# TWO ANDALUSITE PEGMATITES FROM RIVERSIDE COUNTY, CALIFORNIA

ROBERT W. WEBB,
*University of California, Los Angeles, California.*

## CONTENTS

## ABSTRACT

Reported occurrences of andalusite in pegmatite are reviewed and two new occurrences are described in which andalusite, corundum, microcline, and quartz are found in giant intergrowths, in metamorphic terrains. The geological setting is discussed and suggestions are offered as to the genesis of the occurrences. Thermal metamorphism of aluminous sediments and metamorphic differentiation are thought to account for the features of the two occurrences.

## INTRODUCTION

Two pegmatite dikes, locally rich in andalusite, have been found in Riverside County, California. One dike containing giant crystals of andalusite is in Coahuila Mountain, an elongate foothill ridge of granitic peaks sub-parallel to the San Jacinto Mountains. The second locality is in an isolated hill standing above the Hemet Plain, near Winchester, California. The mineralogy, occurrence, and relations of the andalusite-bearing dikes to adjacent pegmatites are discussed.

Pegmatitic andalusite has been described from few localities, but it must be commoner than reports indicate, at least in some districts. The occurrences here discussed increase to five the known occurrences of andalusite in the pegmatites of this petrologic province;[1] two more, presumably from pegmatites, have been mentioned.[2] A few other occurrences have been reported.[3]

## COAHUILA MOUNTAIN AREA

### SKETCH OF THE REGIONAL GEOLOGY

Coahuila Mountain parallels the larger San Jacinto Mountains along their west base. It is separated from the San Jacinto by a major fault zone, containing, according to Fraser,[4] two major faults, the San Jacinto and Bautista. The oldest rocks in the block are a metasedimentary banded gneiss, mica schist, and marble. Hornblende gabbros with many porphyritic facies have invaded these rocks, and form small stock-like bodies in Coahuila Mountain, and batholithic masses to the southeast.[5] Later, granitic magmas extensively enveloped and transgressed the metamorphic and gabbroic rocks, and produced batholithic units that vary in composition from granite to quartz diorite. These are presumed to be of Jurassic age. These formational units and the geology of the entire San Jacinto quadrangle are described in Fraser's report.

