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The mineralogy of the Snake Creek-Williams Canyon
pluton, southern Snake Range, Nevada

by

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Abstract

The Snake Creek-Williams Canyon pluton of the southern Snake Range crops out over an area of about 30 km², about 60 km southeast of Ely, Nev. This Jurassic intrusion displays large and systematic chemical and mineralogical zonation over a horizontal distance of 5 km. Major-element variations compare closely with Daly's average andesite-dacite-rhyolite over an SiO₂ range of 63 to 76 percent.

For various reasons it was originally thought that assimilation played a dominant role in development of the Snake Creek-Williams Canyon pluton. However, based on modeling of more recently obtained trace element and isotopic data, we have concluded that the zonation is the result of in-situ fractional crystallization, with little assimilation at the level of crystallization.

This report summarizes data available for each of the mineral species present in the zoned intrusion. Special attention has been paid to trends that might relate to the variation in the chemical petrology of the pluton.

Introduction

The Snake Creek-Williams Canyon pluton of the southern Snake Range crops out over an area of about 30 km², about 60 km southeast of Ely, Nev. This Jurassic (Lee and others, 1968, 1970, 1983) calcic (Peacock, 1931) intrusion displays large and systematic chemical and mineralogical zonation over a horizontal distance of 5 km. Major-element variations compare closely with Daly's average andesite-dacite-rhyolite over an SiO₂ range of 63 to 76 percent. Since the large and systematic variation in the chemical petrology of this intrusion was first recognized, the essential question has turned on the relative importance of assimilation and fractional crystallization in the development of the pluton. Inasmuch as the most mafic parts of the intrusion are in contact with shale and limestone, the most felsic parts with quartzite, and because the calcium-rich accessory minerals (epidote, sphene, apatite, and allanite) are strongly concentrated in the mafic parts of the intrusion, Lee and Van Loenen (1971) concluded that assimilation played a dominant role. However, based on modeling of trace-element and isotopic data obtained since 1971, Lee and Christiansen (In press) concluded that the zonation is the result of in-situ fractional crystallization, with relatively little assimilation at the level of crystallization.

This discussion of the mineralogy of the Snake Creek-Williams Canyon pluton is complementary to the Lee and Christiansen (In press) report. Indeed, most of it was deleted from that manuscript in order to meet the length restrictions of the journal.

Each of the mineral species present was studied in detail as part of our attempt to understand the processes that have produced this intrusive mass. Systematic mineral separation work was carried out, and pure fractions of most or all of the minerals (except quartz) present in each of 20 rocks were

recovered for study. The results of analytical work on these mineral fractions are summarized in the following discussion; much more detailed information is given in the cited reports on the individual mineral species. Special attention was paid to trends that might relate to the variation in the chemical petrology of the pluton.

The mineralogy of the Snake Creek-Williams Canyon pluton is outlined in figure 1, which has much in common with similar diagrams in the literature that

Fig. 1--NEAR HERE

illustrate the variations and relative proportions of minerals composing major rock types as they result from magmatic differentiation (Pirsson, 1947, p. 117). General relations between amounts of CaO and accessory minerals in these rocks are diagrammed by Lee and Van Loenen (1971, fig. 10).

Mineralogy

Feldspars

Gravimetric analyses have been reported (Lee and others, 1980) for six plagioclase feldspar fractions recovered from samples of the intrusion ranging in composition from 66.3 percent SiO₂ (3.9 percent CaO) to 73.4 percent SiO₂ (1.5 percent CaO). All of the plagioclases studied are in the low structural state. Five are oligoclase and one is andesine. As expected, the anorthite content of these plagioclases increases, and amounts of maximum microcline ("orthoclase") solid solution in the plagioclase phases tend to decrease in the more mafic samples. By means of neutron activation analyses, Cain (1974) found that the lighter rare-earth elements are present in larger amounts than the heavier rare earths in the plagioclases. All of these plagioclases show a large, positive europium anomaly. In a detailed discussion,

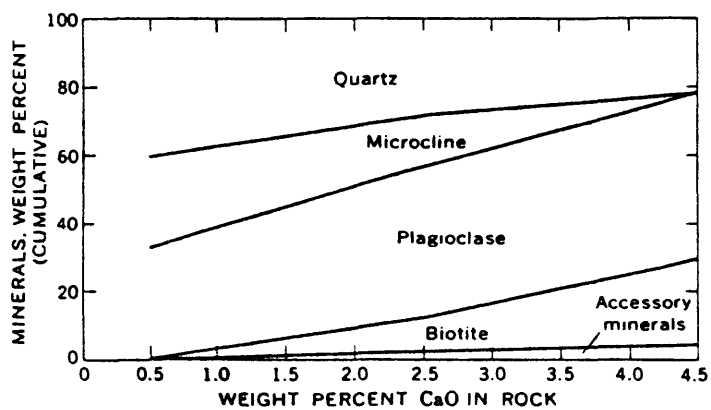


Figure 1 —General relations between CaO content and mineralogy, for granitoid rocks of the Snake Creek—Williams Canyon area. (From Lee and Van Loenen, 1971, fig. 11.)

