in the canyon walls and river downcutting has yet to reach older geological deposits. "Mahogany Mountain is the southeast rim of an ancient volcanic caldera 10 miles in diameter, whereas the Three Fingers caldera just to the northeast, is a circular collapsed depression 8 miles in diameter." [74:85] Saddle Butte caldera is 15 miles in diameter but has been obscured by the more recent activities at the Saddle Butte volcanic field.[74] For size comparison to current volcanoes in the Oregon Cascades, Crater Lake is a caldera 6 miles in diameter and Newberry crater measures 5 miles in diameter.[5]

c. Leslie Gulch

The cliffs of Leslie Gulch are welded tuff from the Mahogany Mountain caldera. The flow in this location is more than 1000 feet thick.[11] "The rocks are soft, sculpted by water and pock marked by the escaping gases of their eruption. Larger holes reveal that sometimes chunks of solid rock are torn from the caldera's throat during eruption . . . and held closely in the ash flow."[11:159]

Figure 2.28 The Honeycombs, lower Owyhee subbasin.

d. The Honeycombs

"The Honeycombs ... represent a minicaldera that produced tuffs and rhyolite flows too viscous to be blown away. Instead, the gas-charged lava froze above its conduit, piling up in a mass of soft, cavity-ridden stone like a giant sponge. Fifteen million years of unceasing labor by wind and water eroded the softer stone, leaving rocks that look as though a shotgun-toting, Paul Bunyan-sized cowboy thought they were local road signs" (Figure 2.28).[11:159]

e. Oregon-Idaho graben

i. Hot springs

"The Owyhee caldera eruptions pumped a lot of magma and molten rock from beneath the surrounding landscape. About 14.5 million years ago, the crust just west of the main calderas began to subside along shallow faults. The resulting down-faulted basin is called the Oregon-Idaho graben. Lakes developed on the valley floor."[11:159] The faults of the Oregon-Idaho graben provided a path for surface water to interact with the magma still below the ground.[86] These super heated waters carried precious metals to surface hot springs where gold, silver, and mercury were deposited in tiny cracks within the rocks. These hot springs created large gold deposits in the lower Owyhee subbasin, but all the flecks of gold are extremely small.[11] Hot springs areas provided heat over long periods of time and altered existing deposits to create “picture rock” (silicified tuff) and zeolite.[30,127]

The fault activity along the Oregon-Idaho graben is dated on the basis of geological layers that were shifted around and geological deposition accompanying the faulting. The suggested onset of mineralization of hot-spring deposits is 14.5 million years ago according to Cummings or 13 million years ago according to Peter et al.[22:131,86:B7] Both of these sources agree that the end of hot-spring deposition was at 10 million years ago. Rytuba and Vander Meulen place the development of hot-spring systems between 14 and 8 million years ago.[80] The real agreement here is that faulting in the Oregon-Idaho graben and its accompanying highly active hot-spring depositions followed volcanism of the calderas and largely ended between 8 and 10 million years ago.

ii. Hot-spring gold deposits

The hot-spring gold deposits were formed in association with the faulting of the Oregon-Idaho graben. Gold carried in the water of the hot springs was deposited in spaces within volcanic rocks and tuff.[23] "Grassy Mountain, Red Butte, and Quartz Mountain, a series of peaks just west of the Owyhee River near Leslie Gulch, all sit atop large deposits of gold so finely divided that the metal can barely be seen in an electron microscope (Figure 2.24). The deposit at Grassy Mountain has been mapped out as 1.05 million ounces of gold contained in 17.2 million tons of rock ."[11:159] Gersic et al. tell us that most of these gold deposits are within the Deer Butte Formation.[35] This suggests that the faulting along Dry Creek, which is discussed below, may be a specific set of the faults associated with the Oregon-Idaho graben, but no references were found.

f. The Deer Butte Formation and the Dry Creek fault system

Following the outpouring of volcanic ash from the Lake Owyhee volcanic field, the deposits were moved by faulting. "Two zones are recognized: the western zone is the Wall Rock Ridge fault zone . . .; the eastern zone is the Dry Creek Buttes fault zone."[21:347] Both of these areas of faulting are within the lower Owyhee subbasin on the western side of Lake Owyhee. The Dry Creek Buttes fault zone has been "estimated at 8-12 km [5-7.5 miles] wide . . . The greatest displacement is near the west edge of Lake Owyhee where minimum throw [or vertical movement] is at least 240 m."[21:347] This fault zone, immediately to the west of Lake Owyhee, is important to the geology of the subbasin because these faults are long, running at least 50 km north to south, and because they moved geological strata up and down, moving volcanic deposits into different positions in adjacent areas. This faulting created north trending basins and ridges. Faulting is estimated to date between 15 and 12.6 million years ago.[22] Later in geological history these basins were home to lakes. Subsequent to the north-south trending lake basins, Dry Creek cut its path across east to west. Very little is known about the Wall Rock Ridge fault zone which is located further to the west and cuts across the higher headwater of the modern day Dry Creek drainage.

Since the fault under the Owyhee Dam runs parallel to faults of the Dry Creek system, it may date from the same geological era.

Since the dates for this fault activity overlap for dating of the Oregon-Idaho graben, it is possible that the two are connected processes, however none of the references mention this or tell us how these two sets of faulting are differentiated.

The north trending basins created by faulting in the Dry Creek and Lake Owyhee area are the setting in which geological layers named the Deer Butte Formation were deposited. These deposits are a mix of volcanic rocks from basalt flows, deposits from hot spring activity along the faults, and sedimentary rocks from river transported sand and ash and airborne ash.[21,22,23] Sediments of these types accumulated in five basins that changed in location on the basis of faulting and were each stable for approximately half a million years. Most of the sand that is part of these formations has its origin in geological formations of Idaho, indicating flow into the basins from the east. [50,80]

g. Grassy Mountain Basalt

The basalt flows that cap Grassy Mountain are called the Grassy Mountain Basalt. These flows are dated to 10 million years ago and are the last Miocene volcanic activity documented along the Owyhee River.[22]

h. Lakes of the Snake River Plain

The northern portion of the lower Owyhee subbasin below the dam is largely in the western end of the Snake River plain. The western Snake River plain appears to have developed from the middle of the Miocene to present times. The "western segment [of the Snake River plain] is bounded by prominent NW-trending faults."[55:4,59,60] The western Snake River plain is filled with sediments and Pliocene and Miocene volcanic rocks to depths of 2 to 3 kilometers.[55,59,96] These observations are consistent with the geological structure known as a graben. The area was covered by lava and ash flows of the Miocene, but when faulting began these geological layers were dropped down great distances relative to where they were originally laid down. Once lower than the surrounding land the western Snake River plain became a lake bed.

The large lake that filled the Snake River Plain has often been called Lake Idaho. Within the lake, water moved slowly allowing for particles to settle on the bottom of the lake and form sedimentary deposits (Chalk Hills and Glens Ferry Formations). As much of the run-off feeding Lake Idaho came from volcanic regions, the sediments deposited in the lake were primarily ashes.[47,58] The high lake levels also produced gradual stream courses in the surrounding hills and mountains. The alluvial sediments deposited in these stream courses are at levels much higher than where creeks and rivers run today within the Owyhee uplands.

