Structure and Petrology of Secret Spring Mountain's Western Slope

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INTRODUCTION

Secret Spring Mountain is an extinct volcano just on the California side of the Oregon / California border. It has been extinct since the late Miocene. The center of the volcano has been gouged out into an amphitheater by an extremely large landslide in the Pleistocene which deposited the material out into the Klamath River gorge to the north. Two relatively flat mesas rise off its flanks to the northwest, while the opposite side of the Klamath River gorge is covered in a series of large, table-like lava flows. The western flank of the volcano has been eroded by stream processes into a series of westward running ridges. The bedding on the western slope of the mountain, with the exception of the capping lavas on the two mesas and the uppermost lava on the mountain, dip ten degrees to the east.

Most of the layers are lavas of dacitic andesite to basalt in nature. However, scattered throughout these layers are several pyroclastic units of note, including tuff deposits, reworked tuffaceous sandstone, and a tuffaceous surge deposit. The most impressive layer here is a two hundred foot-thick tuff breccia layer: composed of ash, cinder, and clasts of vitrophyre. These layers on the western slope of Secret Spring Mountain all dip 10+ degrees east-- into the heart of the volcano. It is certainly not typical volcano behavior for all the beds on one side of the mountain to tip up and out into the air.

Secret Spring is also a kipuka, a relic of older rock (the summit flows are at least 14 MA old), surrounded by much younger lava flows located across the Klamath river to the north and west (from 2-8 MA). The flow at the Hessig Wall at the base of the slope [see Fig. 1] has been dated to early Miocene at 21 MA. It has been hypothesized that most of the layers on this western face are not from the Secret Spring Volcano vent. Rather, there might have once existed a larger volcano to the west or south which erupted explosively, and caused the massive volcaniclastic deposits. Secret Springs volcano would have then formed on the flanks of the remnants of the earlier volcano.

PROCEDURES

This region was field mapped over the summer and rock samples taken. Paleoslope of lava flows were determined through orientation of joint planes when only one set was present. No deductions were made of lava flows with perpendicular joint sets (the Lower Northern Andesite). Thin sections of most of the layers were made to identify more accurately the minerals involved. Major element analysis of 30 samples helped correlate layers, identify trends, and classify the rocks. Neutron activation analysis identified trends in REE, and K-Ar dating of several key layers helped solidify the temporal relationship between flows.

VOLCANICLASTIC UNITS

Airfall tuff / surge

This is the lowest portion of the pyroclastics in the region and rises approximately 100 ft along the slope. It outcrops above the vesicular basalt east/northeast of Hessig Ranch [see Fig. 1], towards and along the sides of Cornflake mesa (though not exposed very prominently there). It is noticeably absent on Albert's Peak and along the northern side of Train ridge as the tuff breccia above this layer continues through those regions. Continuing the regional trend, this layer also dips approximately 10 degrees to the east.

The first layer comprises of a white tuff layer exposed in the hillslopes, consisting of fine horizontal ash layers. This tuffaceous material varies in the level of stratification and organization. It primarily composed of a fine "dirty tuff" matrix, composed of small granules of tuff, pumice, and extra-fine vitric/crystal fragments. The outcrop often alternates between feet-thick beds of this dirty tuff and fine horizontal layers of white ashfall up to 6" thick. Due to the massive bedding and absence of fine laminations and juvenile lava fragments, this can be diagnosed as a tuff airfall.

Stratigraphically contemporaneous with this layer is another ash deposit immediately under the northern-most section of the Greywall. This outcrop is approximately sixty feet thick, and is composed of laminated layers of ash with semi-angular vitrophyre clasts (ranging in size from 1-25 cm. in diameter) interrupting the lamination/ bedding structure. The finer laminae in this formation often bend above and below the clasts, displaying "block sag"-- emplacement by a sub-aerial blast. Wavy-stratified laminae interspersed with juvenile vitric fragments (vitrophyre) is exemplary of a pyroclastic surge deposit. A pyroclastic "base surge," a turbulent, low-density flow caused by a