Cain concluded that these plagioclases probably crystallized from a liquid phase with a lower-rare earth content than is observed in the whole rocks.

Gravimetric analyses were also reported for maximum microcline microperthites coexisting with five of the six plagioclase feldspars discussed above. In general, the anorthite content of the plagioclase phase tends to be less in the microcline microperthites from the more felsic rocks. Cain (1974) found the rare-earth content of these microperthites to be so low that he was unable to detect the presence of any of the heavier (than europium) rare earths in two of the samples.

Microcline is either absent or interstitial in very minor amounts in the most mafic parts of the intrusion.

Biotite

Gravimetric and spectrographic analyses and optical, gravity, and X-ray data were reported (Lee and Van Loenen, 1970) for eight biotites recovered from samples of the intrusion ranging in composition from 66.2 percent SiO_2 (4.1 percent CaO) to 74.9 percent SiO_2 (0.78 percent CaO). The biotite crystallizing from these rocks followed an iron-enrichment trend because oxygen fugacity decreased with temperature, owing to the "buffering" action of magnetite (Wones and Eugster, 1965). Constituent biotites indicate that the most mafic parts of the pluton began to crystallize at a temperature of 780°C and 10^{-13} atm f_{O_2} , and that the most felsic parts finally crystallized at a temperature of 735°C and about 10^{-15} atm f_{O_2} ($\sim\text{NNO}$). Some of the minor-element content of these biotites also relate to temperature of formation; thus Li, Nb, Sc, and Sn contents are higher in biotites from the more felsic

rocks. On the other hand the well-defined increase of MnO and F in biotites from the more felsic rocks probably is due less to temperature of formation than to lack of available sites of the Mn^{+2} and F^{-1} ions present in the surrounding magma during crystallization. The Na_2O content of these biotites never exceeds 0.50 weight percent of individual analyses, but within this restricted range the ratio Na/K + Na shows a trend toward higher values for those biotites from the more felsic rocks. This trend relates to the anorthite contents of the plagioclase feldspars coexisting with these biotites. That is, lower activity of albite in the system correlates with less Na_2O in the biotite.

Opaque oxides

Magnetite is absent from the most felsic parts of the pluton, begins to appear where the rock contains about 75.5 percent SiO_2 (0.75 percent CaO), and gradually increases in abundance until it constitutes about 0.5 weight percent of the most mafic parts of the exposure. On the other hand, ilmenite reaches its greatest abundance (about 0.1 weight percent of the rock) in the most felsic parts of the pluton and is generally absent from rocks more mafic than about 72.0 percent SiO_2 (2.0 percent CaO) where sphene becomes increasingly abundant. Magnetite and ilmenite tend to coexist where the rock contains 72.0 - 75.5 percent SiO_2 .

Cell edges and spectrographic analyses have been reported (Lee and Van Loenen, 1979) for 10 magnetites recovered from samples of the intrusion ranging in composition from 66.3 percent SiO_2 (3.9 percent CaO) to 73.4 percent SiO_2 (1.5 percent CaO). Gravimetric determinations of MgO, TiO_2 , MnO,

and CaO were listed for four of these magnetites. As a group, these magnetites are of petrologic interest for two main reasons. First, they contain only very small amounts of titanium. Buddington and Lindsley (1964, Fig. 7) have diagrammed data for the range of composition of TiO_2 in magnetite of common plutonic igneous and hypabyssal igneous rocks. Our magnetites would plot at the lower end of the lowermost range (that for magnetites from granites and granite pegmatites) of TiO_2 contents featured by these writers. The second point of interest is the fact that these magnetites are similar in chemical composition throughout the range of petrologic types from which they were recovered.

