ANDALUSITE IN PEGMATITE FROM FRESNO COUNTY, CALIFORNIA

G. A. Macdonald and Richard Merriam
University of California, Berkeley, California,

Introduction

Although far from unknown, the occurrence of andalusite in pegmatites is rather unusual. Such an occurrence has been found, however, on the western slope of the Sierra Nevada, in Fresno County, California. The locality was discovered by Dr. Cordell Durrell, and has been studied by the senior author in connection with regional geologic mapping of the surrounding territory. It lies in the west-central part of the Academy Quadrangle, about 17 miles northeast of the city of Fresno, and 8 miles S60°E of the town of Friant, in the south-central part of Section 20, T11S, R22E, Mount Diablo Base and Meridian.

The writers wish to express their appreciation to Dr. Adolf Pabst of the University of California for his aid and advice during the course of the studies.

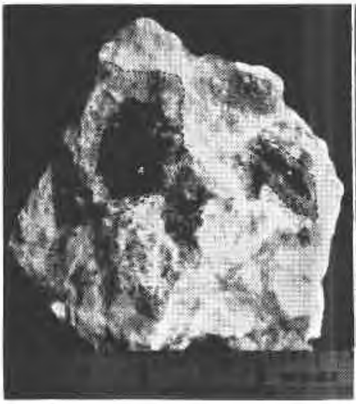
General Geology

The pegmatitie dike in which the andalusite is found is narrow and poorly exposed. Most of the material collected was in the form of float on the hillside below the outcrop. The dike cuts across a series of mesozone schists, consisting largely of plagioclase amphibolites derived by dynamothermal metamorphism from basaltic to andesitic volcanic rocks, with smaller amounts of quartz-mica schist and calc-silicate rocks of meta-sedimentary origin. The two latter types are rare in the immediate vicinity of the dike. The metamorphic terrain is extensively intruded by large bodies of quartz diorite, which form a part of the batholithic complex of the Sierra Nevada.

Paragenesis

The pegmatite is composed almost entirely of quartz and oligoclase (Ab_{83}), with a few flakes of muscovite and a little clinochlore. The last-named mineral has a small 2V, averaging about 15°, and a negative sign; $\beta = 1.596$, $\gamma - \alpha = .009$. The rock is moderately coarse grained, the individual grains averaging about 4 mm. across. The texture is hypidiomorphic to pegmatitic. Throughout most of the rock feldspar is about twice as abundant as quartz, but locally feldspar is nearly or completely absent, and the rock has the aspect of a hypothermal quartz vein.

Andalusite is found scattered irregularly through the pegmatite, in prismatic and radiating masses. In color, it varies from pale pink to dark reddish-violet. The masses range in size from less than 1 cm. to as much as 10 cm. across, and from about 1 cm. to nearly 15 cm. in length. Each mass is partly or completely surrounded by a greenish-gray rim, up to a centimeter in thickness, which is composed of very fine-grained, dense sericite. The outer surface of the sericite envelope is in many instances coated with large flakes of muscovite, and in some specimens muscovite can be seen lying along the cleavage faces within the andalusite.



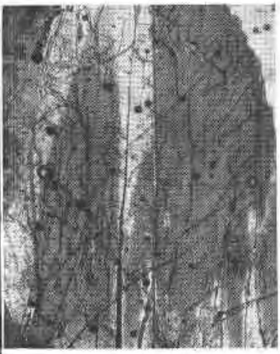


Fig. 1. Andalusite (A) in pegmatite, surrounded by rims of fine grained sericite (S).

Fig. 2. Thin section of andalusite showing alternation of light and dark material. Ordinary light, ×7½.

Under the microscope, the andalusite is seen to carry many small included grains of corundum, scattered with random orientation through the host crystal. They are pleochroic from pale blue parallel to the *c* crystallographic axis to colorless. Each grain of corundum is surrounded by a narrow rim of fine-grained muscovite. In some slides narrow zones of muscovite lie parallel to the prismatic cleavage of the andalusite. Some of the smaller masses of andalusite are made up of a single crystal, but all of the larger masses, and many of the smaller ones are composed of an aggregate of crystals, in nearly parallel arrangement. Rims of sericite irregularly embay the edges of the andalusite, giving the appearance of having replaced it, and in a few places narrow veinlets of the sericite cut irregularly across the andalusite.

COLOR VARIATIONS IN THE ANDALUSITE

Of the greatest interest, however, are the color variations within the andalusite. The color differences mentioned as being apparent in the hand specimen are even more striking under the microscope. In the dark material the X direction is a deep pink in color, while in the light material it is nearly colorless. Y and Z are colorless to very pale oil green in both varieties. All gradations are found from one extreme of color to the other. In most places the light and dark varieties are interdigitated parallel to the *c* axis in a more or less regular manner, but in other places irregular spots of dark material are enclosed within the light. Boundaries between the two varieties are in most places quite sharp. There is present also a zoning parallel to the base, in which bands of lighter material cross the dark grains. In this case the passage from one zone to the next is in most instances gradational.