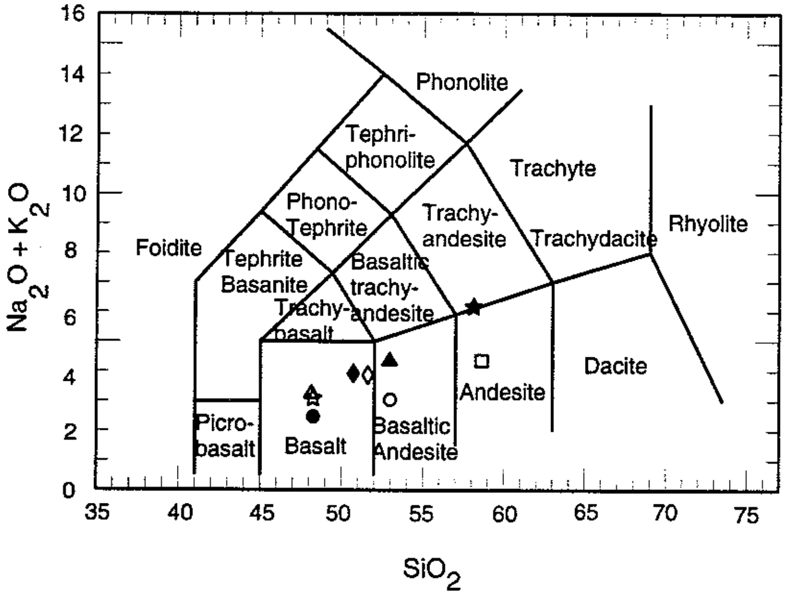


Figure 2: Total alkalies v. SiO_2 diagram after Le Bas, et., al., 1986.

Key

- ☆ △ Basalt porphyry
- ● Antler basalt
- ○ ◊ ♦ Secret Spring basalt
- □ Upper tuff
- ▲ Olivine-phyric basaltic andesite
- ★ Topsy Road andesite

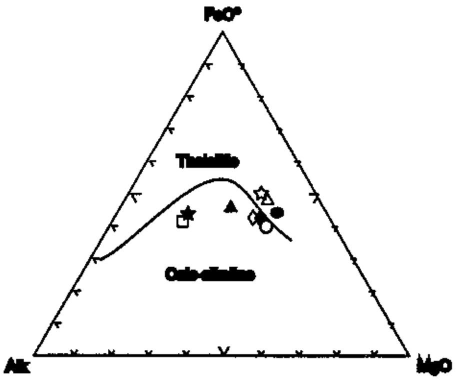


Figure 4: AFM diagram showing tholeiitic v. calc-alkaline samples.

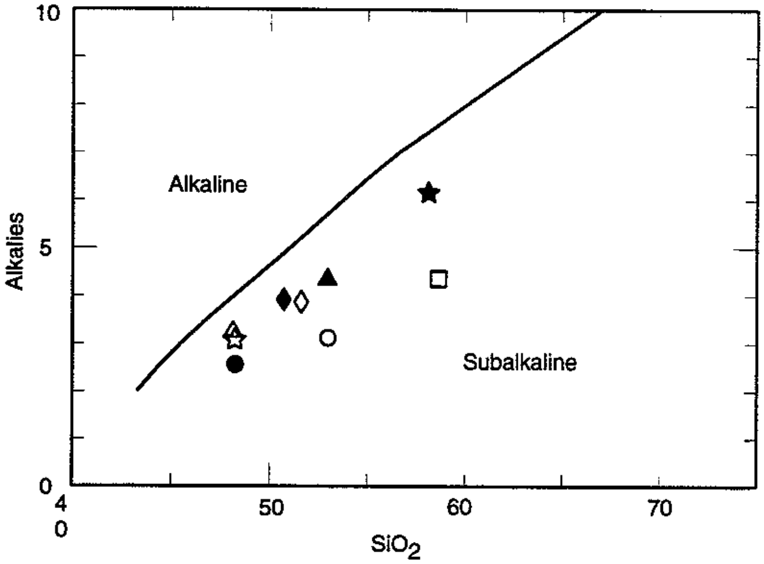


Figure 3: Total alkalies v. SiO_2 diagram: all samples analyzed are subalkaline.