The exact time frames within which Lake Idaho was full of water are in debate among geologists. Kimmel discusses how Lake Idaho actually filled at two separate times. [47] Once at the Late Miocene-Pliocene boundary (6.5 - 9 million years ago) and again during the Pliocene (approximately 2.5 - 3.3 million years ago). Hart comments that significant lake deposits date from 4.1 to 4.5 million years ago, in contrast to 6.5 to 9 million years ago. Either way, the western Snake River plain filled with water twice during the Pliocene and the geological markers of this are the Chalk Hills and Glenns Ferry formations, lake sediments named for where they were identified.[47,90]

With the western Snake River plain full of water, eventually the water needs somewhere to go. Geologists discuss two possible outlets for Lake Idaho. The first is the current path through Hells Canyon. The second is an outlet to the southwest. This is postulated as a possible outlet based on fossil fish and snails that suggest Lake Idaho may have been linked to the California coast.[5,60] It has also been suggested that the southwestern route was the outlet for the earlier lake and the route through Hells Canyon was carved the second time the lake reached a high stand, around 2 million years ago.[47,60] Glenns Ferry sediments are little more than 2 million years old and these are the best marker of the second lake high.[60] Volcanism may have caused the lake outlets to be blocked in both instances when the lake was full.[47] The height of these blocking flows determined the lake level. A major topographic break at 3800 feet above sea level may mark one of the shorelines.[5]

The lake that began forming in the Late Miocene left its mark on the land in fine sediments, sometimes including fish fossils. Faulting after the deposition of lake sediments means that today they can be found at a higher level on the edges of the Snake River Plain (such as at Chalk Hills) because faulting continued to drop the plain to its present level. The exception to this occurs around Adrian where the sediments do not show a clear history of deposition. Kimmel suggests that faulting and subsidence could account for the jumbled arrangement of these sediments. Both Chalk Hills and Glenns Ferry sediments are found in the Adrian area.[47]

A final note on the western Snake River plain is that at the end of the Pleistocene, approximately 15,000 years ago, a lake briefly formed once again. This time the lake was the result of the Bonneville flood.[4,5,60] The various sediments deposited on the floor of the lake in what is now the Treasure Valley have contributed to the type of soils found there and to the difference in soils between the plains and areas above the plains.

6 Lower Owyhee subbasin mineral deposits and mining

"The deposit types considered most important for metallic minerals in the MJARA [Malheur-Jordan-Andrews resource areas] are shallow, hot-spring-related, hydrothermal deposits of mercury, gold and silver. Uranium deposits ... are associated with some of the mercury and precious-metal deposits. ... The hot-spring deposits are shallow and disseminated."[86:B5] Smith ed. and Peters et al. modeled the probable occurrence and quantities of gold, silver, copper, uranium and mercury within the Malheur-Jordan resources areas of the BLM.[76,86] There are no known occurrences of oil or gas within the Owyhee uplands, nor would oil and gas be likely on the basis of the geological deposits.[86]

a. Gold

The known gold deposits within the lower Owyhee subbasin are disseminated gold deposits. The hot springs that formed along the faults of the Oregon-Idaho graben all produced disseminated deposits of gold.[29,73,81] As mentioned above, Grassy Mountain, Red Butte and Quartz Mountain all sit above gold deposits. This gold is very small flecks distributed through large quantities of rock. For example, the Quartz Mountain prospect has 0.04 ounces of gold in each ton of rock.[29] The only commercial method currently known for extraction of disseminated gold is a large open pit mine using heap-leach methods to remove the gold.[8,11] "The gold is extracted from millions of tons of crushed rock by spraying or injecting a cyanide solution onto or into heaps of it and leaching the gold out. Known as cyanide heap-leach mining, the technique uses the cyanide to dissolve gold from the stone, then recovers both cyanide and gold."[11:159]

In 1988 there were 14 commercial exploration sites for hot-spring gold deposits within the subbasin. This exploration followed the announcement made the same year by Atlas Corporation of their discovery of gold at Grassy Mountain.[29] This boom in commercial gold exploration was followed by a downturn by 1991 when most commercial companies had abandoned their prospects,[43] probably due to environmental concerns and Oregon's extremely stringent regulations on heap-leach mining. Ellen Bishop explains that the "technique of extracting the gold calls for large-scale open-pit mining . . . [and the] process requires holding ponds of cyanide laced waters. While an economical method of mining gold, cyanide heap-leach mining carries grave risks and leaves deep scars on fragile arid landscapes."[11:159] Grassy mountain deposits are still of commercial interest.[35]

b. Thundereggs

Thundereggs are well known from the area of Succor Creek. While not a precious stone, thundereggs are collected and sold.[54] "Succor Creek Thundereggs: This deposit is in the far eastern part of Oregon almost on the border with Idaho. This was and is a very large deposit of Thundereggs."[71] "Thundereggs from Succor Creek are from Oregon. The centers are mostly blue agate with white bands. Thunderegg rough sizes are from 1-4 pounds each."[89]

Because thundereggs form in cavities within the ash flows, the type of minerals they will contain is based on the solution which filled the cavities. Thundereggs are sought for agate in particular. "One of the more important nonmetallic minerals in the Owyhee country is gem-quality chalcedony (agate) that is much prized by 'rockhounds' throughout the country. Some of the well known areas where agatized material has been found are along Succor Creek and the Owyhee Reservoir (moss agate and thunder eggs), in Stinkingwater Mountain (petrified wood and agate), and in the Buchanan area (thunder eggs)."[96:83]

The extent of thunderegg deposits within the lower Owyhee subbasin is unknown. Southeast of Skull Springs there is an area where thundereggs have been collected (Figure 2.23).[10] Both moss agate and jasper can be found in Leslie Gulch north of the road and near the Owyhee Reservoir.[10] There is an old jasper mine above the historic Birch Creek Ranch (Figure 2.24).[15]

c. Bentonite and Zeolite

The Teague Mineral Products mill, one mile to the south of Adrian, Oregon, began mining bentonite and zeolite in 1974. "The bentonine deposits are located 20 mi south and east on Succor Creek."[40:7] The main mining occurs in a deposit 20 feet thick that is within the Miocene age ash-tuff beds called the Sucker Creek Formation. This bentonite bed is at or near the surface in various areas within the Succor creek basin and in basins to the east. This main mining bed exceeds 8 miles in length. The Teague Mineral Products mill has also mined a more recent bentonite bed within Succor Creek, but it is unknown if this bed continues to the west to enter the subbasin. The mining is open pit mining.[40]

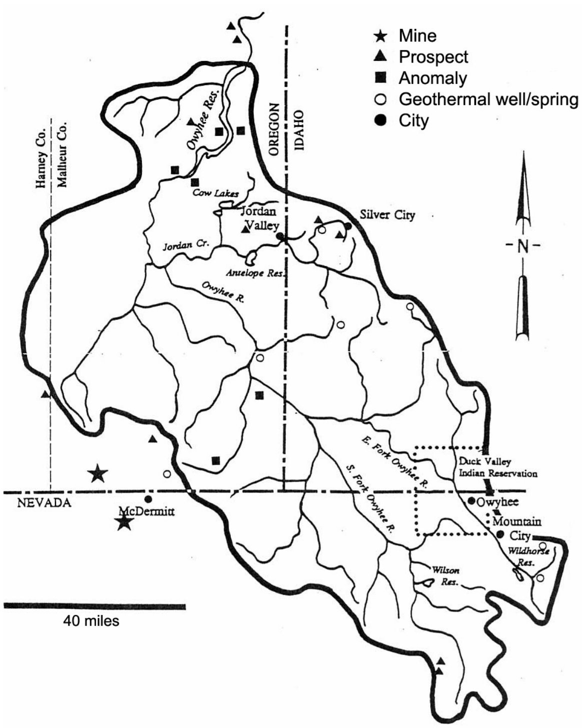


Figure 2.29. Occurrences of mercury prospects and known mercury anomalies in the Owyhee River drainage.
(Adapted from 51)

d. Mercury

Mercury is reported from within the subbasin on the western side of the Owyhee reservoir (Figure 2.29).[1] The occurrence of anomalous high mercury concentrations (>0.2ppm) is also recorded in rock samples taken by the BLM within wilderness study areas. "The study found 10 sample locations with high mercury concentrations in rock chip samples along the west side of Owyhee Reservoir and two locations with high values on the east side of the reservoir."[51]

e. Uranium

The uranium potential within the Oregon-Idaho graben (OIG) was judged to be low. However, "One uranium prospect is known in the OIG at Valley View."[86:B11]

