# AN OCCURRENCE OF DUMORTIERITE NEAR QUARTZSITE, ARIZONA[1]

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## INTRODUCTION

Since 1889, the occurrence of dumortierite in southwestern Arizona has been known, but only as detrital boulders in the Colorado River terrace gravels between Ehrenberg and Yuma. Such was the material from near Clip, Arizona, that was studied by Diller and Whitfield,[2] Ford,[3] Schaller,[4] and Bowen and Wyckoff.[5] Clip is said by local old residents to have been situated across the river from Picacho, California.

In 1927, claims were located on certain dumortierized schist outcrops near Quartzsite, about 45 miles north-northeast of the Clip locality. These outcrops represent the first known Arizona occurrence of the mineral in place. The deposit is of further interest because the three isomeric aluminum silicates, andalusite, cyanite, and sillimanite, are associated with the dumortierite, and show alteration to pyrophyllite instead of to muscovite.

## SITUATION

This dumortierite deposit is in west-central Yuma County, Arizona, about three miles southwest of Quartzsite and fifteen miles east of the Colorado River, in the northwestern portion of T. 3 N., R. 19 W., Gila and Salt River Base and Meridian. The deposit outcrops on the north side of a narrow re-entrant in the low, southeastern portion of an isolated group of hills that stand prominently above the plain near the eastern margin of the Dome Rock Mountains.

## GENERAL GEOLOGY

These hills, which occupy an area about three miles long by two miles wide, are made up of steeply dipping schists of probable pre-Cambrian age, and are surrounded by desert detrital gravels. Microscopic study of the schists indicates them to be dominately

[1] Published by permission of the Director of the Arizona Bureau of Mines.

[2] *Am. Jour. Sci.*, 3d ser., vol. **37**, pp. 216–219, 1889; also *U. S. Geol. Survey, Bull.* **64**, pp. 31–33, 1890.

[3] *Am. Jour. Sci.*, 4th ser., vol. **14**, pp. 426–430, 1902.

[4] *Idem*, 4th ser., vol. **19**, pp. 211–224, 1905; also *U. S. Geol. Survey, Bull.* **262**, pp. 91–120, 1905.

[5] *Jour. Wash. Acad. Sci.*, vol. **16**, pp. 178–179, 1926.

of igneous origin. Certain prominent members definitely represent rhyolites, and a considerable portion of the series is chlorite schist that probably was derived from igneous rocks. A minor portion of the series, on the other hand, is quartz-sericite schist that offers no field or microscopic evidence as to its origin.

In the vicinity of the dumortierite deposit, the schists strike about east-west and dip steeply northward. Minor faulting, principally along the strike of the schistosity, is evident.

## The Mineral Deposit

Form and structure. The outcrop of the dumortierized phase of the schist trends approximately east-west and is divided into two segments, some 450 feet apart, by a tongue of the outwash gravels that also conceal its east and west limits.

The western segment outcrops with a length of approximately 200 feet and a maximum width of 35 feet. In it, the planes of schistosity strike nearly east-west and, as exposed in shallow cuts, dip 65°–80° N.

The eastern segment outcrops with a length of approximately 300 feet and a maximum width of fifty feet. Throughout its western third, the planes of schistosity strike nearly east-west, but, for the eastern two-thirds, they strike about S.70° E. In this segment also, they dip steeply north.

Character of dumortierized schist. A generalized section, from north to south across the western segment of the deposit, is as follows:

| | Thickness in feet |
|---|---|
| (a) Gray, laminated pyrophyllite schist with a few microscopically visible dumortierite prisms | 5± |
| (b) Like (a), but thinly laminated | 1–2 |
| (c) Largely cyanite, andalusite, sillimanite, and pyrophyllite. Contains a little dumortierite | 2/3 |
| (d) Quartz vein with comb structure and containing crystals of rutile and cyanite | 1/3 |
| (e) Like (c), but containing more dumortierite and grading into quartz mica schist | 30 |
| (f) Outwash gravels | |

## Mineralogy

Associated with the dumortierite are quartz, cyanite, andalusite, sillimanite, pyrophyllite, muscovite, hematite, magnetite, rutile, leucoxene, pyrite, limonite, sapphirine (?), and some undetermined species.

