<u>Geology of the Northern California portion of the Cascade-Siskiyou National Monument</u>
Report for the Friends of the Cascade-Siskiyou National Monument, June 1, 2023

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<u>Introduction</u>:

This report describes the geologic framework of the southernmost portion of the Cascade-Siskiyou National Monument (as extended by President Obama in 2011). That extension enlarged the original CSNM designated by President Clinton in 2000. The area (see **Figure 1** and **geologic/topographic map**) is all but inaccessible by vehicle and must be traversed by foot. The only access is through the original Horseshoe Ranch jeep trail which trends west from the Copco Road near Iron Gate Reservoir. The jeep trail ends halfway through the field area. Access requires a key through a locked gate. Old jeep trails, mostly disappearing, provided limited foot access.

Elevations range from over 1,300 meters on the northwest to 710 meters at Iron Gate Reservoir. The area is rugged, hot in late spring, summer, and early fall. It is dominated by forbs and brush such as ceanothus and rabbit brush with oaks at lower elevations. Scattered Ponderosa Pines and related conifers are mixed with oaks at higher elevations (see **Figure 2**). Junipers are present in scattered patches or are isolated on south-facing slopes (in general). Poison oak is dominant only in drainages where it can be quite vigorous.

Major drainages are from west to east: Brushy Gulch, Slide Creek, Camp Creek, and Wildcat Gulch. Dutch and Jenny Creek are the main drainages NE of Iron Gate Reservoir. All creeks except Jenny Creek and Camp Creek were essentially dry in this part of the Monument during late June to early July (2022). In 2021, all creeks contained some flowing water during April through early June.

The Klamathon ("Hornbrook") fire which erupted in July 2018 burned through swaths and isolated patches of vegetation in the map area. This allowed us to access formerly brushy areas that were previously difficult to navigate. The brush is growing vigorously (especially Deer Brush) which should cover the area within a decade as it did previously.

Due to access problems, most of the geology of the Hornbrook, California 7.5' quadrangle was interpreted from aerial photographs. No LiDAR data was available. Previous mapping by D'Allura and others in the Siskiyou Pass, Soda Mountain, and Parker Mountain, Oregon 7.5' quadrangles allowed reasonable geologic correlations to photo-interpreted geologic mapping in northern California. Geologic mapping in the Iron Gate Reservoir and Copco, California 7.5' quadrangles was accomplished by use of aerial photographs and foot traverses.

This report is written primarily for geologists but other readers will extract useful information for botany, geography, and water resources. Unfamiliar geologic terms appear as defined in the body of the report and a glossary at the end of the text followed by a list of references cited. This **report,** accompanying **figures** (see separate Word Document entitled ***Northern California Figures***), and **geologic map and legend** incorporates field and laboratory work. Geologic mapping of rock units, soils, and their relation to the geologic and topographic development of this portion of the Cascade-Siskiyou National Monument was pursued by field investigations, aerial photos borrowed from the Medford BLM office, analysis of mineralogic and rock textural relations using double-polarizing petrographic microscopes, and processing of crushed whole rock data to obtain geochemical results useful in characterizing rock units. Radiometric dates for two tuffaceous samples are yet to be processed by the Oregon State University Geochronology Lab. When they are processed, they will be included as a Word document entitled **Northern California Radiometric Dates.** A table of geochemical results, recalibrated to 100%, volatile-free, total iron as FeO results for ease of comparison to previous data (as per Western Washington State Peter Hooper lab protocol) appear in an Excel table entitled **Northern California Geochemistry**.

Rocks of the Western Cascade and High Cascade volcanic series underlay the entire mapped area. In general, within the CSNM considered as a whole, Western Cascade volcanic rocks range in age from ~36 to ~ 19 **Ma** (**M**illions of years **a**go; see **Figure 3**, geologic time scale). High Cascade rocks in the Monument range from ~ 3.7 Ma to ~ 1.3 Ma. Western Cascade volcanic rocks are comprised of a wide variety of volcaniclastic rocks and lava flows ranging from basalt to rhyolite in composition while High Cascade volcanic rocks are comprised almost entirely of basalt to basaltic andesite lava flows erupted from a variety of shield volcanoes (Harris and D'Allura, 2017).

Western Cascade rocks include the redefined Colestin Formation overlain by the redefined Roxy Formation (see Wells, 1956 for original Formation descriptions). The formations differ in that the Colestin Formation is characterized, in large part, by volcaniclastic rocks including volcanic sandstone, distinctive rhyolite and dacite tuff, and volcanic debris flows, most of which are breccias. Basaltic andesite lava flows comprise a relatively small portion of the section in the Colestin valley south of the Siskiyou Summit yet gain a greater dominance to the south in northern California, especially toward the upper contact with the overlying Roxy Formation.

The Roxy Formation as defined by Bestland (1987) and later by D'Allura (2017) lie above the abundant white tuffs and other volcaniclastic rocks of the Colestin Formation. An extensive series of basaltic andesite lava flows defining the lower contact can be traced from Highway 66 on the north in Oregon to Brushy Gulch to the south in northern California. These distinctive lava flows are mostly aphanitic although plagioclase phenocrysts in some of the layers can comprise up to and exceeding 10-15% are common. The distinctive rusty orange-brown weathering of these flows is seen on aerial photographs as they enter Brushy Gulch in California yet south of the gulch, the character changes to a distinctly porphyritic character. It is quite possible that an intraformational erosional boundary exists in this area which drastically thins and supplants the distinctive series of lava flows comprising the lower boundary of the Roxy Formation.

Rocks which lie below the Roxy Formation boundary contain white tuffs and a notably greater percentage of volcaniclastic rocks than above the boundary. Lava flows become dominant over volcaniclastic rocks above the boundary although lava flows interspersed with white tuffs in the Colestin Formation are much more abundant in the mapped area than to the northeast and especially to the southeast (stratigraphically lower in the formation) along the Copco Road where they comprise only about 10-15% of the stratigraphic column.

Intraformational erosional events characterize both the Colestin and Roxy Formations in this area as can be seen on the geologic map with regard to truncation of major rock units. In addition, "form lines" (dashed lines representing subunits that can be followed on aerial photographs or by field traverses) identify local intraformational unconformities.

Scant public geologic literature exists in the northern California region of the Monument. A very general map by Vance (1984) in the Extended Monument area subdivided his Roxy Formation into a lower Iron Gate member overlain by his Soda Springs tuff member. However, recent mapping by Bestland (1987) and D'Allura (2017) place both of these members in the Colestin Formation based on lithology and radiometric ages. The Camp Creek member of Vance's Roxy Formation corresponds to our lower Roxy Formation. While Vance's map is useful, he lumped many distinct stratigraphic tuffs into one tuff: the Soda Springs tuff. That is likely why his radiometric fission track ages range from 28 to 25.9 Ma.

Hammond (1983) described the geology to the east in the Copco, California and southernmost part of the Parker Mountain, Oregon 7.5' quadrangles both of which overlap the Jenny Creek Falls area of the Extended Monument. Interestingly, the very thick expanse of the Roxy Formation thins drastically, as was detected by D'Allura (2017) and University of Oregon students in the Soda Mountain and Parker Mountain 7.5' quadrangles. Vance (1984) shows a very thin exposure of Roxy volcanic rocks overlain by tuffaceous ("Bogus tuff") of his (and Hammond's) Wasson Formation. It is suspected that a profound regional unconformity which thins the Roxy Formation exists in the area. However, as it lies outside the Monument boundaries and likely concealed under High Cascade lavas, it was not investigated.

High Cascade Pliocene to Quaternary basalt andesite and basalt lava flows from shield volcanoes unconformably overlie rocks of the Western Cascade volcanic series (McCann Harris, and D'Allura, 2017), obscuring relations within the Western Cascade rocks in this part of the Monument.

Standard geologic symbolism is used to designate geologic units that appear on the accompanying map. For example, the collective symbol **Torlf** refers to the *Roxy* Formation: **T** = *Tertiary* (the geologic time Period), **o** = *Oligocene* (the time Epoch), **r** = *Roxy Formation*. Any additional symbols that follow the formation names will refer to subunits that can be identified within those formations (such as ***lf*** = lower flows). For ease of comparison to the map, unit symbols have been included in parentheses after the heading of the unit's name in the following text.

