200 290 no.79-1608

U.S. Geological Survey

Reports-Open file SeriEs

3 1818 00074786 3



GEOLOGICAL SURVEY

Accessory opaque oxides from hybrid granitoid rocks of the southern Snake Range, Nevada

By Donald E. Lee 1921and Richard E. Van Loenen 165 LC-

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Open-File Report 79-1608

This report is preliminary and has not been edited or reviewed for conformity with U.S.Geological Survey standards and nomenclature.

ABSTRACT

Analytical data are presented for 12 magnetite and 6 ilmenite samples recovered from hybrid granitoid rocks of the southern Snake Range, Nevada. The magnetites are unusual for their very low contents of TiO_2 and for their similarity of composition over a range of petrologic types. The ilmenites are somewhat unusual for their high contents of MnO. Most of the titanium in these hybrid granitoid rocks is contained in biotite and sphene.

INTRODUCTION

Granitoid rocks of Jurassic age crop out a few kilometers north of the Mount Wheeler mine in the southern part of the Snake Range, about 80 km southeast of Ely, Nevada. The many well defined differences in the chemistry and mineralogy of these granitoid rocks within an outcrop area of about 50 km² are considered by Lee and Van Loenen (1971) to have resulted mainly from assimilation of chemically distinct host rocks. This paper describes the accessory magnetite and ilmenite present in these hybrid granitoid rocks. Lee and Van Loenen (1971) is a comprehensive field and laboratory study and includes a geologic map and sample localities. Sample numbers used here are the same as in the comprehensive study, where rocks are numbered in order of increasing CaO content; that is, from most felsic to most mafic. The field numbers used in earlier papers cited in this report are keyed to these sample numbers by Lee and Van Loenen (1971, p.11).

The hybrid granitoid rocks from which these magnetites and ilmenites were recovered appear on the map as two separate and distinct masses, one exposed in the Snake Creek-Williams Canyon area, the other in the Young Canyon-Kious Basin area.

The influence of host rock on the chemistry and mineralogy of intrusive rocks of the southern Snake Range is most clearly shown in the Snake Creek-Williams Canyon area, where the intrusive is undeformed, probably has not been eroded to a depth of much more than 1,000 feet, and is well exposed in contact with limestone, shale, and quartzite. Within a horizontal distance of five km the intrusive grades from a granodiorite (63 percent SiO2; 4.5 percent CaO) where the host rock is limestone to quartz monzonite (76 percent SiO2; 0.5 CaO) where the host rock is quartzite. Magnetite is absent from the most felsic parts of the outcrop, begins to appear where the rock contains about 0.75 percent CaO (75.5 percent SiO₂), 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 exposure, and is generally absent from rocks more mafic than about 2.0 percent CaO (72.0 percent SiO₂). Magnetite and ilmenite tend to coexist where the rock contains 0.75-2.0 percent CaO.

Most of the Young Canyon-Kious Basin area intrusive has been sheared and deformed by Miocene movement on a regional thrust fault (Lee and others, 1970). The undeformed portion of this intrusive is exposed in contact with quartzite and is a quartz monzonite that is petrologically similar though not identical to the more felsic parts of the Snake Creek-Williams Canyon exposure. The (undeformed) Young Canyon-Kious Basin area quartz monzonite contains minor amounts of both magnetite and ilmenite.

A third discrete outcrop of granitoid rocks described by Lee and Van Loenen (1971, p. 5, 38, 39), the muscovite-rich mass exposed in the Pole Canyon-Can Young Canyon area, is of interest here only for the fact that it is completely devoid of both magnetite and ilmenite. The biotites present with muscovite in these intrusive rocks contain only about 6.0 percent MgO, leading Lee and Van Leonen (1970) to suggest that they may have been initially equilibrated with respect to a relatively low oxygen fugacity. This is further substantiated by the absence of magnetite.