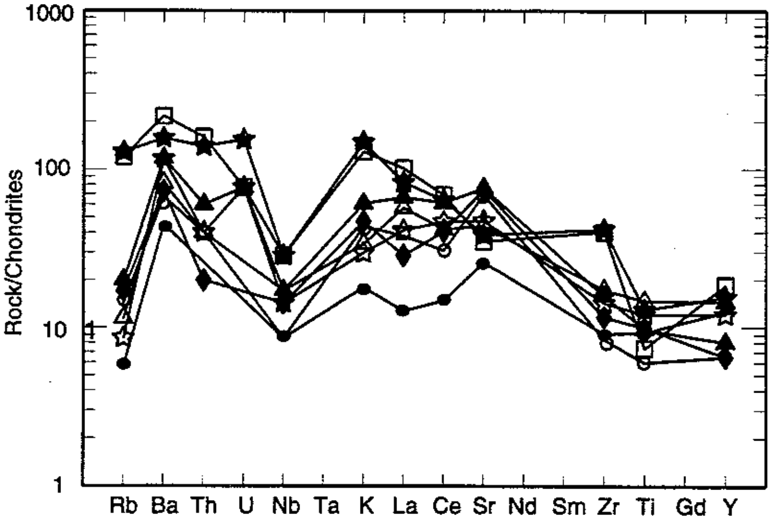


Figure 5: Chondrite-normalized Spider diagram.

directed blast from a vent is most likely the cause of these formations. Due to the turbulent nature of the particles suspended in air during the base surge, cross-bedding is often present, though in this outcrop it is not immediately visible. Assuming a source from the east or west, even exposed laminae would not show much low-angle truncations which would be visible looking at these deposits from the north or south. These laminae are inclined at the same 10 degree dip as the rest of the rocks at this outcrop..

Immediately above this thick package of volcaniclastic sediment is a more massive bed forty feet thick, showing little, if any grading. The rock is supported by a matrix of fine white ash, and is interspersed with small (<5 cm) juvenile vitric clasts. Within this massive layer is a smaller lens of laminated tuff deposit, akin to the larger surge below. This is most likely from a smaller surge blast within the larger massive flow.

Tuff breccia

The main attraction in the region, this formation appears as a 200'+ high wall of grayish "rubble," lending to its nickname as "the Greywall." It outcrops above the tuff surge starting ENE of Hessig Ranch, continues south above Salamander ridge, cuts through Albert's Peak and Train Ridge [see Fig. 1]. The massive scale and continuity of the outcrop also hints at several of the fault structures running through the area. (These fault structures are especially evident in aerial photographs.) This formation is made of an unsorted, gravely matrix comprised of grains ranging from 1-20 mm in diameter, though averaging about 3-5 mm. There is no immediate evidence of welding. Due the weathering rind present on all but the clasts, it is difficult to examine further matrix properties with much accuracy. Clasts in this stratified "conglomerate" comprise of pieces of cinder and vitrophyre once again ranging up to the size of a soccer ball (25+ cm or so). All the apparent bedding in the tuff breccia dip to the east with a range 28-48 degrees.

On the farthest northern section of the Greywall there seemed to be some sort of capping lava and what seems to be a small lava flow within the top 10-20 feet of the Greywall. The lava was quite vesicular and had deteriorated beyond field identification at that point. Other associated flows might include the andesite outcrops on the top of Albert's Peak, where the Greywall crosses that ridge. Chemically, this layer is almost identical to the andesite topping Albert's Peak, aiding to the correlation of the outcrops.

Deposition of the Tuff Breccia

Several hypotheses exist concerning the depositional environment of this tuff breccia unit. Due to the weathering that this layer has undergone, it is unlikely that a fully convincing depositional model can be constructed. The argument involves whether or not this is a primary or secondary deposit. As a primary deposit, the breccia would have been directly emplaced by some sequence of pyroclastic events. As a secondary deposit, the material for this breccia would have already been deposited someplace else, perhaps at a higher elevation, and then eroded and deposited in a series of cohesive debris flows. This secondary deposition might also involve the influence of water, perhaps in the form of a mudflow or alluvial fan.

This deposit could not have been directed from the Secret Springs volcanic vent. If the bedding planes indicated local topographical trends as a primary deposit, the Secret Springs vent would have had to blast all that rock in an upwards cone. This rock would also have to stay in place and not avalanche down back into the vent. Though there are places, such as the Taupo ignimbrites in northern New Zealand, where the deposits surrounding the vent are topographically higher, there were no proximal upwards trending flows. A tuff cone, a large volcanic surge deposit created by a phreatomagmatic (water coming in contact with magma) explosion can produce inward dipping bedding planes near 25 degrees. However, tuff cones are pyroclastic airfall and surge deposits-- finely laminated, which this breccia certainly is not. Even as a secondary deposit, there are very few processes which could create bedding rising away from the source location. A regressive dune set would have this reverse foreset behavior, but it would require extreme flow size and velocity to deposit large clasts in large beds on a scale of 200 feet. Since pyroclastic dune structures are never this large, the Secret Spring vent could not have been a source for these "inward-dipping" deposits in a normal sedimentary system.

