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LARGE ANDALUSITE CRYSTALS FROM CAMPBELL COUNTY, VIRGINIA

Richard S. Mitchell[1], William F. Giannini[2], and
D. Allen Penick, Jr.[2]

During the Fall of 1986, exceptionally large prismatic crystals of andalusite were discovered in association with milky quartz veins at a previously unknown site in Campbell County, Virginia (Giannini and others, 1986; Figure 1). Although many of the crystals have been replaced by kyanite (or to a lesser degree by sillimanite) to form well-preserved pseudomorphs, unaltered andalusite is still present (Figure 2). The pseudomorphs are actually *paramorphs*, since their chemical composition has remained Al_2OSiO_4. There is a strong possibility that these andalusite crystals (both fresh and replaced) are close to record size, having lengths to 31.8 cm and prism face widths to 18 cm (Virginia Division of Mineral Resources R-8947). Unaltered andalusite crystals have been reported at only one other Virginia locality (Genth, 1890), although pseudomorphs after andalusite have been noted at a few other places in the state (Dietrich, 1956; Brown, 1958; Redden, 1962). In addition, rare microscopic andalusite has been observed in petrographic studies of thin sections of Virginia rocks (Reed and Jolly, 1963; Smith and others, 1964).

The deposit is located about 2.75 miles north-northeast of Altavista and a little less than 2 miles east of Lynch Station in southern Campbell County, Virginia. The Universal Transverse Mercator (U.T.M.) numbers in meters are: N. 4,112,000, E. 654,000, zone 17. **The site is posted and cannot be visited without permission.**

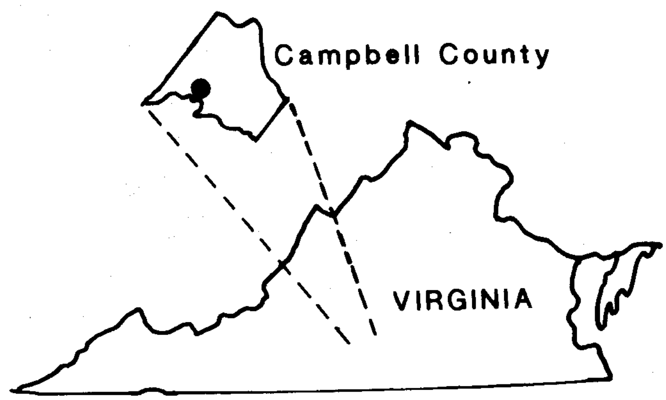

Figure 1. Location of deposit in Campbell County, Virginia.

ANDALUSITE

All of the andalusite crystals in this deposit are square prismatic in habit, being bounded by the orthorhombic prism *m*{110} and the basal pinacoid *c*{001} (Figure 3). Although not common, the following forms also occur: *s*{011}, *r*{101}, and *z*{121} (Figure 4), listed here in order of decreasing frequency. It is rare that the crystals are doubly terminated with pinacoids at both ends. The crystals show a wide variation in size (Figures 5, 6, and 7). Although crystals less than 1 cm across are common, they are associated with much larger crystals in clusters in which individual crystals averaging 8 to 10 cm across and 13 to 15 cm long are common. However, individual crystals larger than these were frequently observed.

That the crystals have been subjected to stress after they formed is shown by the presence of some distorted and curved specimens. Some of these show an offset of portions of a single crystal caused by faulting and then healing during their transformation to kyanite; this results in a stair-step structure. Some are simply bounded by long, curving and somewhat twisted,

[1] University of Virginia, Department of Environmental Sciences (deceased).
[2] Division of Mineral Resources