Marmo (1959) described magnetites (from granodiorites of Central Sierra Leone) that also have very low titania contents. He concluded (p. 144) that ".....there may be, within the same orogeny, a close relationship between this TiO_2 content and the original materials of the host rock.....". He further notes (p. 147) that "A lower TiO_2 - content of magnetite would thus indicate that the primary material was sedimentary.....". This accords with the high $\delta^{18}\text{O}$ values (10.2 - 12.2 permil) of this pluton (Lee and others, 1982) in suggesting that contamination may have occurred at depth.

Spectrographic analyses have been reported for three ilmenites, and for two of these unit cell parameters and X-ray fluorescence data were listed (Lee and Van Loenen, 1979). These ilmenites are in fact ilmenite (FeTiO_3)-pyrophanite (MnTiO_3) solid solutions, and each contains 1-3 percent exolved hematite, as observed in reflected light and shown by X-ray study. Manganoan ilmenites have been reported in pegmatites and quartz monzonites from several other localities (See Tsusue, 1973, and references cited therein). The rather high MnO contents (to 8.9 weight percent) of these ilmenites might be ascribed mainly to the dearth of sites available for Mn^{+2} ions in the felsic parts of

this pluton. Both the biotites and the apatites coexisting with these ilmenites contain relatively large amounts of manganese. Small amounts (<0.05 percent) of manganese-rich garnets also coexist with these ilmenites.

Available data enable us to outline (fig. 2) the distribution of titanium

Figure 2.--NEAR HERE

in the rocks from which these constituent magnetites and ilmenites were recovered. Except in the most felsic parts of the exposure, biotite is seen to be the main reservoir of the TiO_2 present in this pluton, much as has been described for granitoid rocks elsewhere (Znamenskii, 1957). Verhoogen (1962, p. 212) stated: "A notable fraction of the Ti in a rock may occur in the silicate phases". This statement would certainly apply to the more mafic parts of the Snake Creek - Williams Canyon exposure, where much less than one percent of the TiO_2 content of the rock is contained in the only oxide phase present, magnetite. Indeed, in the most mafic parts of the exposure, the rock itself contains more TiO_2 (about 0.7 percent) than does the constituent magnetite (about 0.4 percent).

We note here that diagrams similar to fig. 2 can be constructed for other elements, based on analytical data contained in reports cited herein.

The very low TiO_2 content of the magnetites in this pluton (maximum 0.43 percent) suggests temperatures below 600°C (Buddington and Lindsley, 1964, Fig. 2). An indicated 5-10 mole percent hematite is present as solid solution in the ilmenites, and this, together with the low TiO_2 content of the magnetites again suggest temperatures below 600°C as well as less than 10^{-18} atm f_{O_2} (Buddington and Lindsley, 1964, fig. 5), even allowing for the high MnO contents of the ilmenites (Lindsley, 1963, p. 65). As noted in the previous section, temperatures and oxygen fugacities inferred from coexisting biotites are higher.

Figure 2.--Plot of CaO (rock) versus TiO_2 (rock and minerals) showing general distribution of TiO_2 in granitoid rocks of the Snake Creek-Williams Canyon area. Equivalent ranges of SiO_2 and K_2O (rock) are shown. Amounts of TiO_2 contained in magnetite and epidote exaggerated for ease of presentation.