7 Geologic maps of the subbasin

The Oregon Department of Geology and Mineral Resources has released geologic maps or partial geological maps for some of the USGS 7.5" quadrangles within the subbasin. These are: Owyhee Dam, Owyhee Ridge, Mahogany Mountain, Double Mountain, Mitchell Butte, Keeny Ridge, and Grassy Mountain.[86] Within the Twin Springs quadrangle the area of Red Butte has been mapped at a scale of 1:7500.[22] The rest of the subbasin geology remains unmapped at a fine scale.

8 Erosion of geological deposits within the subbasin

Because lava and ash flows carpeted the Owyhee uplands during the middle to late Miocene, all of the soil that used to exist in the area was buried under these flows. Also the existing stream channels were blocked and covered. All of the sediments and stream locations we see today formed in recent geological history. Since ash and tuff are more susceptible to chemical and physical weathering than basalt and rhyolitic lava, the majority of the sediments are derived from ash and tuff.

Ash flow deposits erode quickly into sediment from both the action of wind and water.[93] These sediments are carried down slope in runoff and by gravity (through rock fall and avalanche). Steep slopes do not hold any of the eroding sediments. As sediments are carried from steep slopes and deposited on lower slopes and along stream courses, we can expect the soils found within the subbasin will differ based on their slope. Ash also settled out on the bottoms of lake beds formed during the Pliocene. As Adrian and the Snake River plain were under water from Lake Idaho, settling ash helped to form the soils.

Lava flow surfaces erode and breakdown very slowly into soil. Young lava flows are covered by soil brought in by the wind or by sediments washing in from higher land. This soil is important for vegetation. In the Owyhee uplands there are many locations where the lava flows are the uppermost geological strata. In these locations soil develops very slowly. If a lava flow is the highest feature in the landscape the only sediment input for soils will come from the wind. Softer, sand-like rock layers that are found below the lava may erode but due to their lower position do not provide sediment for the soil. The various lava flows associated with volcanism around Jordan Craters give us an idea of the time scale required for soil formation. What we map as Jordan Craters is the most recent in a series of lava flows. The three older components are less visible today because they have some vegetation growing on them. However the amount of vegetation is controlled by the amount of windblown dirt that has accumulated. The three areas discussed above have progressively more vegetation the older they are because they have collected a greater amount of windblown soil.[79]

There are still several lava fields that haven't been reclaimed by vegetation along the southern edge of the lower Owyhee subbasin, including the Saddle Butte lava field (Figure 2.24).

9 Mineral deposits and mining in the headwaters of the Owyhee River drainage

As the rocks within the subbasin erode to form the soils, some of the minerals within the rocks and soils will be carried in the water flowing off of the hills for great distances. Rocks and minerals being carried by the Owyhee River when it enters the subbasin come from geological deposits up stream.

a. Gold and Silver

Gold and silver are known from other hot spring deposits within the Owyhee watershed. The most notable are the vein deposits of silver and gold near Silver City, Idaho.[36] Gold and silver washing out of these deposits have been carried downstream.

b. Cyanide

Successful mining of disseminated gold and silver deposits only became economic after 1890 when the cyanide leaching process was introduced commercially in South Africa.[8] If any cyanide heap-leach mining has been used for hot-spring deposits within the headwaters of the Owyhee River, cyanide could be introduced to the water. No record has been found of such activity.

c. Mercury

Mercury has been used in the extraction of gold. This is an anthropogenic addition of mercury to the environment. "The Delmar-Silver City area in Idaho is the only area of mining activity that has been positively identified as a source of environmental mercury in the [Owyhee River] Basin. The Silver City area is suspected as a mercury source because of the use of mercury to recover gold and silver from ores".[51] Once mercury or any other heavy mineral pollution is within the sediments, it will behave as if it were derived from a natural deposit and be moved by water flow, both groundwater and runoff.

Koerber also reports natural mercury deposits within the Owyhee river drainage in the headwaters of Jordan Creek and far to the south in Nevada in the headwaters of the south fork of the Owyhee River.[51] Allen and Curtis record the mercury in the same region of the headwaters of the Owyhee River as mercury deposits (Figure 2.29).[1] Aside from formal deposits, the Owyhee River area has anomalous mercury occurrences recorded from random rock-chip samples. These samples have an average mercury concentration of 0.3 parts per million (ppm) of mercury.[1] The anomalous locations include the Owyhee Breaks area and Three Forks area where BLM rock chip sampling found high mercury concentrations in four and two locations, respectively.[51]

d. Uranium and Mercury deposits

Uranium and mercury are found together in the McDermitt volcanic field (Figure 2.23).[85] Both of these heavy metals were concentrated by the volcanism of rhyolitic calderas and subsequent hot spring activity.[17] "The mercury minerals are deposited from ascending hot waters".[96:26] The Bretz mine, Opalite mine, Cordero mine, McDermitt mine, and Moonlight mine are all commercial mining operations that have worked in the McDermitt volcanic field.[51,85,86] The mercury deposit that has been exploited by the Bretz Mine is the largest mercury deposit in North America.[51,112] These deposits are also associated with arsenic, barium, molybdenum, antimony, and copper.[86] In addition to rich uranium deposits, the rhyolite of the McDermitt volcanic field contains greater quantities of uranium (12 ppm) and thorium (another radioactive metal, 19 ppm) than is standard (6.5 ppm).[17] It is probable that runoff from the McDermitt region will naturally carry some uranium and mercury.

Sediments washed downstream which contain mercury may come from natural deposits or be a legacy of anthropogenic gold mining and processing activities.

e. Potassium

About five miles southwest of Rome, Oregon, one of the ash deposits has a bed one foot thick of high-grade potassium feldspar. "The size and purity of these potentially valuable feldspar deposits are not adequately know [sic] for a meaningful appraisal; however, large volumes of vitric tuffs have obviously been replaced by potassium feldspar. Deposits of similar or higher grade may occur in the tuffaceous rocks of other Cenozoic basins of southeastern Oregon. Some of these deposits may have commercial potential for use by the glass and ceramic industries or perhaps as a source of potash for fertilizer."[96:229]

10 Summary

The beauty of the lower Owyhee subbasin is due to the geology of the area. The rock formations, lava flows and ash deposits within the subbasin are of very recent geological origin. The erosion of these rock formations and of formations upstream in the rest of the Owyhee basin creates the sediments within the region. These sediments may carry minerals from naturally occurring deposits. There are no geologic maps for most of the quadrangles in the subbasin.

F. Soils

Soils are very important to ecosystems. They hold water and nutrients that plants need to grow. In turn, plants contribute organic matter to the soil and help break down bedrock. This section will discuss the basic characteristics of soils from desert climates and what we know about the soils from the lower Owyhee subbasin. In general these soils are composed of material derived from the volcanic and sedimentary rocks and soil depths are shallow. There has been no systematic soil mapping of the Owyhee uplands although mapping is currently underway.