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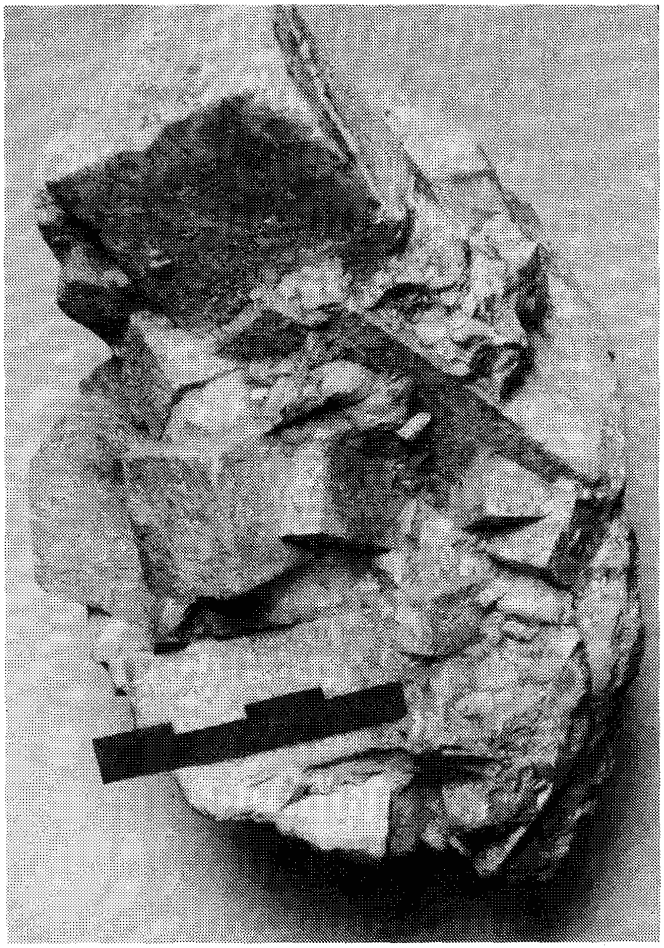

Figure 2. Cluster of andalusite crystals largely altered to kyanite. Milky quartz occurs between some of the crystals. Scale is 4 inches (photograph by T.M. Gathright, II).

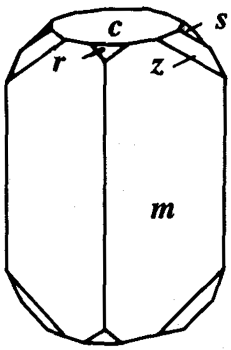

Figure 3. Idealized andalusite crystal habit showing crystal forms described in the text.

prismatic faces.

The andalusite varies from grayish amber, to flesh red, to reddish brown, to dark brown. Fresh specimens have a conchoidal fracture, show cleavage parallel to *m*{110}, and are vitreous to greasy in luster. Although usually opaque, some crystals show areas that are translucent to transparent.

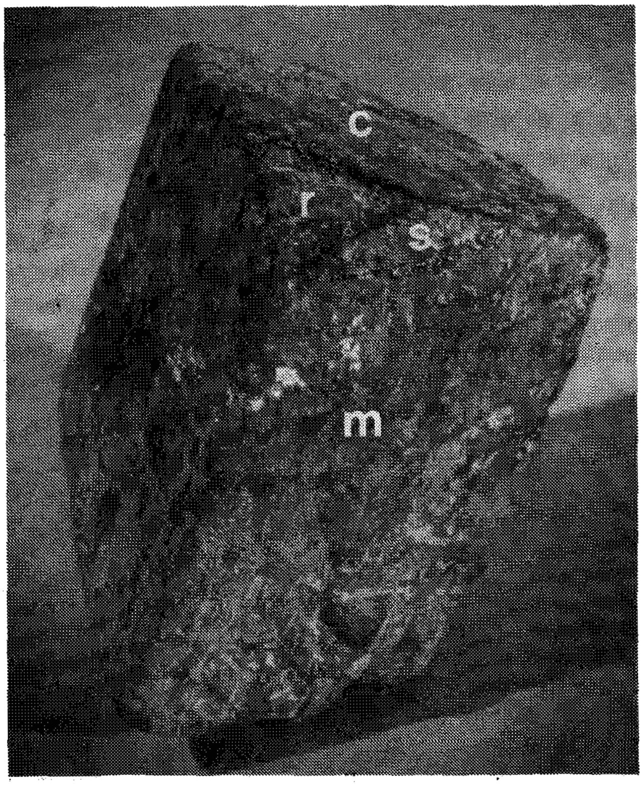

Figure 4. Andalusite crystal showing some of the less common crystal forms. Specimen is 2.3 inches along c-axis and 1.5 inches across prism face (m) (photograph by T.M. Gathright, II).

Figure 5. A small andalusite crystal approximately 0.5 inches across prism face and 2.5 inches along c-axis (photograph by T.M. Gathright, II).