Fig. 3. Thin section of andalusite showing color zoning parallel to the base. The rim of fine grained sericite can be seen embaying the andalusite on the left. Ordinary light, ×7½.

Fig. 4. Thin section of andalusite, showing alternation of light and dark material parallel to the prismatic cleavage. The andalusite is cut by two veinlets of sericite. Ordinary light, ×7½.

In addition to the difference in pleochroic colors, the light and dark varieties of andalusite show slight differences in the indices of refraction and birefringence, and a notable difference in the size of the optic axial angle. The dark variety shows very strong rhombic dispersion, while in the light type dispersion is extremely weak. The indices of refraction were determined by the immersion method, and are subject to a possible error of ±.002. The values for 2V were determined with a universal stage both by direct observation and by the extinction angle method of Berek.[1] They are accurate to about ±2°. Specific gravity determinations were made using thallium formate solution and a Westphal balance. The values obtained for the specific gravities show notable differences between the lightest and the darkest material, although, as is the case with the other properties, there exist all gradations from the lightest to the

---

[1] *Neues Jahrb. Mineralogie, Beil. Band* **48,** pp. 34–62, 1923.

darkest varieties. The properties determined for the two extreme varieties are as follows:

Lightest andalusite	*Darkest andalusite*
$\alpha=1.634$	$\alpha=1.637$
$\beta=1.639$	$\beta=1.641$
$\gamma=1.645$	$\gamma=1.646$
$\gamma-\alpha=0.011$	$\gamma-\alpha=0.009$
$(-)2V=86°$	$(-)2V=75°$
$r<v$, weak	$r<v$, very strong
G. $=3.13$	G. $=3.16$

In order to determine the cause of the differences in properties, both the light and dark material have been analyzed chemically and spectrographically. The spectrographic examinations were made by Dr. T. G. Kennard of Claremont, California, and yield the following results:

	Lightest andalusite	*Darkest andalusite*
Large amount	Al	Al
	Si	Si
Small (X.%)	Fe	Fe
Very small (0.X%)	Na	—
Traces (0.0X or 0.00X%)	Li	Li
	K	Na
	Ca	Ca
	Mg	Mg
	Cr	Cu
	Cu	Ga
	Ga	Ge
	Ge	

The only element present in sufficient quantity and likely to produce the observed differences in properties is iron. Accordingly, the two extreme types of material have been analyzed quantitatively for silica, alumina, and iron. The results are given below.

	Lightest andalusite	*Darkest andalusite*
SiO_2	35.61%	35.46%
Al_2O_3	62.40	60.84
Fe_2O_3	0.51	2.44
FeO	0.60	0.42
H_2O+	0.41	0.24
H_2O-	0.32	0.26
Total	99.85	99.66

R. H. Merriam, *analyst.*

There is thus a notable difference in the ferric iron content of the two varieties of andalusite. Moreover, the difference in percentage of Fe_2O_3 is nearly equal to the difference in percentage of Al_2O_3, suggesting that the ferric iron replaces alumina in the mineral. It is well known that Fe_2O_3 produces dispersion,[2] and the efficacy of small amounts of ferric iron as a coloring agent is generally recognized. It seems, therefore, an entirely justifiable conclusion that the differences in properties between the light and dark varieties of andalusite are caused by the variation in ferric iron content.

Many analyses of andalusite containing ferric iron are recorded in the literature,[3] and Niggli suggests that the iron substitutes for aluminum.[4] The suggestion seems entirely possible, since the two elements do not differ greatly in atomic radii. There has been, however, little or no attempt made to correlate iron content with optical properties, although Simpson suggests that the deep purple color of certain andalusites from Western Australia is caused by the presence of iron and titanium.[5]

Zoned andalusite, in which an inner kernel of deep violet color is surrounded by a pale pink outer border, has been described by several writers from Scaletta Pass in the canton of Graubünden, in Switzerland.[6] The color of this material was ascribed by Gramman to the presence of TiO_2 in the dark variety. Spaenhauer called attention, however, that Gramman's conclusion is not established, since he did not directly demonstrate the presence of titanium. At a still earlier date, Weinschenk argued for titanium sesquioxide as the coloring matter of many minerals,[7] but the suggestion appears to have little to support it in connection with the Scaletta material. However, titanium in any form can not be the cause of the physical and optical differences in the andalusites described in the present paper, since not even a trace of titanium was revealed by the spectrographic analyses.

ORIGIN

Andalusite in igneous rocks is usually regarded as of xenolithic origin, resulting from the metamorphic action of the magma on inclusions of

---

[2] Larsen, E. S., and Berman, H., Microscopic Determination of the Nonopaque Minerals, *U. S. Geol. Survey, Bull.* **848,** p. 32, 1934.

[3] Doelter, C., Handbuch der Mineralchemie, Bd. 2, Abt. 2, pp. 4–9, **1917.**

[4] Niggli, P., Lehrbuch der Mineralogie, Bd. 2, pp. 255–256, **1926.**

[5] Simpson, E. S., Contributions to the mineralogy of Western Australia—Series VI, *Jour. Roy. Soc. W. Australia,* vol. **17,** pp. 137–148, 1931.

