HEAVY ACCESSORY MINERALS OF THE VAL VERDE TONALITE

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INTRODUCTION

Study of the heavy accessory minerals of igneous rocks by means of concentration of the heavy fractions is a fairly recent development in the field of petrology. Originally, work of this type was intended as a means of demonstrating the parent rock from which heavy minerals of various sedimentary deposits had been derived. In this direction, investigations have been of undoubted value. More recently, various workers have advocated the use of accessory minerals of igneous rocks as a means of correlation of igneous intrusions. In many cases their use has yielded results apparently of positive value. However, data on the precision of this type of correlation are still being gathered, and studies concerned with accessory minerals and their variation are of some importance at present.

The construction of the Metropolitan Water District Aqueduct for Los Angeles County, California, has necessitated the drilling of long tunnels at various points en route from the Colorado River. One such tunnel situated approximately one mile south of Val Verde, California, passes through some seven miles of tonalite. This locality offers a very favorable opportunity for the study of accessory minerals, and their variation through a continuously exposed section of igneous rock. The present paper embodies the results of a study of the heavy accessories in the tonalite and their variation through about five miles of tunnel, which distance is the longest continuous exposure of the rock without significant faulting.

P. H. Dudley has published recently (17) an account of the geology of the Perris Block of Southern California. The area reported on by Dudley includes that discussed in the present paper. The reader is referred to this report for a statement of the general geology of the Val Verde district. However, no detailed study of the rocks near Val Verde was presented. E. F. Osborn of the California Institute of Technology is now engaged in a comprehensive petrographic survey of these rocks. He has kindly furnished the following description of the tonalite.

The tonalite is a coarse-grained rock, medium dark in color, and varying only slightly in composition throughout the district. The rock contain 50 to 60% andesine, 15 to 30% quartz, and 15 to 30% biotite and hornblende, the biotite commonly being more abundant than hornblende. Occasionally a very small percentage of orthoclase is present. Magnetite, sphene, apatite, and zircon are the common accessory minerals.

A constant, conspicuous feature of the tonalite is the presence of abundant dark, fine-grained, rounded inclusions. These vary from a few inches to several feet in diameter, but the average is about one foot across. In a few places the inclusions are practically absent and in others occur in swarms making fifty per cent or more of the rock. In the latter instance they are more angular and more tabular in form and have a common orientation striking northwesterly and dipping steeply.

Preparation of Samples for Study

Samples of the tonalite were taken at approximately half-mile intervals in the Val Verde tunnel. In addition, a sample of one of the numerous inclusions was also studied. The specimen numbers represent hundreds of feet from an established bench mark at Parker Dam.

The collected samples were crushed and sieved and thirty grams of material between 100 and 150 mesh grade-size were taken for each determination. The sieved specimens were then panned to about one-half of their original weight. This operation served to eliminate much of the biotite along with the lighter minerals, and afforded a cleaner separation of "heavies" and "lights." Since rock flour was eliminated concurrently, the time consumed was not increased materially. The "heavy" minerals were next separated by the usual bromoform procedure. Electro-magnetic separation of the "heavy" crops into strongly magnetic, moderately magnetic, and non-magnetic fractions, and mounting of the non-magnetic portions completed preparation of the samples. Due to time limitations, and because the more important accessory minerals are usually non-magnetic, the strongly and moderately magnetic crops were given only cursory examination.

Accessory Minerals of the Val Verde Tonalite

The following accessory minerals were identified in the Val Verde tonalite: zircon, apatite, sphene, epidote, clinozoisite, zoisite, allanite?, tourmaline, monazite, anatase, calcite?, thulite?, and pyrite. In addition, several unidentified minerals were of sporadic occurrence. A complete list of "heavies" would include also hornblende, biotite, and magnetite.

The non-magnetic or weakly magnetic accessory minerals of the Val Verde tonalite may be placed in three categories:

(1) primary minerals, in a sufficient abundance to have been recorded in all specimens examined, and to be expected in any normal sample studied. Minerals: zircon, apatite, and sphene.