Cell parameters were obtained by least squares refinement of powder diffractometer data, using an internal standard of CaF_2 and a selfindexing computer program developed by Evans, Appleman, and Handwerker (1963). Semiquantitative spectrographic results are based on their identity with geometric brackets whose boundaries are 1.2, 0.83, 0.56, 0.38, 0.26, 0.18, 0.12, and so forth and are reported arbitratily as midpoints of these brackets, 1., 0.7, 0.5, 0.3, 0.2, 0.15, 0.1, respectively. The precision of a reported value is approximately one bracket at 68-percent, or two brackets at 95-percent confidence.

The difficulties encountered in attempting to obtain a clean fraction of either accessory magnetite or ilmenite for analysis are well known and result from a combination of at least two factors. First, these minerals tend to be intimately intergrown with other minerals in the rock, particularly biotite and the other accessory minerals. Secondly, both magnetite and ilmenite are so heavy (specific gravities about 5.2 and 4.7, respectively) that heavy liquids are of limited usefulness in eliminating grains compounded with other minerals in the rock. The magnetites and ilmenites described in this study were ground to -150 mesh to reduce the number of compound grains, but probably none of the minerals listed in tables 1 and 2 contained less than two percent silicate impurity. However, magnetite and ilmenite themselves are not closely intergrown in these rocks, and so fortunately it was possible to obtain a clean separation of the two.

Analytical data and cell edges are listed (table 1) for 10 magnetites from the Snake Creek-Williams Canyon area and two from the Young Canyon-Kious Basin area. Samples are arranged in order of increasing CaO content (decreasing SiO₂) of the whole rock from which they were recovered.

	Snake Creek-Williams Canyon Area										Young Canyon- Kious Basin Area	
Sample Number	15	22	27	28	35	39	46	55	1 ₇₁	78	101	102
CaO in rock, weight %	1.5	1.8	2.0	2.1	2.2	2.3	2.4	2.5	3.5	3.9	1.2	1.6
Unit cell a (±.001A)	8.391	8.391	8.390	8.391	8.393	8.394	8.393	8.391	8.395	8.391	8.393	8.392
		Pa	rtial Ch	emical A	nalyses	(Elaine I	L. Munso	n Brandt	, Analyst)		
MgO TiO ₂ MnO CaO	 		0.08 .30 .19 .00	0.07 .43 .23 .08	0.11 .21 .15 .08	 					0.04 .43 .23 .18	0.08 .48 .21 .04
	Semiqu	uantitat	ive Spect	trograph	ic Analys	ses, Weig	ght Perc	ent ⁹ (Rob	ert E. Ma	ys, Analy	st)	
Co Cr Mg Mn Mo	0.002 .07 .005 .01 .15 0	0.003 .07 .03 .01 .15 0	0.003 .05 .01 3 3 0	0.002 .03 3.01 3 3 0	0.003 .05 .005 3 3 .005	0.002 .1 .005 .007 .1 0	0.002 .05 .005 .005 .05 0	0.002 .05 .01 .007 .05 0	2 0.005 .005 .01 .007 .15 0	5 0.003 5 .3 .005 7 .01 .07 0	0.002 .03 .005 3 3 0	0.005 .02 .01 3 3 0
Nb Ni Pb Sc Ti V Zr	.001 .007 0 .15 .1 .07	.003 .005 .003 0 .2 .15 .07	.001 .005 .003 9 .15 .07	0 0 0 3 .07 .03	0 0 0 3 .07 .03	0 0 0 .1 .15 .05	0 0 0 .1 .07 .07	0 0 0 .1 .07 .05	.002 .005 0 .0 .15 .007	.001 .015 0 .15 .15 .07	.005 .003 0 3 <u>.001</u> .1 .15	.005 .007 0 3 <u>.001</u> .15 .1

Table 1.--Analytical data for accessory magnetites from the southern Snake Range, Nevada.