*Dumortierite* ($8Al_2O_3 \cdot B_2O_3 \cdot 6SHiO_2 \cdot {}_2O$, Schaller): The dumortierite occurs as fibers and small prisms, both disseminated and in veinlets. Its fibers may be in divergent, parallel, or curved masses that in places are brush or comb-shaped in section. Groups of the parallel fibers show deep blue pleochroism in their long direction. The prisms generally are straight, but in places are forked or sharply bent. They show strong pleochroism, with X = deep blue, rarely violet; Y = colorless to yellow, rarely pale blue to violet; and Z = colorless to pale blue. This pleochroism for a given direction may vary within a single crystal. The mineral has biaxial character, negative elongation, and extinction X $\|c$.

Where disseminated, the mineral penetrates quartz, cyanite, muscovite, and pyrophyllite, but less commonly the andalusite and sillimanite. Within minerals other than quartz, the dissemination usually is rather sparse, so that the dumortierite is scarcely noticeable to unaided eyes. Within quartz, however, the dumortierite may be sufficiently abundant to color the rock a deep, dull, violet-blue that is near 53″ VBi and 51″ BV–Bi of Ridgway's Color Standards and Nomenclature. Certain weathered specimens show a more lavender tint. No accurate analysis was attempted to determine the percentage of dumortierite in the richest rock. However, its specific gravity, as determined by a Jolly Balance, is about 2.73, which, neglecting minor accessory minerals, would fit a composition of 11.11 per cent dumortierite and 88.89 per cent quartz, if the gravity of the quartz be taken at 2.66 and of the dumortierite at 3.30. Microscopic examination shows this blue rock to consist primarily of allotriomorphic crystals of quartz, from 0.1 to 0.75 mm. in diameter, cut by a few quartz veinlets of larger grain. A slight parallel flattening of the crystals, accompanied by wavy extinction, renders the rock faintly schistose. Hematite, rutile, and leucoxene are present in minor amounts. Numerous hair-like fibers of dumortierite, with maximum length of about 0.5 mm. and width of a few microns, penetrate the quartz in every direction. These fibers form felt-like aggregates, such as shown in Figure 1, that give the rock great toughness. A relatively small number of prismatic forms, with maximum observed length of 1.5 mm., width of about 0.15 mm., and strong pleochroism, occur diverging in random directions.

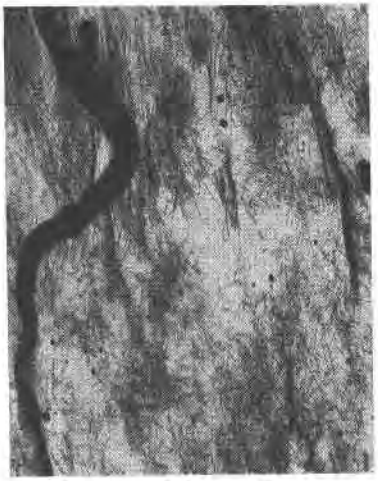

FIG. 1

View perpendicular to schistosity, showing larger curved veinlet, smaller veinlets, and fibers of dumortierite. Dark spots are rutile. One nicol. × 41.


FIG. 2

Different portion of same slide as Fig. 1, but showing muscovite (M), surrounded by veinlet of dumortierite fibers, in allotriomorphic quartz penetrated by fine fibers of dumortierite. Crossed nicols. × 41.


FIG. 3

Andalusite (A), cyanite (c), sillimanite (S), and pyrophyllite (P). Crossed nicols. × 17.


FIG. 4

Sillimanite (S), veinlet of dumortierite fibers (D), and cyanite (C), altering to pyrophyllite (P). Crossed nicols. × 41.

Veinlets of the dumortierite, which vary somewhat in character, traverse areas where these disseminations are thickest and areas where they are absent. In places, aggregates of divergent fibers follow certain bands of schistosity in vein-like fashion, with indefinite walls from 0.1 mm. to 1.5 mm. apart, but generally terminate in brushes. More commonly, the veinlets, either of fibers or of prisms, have rather definite walls that appear to mark surfaces of parting along schistosity and walls of cracks transverse to schistosity. Their maximum widths are 1–2 mm., their forms are sinuous, crenulated, forked, or sharply bent, and, if fibrous, their terminations in many places are brushes, so that when viewed with a low-power objective they resemble wisps of dark-blue smoke. Where in a matrix of coarsely crystalline cyanite, andalusite, and sillimanite, the veinlets more commonly follow boundaries between crystals, but in places cut across them. Veinlets of prisms are less abundant than veinlets of fibers, but resemble them in form and habit of occurrence. The prisms, which attain maximum lengths of 1.25 mm. and widths of 0.2 mm., generally have parallel, but in places net-like, arrangement. These veinlets usually have numerous short interruptions in their continuity.