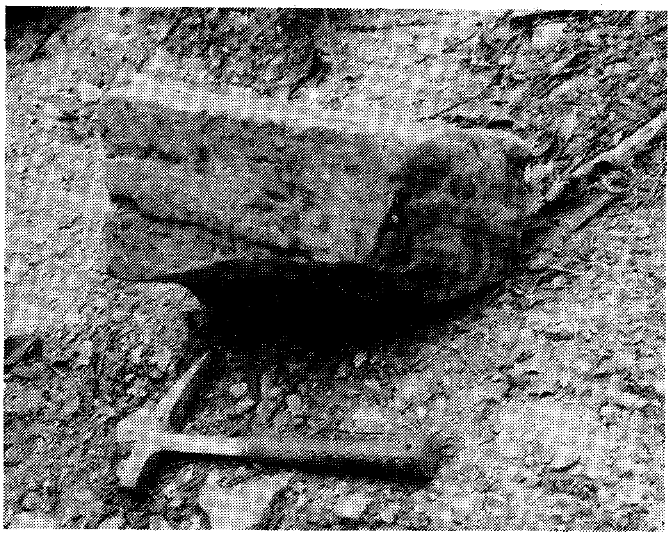

Figure 6. The largest crystal collected from the deposit (Virginia Division of Mineral Resources repository number - R-8947). The specimen is 12 inches along the c-axis and 7 inches across the prism face (photograph by W.F. Giannini).

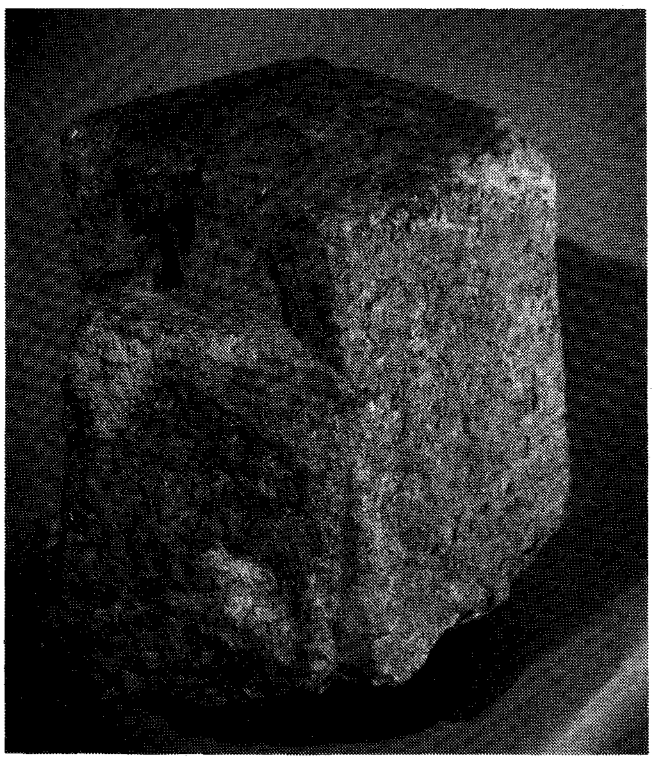

Figure 7. A large andalusite crystal, 4.25 inches across top pinacoid face (c), 6.0 inches along c-axis and mostly replaced by kyanite (photograph by T.M. Gathright, II).

The andalusite crystals are often coated with thin layers of a sericitic mica. Although this mica is commonly paragonite, in some instances it is muscovite. On other crystals an outer layer is muscovite, while paragonite is in direct contact with the andalusite. Some crystals freshly extracted from trenches have kaolinite in natural depressions on the faces.

The majority of the crystal specimens are now paramorphs of kyanite after andalusite, although unchanged andalusite crystals to 8.9 cm across have been noted. Some fresh andalusite crystals also contain much sillimanite, but a complete replacement by sillimanite has not been observed.

Many large clusters of andalusite, and paramorphs after andalusite, have accumulated at the ground surface. Clusters weighing up to approximately 150 pounds are common. The crystals have minor milky quartz between them and apparently formed at the quartz contact with the country rock. The presence of the sericitic layer between them and the quartz probably allowed them to easily pull away from their contact with quartz. The bases of the andalusite crystals are attached to a schist matrix, and some show a transitional zone between andalusite and the schist in both mineralogy and structure.