Descriptive Geology

Where possible, descriptions and names of rock units follow those of previous geologic investigators such as Wells (1956), Vance (1984), Hammond (1983), Bestland (1987), D'Allura (2017), McCann et. al. (2017) although deviations from those rock units, at times, are based on the detailed mapping of this report. Such deviations will be noted in the text. The formation names (Colestin, Roxy, and Wasson) based on lithologic similarities originally defined by Wells (1956) are adopted in this report despite the fact that volcanic rock units normally change character and lithology along strike and are not everywhere time-equivalent. As such, Bestland (1987) and D'Allura (2017) have slightly redefined the original formation boundaries.

General overview of the geology of this region:

The general geology character of this region of the northern California and southernmost portion of the Cascade-Siskiyou National Monument is one of extensive lateral continuity of some distinctive rock units combined with numerous local formational and intraformational unconformities. The geology likely developed on the lower proximal, medial, and alluvial volcanic facies (**Figure 4**) of overlapping volcanic edifices. The lower to middle Colestin Formation (see below) was deposited on the medial to upper alluvial volcanic facies, mostly at a distance from volcanic centers (Bestland, 1987; D'Allura, 2017). However, the upper portion of the formation displays numerous lava flow units characteristic of the medial to proximal volcanic facies. That relation suggests that the volcanic front was moving westward through time. The volcanic rocks of the overlying Roxy Formation contain many more Aa, block, and pahoehoe basaltic andesite lava flows and fewer tuffaceous and volcaniclastic (volcanic sandstone, conglomerate, and breccia) rocks so typical of the Colestin Formation.

Intraformational unconformities in both formations indicate expected erosion events on the flanks of volcanoes and subsequent deposition of newer volcanic units atop those erosional surfaces. Such unconformities are shown by both truncation of major mappable units as well as truncation of "form lines" that follow definite subunits within those units (see **geologic map**). Complicating the issue are local changes in orientation of rock units that normally dip (are inclined) gently to the northeast. Rare bedding attitudes in volcaniclastic rocks as well as the orientation of depositional contacts of units indicate that the area around and to the west of Iron Gate Reservoir is gently warped into shallow ill-defined anticlines and synclines. Vance (1984) noted a similar warping. Dominant northwest-trending faults farther complicate the ease of following mappable units. The change in volcanic stratigraphy up section (into younger rocks) further confuses the issue. For instance, observe the truncation of the laterally extensive basaltic andesite lava flow unit, Torlf [defined by D'Allura, 2017], easily mapped north of the border of California and Oregon). It is seen to be overlain by a series of younger Aa to block lava flows.

Clearly, differentiating the exact volcanic stratigraphy of the area is extremely complex endeavor. Even within mapped units, the composition of lithologic units may change laterally or vertically which require careful mapping of different units. Such differentiation into different mappable units has been attempted but the similarity of lava flow units and other rock types may have caused misinterpretation of some contacts.

Colestin Formation:

The upper contact of the Colestin Formation as described in this report differs slightly from the definition of earlier workers such as Wells (1956) and Vance (1984). The formation lies below the lower lava flow unit of the Roxy Formation as designated by Bestland (1987) and D'Allura (**Torfl** of D'Allura, 2017). A general characteristic of the Colestin Formation, thus re-defined, consists of numerous tuffaceous rock strata which may be followed in the field. The lowest of these tuffs was radiometrically dated from plagioclase as 35.9 Ma in the Colestin Basin south of the Siskiyou Summit Fault and the highest of which is 26.48 Ma ($^{40}Ar/^{39}Ar$ ages; D'Allura, 2017). These tuffs are interbedded with volcaniclastic rocks (sandstones and debris flows with minor conglomerates) and contain several basaltic andesite flow units. The lava flow units become more numerous near the top of the Colestin Formation and especially in the northern California section of the formation.

To the south of the "State Line Fault" (a roughly east-west trending fault; see D'Allura, 2017) that occurs near the Oregon-California State line crossing Interstate Five, the formation thins then thickens again to the south as it approaches the Klamath River. Radiometric ages in tuffs of 32.84 Ma ($^{40}Ar/^{39}Ar$; D'Allura, 2017), slightly north of the border near U.S. Interstate Five, as well as a fission-track date of 31.3 south of the border (Vance, 1984), date the base of the formation south of the State Line Fault. Another fission track date of 33.1 Ma (Vance, 1984) in the same tuff occurs near Willow Creek south of the Klamath river. The lowest part of the section in California, which contains some lava flows and numerous debris flows, is undated.

The upper part of the Colestin Formation yields an $^{40}Ar/^{39}Ar$ radiometric age of 26.48 Ma south of highway 66 in Oregon and 25.9 Ma (fission track age of Vance, near Soda Springs five km SE of Iron Gate Reservoir). We are still awaiting a new $^{40}Ar/^{39}Ar$ age in a tuff (**Tocut**) which underlies the basal lavas of the Roxy Formation near Bushy Gulch in northern California.

In this report, we describe only the upper part of the Colestin Formation in northern California and southernmost Oregon. In order to understand the complex volcanic stratigraphy in this area, mapping occurred not only within the Monument boundaries but eastward toward the west end of Iron Gate Reservoir. Much of that area lies within private property hence access must be granted.

Volcanic stratigraphy is prone to abrupt changes in lithology due to erosion and changing volcanic character of adjacent volcanoes. That produces a terrain wherein following individual lava flows or tuffs commonly is interrupted laterally. Too, even within a particular “lava flow subunit”, not all lava flows comprising that unit may be of the same lithologic character. The same is true of “tuff subunits” which may show a change in composition and grain size vertically through the exposure. Hence, we have lumped different subunits into “rock packages” that contain similar, but not necessarily unique, lithologic characters. We also use “form lines” within major units (such as the Colestin or Roxy Formations) as dashed lines on the geologic map to show rock packages that can be traced by foot or on aerial photographs across the terrain. The intent is to show that there are some lateral continuities within a formation and, in some cases, to show intraformational erosional surfaces.

Lithology

The basic lithologic differences can be subdivided into lava flows, tuffaceous ash flows and ash falls, and volcaniclastic rocks. While tuffs are volcaniclastic, in this report they are commonly separable and can be followed for kilometers across the terrain. The term volcaniclastic used in this report refers to volcanic sandstone (including pebbly sandstone) and debris flows, all of which are comprised of broken and transported rock fragments of varying sizes, composition, angularity, and exhibit different degrees of sorting. Volcanic conglomerates are extremely rare, indicating that most rock units were deposited quickly, covered, and not reworked to a large extent.

Volcanic sandstone and debris flows:

Volcanic sandstones are texturally and compositionally immature containing many different compositions containing uniformly angular fragments embedded in a finer-grained matrix indicating they were deposited with little or no reworking by running water. Most, if not all, contain easily-weathered tuff fragments and, as such, rarely crop out at the surface. Rare exposures are uncovered by digging or are exposed in deeply-incised drainages (**Figure 5**). Volcanic sandstones form gentle slopes replete with grasses, forbs, and shrubs with occasional scattered oaks.

As most volcanic sandstones contain tuffaceous material and are comprised of small grain sizes easily affected by groundwater, soils are dominated by ***shrink-swell clays***. During the wet season the soil is sticky (“swell”) and in the dry season deep cracks (“shrink”) develop as water is lost in the upper part of the soil. Soil colors are light to moderate gray or yellow-brown in contrast to orange-brown to reddish soils developed from lavas. Soil developed on lava flows lacks the distinctive and usually large, shrinkage cracks typical of soil developed on tuffs or volcanic sandstone. The vegetation developed on volcanic sandstone sharply contrasts to that where lava flows or hard volcaniclastic rocks occur: in the latter rock types, vegetation is vigorous, outcrops are common, and slopes are steep or at least steeper. Normally soils developed on volcanic sandstone is clay-rich and pale-reddish brown in color and vegetation is dominated by grasses (**Figures 6a, b**).

Debris flows are quite varied in composition and outcrop character. Where they are *autoclastic* (contain broken fragments of the same composition) they are considered part of fragmental Aa or block lava flows and are normally included within lava flow subunits. Where the clasts (larger fragments) are *heterolithologic* (contain different clast compositions), they are either well indurated (made hard through compaction and cementation) forming bold outcrops or are easily disarticulated forming rubble-strewn slopes. Most clasts are quite angular indicating rapid deposition and little reworking by water. Bedding commonly exhibits erosional features where later debris flows cut into earlier ones, forming minor unconformities (**Figure 7**). Conglomerates containing rounded fragments are extremely rare. Clast sizes in volcanic debris flows vary remarkedly from pebbles or cobbles to huge boulders many meters in diameter. The matrix is comprised of sand- to silt- sized fragments of either similar composition as the clasts or vary widely from clast composition.