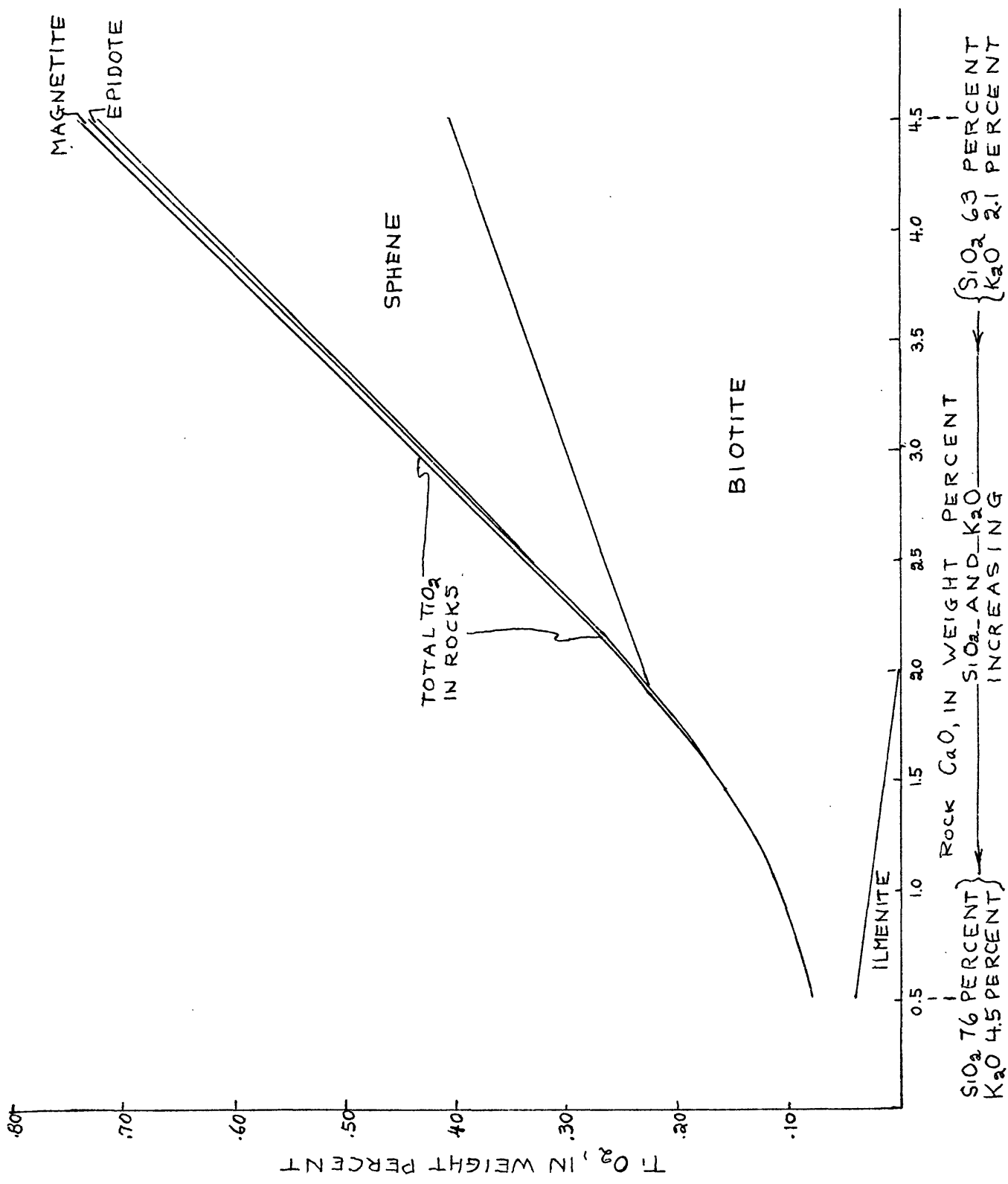


FIG 2

Zircon

Zircon fractions were recovered from 18 rock samples ranging in SiO_2 content from 63.7 - 76.0 percent. Zircon contents decrease from 0.05 weight percent in the most mafic parts of the intrusion to about 0.002 percent in the most felsic (Lee and others, 1968). Those rocks with an SiO_2 content of less than about 71 percent (2.2 percent CaO) contain clear acicular zircons, with elongation ratios in some grains reaching the extreme value of 20. Some investigators (Wyatt, 1954; Taubeneck, 1957; Huang, 1958) have emphasized the presence of this type of zircon in contaminated rocks. Zircons from the most felsic parts of this intrusive mass rarely have an elongation ratio greater than 6, contain many tiny inclusions, and display repeated zoning, with indices of refraction of adjacent zones estimated to differ by 0.005 or more.

Indices of refraction of zircon crystals recovered from a single hand specimen show about as much range as do those from the most mafic to the most felsic parts of the intrusion. Values are in the upper part of the range expected for zircon, indicating relatively fresh, nonmetamict material. For most samples, unit-cell parameters also indicate fresh material. However, the zircons recovered from the two most felsic (SiO_2 76.0 percent) rocks have undergone incipient metamictization, as indicated by slightly expanded cell parameters and less sharp diffractometer patterns.

Zircons from the felsic parts of the intrusive mass contain larger amounts of uranium and thorium than do those from the mafic parts. Values for uranium range from less than 500 to about 5,000 ppm; values for thorium, from about 200 to more than 1,000 ppm. Zircons from the felsic parts of the intrusion also contain larger amounts of yttrium and scandium than do those from the mafic parts, features consistent with fractional crystallization of the pluton.

Apatite

Apatite fractions were recovered from 16 rocks ranging in SiO_2 content from 63.7 to 73.4 weight percent. Optical properties, specific gravity, cell parameters, and spectographic analyses were listed for all of these apatites and major element data were listed for 11 (Lee and others, 1973). The abundance, composition, and crystal habit of the apatite all were found to relate to whole-rock chemistry.