(2) secondary minerals, usually present in sufficient quantity to be expected in a random count. Minerals: epidote group, composed of epidote, clinozoisite, and zoisite (usually rare) in varying proportions.

(3) primary and secondary minerals sufficiently rare or absent in most samples that their presence in a particular sample cannot be predicted.

Minerals: tourmaline, monazite, anatase, calcite?, allanite?, thulite?, pyrite, and undetermined minerals. Monazite and more particularly tourmaline may have a range restricted to the higher-numbered samples but their rarity prevents a definite determination regarding their presence or absence.

Heavy Mineral Per Cent. The per cent. of heavy minerals obtained from the bromoform separation after preliminary panning of the specimens ranged from 5 to 11%. Sample No. 11937 was split and one fraction was separated into its "heavy" and "light" components without preliminary panning. The other fraction received standard treatment. Hence, comparison of the panned with the non-panned fractions of No. 11937 affords a means of roughly estimating the actual heavy mineral content of the tonalite specimens. Such an estimate suggests that the heavy mineral proportion (i.e., including biotite and hornblende) probably averages about 20% (between 10% and 25%).

Sphene apparently was the most abundant accessory mineral, although the effect of both panning and crushing may be to increase the number of grains of this mineral. Zircon was the least abundant mineral in group (1) except at the extreme western end of the tunnel, where it increased rapidly in amount, apparently with concomitant decrease of apatite. An average of panned samples gives zircon—17%; apatite—29%; and sphene—54%: or a ratio of zircon: apatite: sphene of about 2:3:5. A more normal ratio is probably 1:4:5. The table presents the results of the grain counts. Only the primary accessory minerals zircon, apatite, and sphene are recorded.

Notes on Individual Minerals

Zircon: occurred as colorless, well-crystallized, prismatic grains, generally with acute terminations. A few crystals, mostly encountered in specimen No. 11937, exhibited a faint zonal structure. The average zircon was not noticeably elongated, but such crystals occurred throughout the series of specimens examined. A number of the grains showed the effects of corrosion. Most of the zircons possessed a greater or lesser number of inclusions. These were either colorless and prismatic, possibly representing gas bubbles, or brownish to opaque inclusions of less regular shape.

Apatite: colorless or at times slightly yellowish grains, generally prismatic with rounded terminations. In some cases, the grains were terminated by crystal faces. Rarely, the apatite consisted of irregular fragments with no trace of crystal form. Inclusions were fairly common. Generally, they were of lower index than apatite. In some instances, the included material was zircon. Apatite showed a marked decrease in relative abundance in the extreme high-numbered samples (western end of tunnel) correlated with an increase of zircon at this point. This feature may point to a gradation toward a more acid rock type.

Sphene: generally found as irregular fragments without crystal faces, although in some specimens faces were present. A very few grains were essentially euhedral. The usually transparent grains ranged from colorless through pale yellow-green to yellow or yellow-brown. Inclusions were found in some individuals, and others appeared to be clouded by

TABLE OF ZIRCON-APATITE-SPHENE PERCENTAGES

Number	Panned from—to—(gms.)	% Heavies >2.86 s.g.	Total Zircon, Apatite, Sphene grains counted	Zircon		Apatite		Sphene		Crusher
				%	% error ±	%	% error ±	%	% error ±	
11730*† (not panned)	—	5	265	12	11.2	54	3.8	34	5.7	mortar
11755	30–12.1	7	621	5	12	41	3.5	54	2.5	mortar and Braun**
11779	60–20	9	451	12	8.5	39	4	49	3.5	mortar
11804	30–16.2	10	333	4	16.5	21	7	75	2.5	mortar and Braun
11829	30–18	5	317	9	11.5	23	6.5	67	2.5	mortar and C.I.T.††
11866	30–12.8	6	619	15	6.5	35	4	50	3	C.I.T.
11895	30–10.8	7	523	13	8	46	3	41	4	mortar
11914	30–13.1	11	398	19	6.5	25	6	56	3	mortar and Braun
11937† (not panned)	—	23	486	16	7.5	42	4	42	4	mortar
11937	49.9–17.2	9	390	23	6	31	5	46	3.5	mortar
11962	30–14.2	5	299	29	6.5	16	9.5	55	3.5	mortar and C.I.T.
11980	30–15.8	11	179	45	5.5	11	15	44	5.5	mortar and Braun
11742 (dark inclusion in tonalite)	30–15.6	27	488	14	7.5	83	<1.5	3	>13.5	Braun