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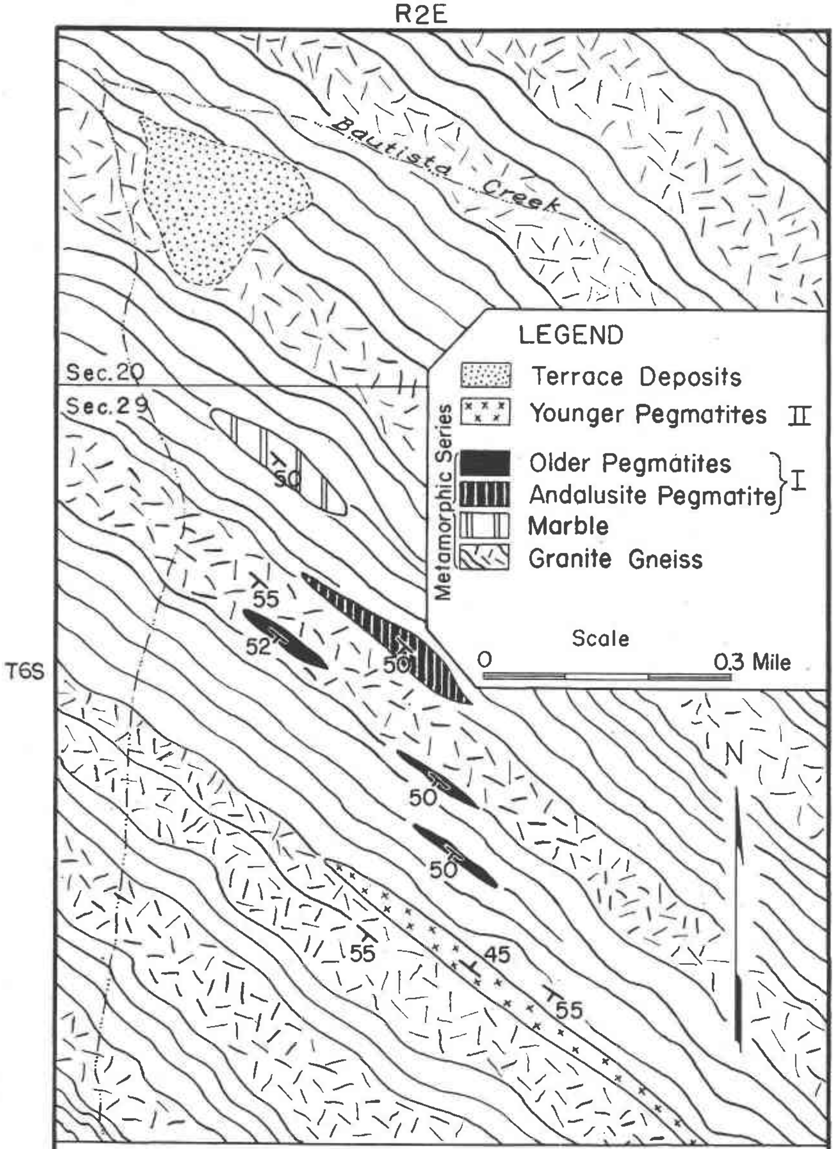
[1] Reported in a pegmatite from magnesite quarry near Winchester, 3 miles from Winchester locality herein described (Murdoch, Joseph, Andalusite in pegmatite: *Am. Mineral.*, **21**, 68–69 (1936); from a newly prospected pegmatite in T. 11 S., R. 3 W., Sec. 9, San Luis Rey quadrangle, near Vista, San Diego County, identified by the writer; and from the Jurupa Mountains, Riverside County, found by Mr. Melvin Swinney of Pomona College (personal communication from Professor A. O. Woodford of Pomona College).

[2] Kunz, George F., Gems, Jewelers' Materials, and Ornamental Stones of California: *Calif. State Min. Bur., Bull.* **37,** 99 (1905); it may be that the andalusite reported from Coahuila is from the same locality as the occurrence here described, but since Kunz gives no description or exact location, this cannot be verified. Dr. W. T. Schaller informed the writer by letter (March 14, 1941) that he had found pink andalusite in the Pala View Claim at Pala, California.

[3] Hess, Frank L., The natural history of the pegmatites: *Eng. Min. Jour. Pr.*, **128,** 289 (1925); Macdonald, G. A., and Merriam, Richard, Andalusite in pegmatite from Fresno County, California: *Am. Mineral.*, **23,** 588–594 (1938). Several localities are listed in Hills, E. S., Andalusite and sillimanite in uncontaminated igneous rocks: *Geol. Mag.*, **75,** 300 (1938).

[4] Fraser, Donald M., Geology of San Jacinto quadrangle south of San Gorgonio Pass: *Calif. Bur. Mines,* State Mineralogist Report, **27,** 518–519 (1931).

[5] Miller, F. S., Petrology of the San Marcos gabbro, southern California: *Bull. Geol. Soc. Am.*, **48,** 1399 (1937).



SKETCH MAP OF GEOLOGIC SETTING IN VICINITY OF ANDALUSITE PEGMATITE, BAUTISTA CANYON, RIVERSIDE COUNTY, CALIFORNIA.
In Sec. 29 T6S R2E San Jacinto Quad.

FIG. 1

## GEOLOGICAL RELATIONS OF THE PEGMATITES

### *General Statement*

Two groups of pegmatites occur in the Coahuila area. They are believed to be genetically separate because of differences in spacial, structural, and mineralogical relations.