Apatite content decreases from about 0.3 weight percent in the most mafic parts of the intrusion to less than 0.02 in the most felsic. In terms of fluorapatite-hydroxyapatite end members, the span of composition deduced from analytical data and physical properties is 10-15 mole percent. The mineral probably is slightly more than 90 mole percent fluorapatite in the most felsic rocks, slightly less in the most mafic. The range of $\text{F} \rightleftharpoons \text{OH}$ substitution in apatite from this outcrop area is much smaller than in the coexisting biotites already described. Except for manganese, strontium, sodium, and the rare earths, there is very limited substitution for calcium in the crystal structure of these apatites. Apatites recovered from the more mafic rocks tend to contain a lighter, more basic assemblage of rare earths, consistent with results obtained for coexisting allanites, monazites and zircons.

In the most mafic rocks the apatite has an acicular habit and a length-to-width ratio that commonly exceeds 4:1, whereas in the most felsic rocks the mineral has a stubby habit. These relations are strikingly similar to those described above for zircon, also a tetragonal mineral. Lee and others (1973) speculated on the apatite forms in the light of experimental work by Wyllie and others, (1962), which showed that apatite crystals precipitated from a liquid during a quench are greatly elongated parallel to the C axis.

Many observers, the earliest being Harker (1895), have recorded the relative abundance and acicular form of apatite crystals in the more contaminated parts of hybrid rocks. Nockolds (1933) cited 14 reports describing the relative abundance of apatite in hybrid rocks. Many of these authors mentioned "apatite needles" or otherwise referred to the acicular habit of the apatite.

In our opinion, any effort to supplement the results of some of these earlier studies by means of the additional tools available today would be well rewarded. Isotope data would provide the common ground necessary to mesh the earlier results with those of recent studies to better understand the processes involved in the development of hybrid rocks.

Sphene

The most mafic parts of the intrusion generally contain the most (to one percent) sphene, and almost all rocks more felsic than 72 percent SiO_2 are practically devoid of sphene, but carry ilmenite instead. However, the relation between chemistry and sphene content of these rocks is not very systematic. Sphene is probably absent from the more felsic parts of the intrusion as a result of the lower oxygen fugacity that prevailed during the later stages of crystallization. Sphene fractions were recovered for 10 rock samples ranging in SiO_2 content from 63.7 to 71.2. Major- and minor-element data were listed for all of these sphenes, and unit-cell parameters were listed for six (Lee and others, 1969). These same writers discussed the tendency of the TiO_2 content of the constituent sphenes to be higher in the more mafic rocks. In other respects, the major-element chemistry of these sphenes is rather similar from one sample to another.

It is well recognized that the sphene structure often carries many elements not represented in the type formula (see for example Deer and others, 1962), and the suite of minor elements present in these sphenes is rather large. Sphene must have scavenged most of the molybdenum present in the magmatic environment, for the element was rarely detected in any of the minerals coexisting with these sphenes. Sphene must have scavenged bismuth too, for this element was not detected in any of the other minerals present in these rocks. These sphenes contain a heavier, less basic assemblage of rare earths than do the coexisting allanites.

Epidote

One of the distinctive features of this pluton is that it contains substantial amounts of early crystallized epidote. Epidote contents of these rocks decrease from 2.0 weight percent in the most mafic parts of the intrusion to zero in those parts that contain more than about 74.0 percent SiO_2 . Epidote fractions were recovered from 14 rock samples ranging in SiO_2 content from 63.7 to 73.4 percent. Spectrographic data were listed for all of these epidotes, unit-cell parameters were listed for many, and major element data were listed for three (Lee and others, 1971). The major-element content of these epidotes shows little variation throughout the large range of composition of the rocks from which they were recovered. Tin tends to be present in larger amounts (to 0.007 percent) in epidotes from the more felsic rocks, but other minor-element content of these epidotes shows little response to whole-rock chemistry. Strontium (to 0.3 percent) is concentrated in these epidotes, and more than 9.0 percent of the strontium present in the most mafic rocks is contained in epidote.

Allanite and monazite

Amounts of allanite present decrease from about 0.12 percent in the most mafic parts of the intrusion to zero where the rock is more felsic than 75 percent SiO_2 (0.80 percent CaO). On the other hand, monazite is concentrated (to 0.01 percent) in the most felsic parts of the pluton and is absent from those rocks more mafic than 72 percent SiO_2 (2.0 percent CaO). Allanite and monazite coexist in those rocks that contain 72-75 percent SiO_2 .