Tuffaceous rocks:

As mentioned earlier, one of the distinctive characteristics of the redefined Colestin Formation is the relative abundance of tuffaceous subunits that can be traced on aerial photos and on foot traverses across the terrain. Tuffs do occur in the Roxy Formation but they are thin and minor in the northern California region of the Monument. Tuffs form few mappable stratigraphic units north of the border (D'Allura, 2017).

Tuffs vary with respect to their induration (hardness) depending on their mode of deposition. *Ash Flow ("Welded") Tuffs* are emplaced as very warm to extremely hot gravity-driven clouds that form as pyroclastic ("fire-broken") clouds are ejected from a volcano, collapse under their own weight, and flow rapidly downslope. If they are hot enough, they fuse (re-melt) pumice and small glass shards into black obsidian with shapes called fiammé (Italian for "flame"). Fiammé appear as black wisps within a brownish mass of broken crystals and rock fragments. If they aren't that hot, they commonly are light to moderate brown in color with distinctive sub-parallel fractures; pumice is normally flattened, elongated, and may be partially fused. Both types are well indurated by heat and form bold, resistant outcrops on which vegetation is sparse. *Ash Fall Tuffs* are formed as eruptive clouds are ejected high into the atmosphere and are carried by prevailing winds to be deposited at some distance as particles settle from the air under gravitational forces. Such tuffs typically don't form bold outcrops and are quite susceptible to weathering and erosion (**Figure 6b**). Commonly such tuffs are revealed by light to moderate gray clay-rich soils supporting grasses; exposures occur only in deeply-incised channels or as occasional thin silica-rich bands or as chips in the soil within the tuff. Those bands and chips are formed as a result of migration of silica-bearing solutions which are deposited along subtle bedding planes or in fractures.

There are numerous tuffaceous units that can be followed and mapped within the field area. Geochemically, all of the above tuffs plot as rhyolites (**Figure XX**) although with 77.14% SiO_2 *NC-2C* may have been partially silicified. Tuffaceous rocks are rhyolitic with relatively higher alkali totals (~7%) than found in tuffs lower in the section in the Colestin Basin of Oregon (D'Allura, 2017). All are crystal-vitric tuffs with a few lithic fragments. Crystals are broken and are dominated by plagioclase without inclusions, quartz in some rocks, a scattering of biotite or lepidomelane and rare hornblende. Pyroxene is very rare to absent in comparison to tuffs lower in the Colestin Formation in Oregon. Glass shard shapes are rare, the groundmass having been recrystallized to microfelsite (mostly microscopic intergrown quartz and feldspar).

Radiometric dates within tuffaceous units north of the California-Oregon border include fission track, K/Ar, and $^{40}Ar/^{39}Ar$ ages (D'Allura, 2017) which conflict with one another. Fission track ages range from 29.9 to 24.9 Ma although the latter age is a too-young fission track date. The Tocutsp (correlated to Vance's Soda Springs tuff) in the original Monument has dates of 29.9 (K/Ar) and 26.48 ($^{40}Ar/^{39}Ar$) Ma. Vance reports a wide range of fission track ages of 28 to

25.9 Ma on the tuff although he failed to recognize that there are many different tuffs which comprise his mapped Soda Springs tuff.

In general, K/Ar dates, especially "whole rock" (rather than mineral separates, normally plagioclase) ages are notably less reliable than $^{40}Ar/^{39}Ar$ ages. The same is true for fission track ages. However, all radiometric and fission track dates are included in this report.

In the northern California region of the Monument we still await a new $^{40}Ar/^{39}Ar$ age on Tocut (upper tuff of D'Allura, 2017) which is Vance's odd-shaped "finger" of tuff extending along Bushy Gulch. We are also waiting a new $^{40}Ar/^{39}Ar$ age on the Tocdct2 (Dry Creek tuff). That same tuff has an older fission track age of 28 Ma (Vance, 1984). That tuff (Tocdct2) marks Vance's upper contact with his Iron Gate member of his Roxy Formation (which we recognize in this report as part of the Colestin Formation).

On the geologic map, all tuffs are shown with the same color (shades of blue) although significant mappable tuffs also are designated by their unit symbols. Note that when a tuff is described, the most abundant component adjective (either glass+pumice=vitric, crystal, or lithic=rock fragments) occurs closest to the rock name (see **Figure 8**, a classification scheme for tuffs based on those three components as well as a size chart for naming of fragmental tuffs).

Iron Gate tuff

The oldest tuff on the geologic map is the Iron Gate tuff which forms a discontinuous unit on the west side of Iron Gate Reservoir (and, in Vance's 1984 map, occurs to the east of the Reservoir). This unit is a very pale orange welded lithic-crystal-vitric rhyolitic tuff with high 77.14% SiO_2. It contains a high percentage (~50%) of remarkably fresh glass shards in a recrystallized glassy matrix (~40%) with carbonized wood, biotite (1mm; 1-2%), quartz (0.5-1mm; 2%), strongly zoned plagioclase (0.5-1mm; 3%+), dark rock fragments (1-3mm; 1%), and pumice (1mm-1cm; 4%). All components are broken, having angular shapes. The glass shards have the usual curved "popped" bubble fragment shapes (**Figures 9A, 9B**). A possible composition of the plagioclase is An_{37} (andesine).

Juniper Point tuff

Another discontinuous but mappable marker unit stratigraphically higher than the tuff just described above and also lies close to Iron Gate Reservoir. It is a light gray partially silicified tuff with the usual quartz, plagioclase, and rare but ubiquitous biotite crystals in a vitric matrix. Rock fragments are common and appear to be related to the tuff (they are darker than the tuff matrix but are silica-rich).

Toct2 (**Dry Creek tuff**)

The next higher stratigraphic tuff, **Toct2** is much thicker, contains numerous subunits, and overlies the upper lava flow unit of the **Tocdf** (Dry Creek lavas). Most of the subunits in the welded tuff are lithic-crystal-vitric tuffs which range in color from pale yellowish green (due to celadonite alteration minerals) to yellowish gray. Some tuffs show evidence of dissolution within earlier-formed plagioclase crystals (**Figure 10**). Coarse volcanic sandstone with abundant pumice, rock fragments, and crystals (including biotite) exhibit crude bedding suggesting slight reworking after deposition. Also associated are easily-weathered air fall tuffs (represented by mostly light gray clay soils). The entire sequence records a history of violent ash eruptions and deposition. We are still awaiting an $^{40}Ar/^{39}Ar$ age determination.

Toctsp ("**Soda Springs tuff"**)

The **Toctsp** tuff in Oregon has two age dates of = 29.9 (K/Ar) and 26.48 ($^{40}Ar/^{39}Ar$) Ma, the latter a more reliable date. D'Allura (2017) originally correlated this tuff to the Soda Springs tuff of Vance (1984. However, this tuff appears to thin and disappear slightly below the

California border despite being a persistent unit that extends northward to Highway 66 (Greensprings Highway).

Tocut (**Colestin upper tuff**):

This tuff is continuous from south of Highway 66 in Oregon (D'Allura, 2017) to Brushy Gulch in northern California. It is comprised of a series of related rhyolitic tuffs (**Figure 11**) which, in places is affected by steeply-inclined silicified fractures (**Figure 12**). In the field the tuffs range from off-white to a light greenish gray weakly magnetic rock, commonly with a pronounced foliation parallel to bedding. The tuffs are lithic-crystal-vitric fine to coarse tuffs. Crystal and lithic clasts are angular. Lithic clasts are varied in texture and composition and comprise up to 5% of the rock and range from 1.5-5mm in size. Crystal clasts comprise 15% of the rock, are ~ 1.5mm in size, and are mostly plagioclase with minor quartz and lesser opaques and biotite (**Figures 13a, 13b**). The vitric portion of the rock consists of mostly devitrified glass shards and celadonite which gives the greenish color to some of the tuffs. We are still awaiting a new radiometric $^{40}Ar/^{39}Ar$ age.