* % error calculated; others from probability curves.
† Sample washed before weighing.
** Braun disc-crusher.
†† Calif. Inst. hand crusher.

the presence of minute inclusions. Some of the colored types were pleochroic in brownish tints. Color variation was irregular and appeared to bear no relation to the position of the sample. Cleavage, fracture and parting frequently combined to form a mosaic pattern. The per cent. of sphene was relatively constant throughout the section examined. However, it was noted that the method of crushing the rock sample had an influence on the number of grains of sphene appearing in the count (see the table).

Monazite: appeared usually as small, euhedral grains which were short, diamond-shaped prisms; typically clove-brown or yellowish to reddish-brown in color. There was no observable pleochroism. A few inclusions were sometimes present. The mineral was quite rare but was recorded in No. 11937, and one doubtful grain was encountered in No. 11914. Its presence in a tonalite is unusual and some grains suggested colored zircon. However, since certain crystals were so like monazite in character, the identification is justified. An alternative determination may be yellow zircon, but this variety is rare.

Tourmaline: ordinarily exhibited strong dark-blue or greenish-blue to very pale reddish-brown pleochroism. The mineral was light brown in ordinary transmitted light. The grains were generally prismatic without definite crystal form. Some of the grains were relatively pure, but fragments of tourmaline commonly exhibited a blotchy or hybrid appearance, sometimes either almost enclosing or intergrown with other minerals. Although, because of the small size of the fragments, origin of the tourmaline cannot be definitely established, this mineral may exist as a replacement of feldspar. However, there is no evidence that suggests the Val Verde tourmaline is post-consolidation. Perhaps, it should be considered a secondary mineral formed as the result of slight pre-consolidation autopneumatolysis.[1] Tourmaline was identified positively in only two samples (Nos. 11937, 11980). Unfortunately, the mineral was too scarce in the samples in which it was found to assume safely that it was absent in the others. However, since the per cent. of zircon increased at the point tourmaline made its appearance, tourmaline may be associated with increasing acidity of the rock mass, and may not have been present in the lower-numbered samples.

Epidote-Clinozoisite-Zoisite: doubtless epidote, clinozoisite, and zoisite are all present in the Val Verde tonalite. However, it was not possible always to distinguish between them, especially if the optic sign could not be determined. The Val Verde epidote was colorless as well as pistachio-green, and there were several examples of yellow or brown epidote as well. Altered grains comprising a mixture of epidote and feldspar indicated the derivation of the epidote minerals from the calcic feldspars. These altered grains were especially numerous in samples in the higher 11900's. The position of the specimens in the tunnel apparently had little influence on the abundance of epidote.

Abnormal Blue Anatase: intense blue or bluish-black grains were found in several of the samples. Their optical characters agreed with those shown by blue anatase except for low birefrigence and apparent biaxial positive optical character. Anatase is sometimes, but not invariably, a pneumatolytic mineral. Since its distribution in the Val Verde tonalite was somewhat comparable to that of tourmaline, its presence may have been due to to pneumatolytic action.

Allanite?: a number of dark brown to yellow grains, scattered throughout the series of specimens examined, appeared to represent the rare-earth mineral, allanite. This species, although probably present, was not an important member of the accessory mineral suite.

Thulite?: specimen No. 11980 yielded one grain of a pleochroic mineral which may represent the manganese zoisite, thulite.