[6] Gramman, A., Ueber die Andalusitvorkommnisse im rhätischen Flüela—und Scalettagebiet und die Färbung der alpinen Andalusite, *Viertelj. Schrift d. Naturf. Ges. Zürich,* vol. **44,** pp. 302–352, 1899; abst., *Zeits. Krist.,* Bd. **35,** pp. 407–410, 1901.

Spaenhauer, F., Die Andalusit—und Disthenvorkommen der Silvretta; *Schweiz. min. und pet. Mitt.,* Bd. **13,** pp. 323–345, 1933.

[7] Weinschenk, E., *Zeits. der deutsch. geol. Gesellschsft,* Bd. **48,** pp. 704–712, 1896; abst., *Neues Jahrb. f. Min.,* II, pp. 372–373, **1898.**

aluminous wall-rocks. On the other hand, large bodies of andalusite have recently been ascribed to the concentration of alumina from surrounding rocks under the influence of high temperatures and abundant emanations from nearby intrusive bodies.[8] In the present case, however, it seems improbable that either of these suggestions will account for the origin of the andalusite. The dike is only a few inches in width, and cuts sharply across the enclosing rocks, making it unlikely that the andalusite masses represent altered xenolithic material. No traces of relict metamorphic structures or textures are present. The surrounding schists are not highly aluminous, and show no evidences of alteration or leaching, so that it appears highly unlikely that there could have been a migration of alumina to the dike from the adjacent wall-rocks. Moreover, if the andalusite had developed by reaction with xenoliths torn from the adjacent rocks, the process must necessarily have involved the almost complete removal of the abundant iron and magnesia present in the latter, since the andalusite and the surrounding pegmatite are almost devoid of these substances. The vein is so narrow that it seems very unlikely that xenoliths of rock types different from those at the present surface could have been carried up from greater depths, and even if this were possible, highly aluminous rocks are totally unknown throughout the entire district. The only alternative left is to consider the andalusite as of magmatic origin, the alumina having been introduced by solutions given off from the magma reservoir at depth.

The andalusite formed later than the quartz and feldspar of the enclosing pegmatite. This period of formation of corundum and andalusite must have been marked by the introduction of solutions, gaseous or liquid, carrying a great excess of alumina. Alkalies must have been nearly absent, since otherwise they would have combined with the alumina and silica to yield feldspar. Moreover, during the period of formation of the corundum, even silica must have been present in insufficient quantity to combine with the alumina to produce andalusite.

At a somewhat later time the concentration of alkalies in the solutions increased to a point at which the previously formed andalusite was no longer stable, and reaction occurred between the andalusite and the alkali-bearing hydrous solutions producing a rim of sericite surrounding the andalusite core. Similar sericitic rims are present in the material from Scaletta Pass described by Spaenhauer,[9] and are likewise ascribed

---

[8] Kerr, P. F., The occurrence of andalusite and related minerals at White Mountain, Calif.: *Econ. Geol.*, vol. **27**, pp. 614–643, 1932.

Kerr, P. F., and Jenney, P., The dumortierite-andalusite mineralization at Oreana, Nev.: *Econ. Geol.*, vol. **30**, pp. 287–300, 1935.

[9] *Op. cit.*, pp. 330–334.

by him to an alteration of the andalusite, involving essentially an addition of alkalies and water.

Andalusite is characteristically a high-temperature mineral, and by analogy with the more complete paragenetic associations described from other localities,[10] both the andalusite and the corundum are probably to be regarded as of pneumatolytic origin. The sericite represents a later, hydrothermal stage, of lower temperature. The latter is in accordance with Rogers'[11] conclusions as to the hydrothermal origin of sericite.

The probable conditions from the foregoing considerations include solutions, hydrous at least in the later stages, which underwent a gradual change in composition. Highly aluminous at the time of formation of the corundum, they became progressively richer, first in silica, and then in alkalies. This theory of gradually changing conditions is similar to that generally invoked to account for the order of deposition of the metallic minerals in ore deposits, and likewise to that set forth by a number of recent writers to account for the formation of many complex pegmatites.[12]

CONCLUSION

The andalusite was developed by pneumatolytic action following the crystallization of the surrounding pegmatite. The aluminous vapors were of magmatic origin. At a later time, hydrothermal solutions attacked the andalusite and altered it in part to sericite. The optical and physical differences between the light and dark varieties of andalusite are due to the larger amount of ferric iron in the latter.

---

[10] Kerr, P. F., *op. cit.*

Kerr, P. F., and Jenney, P., *op. cit.*

[11] Rogers, A. F., Sericite a low temperature hydrothermal mineral: *Econ. Geol.*, vol. **11,** 118–150, 1916.

[12] Schaller, W. T., The genesis of lithium pegmatites: *Am. Jour. Sci.* (5), vol. **10,** pp. 269–279, 1925.

Landes, K. K., The paragenesis of the granite pegmatites of central Maine: *Am. Mineral.*, vol. **10**, pp. 355–411, 1925.

Hess, F. L., The natural history of pegmatites: *Eng. Min. Jour. Pr.*, vol. **128,** pp. 289–298, 1925.