Discontinuous tuffs (t)

There are poorly-exposed and commonly discontinuous tuffs beneath lava units. Those tuffs help separate those lava units where silicified chips or actual rare outcrops are found. These tuffs are designated by small letter "**t**" on the geologic map. Those tuffs are commonly very light gray lithic-crystal-vitric tuffs, most containing small weathered biotite, plagioclase, and quartz. Those tuffs, especially east of the ridge east and south of Wildcat Gulch grade downward to rarely-exposed volcanic sandstone and gray soil. During the dry season the soils developed on these easily-weathered rocks display deep cracks due to the high smectite ("shrink-swell") clays. Easily-weathered volcanic sandstone produces reddish-brown soil, also showing soil cracks due to high smectite content.

The matrix of these tuffs is always vitric, may contain green hornblende or biotite as rare mafic minerals, show outlines of pumice and contain a wide variety of lithic rock fragments. Plagioclase compositions are difficult to determine but the most reliable are sodic-rich oligoclase (An_{22}). Some tuffs show evidence of slight reworking and are clast supported rather than matrix-supported. The color of the tuffs ranges from very light gray to yellowish gray; the tuffs may be weakly magnetic.

Tocu (upper volcaniclastic rocks):

The uppermost unit (Tocu of D'Allura, 2017), is comprised of volcaniclastic quartz-bearing sandstone and light-colored tuffs. The tuffs as describe above (Tocsp, Tocut, and less continuous tuffs) are interbedded with volcanic sandstone and subordinate breccia, all containing some tuffaceous fragments. Due to the weak nature of poorly indurated (soft) volcaniclastic rocks which make up a large portion of the area underlain by this unit, grasses, brush and some conifers prevail. Soils are light brown to pale reddish brown in color. They are largely comprised of shrink-swell clays as are soils developed on tuffaceous units.

<u>Lava flow and related units</u>:

There are a number of relatively continuous lava flow packages that are distinctive enough to separate into laterally mappable units. Lava flows of such units are commonly different in lithologic character from the bottom to the top of individual flows as well as from one flow to another making indisputable correlations difficult but not impossible.

Nevertheless, some of the flow units appear to have remarkable lateral continuity even though the character of their textures (aphanitic to porphyritic) may change. As such we have been able to separate flow units into mappable "lava packages" separated by volcaniclastic subunits (Tocdc).

Small in lateral extent but mappable lava flows are indicated on the geologic map with the letter "**l**". All have basaltic andesite compositions.

Tocdf1 and Tocdf (**Dry Creek lavas**):

The lowest lava flow units of the redefined Colestin in the mapped area are comprised of numerous basaltic andesite subunits spatially related to one another. Collectively they are lumped into **Tocdf**. The **Tocdf** is comprised of several flow subunits that are separated either by erosion or as slightly different flows overlain by finer-grained, easily eroded volcanic sediment (**Tocdc**). Sampled lavas are all basaltic andesites (**Figure XX**).

The lower lava flow in the Iron Gate Reservoir quadrangle extends west to east from the North of Wadsworth Flat to Iron Gate Reservoir (**Figure 14**). The lower flow is a fine-grained medium- to medium-dark gray rock and is strongly magnetic with hackly fracture. The flow is dominated by feldspars with a slight pilotaxitic alignment (feldspars are roughly aligned subparallel with one another) with around 65-70% plagioclase and around 22-25% pyroxenes. The plagioclase is on average 0.5 mm long and strongly zoned, while the augite is 0.2-0.3 mm long and slightly green and equant. Strongly weathered olivine, at less than 1%, is around 0.2-0.3 mm long. Magnetite makes up around 5-7% of the volume, is less than 0.2 mm in size, and is present in the groundmass and as phenocrysts. Less than 1% of the volume is orange-brown volcanic glass.

The upper lava flow is dark gray and moderately magnetic with hackly fracture. Larger phenocrysts of olivine and augite are present with plagioclase only occurring in the very fine-grained groundmass. Groundmass plagioclase is unaligned and makes up 80% of the volume, with crystals around 0.3 mm long. Olivine phenocrysts are 0.9-1.2 mm long and make up 2.5-3% of the volume. Olivine is yellow with reddish-brown iddingsite alteration in cracks and around rims (**Figures 15 a, b**). An opaque alteration within olivine is also present at 5-6% by volume. 0.65mm dark green augite isn't altered and makes up 3% of the volume. The orthopyroxene, hypersthene, comprises less than 1% of the volume and is 1 mm long. 0.1 mm long. Magnetite makes up 4-5% of the volume, providing the magnetic properties to the rock.

A number of these flow subunits contain broken reddish Aa breccia and cinders as well as spatter indicating near-vent sources (**Figures 16 a and b with inserts**). They, marked by the symbol "**C**", occur in the eastern portion of the map area although most lie outside the Monument boundaries. The occurrence of these features indicate that vents lay within this portion the area and are interpreted to be small vent sources on the flanks of ancient Western Cascade volcanoes.

Tocdc (**Dry Creek Volcaniclastic Subunit**)

Separated from the Tocdf lavas and including tuff units are minor lava flows and intervening thin tuff and thicker volcanic sandstone and breccia subunit of the **Tocdc**. It is difficult to follow many of the subunits as they are commonly discontinuous or eroded then overlain by younger subunits. The Tocdc collectively is characterized by easily-eroded volcanic sandstone and breccia lithologies and thin, usually discontinuous tuffs. Where the tuffs are easily followed or apparent on aerial photographs, they are given their own designations.

Tocwf (Wildcat lava flow unit)

The Tocwf is separated from the Tocuf by an intervening subunit of volcaniclastic sandstone and intermittent white tuff south of Slide Creek. That intervening unit disappears on Lone Pine Ridge as well as to the north of Dry Creek where lavas of Tocuf lie directly above Tocwf in an unconformable relation. The Tocwf is quite similar to the Tocuf in that it contains abundant plagioclase phenocrysts as well as lesser amounts of augite and magnetite in a fine-grained groundmass of plagioclase, augite, and magnetite. To the west of Wildcat Gulch, there are several lava flow packages separated by volcaniclastic rocks which are included in the Tocwf (**Figure 17**). The lavas are much more resistant than the volcaniclastic rocks and are expressed as topographic highs or broad rocky exposures.

Tocuf (**Upper Colestin Lava Flow unit**):

In Oregon the upper lava flow unit, **Tocuf** (see D'Allura, 2017), consists of basal basaltic andesite flows lying atop a deep red paleosol and containing red intra-flow paleosols and thicker saprolites. This unit was formerly the basal unit of the Roxy Formation (Wells, 1956; Wiley, McClaughry, and D'Allura, 2011). However as numerous tuffs and volcanic sandstones lie above this unit and aren't as numerous in the breccia- and flow-dominated unit (Torsc of D'Allura, 2017) that lies above the basal lava unit of the Roxy Formation defined by Bestland (1987), this unit is provisionally placed in the Colestin Formation.

K/Ar ages within Tocuf range from 30 Ma (Suttner, 1978) to 26 +/- 0.8 Ma (Fiebelkorn, 1983). An age of 29.9 Ma (Fiebelkorn, 1983) occurs in a flow within the Tocm (middle lava flow unit of D'Allura, 2017) beneath these lavas as does a 30 Ma age on a pumice tuff (Smith, 1983). We are awaiting a new $^{40}Ar/^{39}Ar$ radiometric age on the underlying Tocdt2 tuff unit and the overlying $^{40}Ar/^{39}Ar$ radiometric age of Tocut which will bracket the age of the Tocuf in Northern California.

In Oregon, the upper lava flows (**Tocuf**) are all dark gray porphyritic-aphanitic basaltic andesite (**Figure 18a, b**) with phenocrysts of plagioclase (1-2mm; 5-27%; An_{73}) and augite (0.5mm; <1-2%) with occasional olivine pseudomorphs (0.5-1mm; 1%). Plagioclase is clouded with inclusions suggesting both rapid growth and some dissolution. Glomeroporphyritic clots of augite and plagioclase may occur although they are rare. Groundmasses contain plagioclase with intergranular opaques, pyroxenes, and altered glass (yellow-brown). Lowenstern (1986) reports orthopyroxene in the groundmass but none was observed in this study.