¹Manetite from xenolith

 $^2 {\rm General}$ limitations of semiquantitative method explained in text

³See quantitative data above

As a group these magnetites are of petrologic interest for two main reasons:

- 1. They contain only very small amounts of titanium. Buddington and Lindsley (1964, fig. 7, p. 342) have diagrammed "-----data for the range of composition of TiO_2 (and equivalent Fe_2TiO_4) in magnetite of common plutonic igneous and hypabyssal igenous rocks-----". The magnetites in table 1 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.
- 2. These magnetites are very similar in chemical composition throughout the range of petrologic types (quartz monzonite to granodiorite) from which they were recovered. The low TiO₂ contents and chemical similarity of the magnetites in table 1 are consistent with the narrow range of unit cell edge values measured, all of which are near the value for the magnetite and end-member of the magnetite (Fe₃O₄)-ulvospinel (Fe₂TiO₄) solid solution series (Lindsley, 1962, fig. 3, p. 103). Except for Zr, which can be ascribed to zircon contamination, and CaO, which might result from contamination by Ca-bearing accessory minerals, the small amounts of MgO, MnO, and the minor elements listed in table 1 probably are present in the crystal structure of each of these magnetites.

Each of the ilmenites analyzed contains appreciable manganese (Table 2) and are in fact ilmenite-pyrophanite solid solutions. Manganoan ilmenites have been reported in pegmatites and quartz monzonites from several other localities (See Tsusue, 1973, and references cited therein). Results of the present study indicate that the rather high MnO contents of our ilmenites (table 2) might be ascribed mainly to the dearth of sites available for Mn^{+2} ions in the most felsic of the southern Snake Range intrusive rocks. Both the biotites (Lee and Van Loenen, 1970, p. D202) and the apatites (Lee and others, 1973, p. 92, 93) coexisting with these ilmenites contain relatively large amounts of manganese. Small amounts (>0.05 percent) of manganese-rich garnets also coexist with these ilmenites.

The Finnmarka complex of Norway also shows a trend of manganese enrichment in ilmenite with differentiation (Czamanske and Mihálic, 1972). However, there are at least two important differences between the rocks of the Finnmarka complex and those described here:

- In the Finnmarka complex, ilmenite lamellae are present in magnetite, magnetite lamaellae in ilmenite (Czamanske and Mihálic, 1972, p. 493). Neither of these relations is seen in rocks of the southern Snake Range.
- (2) In the Finnmarka complex the amounts of ilmenite present decrease with differentiation (Czamanske and Mihálic, 1972, table 1, p. 497). In the southern Snake Range ilmenite is absent from the most mafic rocks and reaches its greatest abundance in the most felsic parts of the exposure.

	Snake C	Creek-Wi anyon Are	lliams a	Young	Young Canyon-Kious Basin Area				
Sample		1							
Number	6	15	22	98	101	102			
CaO in Rock, Weight%	0.78	1.5	1.8	0.75	1.2	1.6			
		Cell	Paramete	rs					
a(±.003A)	5.072	5.098		5.095	5.104	5.094			
c(±.03A)	14.08	14.12		14.15	14.13	14.11			
c/a	2.792	2.769		2.776	2.771	2.770			
volume (±0.3A ³)	314.1	317.8		318.0	318.4	317.2			
X-ray F	luorescen	ce Analys	es (Harry	J. Rose, J	r., Analy	st)			
si02	3.1	4.9		4.3	3.0	2.7			
AI203	1.9	2.0		2.8	2.2	2.5			
1102	44.0	41.0		40.4	47.0	44.0			
Fe0 ¹	37.2	38.0		28.1	34.4	37.2			
Mn0	6.2	8.9		16.9	13.2	9.9			
Ca0	0.2	1.6		0.2	1.1	0.3			
Sen	niquantita Percer	tive Spec nt (Robert	trographi E. Mays	c Analyses, Analyst) ²	, Weight				
Ba	0,001	0,001	0.001	0,001	0.001	0,001			
Ce	0	.1	.1	.05	.1	.05			
Co	0	0	.002	.002	0	.05			
Cr	.01	.003	.002	.001	.001	.001			
Ma	1	.07	.015	-007	.07	.007			
Nb	.1	.07	.1	.1	.05	.07			
Pb	0	.003	0	.007	0	0			
Sc	.02	.005	.01	.01	.01	.01			
Sn	.02	.00/	.007	-015	.02	.01			
Y	-05	.015	.02	-02	-05	.02			
Yb	.002	.001	.001	.002	.002	.001			
Zn	0	0	0	.15	0	.1			
Zr	.05	.03	.02	.05	.1	.05			

[Leaders (---) in figure column indicate no determination]

 $^{1}_{\text{C}}$ Total iron as FeO. $^{2}_{\text{C}}$ General limitations of semiquantitative method explained in text.