If the Secret Springs volcanic vent, east of these deposits, is not the source, then the source must lie to the west of the Greywall. The bedding angle is now more realistic of a downhill flow. As a primary deposit, the tuff breccia would have been structurally formed from a series of dense pyroclastic flow sheets-- "block and ash" flows, based on the clast size ranging up to 25 cm. The continuous series of these beds suggest wide flows compounding on top of one another, perhaps due to pulsation in the magma chamber.

As a secondary deposit, the Greywall is most likely part of a giant volcaniclastic alluvial fan. Pyroclastic deposits, since they often involve large amounts of tuff, are fairly erodable. These primary deposits are eroded and carried away from the cone, most likely flowing off of former flows onto an alluvial fan. The Greywall displays the same layered massive bedding that a cross-section of a giant alluvial fan might have. Compositionally, the small mm-scale tuff matrix granules can be attributed to accumulation during transport in a wet environment. These granules are known as accretionary lapilli. The deposits will exhibit more or less gradual bedding depending on the lack or abundance of water during transport -- accounting for the variability in composition found in the different beds. The only thing relatively atypical about this alluvial fan model is the horizontal continuum of strata. Alluvial fans are usually built up by a series of small channelized flows, and by doing so, their cross-section should be broken up into small "lenses." The observed horizontal continuity could be explained by the debris flows traveling in wide sheets instead of flows, though this is still conjecture. As mentioned before, due to the difficulty of analyzing ancient volcaniclastic deposits, the analysis of this feature is only preliminary. Only after a thorough evaluation of the *complete* set of characteristics of the lithologies has been made, can one begin to make sound deductions on the outcrop genesis (Cas and Wright, 1987).

Conclusion on Volcaniclastics:

The major pyroclastic layers all dip at least ten degrees to the east. According to K-Ar dating methods, these deposits are around 19.6 MA, placing their deposition not much later than the Hessig Wall lava. The airfall tuff and pyroclastic surge deposits mantle topography, indicating paleoslope but not direction of emplacement. The volcaniclastic breccia could only have been emplaced from a source to the west, due to the steep bedding angles. Relevant joint plane orientations from the Hessig wall, the dacitic andesite, northern lower andesite, and Anders' basalt layer depict a paleoslope of ten degrees to the east. A slightly inclined paleoslope with lava flows and volcaniclastic deposits is typical of flanking facies of a stratovolcano (Best, 1982)

VOLCANIC PROGRESSION

One of the most prominent aspects of the volcanic succession on the west flank of Secret Spring Mountain is the trend from silica-rich dacite at its base to silica-poor Anders' basalt near the peak. Confusing as it may be, this does run against the common perception of fractionation driving the chemical trend. In that model, magma pools into a chamber where it then proceeds to differentiate into silica rich melts. The magma chamber initially erupts basalt, then fractionates to andesite, then dacite, and then sometimes even to rhyolite. On the western slope of Secret Spring Mountain, the progression is more alternating, with an almost reverse fractionation trend.

Using silica or MgO as a fractionation indicator, it is possible to follow the trend of the erupted lavas and volcaniclastic material. The extruded flows exhibit a trend of decreasing fractionation from the Hessig Wall Dacite to the Lower Northern Andesite. This trend culminates in the basic Lower Basalt, which caps the Lower Northern Andesite.

Fractionating from this Lower Basalt, the Lower Southern Andesite rises up to Albert's Peak and under Train Ridge. This could be divided into two layers: a lower layer comprised of flows with near 55% silica and an upper layer with flows around 57% silica. The boundary between these is quite arbitrary, and it otherwise just useful to note that there is a general trend of increasing fractionation the further up one goes. (Higher lava flows denote later flows.) This culminates with the Greywall volcaniclastic deposits -- 58% silica by weight. It is interesting to note that the Greywall chemical composition is remarkably similar to the andesitic lava flow on top of Albert's Peak. If the Greywall was determined to be a primary pyroclastic deposit, the outcrops on top of Albert's Peak at #13 could be classified as post-eruption flows related to the massive deposit. The Greywall passes through Albert's Peak at this point, and the outcrops at #13 are technically on top of it, creating an interesting stratigraphic question. The other possibility is that these outcrops are pinnacles of older rock as the Greywall was deposited around it. This remains conjecture as further in-depth mapping of the contact and analysis of the Greywall's origin would be required.