The prominent ridge to the east and SE of Wildcat Gulch contains several lava flows which are olive black to greenish black, are strongly magnetic, commonly vesicular near their tops, and most are porphyritic although some contain small phenocrysts (**Figure 19**). Plagioclase phenocrysts (1-2mm; 25%) appear to have grown rapidly contain abundant inclusions of magnetite and augite. Boxy-cellular and wormy-cellular textures within some of the plagioclase as well as strong zoning indicates the magma was quite unstable. Cores are of labradorite (An_{60}) although the rims are much more sodic. Augite (1mm;<1%) and olivine (1mm or less;<1%) and magnetite comprise the mafic minerals. The groundmass is intergranular with plagioclase and augite crystallizing at about the same time; magnetite comprises less than the plagioclase and augite; minor celadonite is present indicating diagenetic alteration. Sizes of crystals within the groundmass are ~ 0.3-0.4mm.

<u>Roxy Formation</u>:

As mentioned earlier, the base of the Roxy Formation, as redefined by Bestland (1987) and D'Allura (2017), is expressed by a distinctive, thick, and laterally continuous series of lava flows which overlie the white tuffs and other rocks of the re-defined Colestin Formation. Those flows were lumped into a rock unit whose designation is **Torlf** (D'Allura, 2017). Those flows are overlain by other lava flows and breccias, many of which are seen to overlie erosional unconformities developed on earlier lava flow packages. With the exception of Torlf, most lava flows in the northern California area are stubby Aa or block flows characterized by basaltic andesite autoclastic breccia and rare semi-continuous lava tongues.

Lithology

Torlf (**lower Roxy flow unit**):

The basal flow unit of the Roxy Formation as defined by Bestland (1987) and herein mapped as the Lower Roxy lava unit (**Torlf**) is comprised of mafic augite basaltic andesite and silicic basalt. This unit overlies and appears slightly unconformable with the upper volcaniclastic unit of the Colestin Formation. The Torfl unit, consisting of numerous closely-spaced lava flows, is continuous from the California-Oregon border (near Brushy Gulch) to southeast of Emigrant Lake in Oregon. These flows herald a change from the dominantly volcaniclastic Colestin Formation to volcanic deposits consisting of coarse volcaniclastic rocks and lava flows with notably few tuffaceous deposits. Hence, they are considered to have been deposited closer to major volcanic centers rather on alluvial fans as was the case with rocks of the Colestin Formation in Oregon (Bestland, 1987; D'Allura, 2017). That relation suggests westward migration of the volcanic axis possibly corresponding to a steepening dip of the subduction zone or perhaps building of larger composite volcanoes which extend their lavas farther west.

An extensive reddish paleosol underlies these lavas. The paleosol is best developed north of the CA/OR border and can be followed for kilometers northward from the border. South of the border the paleosol is thin (see **Figure 20**) to absent yet the unconformable relationship with the underlying Colestin Formation is expressed by the truncation of stratigraphic units which are overlain by Torfl lavas.

The **Torlf** consists of numerous thin (3-10m) lava flows (**Figure 20**) and local interflow breccia deposits. The lava flows show variable thicknesses but cover the greatest area NW of Pilot Rock in Oregon thinning both to the north and the south.

The number of basal lava flows, which sit atop one another separated by small benches of flow breccia, varies from three to more than seven. Most lava is uniformly fine grained to aphanitic with few phenocrysts. Plagioclase (1-1.5mm; 1-10%) phenocrysts, when present, have calcic cores (An_{74}) and more sodic rims (An_{66}). Groundmass plagioclase can be as sodic as An_{38} but normally is ~ An_{50}. Augite (<1mm; 1%) contains opaque minerals and is, by far, the dominant ferromagnesian mineral found either as phenocrysts or within the groundmass. The groundmasses of such lavas are characterized by dominant trachytic to pilotaxitic plagioclase laths, augite, opaques, and brown to yellow-brown glass in descending order of abundance. The rocks are moderately to strongly magnetic.

Rocks that contain more abundant phenocrysts (~30%) contain plagioclase and augite with some pigeonite. Plagioclase is oscillatory-zoned with abundant zones of inclusions. Rare patches, with crude crystal outlines that might have been olivine replaced by iddingsite, occur in two samples. The groundmasses are similar to the aphanitic varieties although glass is less common.

Other lavas in northern California are also porphyritic-aphanitic with large plagioclase feldspars (1-3mm; 20%) containing inclusions of magnetite, augite, and rare light brown glass.

The rock is strongly magnetic and dark greenish gray in color. Dissolution fabrics and overgrowths of later plagioclase with fewer inclusions also occur suggesting reaction of early-formed plagioclase with the magma. Compositions of the plagioclase are labradorite (An_{65}) rimmed with more sodic plagioclase. Augite (1-3mm; 3+%) and magnetite (0.2-0.6mm; 1%) comprise the rest of the phenocrysts. The groundmass texture is felted and diabasic with augite and magnetite interstitial to larger plagioclase crystals (plagioclase 60-65%; augite 30%; magnetite 5-10% and sizes much less than 0.5mm).

Torlf lavas are overlain by epiclastic sandstone and poorly-sorted breccia in the Siskiyou Pass and Soda Mountain quadrangles near and north of the Oregon-California border. These volcaniclastic rocks become less dominant into the northern California area where lava Aa and block flows gain ascendancy. The change in lithology is likely due to approaching the proximal volcanic facies closer to the source area of volcanism. In addition, numerous flow units are separated by local erosional unconformities which would be expected on the proximal flanks of volcanoes.

In contrast to mostly volcaniclastic breccias which dominate over lava flow subunits north of the Oregon-California border (**Torsc** [dominated by volcaniclastic rocks; D'Allura, 2017] and **Torsl** [dominated by lava flows]), rocks of the Roxy Formation in northern California are largely comprised of lava flows and autoclastic lava flow breccias. These units can be seen on the geologic map as well as on **Figures 21a, 21b** which are images of color aerial photo 13-75-7 flown on 7/5/91. **Figure 21a** shows the original photo while **Figure 21b** shows annotations representing form lines within units and the major unconformities separating units **Torbf** and **Torsf**.

Torbf (**Bushy Gulch lava flow unit**):

A, unit primarily comprised of block, Aa, and some thick flows, are separated from the underlying Torlf and overlying Torsf by unconformities, bears similarities to those two units. Although many contain notable plagioclase and lesser augite phenocrysts, others are nearly aphanitic, moderately to strongly magnetic, and medium dark gray in color. The "phenocrysts" normally occur in glomeroporphyritic clots (1-2mm; <5%) of primarily augite with smaller and less abundant magnetite and plagioclase. Subordinate clots are comprised mostly of plagioclase. Plagioclase compositions range from high labradorite (An_{56}) to bytownite (An_{76}). Textures are normally trachytic to pilotaxitic with smaller crystals comprising the "groundmass" of mostly augite with plagioclase and magnetite. What may have been olivine (1-2%; 1mm or less) has been replaced by chlorophaeite, celadonite, and iron hydroxides. Most of the plagioclase within the rock shows evidence of rapid crystallization with numerous inclusions of small augite crystals, glass, and opaques as well as minor apatite.

Torsf (**Slide Ridge lava flow unit**):

The lower section of this unit is comprised of porphyritic aphanitic Aa to block lava flows ranging from 3 to 6+m in thickness and are normally of limited lateral extent. The basal units are characterized by oxidation and sintered cinder- to block-sized fragments as well as exhibiting radical changes in orientation of rafted blocks (**Figures 22a, b, c**). Irregular vesicles are common. Phenocrysts are of plagioclase (0.1-1.5mm; 11-12%), augite (0.1-1.5mm; 1.5-2%), and opaques (0.5mm; 1%) in a crystalline groundmass of plagioclase, augite, opaques, and oxidized reddish brown glassy material. The anorthite content of the plagioclase is An_{62} (labradorite). In other rocks near the base of the unit, the plagioclase shows distinct signs of reaction with the magma (cloudy inclusions, wormy-cellular texture, and recrystallization). The rocks are weakly magnetic and range from moderate brown or medium dark gray to dusky red. Vesicles are common in all but the finest grained rocks.