### *Pegmatites of Group I*

The first group, less prominent and less extensive than those of group II, is associated with the metamorphic series, chiefly in gneissic rocks. Many of these pegmatites are lenticular, augen-like masses, parallel to the gneissic banding. They change abruptly in thickness along the strike of the gneissic zones; many terminate in a few dozen feet, reappear, and continue on the same strike. All those observed conform with the structure of the metamorphic rocks and to a regional strike of N. 45°–55° W., and regional dip of 45°–55° S. They range from a few inches to eight feet in width, and in the few exposed vertical sections show little persistence downward. The andalusite-bearing pegmatite is one in this group.

### *Pegmatites of Group II*

The pegmatites of the second group cut rocks as young as the granitic intrusive with which they are associated in origin. Many dikes are found in the granodiorite, some in the gabbro, and some transgress the regional structure of the metamorphic series. The pegmatites of this group have greater linear persistence, often continuing unbroken along their strikes for a half mile or more. Dikes range from six inches to twenty-five feet in thickness, and are more constant in thickness along the strike than those of group I. Some of these pegmatites may be traced directly into the parent granitic body. This granitic massif is one of the widespread granitic intrusives of southern California,[6] with which pegmatites are associated in many other California areas.[7]

## MINERALOGY OF THE PEGMATITES

### *Group I*

General Mineralogy. In the comparatively few pegmatites in the metamorphic series, the normal quartz-microcline association is every-

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[6] Reed, R. D., *Geology of California*, 96 **(1933)**.

[7] Schaller, W. T., The genesis of lithium pegmatites: *Am. Jour. Sci.*, (5) **10,** 269–279 (1925); Rogers, A. F., Minerals from the pegmatite veins of Rincon, San Diego Co., Cal.: *School Mines Quart.*, **32,** 398–404 (1911); Schaller, W. T., Dumortierite: *Am. Jour. Sci.* (4), **19,** 211–224 (1905); *U. S. Geol. Surv., Bull.* **262,** 96–102 (1905); and others.

where present together with schorlite, biotite, and muscovite. Other minerals are rare, except that large pink and white andalusite crystals abound in one large pegmatite in sec. 29, T. 6 S., R. 2 E. (San Jacinto Quadrangle).[8] Shattered masses of translucent white, iron-stained quartz enclose large microcline and schorlite crystals, and giant bundles of pink and white andalusite. These grow in clusters in the quartz. Muscovite plates occur on faces of the andalusite and tourmaline, and as small books elsewhere in the dike. A little corundum occurs in the andalusite.

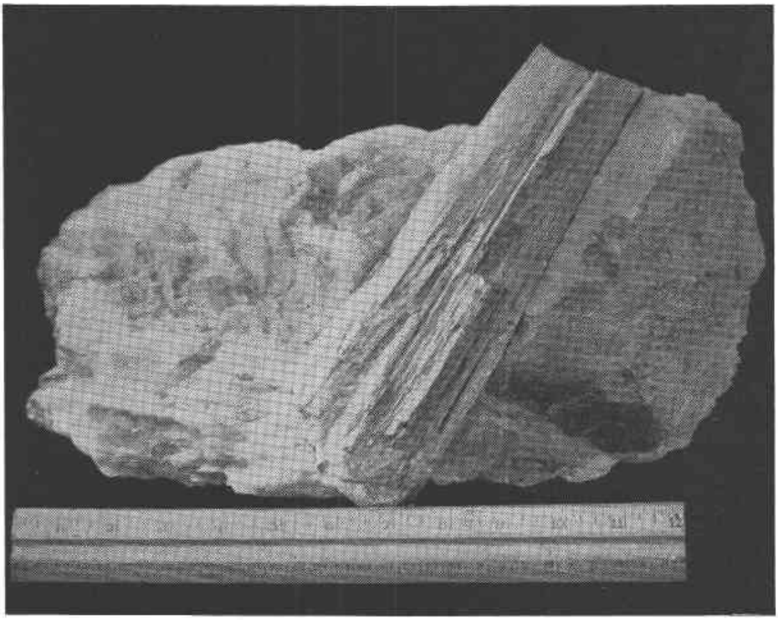

FIG. 2. Giant andalusite crystal in shattered quartz matrix. Note the similarity between this and the tourmaline form; there is no evidence, however, that andalusite is pseudomorphous after tourmaline. From Coahuila Mountain.