The c dimensions of ordinary iron ilmenite (FeTiO₃) and pyrophanite are 14.16A and 14.36A, respectively (Deer and others, 1962, p. 31). One would expect the c values listed in table 2 to fall between 14.16A and 14.36A, as reported for manganoan ilmenite by Snetsinger (1969). We speculate that the c dimensions listed in table 2, smaller even than the value of ordinary iron ilmenite, might indicate shrinking of the cell size due to the presence of Fe_2O_3 as a solid solution in these ilmenites. Each of these ilmenites contains 1-3 percent of exsolved hematite, as observed in reflected light and shown by X-ray study. Even allowing for this exsolved hematite, calculations based on the data in table 2 indicate an excess of iron in each of the analyzed minerals over that present in stochiometric ilmenite, thus supporting the idea that additional hematite may be present as a solid solution in the ilmenites. The a dimensions listed in table 2 also are smaller than one would expect for manganoan ilmenite. Additional work would be needed in order to prove conclusively that the reduced cell parameters listed in table 2 are indeed due to the presence of hematite as a solid solution in these ilmenites.

DISCUSSION

Petrological, mineralogical, and chemical data available enable us to outline the distribution of titanium in the rocks from which these constituent magnetites and ilmenites were recovered. This is shown in figure 1, which is based on data presented by Lee and others (1969, 1971) and Lee and Van Loenen (1970; 1971, fig. 3G, p. 23, and figs. 10 and 11, p. 28). Except in the most felsic parts of the exposure, biotite is seen to be the main reservoir of the TiO₂ present in the granitoid rocks of the Snake Creek-Williams Canyon area, much as has been described for granitoid rocks elsewhere by Znamenskii (1957). Verhoogen (1962, p. 212) states: "A notable fraction of the total 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 TiO₂ 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 TiO₂ (about 0.7 percent, fig. 1) than the constituent magnetite (about 0.4 percent, table 1).



A study of the biotites coexisting with these magnetites and ilmenites indicates that the most mafic parts of the outcrop area (63 percent SiO₂) began to crystallize at a temperature of about 780°C and about 10^{-13} atm f₀, and that the most felsic parts of the outcrop area (76 percent SiO₂) finally crystallized at a temperature of about 735°C and about 10^{-15} atm f₀ (Lee and Van Loenen, 1970, esp fig. 8). Conditions deduced from the data in tables 1 and 2 and the results of experimental work on magnetite and ilmenite indicate lower temperatures and a lower fugacity of oxygen than do the data for biotites.

The very low TiO₂ contents of the magnetites in table 1 (maximum 0.48 percent) suggest temperatures below 600°C (Buddington and Lindsley, 1964, fig. 2). Calculations based on the data in table 2 indicate 5-10 mole percent hematite as solid solution in the ilmenites, and this, together with the very low TiO₂ contents of the magnetites again suggest temperatures below 600°C as well as less than 10^{-18} atm f_0 (Buddington and Lindsley, 1964, fig. 5), even allowing for the high MnO contents of the ilmenites (Lindsley, 1963, p. 65).

Marmo (1959) describes magnetites (from granodiorites of the Central Sierra Leone) that have very low titania contents, similar to those listed in table 1. He concludes (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-----". In view of the fact that the TiO_2 -poor magnetites in table 1 were recovered from hybrid granitoid rocks that assimilated sedimentary host rocks, Marmo's results seem to bear directly on the present study. We are now engaged in oxygen isotope work and strontium isotope work on the rocks from which the minerals in tables 1 and 2 were recovered in an effort to better understand the conditions under which these rocks crystallized.

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