Higher in the section, block and Aa flows become thicker and less oxidized, are dark gray, and strongly magnetic. The flows are porphyritic aphanitic with phenocrysts of plagioclase (1.5-3mm;10%), augite (1mm; 1-3%), and olivine (<1mm; 1+%); **Figures 23a, b**. The groundmass is intergranular with augite, olivine, and opaques forming between plagioclase laths. Augite and plagioclase in the groundmass are approximately equal in percentage. Geochemical compositions of these flows are basaltic andesite with an SiO_2 percentage of 54.15.

<u>Intrusions</u>:

Intrusions occur throughout the upper Colestin and Roxy Formations in the mapped area. Such intrusions are marked by their shapes (normally forming topographic highs) and cross-cutting relation to rocks which they intrude. All intrusions contain notably larger and more numerous crystals than all lava flows.

Scotch Creek Intrusive Body (Tisc):

The largest of these intrusions is the Scotch Creek Intrusive (**Figure 24**). This massive and resistant intrusion is porphyritic with columnar and platy structures with local onion-skin weathering. Petrographically the intrusion is mostly plagioclase (1-2mm; 60%) of labradorite composition (An_{62}). Crystals are closely packed as if formed in a crystal mush. The plagioclase appears to be heavily altered and cloudy with many inclusions. Pyroxene (augite; up to 5mm; 5%) and opaque minerals (0.1-0.2mm; 3%) which crystallize throughout and are mostly corroded. The opaques cause the rock to be strongly magnetic. Geochemically (**Figure 27**) the composition of the intrusion lies between andesite and basaltic andesite with an SiO_2 composition of 57.02%.

The groundmass contains two pyroxenes, augite and hypersthene (with hypersthene at 8% > augite at 2-4%) smaller than 1 mm in size plus magnetite which is interstitial to the phenocrysts. Hypersthene is rare to absent in the surrounding lava flows…

Little Pilot Rock intrusive (Tilp)

While this intrusion wasn't sampled, it forms an obvious intrusive shape on aerial photographs and as seen from an airplane. Its craggy aspect is quite similar to Pilot Rock.

Other smaller intrusions are porphyritic with plagioclase and augite in an aphanitic to finely crystalline groundmass. They are basaltic andesite to andesite in composition.

Dikes:

A small number of dikes are evident in the field. Compositions of all of them are basaltic andesite. Many are injected along the NW-trend of large fractures and faults. A massive dike, (**Figures 25a, b**) on the ridge south of Slide Creek where Scotch Creek joins the major drainage, was likely emplaced along a NW-trending fault but offset along that fault was not seen in the field although the unexposed fault is suspected to cause the clockwise bending of the dike just north of Slide Creek and along Scotch Creek. That bending may indicate drag due to some slight right-lateral motion along the unidentified fault.

There are numerous small basaltic andesite dikes that intrude the steep northwest-trending faults. One such fault/dike set can be seen in **Figures 26a, b**. Those parallel dikes can be seen on the geologic map western side of section 5 and eastern side of section 6 T.48N., R.5W. west of Iron Gate Reservoir. These dikes are best seen where they intrude the easily-weathered volcanic sandstone and, hence, stand out in bolder relief than those which intrude harder lava.

Geochemical Analysis

Few geochemical analyses were processed during this study. Most were done to typify as close as possible the chemistry of various lava and tuff entities. They are shown on an Alkali-Silica plot (**Figure 27**) used to designate rock names and geochemical affinities.

Earlier geochemical analyses are included where general characteristics of formations and units were required. The following remarks are taken from D'Allura, 2017 with regard to Colestin chemistry in the Colestin Basin south of the Siskiyou Summit Fault.

"Colestin tuffs group in different areas on the silica vs alkali plot indicating a change in the chemistry of the eruptive units. Early tuffs (Tocl) are mostly dacitic with an alkali content of ~4.5%, middle tuffs (Tocm) are rhyolitic with a low alkali content (~2.5%), and the upper tuffs (Tocu) are rhyolitic with high alkali contents (~7%). Moreover, the Tocl tuffs have higher HREEs and lie closer to the rock/chondrite plot of Aleutian tuffs while the Tocm and Tocu tuffs lie closer to Rainier tuffs and have lower HREE and higher, K, Ba, Th, and U. These results suggest that the early Colestin tuffs are more "primitive" than later tuffs, again suggesting that the early eruptive episodes of Colestin volcanism rose through relatively thin crust deriving lesser amounts of continental material through assimilation than later magmas."

Geochemistry of the overlying Roxy Formation indicates a maturing of continental volcanism erupted through thicker crust than was present during the deposition of the Colestin Formation rocks. Generally, the rocks show a change from a single pyroxene mineral (augite) such as seen in the Colestin Formation to a two-pyroxene rock (augite and hypersthene). That indicates a geochemical change with respect to the miscibility gap within the magma producing two rather than a single pyroxene.

Structural Geology

The structural fabric of the area includes both gentle folding, dominated by NE-dips of rock units, and NW-trending high angle (steep) faults and fractures. Gentle folding was mentioned by Vance (1984) but he didn't recognize any NW-trending high angle faults.

The varying strikes and dips of rock units are present in volcaniclastic rocks and tuffs with some relatively reliable orientations of platy joints in lava flows. Although these orientations vary considerably on the geologic map, the general aspect is a regional dip toward the northeast. The variation in strike and dip indicates the effect of not only local drag along faults but a gentle folding of the crust, especially west of Iron Gate Reservoir. The trace of geologic contacts also reflects the gentle warping and low angle inclination (dip) of the area to the NE. Note that the ridge formed by **Tocuf** (upper Colestin lavas) shows a progressive elevation lowering of the contact approaching Slide Creek, a trend consistent with a gentle NE dip of the lavas.

Offsets along the steeply-inclined faults are notable but not of great magnitude. Slickensides (planar fault surfaces) and slickenlines (linear features scraped along moving portions of the fault) are rare but best exposed along parallel quartz veins in partially silicified tuffs (**Figures 28a, b, c**). The slickensides strike N.40-55W. dipping steeply to both the NE or SW (75-80°). Slickenlines uniformly plunge 12-34° to the SE suggesting some component of lateral motion in tandem with the dominant normal (up and down) motion along faults in a combination known as *oblique motion*. Similar oblique motion along faults in the Oregon portion of the Monument was noted by D'Allura (2017).

General relations of geology to vegetation and water

Topography (and ***aspect***: sun-facing southern slopes, shadowy north slopes) determine in large part which areas will provide shelter from the sun during the hot months of our Mediterranean climate. Deep canyons or the back sides of east-west oriented topography retain more moisture through any given day than slopes facing direct sunlight. Moreover, deeper canyons generally are fed by groundwater systems for a longer period of time than on gentle slopes.

Shrink-swell clays are commonly developed on soils developed from tuffaceous rock or volcanic sandstone containing a high content of glass shards, pumice, or tuff fragments that weather to smectite (montmorillonite, bentonite) clays. Such soils absorb water during the wet season and expand, reducing percolation, providing surface area for water run-off and much slower percolated deep into clay-rich soils. Hence deep-rooted vegetation is commonly "starved" of water in such soils. Those soils, especially in steeper terrain and overlain by harder rock, commonly fail producing rock falls, talus, or landslides. Shrink-swell (smectite) soils are normally light color, sticky when wet, and exhibit irregular, sometimes deep cracks due to shrinkage during the dry season.

Fractured rock units (such as lava flows or well-indurated volcaniclastic rocks that cool and crack as volume is reduced upon cooling) that overlie less permeable (e.g.: volcaniclastic rocks and tuffs that weather to shrink-swell clays) localize rain water in cracks and joints during the rainy season. These reservoirs provide water for deeper-rooted plants such as shrubs, large brush, or trees as contrasted to shrink-swell soils. Hence mapping of units underlain by lava flows are likely to have a greater variety of plants and more trees than areas underlain by air fall tuffs or easily-weathered volcaniclastic rocks which have a higher percentage of shrink-swell clays than lava flows or well-indurated volcaniclastic rocks (such as welded tuffs or cemented breccias).

Secondary fracture systems and faults (which break up rocks, causing a secondary porosity and commonly increased permeability) can provide limited reservoirs for trapped surface water and may act as conduits for groundwater. The high-angle (steep) faults and fractures typical of the Western Cascade rocks in the Monument are often recognized by straight traces of vegetation growing along those rock breaks in contrast to less vigorous or shorter vegetation outside the fracture zones.