The dumortierite, where in a gangue of cyanite, andalusite, and sillimanite, has undergone some alteration to pyrophyllite.

*Quartz.* The original quartz of the schist appears in thin section as a mosaic of small, allotriomorphic crystals with wavy extinction. Such cracks as traversed it are now filled with veinlets of dumortierite, later quartz, cyanite, and pyrophyllite.

The later quartz generally does not show wavy extinction. It shows penetration by the dumortierite fibers only to a slight extent and mainly around its boundaries, contains inclusions of muscovite and magnetite (?) dust, and probably is earlier than the aluminum silicates.

Certain ragged cavities in the andalusite, sillimanite, and cyanite are filled by aggregates of pyrophyllite and of quartz that probably is secondary and later than the aluminum silicates. This quartz is very irregular in outline and in places is crowded with parallel inclusions of probable pyrophyllite, together with some finely divided magnetite (?).

*Cyanite* ($Al_2SiO_5$). The cyanite occurs as bladed crystals of a color that lies between the Bremen Blue (43′ GBb) and Cendre Blue (43GBb) of Ridgway's Color Standards and Nomenclature.

They commonly range in size from 0.5 mm. by 1 mm. to 1.25 mm. by 7 mm., and, in vein quartz, are as much as 10 mm. by 30 mm. Twinned forms are common. Optically, the mineral shows the normal properties of cyanite. It is definitely earlier than the sillimanite and dumortierite, and shows strong alteration to pyrophyllite and quartz. The cyanite, associated most abundantly with andalusite and relatively less abundantly with sillimanite, quartz, dumortierite, and the other minerals of the deposit, forms friable bands and bunches a few inches wide.

*Andalusite* ($Al_2SiO_5$). The andalusite occurs as rough prisms, gray to pinkish gray in color, that commonly range in size from 1 by 2 mm. to 3 by 5 mm. Prismatic cleavage at right angles and a few nearly square cross sections are evident. The mineral has the following properties of andalusite: Parallel extinction, negative sign and elongation, large optic angle, moderately high relief, medium birefringence, and crimson pleochroism along cracks in the direction of X. In addition, its indices of refraction, as determined by immersion liquids that were standardized on an Abbé refractometer, are: $\alpha=1.631$, $\beta=1.637$, $\gamma=1.642$. Although these values may be a few points in error in the third decimal place, they fit the known indices of andalusite. It is infusible and insoluble, and gives a blowpipe reaction for alumina.

The andalusite is earlier than the sillimanite, but may be later than the cyanite. It carries inclusions of pyrophyllite, rutile, finely divided magnetite, and leucoxene, and alters readily to pyrophyllite and quartz.

*Sillimanite* ($Al_2SiO_5$). The sillimanite occurs as slender, roughly terminated prisms that commonly are about 0.3 mm. wide and 1.5 to 3 mm. long. Megascopically, the mineral is not readily identifiable, but, optically, it has the normal properties of sillimanite. It is later than the cyanite and the andalusite but carries similar inclusions. Alteration has affected this mineral less strongly than it has the cyanite and andalusite, but has developed pyrophyllite and quartz. A very thin film of a dull-gray alteration product (leucoxene (?) ) generally surrounds the outer borders and accentuates the relief of the sillimanite, but does not appear to have been derived from it.

In this deposit, sillimanite appears to be only one-sixth or one-tenth as abundant as andalusite and cyanite.

*Pyrophyllite* ($H_2Al_2Si_4O_{12}$). Pyrophyllite, in compact aggregates,

is the principal constituent of certain members of the schist. As small, micaceous flakes, it is abundantly disseminated throughout certain portions of the deposit. As radiating fibers, 2 cm. in maximum length, it occurs in thin seams along fractures, principally within the andalusite-cyanite-sillimanite aggregates. Such seams generally grade into irregular bunches that clearly were formed through alteration of the minerals of these aggregates. Any dumortierite originally present in such areas also has partially gone over to pyrophyllite.