Above the Greywall and tuff deposits, the fractionation cycle begins anew with the trachytic Anders' basalt. Dated at 19.3 MA, these lavas were emplaced not too far after the Greywall deposition. This unit is exemplified by the abundance of plagioclase laths in the groundmass and hgh alumina content. The composition of this layer is similar to the Lower Basalt in major element composition. Of interest is a lone dike-like formation (#24, see Fig. 1) which contains the least fractionated basalt present on the western side of Secret Spring Mountain. This flow contains low silica (49%) and comparatively high amounts of Ni & Cr (226 ppm and 416 ppm, respectively), trace elements whose abundances diminish quite quickly as fractionation progresses.

The Upper Tuff sharply contrasts with the Anders' basalt, as it is quite andesitic in nature-- possessing 60% silica. It is significantly younger than the Anders' Basalt, as it was K-Ar dated to 17.6 MA. Above this tuff is the 14 MA Secret Spring basalt which has been extruded by the Secret Spring volcano vent, unrelated to the vent that deposited the rest of the flows. (There is also a large temporal gap between the Anders Basalt/ Upper Tuff and the Secret Spring Basalt-- more than three million years.)

Discussion on Volcanic Progression

Given this cyclic "reverse" fractionation trend, it is hypothesized that this behavior is caused by a combination of crustal contamination and fractional crystallization. This could be evident of a series of magma diapirs rising towards the crust. As the first surge of hot magma rises, it partially melts the crust above it, and eventually erupts as a silica rich flow. Successive surges rise to the same spot and partially melt more crust above the "plume." Since the crust above had been already been partially melted, less silicic material is added to the successive melts. (McBirney & White, 1982) Eventually the melt rises through the crust with little contamination, forming such layers as the Lower Basalt.

Fractional crystallization is also at work in the complex plumbing system of stratovolcanoes. As magma lingers in chambers, it is postulated that it differentiates gradually into increasingly variable products. The longer the magma spends fractionating, the more silicic the magma can become. This explains the increasing silica trend, such as the progression from Lower Basalt to Lower Southern Andesite to Greywall volcaniclastics. The presence of high-alumina Anders' Basalt is explained, as Crawford et al. (1987) has demonstrated that this form of basalt originates by differentiation and plagioclase accumulation from more mafic parents. The separation of a magma into basaltic and andesitic end members is evident in the alternation of Anders' Basalt with the andesitic Upper Tuff layer. This behavior is typical of complex volcanos (McBirney & White, 1982) as they often simultaneously erupt basalt in flank flows and dacite/rhyolite from the main vent.

CONCLUSION

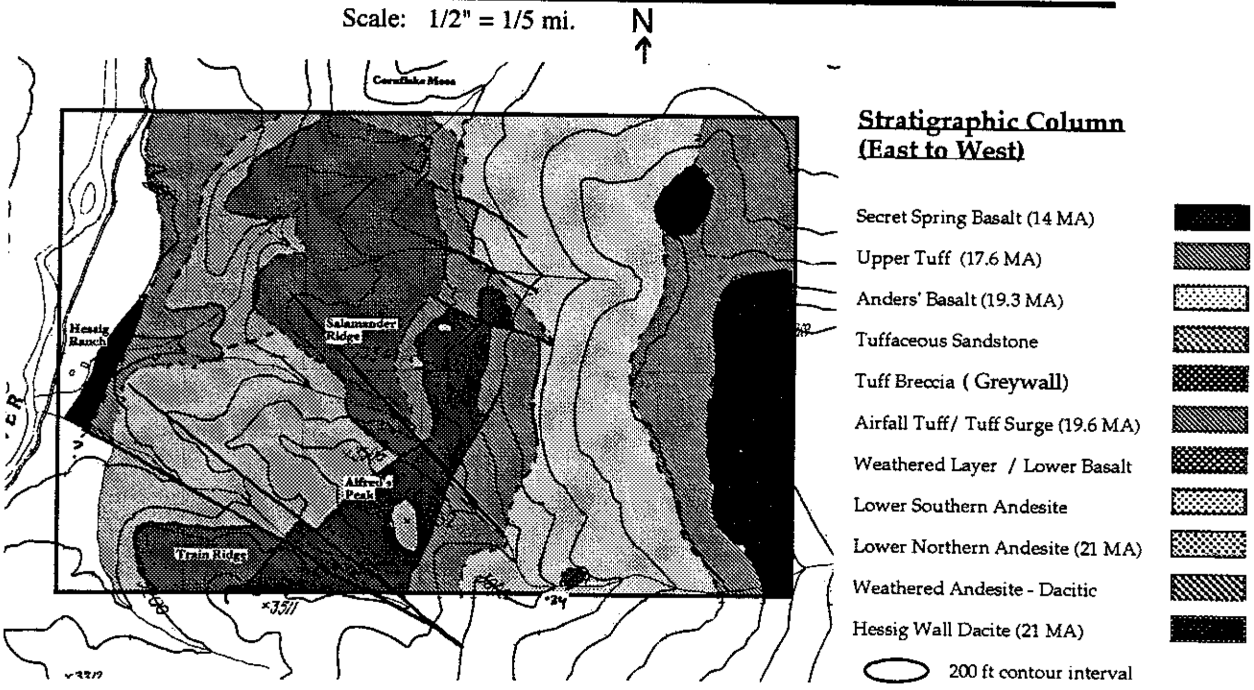
With the exception of the capping Secret Spring basalt, the layers exposed on the western slope of Secret Spring Mountain originated from an unknown vent located somewhere to the west. Petrologic analysis concludes that the vent involved has a history of cyclical melt composition. This complex behavior can be explained by rising diapirs of magma from the mantle wedge successively assimilating the continental crust. Further research might be able to determine to what extent the crust played in the development of the extrusives as well as unravelling the exact nature of the tuff breccia deposition.