1 Basics of soil

Soil can be defined as the product of weathering processes. Physical weathering breaks a rock down into minerals, but does not change the composition of the original rock. The amount of physical weathering generally effects the grain size. Since chemical weathering alters the mineral composition of rocks, it slowly removes the least stable minerals.

The make-up of soil is controlled by six factors: the original bedrock, time, vegetation, slope, precipitation, and human action. The minerals that make up the soil begin with those which were in the **bedrock**. The bedrock breaks into smaller particles with weathering. **Time** is also a factor in soil development; the longer a soil has been exposed to the surface the more weathering can occur. **Precipitation** serves as a basic control on the amount of chemical weathering that goes on in the soil by providing water to carry away dissolved minerals. The **vegetation** growing on any spot of soil can change the soil chemistry by taking up nutrients, by providing organic matter from fallen leaves or dead plants, by rain leaching nutrients from the plants into the soil, and by the root structure helping secure the soil in place. The **slope** of the land surface determines in part the stability of that surface. Steep slopes that are prone to landslides have little chance for soil development as the slides remove developing soils. On a smaller scale, any hill slope will experience erosion while flat areas have the opportunity to hold onto soil. **Human action** can change soils by adding organic matter, removing vegetation and adding mulch. Human action is most pronounced in areas with long term agriculture and urbanization, for example some soils in Europe have experienced so many years of mulching that their present composition is almost entirely based on this human action. The development of a soil, also known as **pedogenesis,** is controlled by these six factors.

Soils are described on the basis of a **soil profile**, a description of the physical and chemical characteristics of the soil from the surface to the bedrock.[32] Researchers dig multiple holes across the landscape to map out the soil type and its variations. To describe soil, scientists designate **horizons**, or layers that have consistent physical and chemical characteristics. The combination of horizons found in a single hole allows a researcher to classify the type of soil they have found. In addition the soil scientist uses principles of geology to understand the distribution of soils because different land forms, like hills, slopes, and flood plains, will have different types of soil.

2 Desert soils

"The climatic regime of arid lands can be expressed as one in which potential evaporation greatly exceeds precipitation during most of the year, and no or little water percolates through the soil. This implies of course a slow rate of chemical weathering and other water based chemical transformations, a low rate of biological activity because of water stress on plants of all kinds, and a consequent reduction of plant cover." [19:16] While semiarid climates have a slightly higher quantity of precipitation than arid lands, chemical weathering is less important than physical weathering. One of the results of less chemical weathering is that, "soils inherit many of their characteristics from the parent material"[19:17] With physical weathering, the bedrock is broken down into smaller and smaller pieces, but it is not transformed chemically into another type of mineral.[33] Physical weathering in the form of extreme rainfall is recognized as one factor driving erosion and creating differing soils on slopes and flood plains.[41]

The other defining characteristic of soils in arid and semiarid environments is that regular precipitation events do very little leaching of minerals from the soils. This can leave layers within the soil with high concentrations of salts. "The most striking feature of desert soils is the presence of layers of accumulation of calcium carbonate [or lime], gypsum, sodium chloride or other salts."[19:17] At times these salt layers become so cemented that they inhibit the growth of plant roots. The development of salt concentrations is normally a factor of age.[19] Layers of sodium chloride and calcium carbonate (know locally as caliche) were commonplace in low lying parts of the lower Owyhee subbasin that have been converted to irrigated agriculture. These salt and calcium carbonate layers had to be broken and dispersed by deep plowing to allow crop production.

a. Factors in desert soil formation

Soil formation does not occur in isolation from other parts of the ecosystem. Climate, vegetation and geology all influence soil. And, soil in turn influences the growth of vegetation and the break down of bedrock.

"The scarcity of vegetation limits the amount of residue available for soil organic matter production in arid climates. Since nitrogen is carried in soil organic matter, it is low in desert soils."[33:40] In addition, temperature controls the rate of decomposition of organic mater. In warm wet climates, decomposition takes place year round, in colder climates decomposition only occurs in the warmer months when moisture is present. The cycling of organic material is dependent upon microorganisms in the soil that break leaf litter and branches into their component parts.[27,33]

In deserts most rain "falls rapidly. Soil washing, erosion and runoff are intense. The high runoff rate further reduces the rain's effectiveness for plant growth except along stream channels, arroyos, and valleys were water accumulates. Shrubs and trees grow more densely along these water drainageways, and soils show the effect of more organic matter."[33:40] "The consequences of the high-intensity rain are rapid runoff and accelerated erosion."[27:208] Low topographic areas accumulate soil while the slopes lose soil to erosion.[100]

While erosion of desert soils is often high, topography, vegetation, and storms play into how erosion actually works. Soil loss is greater when either the steepness or length of a slope increases. "Longer slopes are more susceptible to erosion on the lower end because more water accumulates on long than on short slopes. Vegetation directly affects the erosion hazard in two ways: (1) plant canopies and residues reduce the impact of raindrops on the soils surface; and (2) anchored vegetation slows water movement across the land"[27:208] Another aspect of erosion is the duration of rainfall; the longer the duration the more likely that the soil's maximum water infiltration rate will be exceeded. It is when infiltration rates are exceeded that water runs across the surface of the ground because it can not be absorbed. This is more likely if the rain is very intense or lasts for a long time.

Soil moisture is controlled by infiltration rates, the rate at which soil can absorb rainfall, and water holding capacity. The water holding capacity of a soil is based on the type and quantity of pores it has and its depth. "Rain in the arid regions tends to come in high-intensity storms in which the rainfall rate greatly exceeds the infiltration rate."[27:208] After rainfall, the water held within the soil will be depleted as atmospheric evaporation and plant transpiration use the water. "Water storage is greatest when the initial evaporation rate is high and a dry surface soil is formed rapidly."[27:211] This means that the flow of water between pores in the soil does not bring deeper water to the surface where it will be evaporated. A study on water retention in semiarid soils of New Mexico showed that "moisture conditions most favorable for plants occurred in areas where: (1) the landscape was level or nearly level, with little or no evidence of erosion; (2) there was a thin coarse-textured surface horizon to permit maximum infiltration of moisture; and (3) the subsoil was fine textured and/or indurated to prevent deep moisture movement. A coarse-textured surface soil not only permits rapid infiltration of water but also dries rapidly and protects subsoil water from evaporation losses."[27:212]

b. Soil nutrients

Certain types of desert vegetation alter the soil in which they live by accumulating soluble minerals, normally salts. "The soil located under and in close proximity to these plants may take on a wholly different physical character."[33:40-41] The salt cedar that is becoming established as a weed in the lower Owyhee subbasin is know to concentrate salt in surface soils.

The availability of soil nutrients to plant life is dependent upon the organic material produced by vegetation growing on the soil which is subsequently deposited as litter from leaves, seeds, and wood.[100] Plants need nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, and micronutrients.[32] Normally these nutrients become available for plant uptake from chemical weathering of the soil such that it is broken into component minerals. Because chemical weathering rates are reduced in desert soils, there are less nutrients available for plant use. Additionally, plants need a certain balance between nitrogen, phosphorus, potassium, and other nutrients. In desert soils, generally nitrogen and phosphorous levels are usually insufficient for maximum growth.[32]

Desert soils are also known for their spotty distribution of nutrients. The areas around shrubs where organic litter is greatest generally have higher quantities of phosphorus, potassium and nitrogen.[83,84] This patchy distribution of nutrients is very good for the shrubs, but can have long lasting effects on fertility even after shrublands have been turned to grass.[84] The processes that lead to the development of shrub patches with high quantities of nutrients are still unknown.[84] Schlesinger and Pilmanis suggest that the formation of these islands of fertility may be due, in part, to the collection of a soil mound around the base of the shrubs, the sediment coming from wind erosion of the open spaces between shrubs.[83] The formation of nutrient rich zones around desert shrubs allows for the continuation of shrub vegetation. And, the replacement of grassy deserts with shrub deserts generates an increase in the amount of dust.[83]

3 Soil classification system

The United States has developed a classification system to describe all soils. The classification has orders, suborders, great groups, subgroups, families and series. Each stage of the classification process describes the soil profile in greater detail.[14,88]

Most soils in the lower Owyhee subbasin fall into the order of Aridisols or Entisols.