Springs commonly appear at different rock interfaces or along fractures/faults. Water flowing through fractured rock which lies above clay-rich rock/soil produce springs. Fractures may also localize springs where groundwater flows along the fractures (or faults) reach an impediment then issue forth at the surface. (**Figure 29**).

Vegetation clearly marks the location of fractured lava flows which retain water better than clay-rich soils. Hence deeper-rooted vegetation can survive in these fractured rocks. Areas underlain by lava flows also support more vigorous vegetation. The NW-trend of secondary fracture systems which also localize fracture reservoirs for water; hence they are also the locus of deeper-rooted vegetation.

Numerous examples of fault-related and rock unit spring interfaces can be seen on the geologic map. For example, in sections 31 and 32 west of the Juniper Point Picnic area near

Iron Gate Reservoir, springs occur along two NW-trending faults. An example of rock unit interface differences occurs near the eastern line of section of 32. There a thin but prominent lava flow traps water that reaches the surface in springs along the contact between fractured lava and less permeable tuff/soil under the lava. The general rule of thumb is that wherever springs occur, their appearance is due to an underlying geologic cause.

Rare examples of fossil springs occur. One such spring (**Figure 30**) is revealed by the presence of salts (calcium carbonate, calcite, is the most common salt) precipitated from groundwater carrying dissolved salts as the salty water reached the earth's surface and evaporates.

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Glossary:

Compositional names such as *basalt, basaltic andesite, andesite, trachyandesite, dacite, and rhyolite* are based on both field and geochemical criteria. Geochemical classification uses the standardized IUGS system where alkalis (sodium, Na_2O, and potassium, K_2O) are plotted against silica, (SiO_2); see **Figure 27**. Normally, using field identification using a hand lens (10X loupe), basalt, containing higher iron-bearing minerals, exhibits the darkest color and rhyolite, with the least amount of iron, exhibits the lightest color.

Some common abbreviations used in the text:

HC: High Cascade volcanic rocks

K/Ar (Potassium-Argon): Ratio of radiogenic elements used for age dating; **$^{40}Ar/^{39}Ar$**: radiogenic argon isotopes are also used for radiometric dating.

Ma: **M**illions of years **a**go

WC: Western Cascade volcanic rocks

An content: An, short for anorthite (the calcium-rich end member of a solid solution from calcium plagioclase to sodium plagioclase) carries a subscript showing the amount of calcium versus sodium in plagioclase. For example, An_{70} represents 70% calcium and 30% sodium ion in plagioclase. Normally mafic (high iron and magnesium) rocks contain more calcium than silicic (high silicon and alkalis) rocks which crystallize at lower temperatures.

Anhedral: refers to poor crystal shape normally induced by many grains growing at the same time and impeding the formation of good crystal faces (antonym: euhedral).

Aphanitic texture: is a fine-grained texture in rocks, normally lava, in which minerals can't be readily identified with the naked eye.

Augite: is an iron- and magnesium-bearing silicate mineral member of the pyroxene group characterized by its dark green color and rectangular shape.

Breccia: describes a poorly sorted (containing many different sizes of rock material) mixture of clay, sand, and larger usually angular fragments. It looks like a fruitcake with the larger particles suspended in a finer-grained matrix. *Heterolithologic breccia* refers to breccias characterized by clasts (larger rocks) of different composition that likely represent reworking of earlier deposits mixed with younger deposits. *Monolithologic breccia* refers to broken rock fragments of the same composition such as are found at the tops or bottoms of blocky or Aa lava or when lava flows break up into flow debris (in which case it is called *autoclastic*).

Colluvium: rock fall and tumble debris that is older or distinct from rock falls but which has not been worked by water.

Diabasic and intergranular textures: describes the relation of minerals to one another. *Diabasic* proper refers to pyroxenes such as augite or hypersthene filling the spaces between earlier-formed plagioclase while *intergranular* refers to any type of mineral or minerals crystallizing between earlier-formed plagioclase laths.

Diagenesis and metamorphism: both describe changes in mineral composition as a result of increased temperature and pressure. Diagenesis describes changes at the lowest end of alteration below the zone of weathering and grades to low grade metamorphism with increasing temperature and pressure.

Dike: is an intrusion of liquid rock (magma) into a crack or fissure. Dikes normally are harder than the rocks they intrude hence commonly protrude above the landscape like a dike wall or the sail of a ship.

Euhedral, subhedral, anhedral: all describe the crystal shape of a mineral; euhedral = “good crystal shape” while anhedral = “poor or severely altered shape of crystal”.

Felty (or felted) texture: a texture wherein minerals of a rock, especially plagioclase, show random orientations; it is interpreted as an indication of sluggish flow of lava.

Fiammé: (Italian for “flame”) are wispy shapes within a brownish mass of broken crystals and rock fragments and are formed by compaction and partial melting of pumice particles.

Fission track dating: a method of calculating age of a mineral by measuring the paths of radiation damage produced by radioactive decay and expulsion of particles from a decaying radioactive element. The number of fission tracks is proportional to the mineral’s age.

Formation: a geologic term that defines a persistent body of rock which has definite recognizable upper and lower boundaries and has internal lithologies that typify the formation. It is a lithologically-defined entity which may or may not be time-transgressive.

Form lines: lines on a geologic map that shows a particular rock body that can be followed in the field but is smaller than a geologic unit. It shows internal stratigraphy within a unit or formation.

Glomeroporphyritic texture: refers to clots or “gloms” of early-formed crystals that occur in clumps, sticking together in a liquid magma by virtue of surface tension.

Hypersthene: is an iron- and magnesium bearing silicate member of the pyroxene group characterized by its black color and rectangular shape.

Iddingsite: is an alteration product of olivine; it ranges from yellow- to deep-brown and nearly black (depending on the mosaic of minerals that form) and is comprised of a mosaic of iron oxides and hydroxides. Serpentine and chlorophaeite may color altered olivine greenish. Calcite may also be present.

Joints: regular fracture sets formed in rocks as a result of cooling (as in solidifying magma such as lava which contracts upon cooling) or later tectonic stresses. For example, *columnar* and *platy* joints form as lava cools and contracts. *Columnar joints* such as seen at the Table Rocks form perpendicular to the cooling surfaces (hence most are generally vertical or nearly so). *Platy joints* are cooling features formed roughly parallel to the flow surfaces of lava (hence are generally horizontal or nearly so yet they normally follow flowage bands in lava). *Tectonic joints* are regular fractures in rocks generated by regional or tectonic stresses. If movement occurs, then those joints transition to faults.

Kipuka (“Steptoe”): Hawaiian term used to describe an isolated protrusion of bedrock; in this case the protrusion is surrounded by younger lava flows.

Lava flows, types: there are a wide variety of lava flow types. *Pahoehoe* lava is rare in the Monument but where found it is "ropey" due to its fluidity; *Aa* lava is comprised primarily of vesicular to poorly-vesicular broken lava ("rubbly"); *Block lava* is comprised of largely poorly-vesicular lava (except at the tops and bottoms of flows) and consists or relatively large jumbles of blocks. Fluidity decreases from pahoehoe to Aa to blocky lava.

Mafic: this term represents rocks rich in Fe (iron) and Mg (magnesium) which are normally found in "primitive" (basalt and basaltic andesite) magmas more commonly than silicic magmas. Associated in mafic magmas are small size large charge cations (Ti, Ni, Cr, V, Co, Sc), HFSE (High Field Strength Elements such as Nb, Ta, Y, Zr, and Hf), and HREE (Heavy Rare Earth Elements (Gd through Lu).

Common mafic minerals: olivine, pyroxenes (stubby augite and elongate hypersthene), hornblende (black, elongate mineral), and biotite (black flaky mica).

Microfelsite: recrystallized glassy material that resembles small particles comprised mostly of feldspar and quartz.

Oscillatory zoning: commonly seen in plagioclase as successive zones that alternate from calcium-rich to sodium-rich; indicates a temperature or chemical instability in the magma; *normal zoning* in plagioclase is exhibited in calcium-rich crystal cores to sodium-rich rims. Commonly the cores of such plagioclase are calcium rich trending to sodic rich as the magma cools (known as "normal zoning").

Olivine: an iron and magnesium rich silicate mineral that forms at high temperatures, becoming less stable at surface conditions on earth's surface; it is commonly called peridot and is characterized by its green color; it is often altered to *iddingsite (brown to yellow-brown)* or *chlorophaeite or serpentine (both green)*.