REFERENCES CITED

Best, Myron G. (1982) Igneous & Metamorphic Petrology W.H Freeman and Company New York
Cas, R.A.F. & Wright, J.V (1987) Volcanic Successions: Modern and Ancient Allen & Unwin, London
Crawford, AJ & Falloon, T.J & Eggins, S. "The origin of island arc high-alumina basalts" *Contributions to Mineralogy and Petrology* 1987;97:417-430
Hyndman, Donald W. (1985) Petrology of Igneous and Metamorphic Rocks 2nd Ed. McGraw-Hill Inc., Boston
McBirney & White (1982) "The Cascade Province" p. 115-135 Andesites Thorpe, R.S. ed, John Wiley & Sons, Chichester, England

Fig. 1

Geologic map of the western slope of Secret Spring Mountain



Tectonic Controls on Magma Genesis in Southern Oregon

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Introduction:

The Blanco Fracture zone between the Juan de Fuca and Gorda North plates comes ashore in the vicinity of Keno, Oregon, just north of the California/Oregon. The Blanco Fracture Zone began forming 4.9 Ma when the Explorer plate separated from the Juan de Fuca plate causing rotation of the Pacific/Juan de Fuca pole of rotation (Embley et al., 1984). Right lateral movement along the northwest-trending Blanco Fracture Zone is driven by the relative motions of the Gorda North and Juan de Fuca plates. Overall subduction rates in the Pacific Northwest have slowed 60% since 6.9 Ma and subduction of the young, buoyant Gorda Block has ceased altogether (Spence, 1987). The Juan de Fuca plate continues to be subducted at a rate of 40 mm/yr (Goldfinger et al., 1997). The Blanco Fracture Zone extends under the continent of North America where the right lateral shear generates east-west extension (Pease, 1969). It is hypothesized that this complex tectonic history has influenced magmatism in the northern California/southern Oregon region.

Methods:

The mapping area for this project was a strip one mile wide and seven miles long located just southwest of Keno, Oregon and extending south from Oregon Rte 66 to the Oregon/California border (T40 and 41S, R5E Sections, 1, 12, 13, 24, 25, 36, and 1 on the Mud Spring Mtn 7 ½ minute Quadrangle) (Fig. 1). Three additional one mile wide swaths were mapped by other workers, one immediately to the east, and two to the west. Geology of the area was mapped, field units were identified, and representative hand samples were collected from each unit. From these samples, thirty were selected for thin section analysis. Using thin sections and hand samples, the petrography of the units was described. Geochemical analyses (x-ray fluorescence, loss on ignition, and Fe^{+2} titration) were performed on 27 of those samples. Geochemical data was then analyzed to confirm unit identities and distinguish petrogenetic trends within units and the entire study area. K-Ar age dating was performed by Dr. Stanley Mertzman.

Figure 1