*Muscovite.* Muscovite, although not abundant in the deposit, has two observed forms of occurrence.

One form, which occurs in the quartz-mica schist, is that of long shreds which are parallel to the schistosity and probably are contemporaneous with the schist. The dumortierite penetrates these shreds in a few places, but more generally surrounds their outer margins.

The other form is that of inclusions within later quartz in the schist.

*Iron minerals.* A black, opaque iron mineral occurs, in places abundantly, as irregular bunches and interrupted veinlets along certain partings of schistosity, and as scattered, irregular grains throughout the deposit. The veinlets have a maximum width of about 2–3 mm., and the grains range in diameter from a few microns up to 1.5 mm. This mineral has a red-brown streak and, in polished surface and thin section, the appearance of hematite. It is magnetic, probably due to admixed magnetite, but the intensity varies with different specimens. Qualitative chemical tests upon it by W. A. Sloan, of the U. S. Bureau of Mines, revealed only iron oxide and traces of sulphur. This sulphur probably came from pyrite, for a small stringer of this mineral was observed within the dumortierized schist. In a few places, the hematite has altered to limonite.

*Rutile.* Grains of rutile, from a few microns to about 1 mm. in diameter, and with rounded to faintly crystalline outlines, are scattered thinly throughout the deposit. It appears to be penetrated by the dumortierite, and in places is associated with hematite and lucoxene. Well-formed, clove-brown crystals of rutile, several millimeters in maximum diameter, are scattered along fractures through the vein quartz.

*Sapphirine* (?). Irregular grains, not over 0.75 mm. in diameter,

of a pale blue mineral occur sparingly in the dumortierized schist and the pyrophyllite schist. Although positive identification of the mineral could not be made, it has the following properties of sapphirine ($Mg_5Al_{12}Si_2O_{27}$): High refraction, low birefringence, biaxial character, and sky-blue, blue-green, and colorless pleochroism. No cleavage or twinning are visible.

*Principal unknown minerals.* (a) An unknown mineral occurs rather abundantly in an aggregate of fine-grained, allotriomorphic quartz and scaly pyrohyllite, cut by small prisms and veinlets of dumortierite. It is in the form of small, colorless, apparently tetragonal prisms whose nearly square cross sections show good diagonal cleavage. Optically, it has high refringence, rather strong birefringence, parallel extinction, and uniaxial positive character.

(b) An unknown mineral occurs sparingly along fractures and occupying vugs in the dumortierized schist. It is in both amorphous and elastic, fibrous forms of peach-red to pink color. Bead tests for cobalt, manganese, and iron were negative, and not enough material was available for further qualitative analysis.

(c) Assays made upon the dumortierized rock by Prof. J. B. Cunningham, of the University of Arizona, showed traces of gold. Possibly this gold accompanies one or more of the iron minerals.

## Origin

Probably a granitic magma invaded the schists at considerable depth and permeated favorable portions of them with hot, pegmatitic emanations that were high in silica and alumina but contained also some boron, iron, and titanium. The distribution of the resultant minerals, which appear to have replaced metasomatically the schist, indicates these emanations to have been very fluid and possibly under great pressure. Microscopic study indicates the following sequence of deposition for the principal minerals: vein quartz; cyanite and andalusite; sillimanite; rutile and primary iron minerals; dumortierite; latest quartz and pyrophyllite. Probably these minerals were deposited at temperatures below 575°C., within the range given by Wright and Larsen[6] for vein and geode quartz.

The temperature and pressure probably dropped considerably before the development of the pyrophyllite, for this mineral commonly forms under moderate conditions of temperature and pres-

[6] *Am. Jour. Sci.*, 4th ser., vol. **27**, pp. 446–447. 1909.

sure. As already pointed point, a large part, at least, of the pyrophyllite was developed through alteration of the anhydrous aluminum silicates. Such a reaction appears to be relatively simple and to require merely the introduction of silica and water:

Andalusite, cyanite,
or sillimanite Pyrophyllite

$$Al_2SiO_5 + 3SiO_2 + H_2O = H_2Al_2Si_4O_{12}$$

The possibility of pyrophyllite being derived from andalusite has been suggested by Knopf[7] but, so far as the writer is aware, pyrophyllitization of cyanite and sillimanite has not previously been described.

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[7] *U. S. Geol. Survey, Bull.* **762,** p. 19, 1924.