Opaques: refers to iron-rich minerals (mostly oxides or hydroxides) that are opaque in transmitted light as seen in polarized light used in petrographic microscopes. Opaques are difficult to identify but in the CSNM volcanic rocks they are magnetite, hematite, titanomagnetite, and/or ilmenite (the latter of which is very rare). Magnetite is the most common opaque mineral.

Ophitic and subophitic textures: these textures are the result of slower cooling and normally have larger crystals than that which creates intergranular or diabasic textures. In ophitic texture augite encloses smaller crystals of plagioclase. In subophitic texture augite partially encloses plagioclase crystals.

Oscillatory zoning: commonly seen in plagioclase as successive zones that alternate from calcium-rich to sodium-rich; indicates a temperature or chemical instability in the magma; *normal zoning* in plagioclase is exhibited in calcium-rich crystal cores to sodium-rich rims. Commonly the cores of such plagioclase is calcium rich trending to sodic rich as the magma cools (known as "normal zoning").

Paleosol: "old soil" developed as a result of weathering at some distant time in the past; in the CSNM they are normally reddish to rarely brownish-red as a result of oxidation. Very few are yellowish-brown. Red colors are due to severely oxidized iron (hematite); brown to a mixture of hematite and limonite or goethite; yellow due to a dominance of limonite.

Petrographic microscope: a microscope with two polarizers oriented at right angles to one another that allows analysis of rock thin sections cut to 30 microns of standard thicknesses. The identity of different minerals and their textural relations is facilitated based on their responses to polarized light. Magnification allows inspection of fine-grained mineral textures that elude investigations by using a 10X loupe.

Phenocrysts: large crystals immersed in a finer-grained *groundmass* of tiny crystals or glass. Phenocrysts represent slow-crystallizing early formed minerals in contrast to the *groundmass* which crystallized much more rapidly.

Pilotaxitic: a texture wherein plagioclase feldspar laths are slightly arranged (not strongly arranged as in trachytic texture but show more alignment than **felty** texture).

Plagioclase: is a rectangular to lath-shaped silicate mineral characterized by its light translucent color; it is common in almost all rocks and contains silicon, sodium, calcium, and aluminum as the primary elemental constituents.

Porphyritic-aphanitic: the texture of a volcanic rock in which large crystals (phenocrysts) occur in a fine-grained groundmass (aphanitic) indicating a two-stage history of the rock: slow cooling (phenocrysts) and rapid cooling (groundmass) during eruption.

Pseudomorph: "false form", it refers to the replacement of one mineral by another yet still keeping the shape of the original mineral. For example, "iddingsite after olivine" is a phrase describing the formation of iddingsite minerals yet the shape of olivine is preserved.

Pyroclastic rocks: are "fire broken" as the Greek word implies. The sizes of the broken particles range from volcanic ash to huge blocks as seen in breccia.

Shield volcano: these are relatively low angle volcanoes similar in shape but steeper than those in the Hawaiian Islands. They aren't as steep as *composite or "strato" volcanoes* such as Mount Shasta or McLoughlin which are comprised of "stickier" silica-rich lava and pyroclastic rocks.

Silicic: refers to rocks high in Si (silicon) and Al (aluminum) such as rhyolite, dacite, and silicic andesite in contrast to mafic rocks which are high in Fe (iron) and (magnesium). Silicic volcanic rocks are high in Si, Al, Na, K, small charge with large size cations (Rb, Ba, Sr, Cs, Th, U, Pb) and LREE (Light Rare Earth) elements (La through Eu).

Smectite clays: clays unlike kaolinite and illite clays, which have the ability to shrink or swell depending on the availability of water. Such clays, when wet, swell and become "sticky" and when dry and shrink producing cracks. They are very unstable on steep slopes often failing during rain storms. Volcanic tuffs are prone to change to smectite or bentonite clays both of which have shrink/swell properties. When dry they can absorb water and swell which cuts off the permeability of such clay-rich soil causing erosive run-off of water.

Talus ("scree"): is comprised of broken debris derived from steep cliffs and normally forms steep slopes at the base of those cliffs or sweeping steep fans.

Tuff: fine to pebble size volcanic fragments. *Ash FlowTuffs* are produced during the expulsion of fragmental material that forms an ash cloud that collapses under its own weight; if the heat retained upon deposition is great enough, particles may partially or totally re-melt; *Ash Fall Tuffs* are those which are carried by the wind and settle under the influence of gravity.

Trachytic texture: describes a rock fabric wherein platy plagioclase minerals are aligned parallel or subparallel to one another during flow of a lava or dike.

Scoria: the typical red to black cinders with ~ 50% gas vesicles that are commonly used during winter to provide traction on ice or snow-covered roads; they are typified by many small holes or vesicles resulting from degassing from silicate magmas high in volcanic throats.

Stratovolcano also called a Composite Volcano: a large volcano comprised of lava flows and volcaniclastic rocks normally comprised of magmatic rocks higher in silica than those of shield volcanoes. They produce large, striking landforms such as Mount McLoughlin and Mount Shasta.

Unconformity: defines a gap in time between rock units. An unconformity is formed by either non-deposition or, more commonly, erosion of older rock prior to deposition of younger rock. An *angular unconformity* is defined by an angular discordance between younger and older rock units. There may or may not be a paleosol developed on the top of the older unit.

Unit: as used in this report, it is a lithologically-defined entity that bears internal consistencies that may be followed in the field; it is smaller than a geologic formation and is considered a subset of that formation.

Volcaniclastic rocks: an inclusive term to describe both initial eruptive products (like airfall and ash-flow tuff and breccia) and reworked sediment eroded from pre-existing volcanic rocks. All are comprised of fragments of various sizes. Sometimes called volcanogenic sediment.

Zeolite: small to microscopic, normally white, minerals that occur within or lining volcanic gas vesicles and fractures or are introduced into altered volcanic rocks during diagenesis or low-grade metamorphism.

References:

Bestland, E., 1987, Volcanic stratigraphy of the Oligocene Colestin Formation in the Siskiyou Pass area of southern Oregon: Oregon Geology, v. 49, n. 7, p. 79-86.

D'Allura, J., 2017, Final Report: Geology of the Original Cascade-Siskiyou National Monument, August, 2017: Medford BLM office, Medford, Oregon, 77 pages of document with figures and map, unpublished.

Fiebelkorn, R., and others, 1983, Index to K-Ar determinations for the State of Oregon: Isocron/West, the Bulletin of Isotopic Geochronology, number 37, p.3-53.

Hammond, P., 1983, Volcanic Formations along the Klamath River near Copco Lake: California Geology, May, p. 99-109.

Harris, M., 2017, Late Miocene to Early Pleistocene volcanism in the 7.5' Parker Mountain quadrangle of Southern Oregon: Oregon Academy of Sciences, Feb, 24, 2017, v. LXXVI, p. 33.

Lowenstern, J., 1986, Petrology, geomagnetism, and tectonic significance of the lavas of the Colestin Formation, Jackson County, Oregon: undergraduate thesis, Dartmouth College, New Hampshire, 61 pages.

McCann, K., M. Harris and J. D'Allura, 2017, Geology of the west there-quarters of Parker Mountain 7.5' Topographic Quadrangle and southeastern part of the Soda Mountain Quadrangle, Cascade-Siskiyou National Monument: Report to the Friends of the Cascade-Siskiyou National Monument, text, figures, and diagrams.

Smith, J., N. Page, B. Moring, and F. Gray, 1982, Preliminary Geologic Map of the Medford 1° X 2° Quadrangle, Oregon and California: US Geological Survey Open File Report 82-955.

Vance, J. A., 1984, The Lower Western Cascades Volcanic Group in Northern California: *in* Nilsen, T., ed. Geology of the Upper Cretaceous Hornbrook Formation, Oregon and California: Pacific Section S.E.P.M., vol. 42, p. 195-196.

Wells, F., 1956, Geology of the Medford Quadrangle, Oregon-California: U.S. Geological Survey Quadrangle Maps GQ 89; map and text.

Wiley, T., J. McClaughry, and J. D'Allura, 2011, Geologic database and generalized geologic map of Bear Creek Valley, Jackson County, Oregon: Oregon Department of Geology and Mineral Industries, Open File Report 0-11-11. Maps, data tables, and text.