Andalusite. The andalusite occurs predominantly in local, wide zones in the pegmatite, as bundles of prismatic crystals in parallel and subparallel intergrowths. The bundles commonly range from two to five inches in thickness, and from six to fifteen inches in length. These exceptionally large groups are pink or brownish-pink, or shades thereof. Andalusite also occurs sparsely as rosettes and small radiating masses of white crystals in pockets in the dike, and along faces and contacts with microcline. In many places the two habits are closely associated.

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[8] Briefly described by Funk, B. Gordon, The sillimanite minerals: A summary: *The Mineralogist,* **8,** 131 (1940).

The andalusite of the first type shows pronounced color variation. In prismatic section, and commonly in the same individual, $X$ varies from pale flesh-pink to colorless, and rarely to deep brownish-pink. The color changes are gradational in most specimens, but some crystals show sharp lines of demarcation between two sections with strong pleochroic contrasts.[9] Color zones are elongated parallel to $c$, but in some cases they transgress the elongation. Some basal sections show a pale flesh-pink to colorless pleochroism for $Y$ and $Z$. Iron oxide stains were noted in the areas of pink pleochroism, but were absent in the colorless areas. In a recent paper,[10] the pleochroic variation in $X$ was shown to be partly, if not entirely, due to variation in ferric iron content, present as an impurity in the andalusite.

Other Minerals. Large muscovite flakes coat the faces of individual prisms in the andalusite bundles; they also occur inside the crystals where some flakes are oriented parallel to the $c$ axis, but mostly normal to it. Muscovite also occupies fracture and cleavage planes in the andalusite, commonly with its cleavage parallel to the planes of fracture or cleavage of the andalusite. This relation was noted in the andalusite from Fresno County.[11]

Where muscovite is abundant, nests of muscovite enclosed by andalusite contain small anhedral to subhedral grains of corundum. Most of these show the intense blue color of sapphire, some are colorless, and some are pleochroic with $\epsilon$ various shades of blue and $\omega$ colorless. Muscovite nests filled with granules of corundum are apparently common in andalusite deposits.[12] A few grains of corundum are in direct contact with the andalusite.

The andalusite shows prominent alteration rims of sericite from $\frac{1}{4}$ to $\frac{3}{4}$ inch thick. The sericite is compact, fine grained, and commonly surrounds muscovite flakes. Such sericitic rims are prominent on andalusite from most areas.[13] An exception is the occurrence at Winchester (see below).

Microcline perthite is abundant. It occurs in imperfect crystals ranging from a few inches in prism dimension to 1×1×3 feet. The larger crystals are the commoner. They show the prism zones well developed, with some terminations. In many places the microcline is shattered.

Large schorl-tourmaline crystals interfinger all other minerals. Many are single crystals, with well developed terminations. The crystals vary

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[9] Macdonald and Merriam, *op. cit.*, p. 589.

[10] Macdonald and Merriam, *op. cit.*, p. 592.

[11] *Ibid.*, p. 589.

[12] Kerr, Paul F., Andalusite and related minerals at White Mountain, California: *Econ. Geol* **27,** 625 (1932); Macdonald and Merriam, *op. cit.*, p. 589.

[13] Kerr, *op. cit.*, p. 635; Macdonald and Merriam, *op. cit.*, p. 589.

from an inch to five inches in diameter, and from six to sixteen inches in length. Microscopically they show no unusual features. Many are bent and fractured.

### *Group II*

General Mineralogy. Pegmatite dikes of the second group are numerous. Most of them lie within the granodiorite and contain fairly simple and common pegmatitic minerals: microcline, quartz, schorlite, hessonite, muscovite, and biotite, in the usual giant texture relations. Graphic granite is rare. Rose quartz occurs in exceptionally well-colored, large, translucent masses, with some smoky quartz, hard jet-black schorlite crystals (up to three feet long), and occasional beryl. Some microcline has been produced commercially from a particularly wide dike in Sec. 22, T. 7 S., R. 2 E.