Considering allanites and monazites together, the lighter rare earths are concentrated in those minerals recovered from the more mafic rocks, and the rare-earth assemblage present tends to become progressively heavier in those minerals from the more felsic rocks. Where the two minerals coexist, the heavier rare earths tend to be concentrated in allanite, the lighter in monazite (Lee and Bastron, 1967).

Other minerals

Several minerals are present in such tiny amounts that they were detected only during mineral separation work. The presence of such a mineral might only be apparent when it concentrates in a particular specific gravity and(or) magnetic fraction.

The most felsic rocks contain about 0.05 weight percent spessartine-almandine garnet, and much smaller amounts (<0.001 percent) of anatase(?) and an unidentified tabular yellow isotropic mineral with extreme refrigence ($N >> 1.98$). The unidentified mineral might be one of the multiple oxides of tantalum-niobium.

A few grains of a mineral identified optically as barite fractionated

with the zircon from sample 78 (SiO_2 = 66.3 percent). This is the only sample in which barite was detected, and it probably makes up much less than 0.01 percent of the rock (0.01 percent barite would be equivalent to about 66 ppm barium in the rock). A few scattered grains of calcite fractionated with the feldspars from the more mafic rocks. Minor amounts of zoisite were recovered from rocks with an SiO_2 content of less than about 70 percent.

Summary and conclusions

The Middle Jurassic Snake Creek-Williams Canyon pluton has not been eroded to a depth of more than about 300 meters, and contact relations indicate that the magma was behaving largely as a closed system at the level of crystallization, with little chemical exchange between itself and the country rock. Within a horizontal distance of 5 km the intrusion grades from a tonalite (63 percent SiO_2 , 4.5 percent CaO) where it is exposed in contact with limestone to a granite (76 percent SiO_2 , 0.5 percent CaO) where it is in contact with quartzite. Other major elements and minor elements vary as one would expect in a normal differentiation sequence. For various reasons this pluton is ideal for a study of igneous processes, especially the interplay between assimilation and fractional crystallization.

The biotites crystallizing from the magma followed an iron-enrichment trend, because oxygen fugacity decreased with temperature. The constituent biotites indicate that the most mafic parts of the pluton began to crystallize at a temperature of 780°C and 10^{-13} atm f_{O_2} , and that the most felsic parts finally crystallized at a temperature of about 735°C and about 10^{-15} atm f_{O_2} . The magnetite and(or) ilmenite coexisting with these biotites indicate lower temperatures and lower fugacities of oxygen, probably due to differences in degree of sub-solidus equilibration of different mineral phases.

Amounts and compositions of the feldspars present in these rocks vary with rock chemistry much as one would expect in a series of "normal" differentiates. The alkali feldspars are maximum microcline microperthites, indicating temperatures perhaps below 400°C . As with the opaque oxides, lack of agreement between this temperature and those deduced from study of the coexisting biotites is probably to be explained by differences in degree of subsolidus equilibration.

Accessory minerals present respond to rock chemistry, indicating that

their development was controlled by liquid ~~-----~~ crystal equilibria. Thus amount, crystal habit, and composition of both zircon and apatite change gradually from the mafic to the felsic parts of the exposure. The amount and composition of both allanite and monazite and the amounts of sphene, epidote, and the opaque oxides also vary with rock composition.

The gradual and systematic change of accessory mineral types precipitated during crystallization is one of the most striking features of this pluton. The most mafic parts of the mass (63 percent SiO_2) contain 2 weight percent epidote, 1 percent sphene, 0.5 percent magnetite, and well-developed allanite, apatite, and zircon. This is an I-type assemblage. As SiO_2 increases, the amounts and types of accessory minerals change gradually, until the most felsic parts of the intrusion (76 percent SiO_2) contain only ilmenite, garnet, monazite, and trace amounts of apatite and zircon, an S-type assemblage. The entire suite of accessory minerals comprises only about 0.1 weight percent of the most felsic parts of the intrusion. About 90 percent of the rare earths present in the pluton are contained in the accessory minerals.

Although major-element variations in the pluton compare closely with Daly's average andesite-dacite-rhyolite over an SiO_2 range of 63 to 76 percent, trace-element (Rb, Sr, Ba) variations show that the zonation is the result of in-situ fractional crystallization, with the formation of relatively mafic cumulates on at least one wall of the magma chamber. Models of trace element and isotopic data indicate that relatively little assimilation took place at the level of crystallization. (Lee and Christiansen, in press).

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