Pyrite: several samples showed infrequent grains of an opaque, yellowish (non-mag-

[1] Regarding the use of the term secondary in reference to preconsolidation minerals see 10, pp. 321–322, 329–330.

netic?) mineral apparently representing pyrite. Some of the grains were coated with a red decomposition product (hematite).

Calcite?: calcite or a related carbonate was of sporadic and extremely rare occurrence in the Val Verde tonalite.

High Index Mica: a micaceous mineral with index of refraction about 1.70 was recorded from the tonalite. Relatively rare, it was probably most abundant in the inclusion sample studied.

Undetermined Minerals: several undetermined minerals were present in the samples. They were of too infrequent occurrence to be of much importance.

As mentioned previously, hornblende and biotite formed the bulk of the heavy minerals. The extremely magnetic crops of the samples yielded magnetite, and a red iron oxide apparently derived from altered biotite.

Sources of Variation of the Accessory Minerals

It is to be noted from the percentages expressed in the table (and in the other minerals not listed) that some variation exists in the frequency of occurrence of the accessory minerals of the Val Verde tonalite. Since part of this variation is not due to changes in composition of the tonalite, it is pertinent to consider the possible sources of variation observed in the grain counts made during the course of the work.

Variation may be introduced by lack of absolute control during preparation of the samples for study. A certain amount of fluctuation cannot be avoided in either the bromoform separation or the subsequent electromagnetic separation. Moreover, in regard to the latter factor, the presence of a large amount of lamellar biotite and hornblende apparently served to carry, during separation, non-magnetic minerals into the magnetic crops. The flat, relatively large surface area of the grains perhaps accounts for this phenomenon.

Panning appeared to eliminate apatite at a faster rate than either zircon and sphene so that the relative amount of apatite was reduced. Doubtless in the present instance, the relative decrease of apatite is caused chiefly by the lower specific gravity of this mineral as compared to sphene and zircon. However, if attention is confined to the panned samples, although apatite may be reduced in an absolute sense, the variation of apatite from one sample to another will be a measure of actual conditions in the rock mass.

Sphene was generally present as irregular grains without much trace of original crystal form. Since in many cases the grains were traversed by a network of fracture, parting and cleavage cracks, it was suspected that during the course of crushing, a single grain of sphene might break into several. If attention is given to the table wherein are listed the percentages of zircon, apatite, and sphene in regard to each other, it will be seen that the type of crusher used has affected the apparent abundance of sphene. Crushing by a Braun disc-crusher or a large mill-stone type designated as the California Institute crusher in the table, resulted in the formation of a larger number of grains than in specimens where a relatively light mortar and pestle was used. For this reason, comparisons of the zircon-apatite-sphene ratios should be confined to panned samples which were crushed on either the Braun or mill-stone types.

Errors in identification are another source of variation in grain counts. In the present instance, at least insofar as the minerals of the table are concerned, errors arising through misidentification can have only a negligible effect on the results.

An important source of variation is the strictly mathematical one of error introduced because only a limited number of grains are counted for each specimen. The accuracy of the counts increases as the square-root of the total number of grains counted. The counts in the present work averaged between 300–400 grains of the primary accessories zircon, apatite, and sphene. The table gives the probable per cent. error, plus or minus, in each per cent. for the Val Verde samples. Data for the probable error were taken from an article by A. Lincoln Dryden Jr. (16). As may be seen from the table, this factor affects chiefly the minerals present in small amounts.

Lastly, variation in frequency of mineral occurrence may be due to actual changes in the constitution of the rock. Considering the deviation which is introduced by other means, it is difficult to reach an unequivocal determination of such variation. However, the Val Verde tonalite exhibited a certain directional change which it seems reasonable to attribute to actual diversification in the rock.