Cream-white microcline perthite is the most abundant mineral; albite is rare except in perthitic intergrowths. The microcline is subhedral and forms large aggregates, many of which show uniform cleavage trends over areas two or three feet square.

Two varieties of quartz are common: normal milk-white to colorless, and rose quartz. Masses of rose quartz 25 to 50 feet in two dimensions are common. Fracturing is slight, in contrast with much California rose quartz, and unbroken masses are obtainable.

The jet-black schorlite is massive and abundant in all dikes. Crystals from ten to forty inches long, in subparallel bundles, occur in white quartz and microcline in a very large dike in Sec. 30, T. 6 S., R. 2 E. Muscovite, biotite, or both, occur in all of the dikes, with muscovite predominant. Most of the tourmaline-rich dikes lack biotite. Beryl, in small yellowish-green crystals, was found in one dike. Biotite is commonly arranged along cleavages and fractures in the quartz and microcline, the biotite plates often arranged normal to the dike walls and marginal thereto.

## EVIDENCE FOR TWO GENERATIONS OF PEGMATITES IN THE COAHUILA AREA

The two groups of pegmatites of the Coahuila area differ sufficiently to suggest that they may be genetically separate. This suggestion is based on the following evidence:

Space relations: (1) The dikes of the first group are confined to the metamorphic terrain; those of the second occur in all the rocks of the area and are especially numerous in the granitic formations. (2) The dikes of the first group conform with the regional structure of the gneisses; those of the second, though not observed to cut the first set, have strikes parallel, but dip nearly normal to the dip of the first group (see Fig. 1). (3) The habits of the dikes of the two groups differ notably; those of group I are interrupted, lenticular, and short; those of group II are tabular and persistent.

Internal structural relations and mineralogical contrasts: (1) Lack of oriented minerals in dikes of group I, compared to marginal orientation in group II, e.g., biotite. (2) Concentration of less usual minerals, e.g., andalusite, schorlite, in thickened zones of I, with uniform distribution of tourmaline in II.

## Winchester Area

### Sketch of the Regional Geology

Winchester is situated on the southern edge of the Perris plain. Monadnock-like hills, composed of metamorphic rocks, assigned by Dudley[14] to the Triassic, rise above the plain. These have been invaded by batholithic rocks varying in composition from gabbro through quartz monzonite, emplaced in order of increasing silicity. The geology of the region is discussed by Dudley.[15] In the hill in which the pegmatite in question occurs, schistose rocks are cut by gabbro, each the probable equivalent of a similar rock in adjacent hills. Deep weathering of the metamorphic series handicaps observations, but granitic gneisses and chlorite schists are present in the series.

### Geological Relations of the Pegmatites

The andalusite-bearing pegmatite outcrops across the brow of a small hill, in T. 5 S., R. 2 N., Sec. 12 (Elsinore quadrangle). Prospectors have cross-cut the dike at two places, and a shaft descends about 20 feet down the dip. Deep weathering obscures the mineral relations. The dike, which strikes N. 45° W., dipping SW. at 30°, is parallel to the foliation of the metamorphic series and is from six to seven feet thick, with a few small subparallel branches. The dike is lenticular along the strike, pinching irregularly, and dying out completely in about thirty feet. Down the dip, the dike shows no evidence of thinning as far as it is exposed. The second generation pegmatites are represented by a single dike six to eight feet thick, striking N. 10° E. and dipping SW. at 38°. This dike cuts the gabbro, which in turn intrudes the metamorphic rocks. The mineral composition of this second pegmatite is simple, except for beryl and small blue tourmaline crystals.

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[14] Dudley, Paul H., Geology of a portion of the Perris block, southern California: *Calif. Jour. Mines and Geol.*, State Mineralogist's Report, **31**, 487–506 (1935).