"Aridisols are mineral soils of the arid regions. They have a low organic-matter content. During most of the time when temperature range is favorable for plant growth, the soils are dry or salty, with consequent restrictions on growth. During the warm season, there is no period of three months or more when soil moisture is continually available to plants, except in places where a water table is close to the surface."[27:42] Common aspects of aridisols are a layer of pebbles on the surface of the ground and a subsurface zone where salts have accumulated to form a hard or cemented layer. However for soils to form distinctive layers through their depth they must be on relatively stable landforms, where erosion is minimal. On some desert tablelands with resistant geological layers, such as basalt, clay rich soils will form when the tableland is "isolated for tens or hundreds of thousands of years"[27:49]

Entisols have no development of layers within the soil that show distinctive physical or chemical modification to the parent material and, as such, are lacking layers referred to by soil scientists as pedogenic horizons. "Entisols are mineral soils showing little or no development of pedogenic horizons. . . . Pedogenic horizons have not formed because, primarily, the soils are too young due to recent deposition of fresh material or to eroding away of the previous surface."[27:43] A basic example of an entisol would be a sand dune, where there is no differentiation between sand at the top where plants are growing and the mineral sand that formed the dune. Other entisols occur in areas of recent deposition such as flood plains and areas of ongoing erosion such as hill slopes.[27] Shallow stony soils over bedrock also fall in this category.

4 Data on soils in the lower Owyhee subbasin

The above discussion of desert soils lets us know what type of soils we should expect in the subbasin, but this does not describe the variability in soils or their current attributes and distribution.

There is almost no data on soils in the lower Owyhee subbasin. The only soil surveys are below the dam on agricultural soils and in archaeological excavations at Birch Creek along the Owyhee River. In addition we have data from work with vegetation on the Owyhee plateau to the south of the subbasin.

a. Agricultural soils

The agricultural portion of northeastern Malheur County has an intensive soil survey.[57] This soil survey includes maps that break down every field into specific named soil series. The soil series are based upon physical and chemical characteristics and subsequently each series is divided by soil texture and slope. This detail can be overwhelming, but is very useful for planning purposes.[57] The agricultural soils within the lower Owyhee subbasin are classified into 9 series along the Owyhee River and its previous meanders and an additional 11 series for the slopes and plains around the river.

The basic characteristics of these soils, despite the 20 series names are very similar. From the region's geology we know that these soils have their origin in the sediments deposited on a lake bed and flood plain deposits of the Owyhee River. The soil textures are silty loam and sandy loam.[57] The depth to bedrock is always greater than 60 inches, however many soils have a cemented layer, or pan of calcium carbonate, between 20 and 40 inches depth. This is an accumulation of salts that is common in desert soils and which farmers have broken with ripping or deep plowing. All of the soils classify as either Entisols or Aridisols. Risk of flooding and a high water table also characterize the soils adjacent to the Owyhee River.[57]

b. Soils at Birch Creek on the Owyhee River

During archaeological investigations at the location of Birch Creek Ranch on the Owyhee River the soils of the Owyhee River flood plain were described.[7] The sample location is on the east side of the river and in what used to be a farmed field. There are three terraces, each of which represents the flood plain of the river at a different period in time. The highest terrace is the oldest and furthest away from the current river. The lowest terrace is the youngest and closest to the river. The soils on all three terraces are Entisols.[7]

"The highest terrace is believed to be late Pleistocene in age"[7:82] meaning that it would be between 15,000 and 10,000 years old. This terrace is made up of gravels that rolled down from the canyon slope above it and sand and gravel deposited by the Owyhee river. This soil also has the formation of lime (calcium carbonate) concentrations where the lime has been washed by rainfall but not leached from the soil. [7] In addition, there are clays in the soil. Clay likely formed when the climate was wetter. The highest terrace also preserves, in places, evidence of large scale flooding that carried much of the gravel away and predates the formation of the middle terrace.[7]

The middle terrace is quite different from the one above it. The material is primarily Owyhee River sands. These sands were deposited on top of flood gravel and the Mazama volcanic ash which dates to 6,700 years before present.[7] This means that the middle terrace has formed over at least the last 7,000 years. Rainfall has transported some lime down in this soil, but the concentration is lower than that of the higher terrace.[7]

The lowest terrace "contains a very young soil with minor indications of soil development."[7:82] The parent material is sands and some silts deposited by the Owyhee River during flood stages.

c. Soils south of the subbasin on the Owyhee plateau

To the north of Jordan Creek, but south of the lower Owyhee subbasin Culver studied vegetation.[20] Part of this study was an exploration of the soils that were found in association with each vegetation type. He describes ten different soil profiles from holes he dug in the region. In two of his pits he hit volcanic rock at less than 20 inches. In six of the other samples he hit a hard layer of lime or basalt between 20 and 35 inches. Only two of the samples have soil extending deeper than 37 inches.[20] The depth at which root growth is inhibited is a major factor in determining the vegetation that can grow in a soil.[56] The soil classification terminology used by Culver is no longer in use.[7]

5 Conclusions

Very little is known about soils within the lower Owyhee subbasin. From geology, topography, and the semiarid environment we expect that many of the soils are recent in origin and will reflect the chemical composition of the volcanic parent material. Known soils fall within the Aridisol and Entisol orders of the U.S. soil classification scheme, as expected. On going soil survey work will greatly enhance knowledge of local soils in the near future.

Bibliography

1. Allen, S.M. and L.R. Curtis. 1991. An ecoregion approach to mercury dynamics in three Oregon reservoirs. Department of Fisheries and Wildlife, Oregon State University, Corvallis, Oregon.
2. Alluvium. 2006. *Wilkipedia: the free encyclopedia*. Accessed 7/25/2006. http://en.wikipedia.org/wiki/Alluvium
3. Alt, David D. and Donald W. Hyndman. 1978. *Roadside Geology of Oregon*. Mountain Press Publishing Company, Missoula, Montana.
4. Alt, David D. and Donald W. Hyndman. 1989. *Roadside Geology of Idaho*. Mountain Press Publishing Company, Missoula, Montana.
5. Alt, David D. and Donald W. Hyndman. 1995. *Northwest Exposures: A geological story of the Northwest*. Mountain Press Publishing Company, Missoula, Montana.
6. Anderson, E. William, Michael M. Borman, and William C. Krueger. 1998. *The Ecological Provinces of Oregon: A treatise on the basic ecological geography of the state*. Oregon Agricultural Experiment Station.
7. Andrefsky, W. and K. Presler. 2000. Archaeological Investigations at Birch Creek (35ML181): 1998-1999 Interim Report. *Contributions to Cultural Resource Management No. 66*. Center for Northwest Anthropology, Pullman, Washington.
8. Ashley, Roger P. 1991. Gold and silver deposits of the United States. In *The Geology of North America, Vol. P-2, Economic Geology U.S.*, edited by H.J. Gluskoter, D.D. Rice and R.B. Taylor, pp 3-22. The Geological Society of America, Boulder, Colorado.