Mineralogical Variation in the Val Verde Tonalite

Notwithstanding a considerable amount of variation in the accessory minerals of the Val Verde tonalite, the composition is as homogeneous as could be reasonably expected in an igneous mass as large as that surveyed. The accessory mineral suite remained limited in number of species throughout the portion examined, and was uniformly characterized by a high per cent. of sphene. Ratios of zircon to apatite were variable, but the variation was gradual and directional. Generally, apatite was much more abundant than zircon, and if variations due to panning and crushing were eliminated, apatite in most cases would be quite comparable to sphene in abundance. The only other accessory minerals which were ever common were the secondary minerals of the epidote group. Other minerals which were present occasionally were always very limited in amount. Hence, the present study serves to bear out the view that in a homogeneous rock mass the accessory minerals remain fairly constant and distinctive.

The only variation in composition which appeared to be important suggested the thesis that the rock is more acidic at the western end of the tunnel than at the eastern end. Thus, in the higher-numbered samples there was an increase in zircon and a decrease in apatite. At the same time there was an introduction of tourmaline, monazite, and anatase. An increase in the degree of corrosion of zircon was also noted at this point. The average length of zircon crystals may have been somewhat greater although this is open to question. It should be stressed that the samples studied were typical specimens of the Val Verde tonalite. These more acidic-appearing samples were not dike rocks or similar types. An explanation may be furnished by the fact that the tonalite is closer, at this point, to overlying and intruded schists, and hence to the margin of the batholith.

Val Verde Inclusions

Inclusions are fairly numerous in the Val Verde tonalite. A description of their appearance has already been given.

A sample of one of these inclusions (No. 11742) was studied and proved to be quite distinctive when compared to normal specimens of the tonalite. The per cent. of heavy minerals was almost double that of the ordinary Val Verde specimens. Apatite was the chief accessory mineral present. Sphene was extremely rare. The per cent. of zircon was similar to that of normal specimens but the grains were considerably broken and fractured. Perfect euhedral crystals were not as abundant as in other samples, and many of the grains showed marked corrosion. Another point was the extreme scarcity of epidote and zoisite in the sample. The inclusion occurred at a place in the tunnel in which epidote was very common.

A study of the accessory minerals of No. 11742 indicated the intrusion of the tonalite into a rather basic type of rock, and the stoping or breaking off of fragments of the rock to furnish the material of the inclusions.

Percentage Representation of Minerals

After some consideration it was decided to restrict the calculation of percentages to the primary minerals zircon, apatite, and sphene. Neither the secondary minerals of the epidote group, nor the primary minerals of rare occurrence are of much importance in a study of the constancy of accessory minerals in the Val Verde tonalite. Attention is directed generally toward the relatively abundant primary accessories.

Representing mineral frequency of occurrence in per cent. has certain objections which have been pointed out by several workers. W. M. Cogen (13, p. 5) has recently reviewed the chief objections to percentage representation. By limiting the calculations in the present instance most of the objections are not serious. Since sphene remained fairly constant, the apparent increase of either apatite or zircon was essentially real. Unfortunately, with the data as given in the table, a general increase of all three minerals cannot be detected. If the per cent. of these minerals to the total heavy fraction could be determined this would not be the case. However, some of the non-magnetic samples were so small that the entire specimen was mounted for counting. Others possessed many times this amount but the samples were always too small to make use of a miniature sample splitter or other device without serious danger of losing most of the crop. Hence, this per cent. could not be determined with any reasonable accuracy.

Conclusions

1. The Val Verde tonalite possesses a relatively limited suite of minerals of fairly constant frequency.
2. High-numbered samples at the western end of the Val Verde tunnel point to the existence of a more acid phase of the tonalite in this region.
3. The accessory minerals are sufficiently uniform and characteristic to suggest their use in correlation.

Since the work was confined to the study of accessories from a single rock type of quite homogeneous aspect, it is perhaps not demonstrated that the minerals are adequately distinctive for correlation criteria. Apatite, sphene, and zircon are very common in many and varied rocks. However, the present study indicated a constancy in the accessory minerals which intimates that distinctive comparisons with other rocks can be made. The inclusion sample studied was certainly quite discriminative. At least, it may be stated that the Val Verde tonalite accessories do not vary sufficiently to demonstrate in themselves that correlation is not possible.

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Bibliography

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