[15] *Ibid.*

## ANDALUSITE

The andalusite occurs in a lens two feet thick along the hanging wall of a simple biotite-quartz-microcline pegmatite. The andalusite lens pinches out down dip within twenty feet. Within the lens andalusite occurs in prism bundles up to three inches long, in pods of partially chloritized biotite. These pods possess no positive orientation in the marginal lens, but the biotite of the pods forms a distinct coating about the andalusite. Such biotite "coronas" are commonly $\frac{1}{4}$ inch thick, with an onion-skin wrapping of biotite plates.

The biotite pods are, in turn, arranged in lenticular groups within the larger lens. The axes of the smaller lenses usually lie across the trend of the larger one. Three or four pods compose these smaller lenses, each in turn enclosing andalusite prism bundles (Fig. 3).

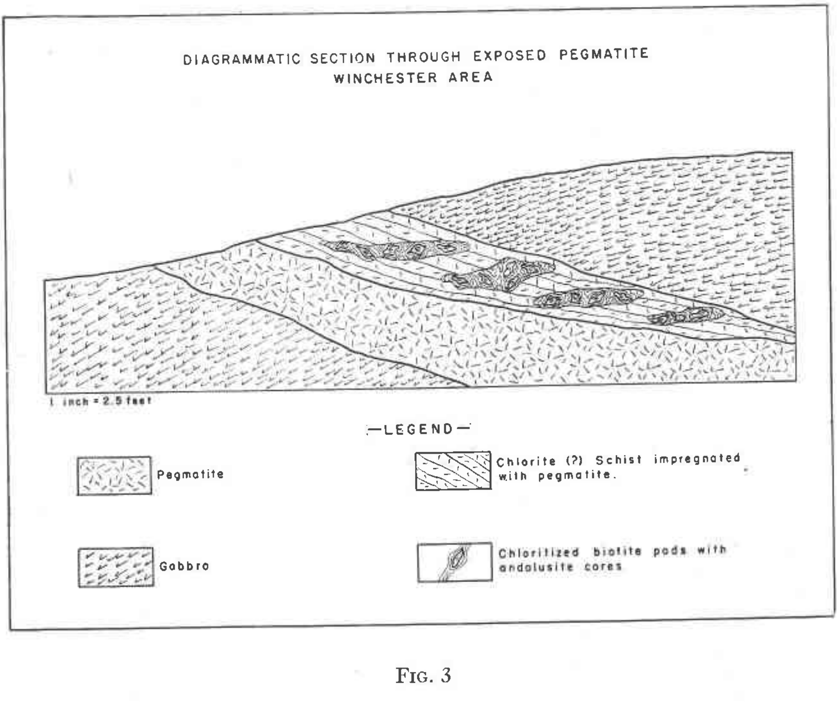

FIG. 3

## CORUNDUM

Corundum occurs disseminated in the andalusite prisms, and in euhedral crystals up to three inches in length. The corundum shows color zoning from sapphire-blue to gray. Though intimately associated with the andalusite, the corundum is rarely in parallel orientation with it. The corundum is confined to the andalusite-bearing areas of the dike.

## ORIGIN OF ANDALUSITE AND OTHER ALUMINUM SILICATES

### INTRODUCTION

The published accounts of andalusite suggest its origin by three general processes: (1) alteration of xenoliths; (2) magmatic sources; (3) concentration from wall rocks under high temperature, accompanied by igneous emanations; or a combination of these processes. The important andalusite deposits in the White Mountains of California have been attributed to metamorphism of aluminous layers by igneous intrusions,[16] as have the deposits of dumortierite and andalusite at Oreana, Nevada.[17] Xenolithic alteration has been suggested for the origin of several deposits of aluminum silicate minerals, notably some of the important kyanite and sillimanite deposits of India.[18] Magmatic emanations have been invoked to explain some small deposits of andalusite,[19] and larger ones of kyanite.[20] Pyrogenic andalusite has also been described.[21]