9. Basalt. 2006. *Wilkipedia: the free encyclopedia*. Accessed 7/25/2006. http://en.wikipedia.org/wiki/Basalt
10. Big Sky Maps. 1993. Malheur County, Oregon, North Half. Big Sky Maps, Clackamas, Oregon.
11. Bishop, Ellen Morris. 2003. *In Search of Ancient Oregon: A geological and natural history*. Timber Press, Portland, Oregon.
12. Brobst, Donald A. 1991. Other selected industrial minerals. In *The Geology of North America, Vol. P-2, Economic Geology U.S.*, edited by H.J. Gluskoter, D.D. Rice and R.B. Taylor, pp 189. The Geological Society of America, Boulder, Colorado.
13. Bryan, Kirk. 1929. *Geology of reservoir and dam sites with a report on the Owyhee irrigation project, Oregon*. Water-Supply Paper 597-A. United States Government Printing Office, Washington D.C.
14. Buol, S.W., R.J. Southard, R.C. Graham, and P.A. McDaniel. 2003. *Soil Genesis and Classification*, 5th edition. Iowa State Press, Ames, Iowa.
15. BLM Vale District. 1995. Recreation Guide, Malheur Resource Area. Bureau of Land Management, U.S. Department of the Interior.
16. Bureau of Land Management. 2002. *Southeastern Oregon Resource Management Plan*. Bureau of Land Management, U.S. Department of the Interior, Vale, Oregon.
17. Castor, Stephen B. and Christopher D. Henry. 2000. Geology, geochemistry, and origin of volcanic rock-hosted uranium deposits in northwestern Nevada and southeastern Oregon, USA. *Ore Geology Reviews* 16:1-40.
18. Chitwood, L. A. 1994. Inflated basaltic lava - examples of processes and landforms from central and southeastern Oregon. *Oregon Geology* 56(1):11-21.
19. Claridge, G.G.C. and I.B. Cambell. 1982. A comparison between hot and cold desert soils and soil processes. In *Aridic Soils and Geomorphic Processes*, edited by D.H. Yaalon, pp 1-28. Catelina Verlag, West Germany.
20. Culver, Roger N. 1964. An Ecological Reconnaissance of the *Artemisia* Steppe on the East Central Owyhee Uplands of Oregon. Master of Science Thesis, Oregon State University, Corvallis, Oregon.
21. Cummings, Michael L. 1991. Geology of the Deer Butte Formation, Malheur County, Oregon: faulting, sedimentation and volcanism in a post-caldera setting. *Sedimentary Geology* 74:345-362.
22. Cummings, Michael L. 1991. Relations among volcaniclastic sedimentation, volcanism, faulting, and hydrothermal activity west of lake Owyhee, Malheur County, Oregon. In *Geology and Ore Deposits of the Great Basin: symposium proceedings*, edited by G.L. Raines, R.E. Lisle, R.W. Schafer and W.H. Wilkinson, pp 111-132. Geological Society of Nevada, Reno, Nevada.
23. Cummings, Michael L. and Lawrence P. Growney. 1988. Basalt hydrovolcanic deposits in the Dry Creek arm area of the Owyhee Reservoir, Malheur County, Oregon: Stratigraphic relations. *Oregon Geology* 50(7/8):75-82.
24. Daly, Christopher. 2006. Guidelines for assessing the suitability of spatial climate data sets. International Journal of Climatology 26:707-712.
25. Desert. 2006. *Wikipedia, the free encyclopedia*. Accessed 8/4/2006. http://en.wikipedia.org/wiki/Desert.
26. Dike(geology). 2006. *Wilkipedia: the free encyclopedia*. Accessed 7/25/2006. http://en.wikipedia.org/wiki/Dike_%28geology%29
27. Drengne, H.E. 1976. *Soils of Arid Regions*. Developments in Soil Science 6. Elsevier Scientific Publishing Company, New York.
28. Feibert, Erik B.G. and Clinton C. Shock. 2006. 2005 Weather Report. *Oregon State University Agricultural Experiment Station, Special Report 1070*.

29. Ferns, Mark L. 1989. Mining activity and exploration in Oregon, 1988. *Oregon Geology* 51(2):27-32.

30. Ferns, Mark L. 1997. Field trip guide to the eastern margin of the Oregon-Idaho graben and the middle Miocene calderas of the Lake Owyhee volcanic field. *Oregon Geology* 59(1):9-20.

31. Fossil. 2006. *Wilkipedia: the free encyclopedia*. Accessed 8/21/2006. http://en.wikipedia.org/wiki/Fossil

32. Fuller, W.H. 1975. *Management of Southwestern desert soils*. University of Arizona Press, Tucson, Arizona.

33. Fuller, W.H. 1975. *Soils of the Desert Southwest*. University of Arizona Press, Tucson, Arizona.

34. Geode. 2006. *Wilkipedia: the free encyclopedia*. Accessed 8/21/2006. http://en.wikipedia.org/wiki/Geode

35. Gersic, J. J.M. Achuff, A.G. Hite, G.R. Peterson and D.G. Willard. 1994. Mineral resource assessment for the BLM Malheur-Jordan Resource Areas, Oregon. *Mineral Land Assessment Open File Report, volume 1*, United States Department of the Interior, U.S. Bureau of Mines.

36. Gillerman, Virginia S. Idaho Mining and Geology. *Geo Note* 40, Idaho Geological Survey, Moscow, Idaho.

37. Gold. 2006. *Wilkipedia: the free encyclopedia*. Accessed 9/12/2006. http://en.wikipedia.org/wiki/Gold

38. Gore, Pamela J.W. 1996. Radiometric Dating. Accessed July 21, 2006. http://www.gpc.edu/~pgore/geology/geo102/radio.htm

39. Graben. 2006. *Wilkipedia: the free encyclopedia*. Accessed 7/25/2006. http://en.wikipedia.org/wiki/Graben

40. Gray, J.J., R.P. Geitgey, and G.L. Baxter. 1989. *Bentonite in Oregon: Occurrences, analyses, and economic potential*. Special Paper 20, State of Oregon Department of Geology and Mineral Industries, Portland, Oregon.

41. Guthrie R.L. 1982. Distribution of great groups of aridisols in the United States. In *Aridic Soils and Geomorphic Processes*, edited by D.H. Yaalon, pp 29-36. Catelina Verlag, West Germany.

42. Hart, W. K. and S. A. Mertzman. 1983. Late Cenozoic volcanic stratigraphy of the Jordan Valley area, southeastern Oregon. *Oregon Geology*, 45(2):15-19.

43. Hladky, Frank R. 1992. Mining and exploration in Oregon during 1991. *Oregon Geology* 54(3):57-64.

44. Hooper, P.R., G.B. Binger, and K.R. Lees. 2002. Ages of the Steens and Columbia River flood basalts and their relationship to extension-related calc-alkalic volcanism in eastern Oregon. *GSA Bulletin* 114:43-50.

45. Hurley, Braden, Simon Welte, Wendell King, Daniel Gilewitch, and John Brockhaus. 2004. Desert analysis: the quest for training areas. Center for Environmental and Geographic Sciences, West Point. Accessed 8/4/2006. http://gis.esri.com/library/userconf/proc04/docs/pap1744.pdf.

46. Jordan, B.T., A.L. Grunder, R.A. Duncan and A.L. Deino. 2004. Geochronology of age-progressive volcanism of the Oregon High Lava Plains: Implications for the plume interpretation of Yellowstone. *Journal of Geophysical Research* 109, B10202.

47. Kimmel, Peter G. 1982. Stratigraphy, age, and tectonic setting of the Miocene-Pliocene lacustrine sediments of the western Snake River plain, Oregon and Idaho. In *Cenozoic Geology of Idaho*, edited by Bill Bonnischsen and Roy M. Breckenridge, pp.559-578. Bulletin 26, Idaho Department of Lands Bureau of Mines and Geology, Moscow, Idaho.

48. Kittleman, L.R. 1962. Geology of the Owyhee Reservoir Area, Oregon. Unpublished Ph.D. dissertation, Department of Geology, University of Oregon.

49. Kittleman, Laurence R. 1973. Guide to the geology of the Owyhee region of Oregon. *Bulletin of the Museum of Natural History*: 21. University of Oregon, Eugene, Oregon.

50. Kittleman, L.R., A.R. Green, A.R. Hagood, A.M. Johnson, J.M. McMurray, R.G. Russell, and D.A. Weeden. 1965. Cenozoic stratigraphy of the Owyhee region, southeastern Oregon. *Bulletin of the Museum of Natural History*: 1. University of Oregon, Eugene, Oregon.

51. Koerber, Sarah. 1995. *Mercury in the Owyhee River Basin: Oregon, Idaho, and Nevada*. Oregon Department of Environmental Quality, Portland, Oregon.

52. Lawrence, David C. 1988. Geologic field trip guide to the northern Succor Creek area, Malheur County, Oregon. *Oregon Geology* 50(2):15-21.

53. Lawrence, David C. 1988. Geology and revised stratigraphic interpretation of the Miocene Sucker Creek Formation, Malheur County, Oregon. Boise State University, Department of Geology and Geophysics

54. Lawson, Paul F. 1989. Thunderegg collecting in Oregon. *Oregon Geology* 51(4):87-89.

55. Leeman, William P. 1982. Development of the Snake River Plain-Yellowstone Plateau Province, Idaho and Wyoming: An Overview and Petrologic Model. In *Cenozoic Geology of Idaho*, edited by Bill Bonnischsen and Roy M. Breckenridge, pp.139-153. Bulletin 26, Idaho Department of Lands Bureau of Mines and Geology, Moscow, Idaho.

56. Lentz, R.D. and G.H. Simonson. 1987. Correspondence of soil properties and classification units with sagebrush communities in southeastern Oregon: comparisons between mono-taxa soil-vegetation units. *Soil Science Society of America Journal* 51:263-1271.

57. Lovell, B.B. 1980. *Soil Survey of Malheur County, Oregon: northeastern part*. United States Department of Agriculture, Soil Conservation Service in cooperation with Oregon Agricultural Experiment Station.

58. Luedke, Robert G. and Robert L. Smith. 1991. Quaternary volcanism in the western conterminous United States. In *The Geology of North America, Vol. K-2, Quaternary Nonglacial Geology: Conterminous US*, edited by Roger B. Morrison, pp 75-92. The Geological Society of America, Boulder, Colorado.

59. Mabey, Don. R. 1982. Geophysics and tectonics of the Snake River Plain, Idaho. In *Cenozoic Geology of Idaho*, edited by Bill Bonnischsen and Roy M. Breckenridge, pp.139-153. Bulletin 26, Idaho Department of Lands Bureau of Mines and Geology, Moscow, Idaho.

60. Malde, Harold E. 1991. Quaternary geology and structural history of the Snake River Plain, Idaho and Oregon. In *The Geology of North America, Vol. K-2, Quaternary Nonglacial Geology: Conterminous US*, edited by Roger B. Morrison, pp 251-281. The Geological Society of America, Boulder, Colorado.

61. National Register of Historic Places. 2006. Oregon - Malheur County - Historic Districts. Accessed 8/1/2006. http://www.nationalregisterofhistoricplaces.com/or/Malheur/state.html.

62. Natural Heritage Advisory Council to the State Land Board. 2003. *Oregon Natural Heritage Plan*. Accessed 7/26/06. http://oregonstate.edu/ornhic/ornh_plan.pdf.

63. Noy-Meir, Imanuel. 1973. Desert ecosystems: environment and producers. *Annual Review of Ecological Systems* 1973.4:25-51.

64. NRCS. 2005. Lower Owyhee - 17050110: 8 digit hydrologic unit profile. Accessed 5/23/2006. ftp://ftp-fc.sc.egov.usda.gov/OR/HUC/basins/snake/17050110_11-03-05.pdf.

65. NRCS. 2005. MLRA definitions. Accessed 7/27/2006. http://soils.usda.gov./survey/geography/mrla/mrla_definitions.html.

66. NRCS. 2006. *Land Resource Regions and Major Land Resource Areas of the United States, the Caribbean, and the Pacific Basin*. United States Depart of Agriculture Handbook 296. Accessed on line 7/26/06. ftp://ftp-fc.sc.egov.usda.gov/NSSC/Ag_Handbook_296/Handbook_296_high.pdf.

67. NRCS. 2006. National coordinated common resource area (CRA) geographic database. Accessed 7/27/2006. http://soils.usda.gov/survey/geography/cra.html.

68. NRCS. 2006. Oregon NRCS GIS resources. Accessed 7/27/2006. http://ice.or.nrcs.usda.gov/website/cra/viewer.htm.

69. Omernik, James M. and Robert G. Bailey. 1997. Distinguishing between watersheds and ecoregions. *Journal of the American Water Resources Association* 33 (5):935-949.

70. Omernik, J.M. and G.E. Griiffith. 1991. Ecological regions versus hydrological units: frameworks for managing water quality. *Journal of Soil and Water Conservation* 46(5):334-340.

71. Oregon Department of Geology and Mineral Industries. Gems and Minerals in Oregon. Accessed 8/21/2006. http://www.oregongeology.com/sub/learnmore/thundereggs.HTM

72. Oregon Natural Heritage Program and Oregon Department of Fish and Wildlife. 1995. Metadata and ecoregional descriptions. Accessed 7/26/ 2006. http://www.gis.state.or.us/data/metadata/k250/ecoregion.pdf.

73. Oregon's mineral exploration in 1988 focused on gold. 1989. *Oregon Geology* 51(1):20.

74. Orr, Elizabeth L., William N. Orr, and Ewart M. Baldwin. 1992. *Geology of Oregon, 4th edition*. Kendall/Hunt Publishing Company, Dubuque, Iowa.

75. Otto B. R and D. A. Hutchison. 1977. The geology of Jordan Craters, Malheur County, Oregon. *Ore Bin*, 39(8):125-140.

76. Peters, S.G., G.T. Spanski, H.C. Brooks, J.G. Evans, R.R. Carlson, G.K. Lee, K.A. Connors, JJ. Rytuba, A. Griscom, G.V. Albino, and P.F. Halvorson. 1996. *Resource assessment of the Bureau of Land Management's Malheur, Jordan and Andrews resource areas, southeastern Oregon: Deposit models, tracts, and estimation of endowment for undiscovered metallic resources in the BLM's Malheur, Jordan and Andrews resource areas, southeastern Oregon*. United States Department of the Interior, U.S. Geological Survey

77. Rhyolite. 2006. *Wilkipedia: the free encyclopedia*. Accessed 7/25/2006. http://en.wikipedia.org/wiki/Rhyolite

78. Romberger, Samuel B. 1991. Transport and deposition of precious metals in epithermal deposits. In *Geology and Ore Deposits of the Great Basin: symposium proceedings*, edited by G.L. Raines, R.E. Lisle, R.W. Schafer and W.H. Wilkinson, pp 219-232. Geological Society of Nevada, Reno, Nevada.