### GENESIS IN THE COAHUILA MOUNTAIN DEPOSIT

Granitic gneisses and biotite-rich schists are typical rocks of the metamorphic sequence in which the andalusite pegmatite is developed. Rarer types are corundum-muscovite and corundum-biotite schists, not present in the immediate area, but found abundantly on the north flank of the San Jacinto Mountains at a locality reported by Hazen.[22] These types are widely distributed in the metamorphic terrain.[23] The metamorphic sequence in Coahuila Mountain is probably equivalent to that of the San Jacinto Range, since xenoliths and pendants of similar type are more or less continuous northwesterly to the known corundum-bearing areas. The original sedimentary character of the metamorphic series is attested by interbedded lenses of marble with relict stratification. Thermal metamorphism is suggested by the presence of abundant graphite in the marble, which is composed largely of grains of calcite one-quarter inch

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[16] Kerr, Paul F., *op. cit.*, p. 642.

[17] Kerr, P. F., and Jenney, Philip, Dumortierite-andalusite mineralization, Oreana, Nevada: *Econ. Geol.*, **30**, 287–300 (1935).

[18] Dunn, J. A., Andalusite in California and kyanite in North Carolina: *Econ. Geol.*, **28**, 695 (1933).

[19] Macdonald, G. A., and Merriam, R., *op. cit.*, p. 594.

[20] Stuckey, Jasper L., Kyanite deposits of North Carolina: *Econ. Geol.*, **27**, 670 (1932).

[21] Hills, E. S., *op. cit.*, p. 300.

[22] Hazen, Guy E., Corundum crystals—California: *The Mineralogist*, **9**, 81–82, (1941).

[23] Murdoch, J., and Webb, R. W., Notes on some minerals from southern California. III. Corundum and associated minerals near Banning, San Jacinto Mountains, California: *Am. Mineral.*, **27**, 328–329 (1942).

across. Orientation of the flake graphite along relict stratification planes, suggests that the graphite originated from organic matter contained in the limestone. The development of graphite under these conditions has generally been considered diagnostic of high temperatures.[24] Abundant lenticular silexite masses (dikes and veins) are found in the metamorphic terrain. According to Tyrrell,[25] andalusite may form from the alteration of a muscovite-rich rock under thermal metamorphism, when silica is present, by the equation:

$$H_2KAl_3(SiO_4)_3+SiO_2 \rightarrow Al_2SiO_5+KAlSi_3O_8+H_2O$$

That this may have been the course of development of the Coahuila andalusite is suggested by the presence of at least two of the necessary factors for Tyrrell's hypothesis, although original quartz in the muscovite-rich rock may have been the source of silica in the reaction.

Additional evidence in support of generation in place may be deduced from suggestions regarding the origin of the corundum in the dike. The corundum grains, occurring as anhedrons in nests of muscovite, may be interpreted as residual grains from an original corundum-rich rock, the muscovite now enveloping the corundum because it developed by alteration of the corundum itself. Thus an original highly aluminous sediment, subjected to thermal metamorphism developing a muscovite-corundum schist, might by addition of silica, and continued thermal conditions, produce an andalusite-quartz-corundum rock. If reaction between these minerals were incomplete, corundum residuals in andalusite should be expected, especially since muscovite might be looked upon as forming "coronas" about corundum, thus isolating the corundum from further reaction as later chemical changes occurred.

Associated pneumatolytic processes during and following the andalusite formation are evidenced by intergrowth of schorl-tourmaline with andalusite, indicating the introduction of boron. Under these circumstances tourmaline might form by reaction of boron compounds with corundum and quartz.

Corundum, when associated with andalusite, has commonly been considered a late-forming constituent in most pegmatitic occurrences. In attempting to ascertain whether corundum formed before or after the andalusite, it was suggested,[26] since tourmaline formed simultaneously and following the andalusite in this dike, that the presence of boron in the corundum would suggest corundum formation before tourmaline, and therefore before andalusite. Accordingly a spectrographic analysis

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[24] Clarke, F. W., Data of Geochemistry: *U. S. Geol. Surv., Bull.* **770,** 330 (1924).