79. Russell, Israel C. 1903. *Notes on the geology of southwestern Idaho and southeastern Oregon*. United States Geological Survey Bulletin 217. Government Printing Office, Washington D.C.

80. Rytuba, James J. and Dean B. Vander Meulen. 1991. Hot-spring precious-metal systems in the Lake Owyhee volcanic field, Oregon-Idaho. In *Geology and Ore Deposits of the Great Basin: symposium proceedings*, edited by G.L. Raines, R.E. Lisle, R.W. Schafer and W.H. Wilkinson, pp 1085-1096. Geological Society of Nevada, Reno, Nevada.

81. Rytuba, James J., Dean B. Vander Meulen, Vincent E. Barlock, and Mark L. Ferns. 1991. Hot spring gold deposits in the Lake Owyhee volcanic field, eastern Oregon. In G*eology and Ore Deposits of the Great Basin: Field Trip Guidebook Compendium, vol. 2,* edited by Ruth H. Buffa and Alan R. Coyner, pp. 634-712. Geological Society of Nevada, Reno, Nevada.

82. Schaaf, Dick Vander. 1996. A report on the Owyhee Uplands ecoregion: Oregon, Idaho, Nevada. Vale District Bureau of Land Management and The Nature Conservancy.

83. Schlesinger, W.H. and A.M. Pilmanis. 1998. Plant-soil interactions in deserts. *Biogeochemistry* 42:169-187.

84. Schlesinger, W.H, J.A. Raikes, A.E. Hartley, and A.F. Cross. 1996. On the spatial pattern of soil nutrients in desert ecosystems. *Ecology* 77:364-374.

85. Shawe, D.R., J.T. Nash, and W.L. Chenoweth. 1991. Uranium and vanadium deposits. In *The Geology of North America, Vol. P-2, Economic Geology U.S.*, edited by H.J. Gluskoter, D.D. Rice and R.B. Taylor, pp 103. The Geological Society of America, Boulder, Colorado.

86. Smith, Cole L. ed. 1994. Mineral and Energy resources of the BLM Malheur-Jordan Resource Areas, Southeastern Oregon. U.S. Department of the Interior and U.S. Geological Survey.

87. Smith, S. D., R. K. Monson and J.E. Anderson. 1997. *Physiological Ecology of North American Desert Plants*. Springer.

88. Soil Survey Staff, Soil Conservation Service, U.S. Department of Agriculture. 1999. *Keys to Soil Taxonomy*, 8th edition. Pocahontas Press, Blacksburg, Virginia.

89. Stone Age Industries. Rough: Thundereggs, Succor Creek. Accessed 8/21/2006. http://www.stoneageindustries.com/rough_thundereggs_succor_creek.html

90. Swirydczuk, Krystyna, Gerald P. Larson, and Gerald R. Smith. 1982. Volcanic ash beds as stratigraphic markers in the Glenns Ferry and Chalk Hills formations from Adrian, Oregon, to Bruneau, Idaho. In *Cenozoic Geology of Idaho*, edited by Bill Bonnischsen and Roy M. Breckenridge, pp.543-558. Bulletin 26, Idaho Department of Lands Bureau of Mines and Geology, Moscow, Idaho.

91. Thunderegg. 2006. *Wilkipedia: the free encyclopedia*. Accessed 8/21/2006. http://en.wikipedia.org/wiki/Thunderegg

92. Trimble, S. 1989. *The Sagebrush Ocean: A Natural History of the Great Basin*. Las Vegas: University of Nevada Press.

93. Tuff. 2006. *Wilkipedia: the free encyclopedia*. Accessed 7/25/2006. http://en.wikipedia.org/wiki/Tuff

94. Univ. of Illinois Dept. of Biology. 2006. Introduction to ecology: desert. *Biology of Populations and Communities*. Accessed 8/4/2006. http://www.uic.edu/classes/bios/bios101/ecologie/sld045.htm.

95. US Census Bureau. 2000. Fact sheet: Malheur County. *American Fact Finder.* Accessed 8/1/2006. http://factfinder.census.gov/servlet/SAFFFacts?_event=Search&_lang=en&_sse=on&geo_id=05000US41015&_county=Malheur%20County&show_2005_tab=&redirect=Y.

96. USGS. 1969. *Mineral and Water Resources of Oregon*. US Government Printing Office, Washington D.C.

97. USGS. 2004. Geologic Time Scale. Accessed July 21, 2006. http://3dparks.wr.usgs.gov/coloradoplateau/timescale.htm

98. USGS. 2006. Hydrologic unit maps. *Water Resources of the United States*. Accessed 7/25/2006. http://water.usgs.gov/GIS/huc.html.

99. VandenDolder, Evelyn M. 1991. How geologists tell time. *Oregon Geology* 53(6):123-129.

100. Wallwork, J.A. 1982. *Desert Soil Fauna*. Praeger Publishers, New York, New York.

101. Weisbrod, Noam. 2006. Desert hydrology. *Water Encyclopedia*. Accessed 6/26/2006. http://www.waterencyclopedia.com/Da-En/Desert-Hydrology.html.

102. Western Regional Climate Center. 2006. Adrian, Oregon (350041). Accessed 8/3/2006. www.wrcc.dri.edu/cgi-bin/cliRECtM.pl?or0041.

103. Western Regional Climate Center. 2006. Beulah, Oregon (350723). Accessed 8/3/2006. www.wrcc.dri.edu/cgi-bin/cliRECtM.pl?or0723.

104. Western Regional Climate Center. 2006. Danner, Oregon (352135). Accessed 8/3/2006. www.wrcc.dri.edu/cgi-bin/cliRECtM.pl?OR2135.

105. Western Regional Climate Center. 2006. Malheur Branch Exp Stn, Oregon (355160). Accessed 8/3/2006. www.wrcc.dri.edu/cgi-bin/cliRECtM.pl?or5160.

106. Western Regional Climate Center. 2006. Owyhee Dam, Oregon (356405). Accessed 8/3/2006. www.wrcc.dri.edu/cgi-bin/cliRECtM.pl?or6405.

107. Western Regional Climate Center. 2006. Parma Experiment Stn, Idaho (106844). Accessed 8/3/2006. www.wrcc.dri.edu/cgi-bin/cliRECtM.pl?id6844.

108. Western Regional Climate Center. 2006. Rome 2 NW, Oregon (357310). Accessed 8/3/2006. www.wrcc.dri.edu/cgi-bin/cliRECtM.pl?or7310.

109. Western Regional Climate Center. 2006. Vale 1 W, Oregon (358797). Accessed 8/3/2006. www.wrcc.dri.edu/cgi-bin/cliRECtM.pl?or8797.

110. Western Regional Climate Center. 2006. Warm Springs Reservoir, Oregon (359046). Accessed 8/3/2006. www.wrcc.dri.edu/cgi-bin/cliRECtM.pl?0r9046.

111. Wood and Kienle 1990. *Volcanoes of North America: United States and Canada.* Cambridge University Press.

112. Worl, Ronald G. 1991. The other metals. In *The Geology of North America, Vol. P-2, Economic Geology U.S.*, edited by H.J. Gluskoter, D.D. Rice and R.B. Taylor, pp 125. The Geological Society of America, Boulder, Colorado.

113. Zeolite. 2006. *Wilkipedia: the free encyclopedia*. Accessed 8/21/2006. http://en.wikipedia.org/wiki/Zeolite

114. Press, Frank and Raymond Siever. 2001 *Understanding Earth, third edition*. W.H. Freeman and Company, New York.