[25] Tyrrell, G. W., *Principles of Petrology*, 294 **(1926)**.

[26] Personal communication from Professor G. E. Goodspeed of the University of Washington.

of carefully sorted corundum granules was obtained, with the following results:

| *Elements* | *Estimated Quantity* | |
|---|---|---|
| Al | Principal Constituent | |
| Si | .1–1% | from andalusite |
| Fe | .1% | |
| Ti | .1% | |
| B | .01% | from tourmaline |
| Mg | .01% | |
| Ca | .001% | |
| Cu | .0001–.001% | |

Analysis by Applied Research Laboratories, Glendale, California. Quantities estimated to the closest power of ten.

The analysis is not considered conclusive, but the question may be raised as to where the boron in the corundum originated, unless it were introduced into the corundum when the tourmaline formed. The presence of boron in the corundum may be suggestive of the genetic sequence (1) corundum, (2) andalusite, (3) tourmaline.

Late hydrothermal activity is shown by the sericitic rims about all the andalusite crystals.

The general features of (1) lenticularity, (2) unusual mineral association, and (3) limited distribution of pegmatite are less common features of magmatic pegmatites than of other types. The similar composition of the wall rocks of the pegmatite, both against the dike and in the metamorphic body as a whole, indicates no addition of material from the pegmatite into the wall rocks. Magmatic processes thus seem even more remote as the contributing factors in the origin of the Coahuila pegmatite. Again, the hypothesis of xenolithic alteration may be discarded because the pegmatite is part of a large metamorphic mass of similar composition, which is in itself a huge xenolith, and should on the xenolithic hypothesis be itself partially transformed. The presence of the characteristics just enumerated in themselves suggest generation of andalusite in place by metamorphic differentiation.

## GENESIS IN THE WINCHESTER DEPOSIT

Chlorite schists compose the small areas of metasediments included in gabbro intrusives, cut by simple pegmatites, in the Winchester occurrence. The fact that the andalusite is confined to the margin of a single dike, in a large lentil containing pods which simulate xenolithic blebs, separated by biotite-rich gneissic zones, suggests the applicability of the xenolithic hypothesis for the Winchester occurrence. An original argillaceous xenolith under high temperature can be expected to proceed toward the production of andalusite, with simultaneous development of corundum (if the alumina content is high in the inclusion). The rims of chloritic biotite enclosing andalusite prisms may have resulted from the recrystallization of the chlorite of the xenolith since andalusite contains insufficient iron (and no magnesium) to satisfy the biotite forming thereon.

### Summary of Genesis

Two andalusite pegmatites are ascribed to the thermal metamorphism of original aluminous sediments; one by thermal metamorphic differentiation in a series of metasediments, producing a pegmatite lens in highly metamorphosed rocks; the other by hydrothermal metamorphism of regionally metamorphosed sediments, included as xenoliths in a simple pegmatite.

## Acknowledgments

These investigations have been conducted as part of a program of study of the pegmatites of southern California, in progress with Dr. Joseph Murdoch of the University of California, Los Angeles. His cooperation in reading the manuscript, and in the field, is appreciated. Drs. James Gilluly, Cordell Durrell, and Adolf Pabst kindly criticized the manuscript. The Coahuila pegmatite is owned by Mr. Roy Fairchild of Los Angeles and Mr. Don Roland of Hemet, California, who permitted the writer free access to the deposit. Mr. B. Gordon Funk, former student of the writer, assisted in the field and first brought the deposit to the writer's attention. The Winchester property is owned by Dr. Donald Skillen, Flintridge, California, who likewise permitted study of the pegmatite. Financial assistance was received from the Board of Research, University of California, Los Angeles. All of these services are gratefully acknowledged.