Although it is difficult to state beyond doubt that these crystals, both fresh and altered, are of record size for well-formed andalusite, this possibility exists. The authors have consulted both Clifford Frondel and Peter C. Rickwood, each of whom has published papers on mineral crystals of record size (Frondel, 1935; Rickwood, 1981); neither has knowledge of larger individual andalusite crystals. However, large andalusite crystals have been found in the United States in the past. Delaware County, Pennsylvania, has yielded crystals (some altered to kyanite) measuring 6 x 23 cm that are in groups weighing 60 pounds (Gordon, 1922). This occurrence was earlier reported by Dana (1868), who mentioned individual crystals weighing 7.5 pounds. Large andalusite crystals have also been collected from the Pink Lady claim northwest of Berne, South Dakota (Roberts and Rapp, 1965). Roberts (written communication, 1987) determined that the largest crystal, a broken piece, measures 11.4 cm across its widest prism face and is 15.2 cm long. A Hill City, South Dakota, locality yielded a crystal 3.8 x 21.6 cm; another occurrence, on the west side of U.S. Highway 385-16, near the Pennington-Custer County line between Hill City and Custer, South Dakota, yielded a crystal measuring 7.6 x 17.8 cm. It is apparent that larger ones from this deposit are known but have not been measured. Webb (1943) described large bundles of pink and white andalusite in a pegmatite in Riverside County, California. The bundles range from 5 to 12.7 cm in thickness and from 15.24 to 38 cm in length. In an earlier paper on this deposit, Funk (1940) reported crystals to 61 cm long. Although Webb was familiar with Funk's report, he revised the size downward.

KYANITE AND SILLIMANITE PARAMORPHS AFTER ANDALUSITE

Kyanite, very common in the deposit, is essentially limited to replaced andalusite crystals as paramorphs. It occurs as elongate bladed to prismatic crystals, closely crowded together. The individual crystals range from minute needles to distinct blades measuring about 0.3 to 0.5 cm wide and several centimeters long. Some specimens show an apparent crystallographic control of the kyanite orientation in which the long prisms (*c*-axis elongation) are nearly parallel to one another and are also parallel to the former *c* axis of the andalusite (Figure 8). However, even within specimens showing these relationships, there are also radiating, apparently randomly oriented blades. Other specimens show no obvious relationships between the orientation of the kyanite and andalusite (Figure 9). The kyanite varies from colorless to light blue. Some of the very fine-grained aggregates have a porcelaneous appearance, while the larger bladed material is vitreous to silky in luster.

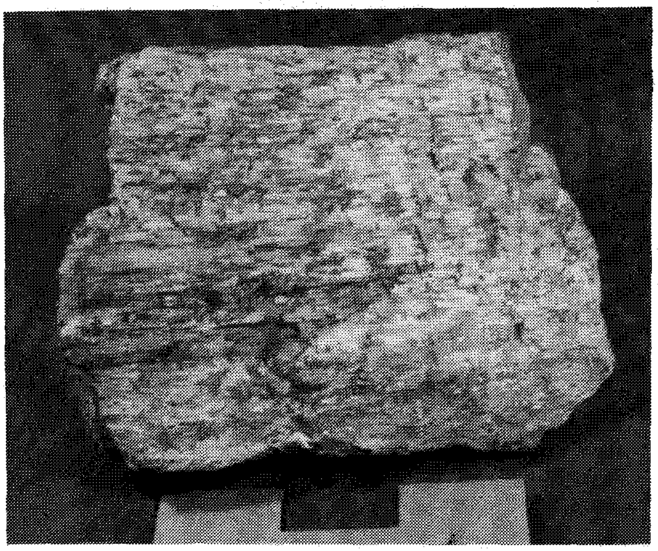

Figure 8. Coarse kyanite blades in the body of a former andalusite crystal (paramorph). Specimen is 4.5 inches long (photograph by T.M. Gathright, II).

Figure 9. Cluster of andalusite crystals, 10.0 inches across and 12 inches high, mosty replaced by kyanite (photograph by T.M. Gathright, II).

The kyanite occurs wholly within the body of the earlier large andalusite crystals. The andalusite typically appears to be completely converted to an aggregate of kyanite (commonly with paragonite); in some instances, however, remnants of andalusite occur. Some crystals show unaltered andalusite near the prism faces with interior zones of kyanite. Other specimens show zones of fibrous sillimanite associated with the kyanite within the paramorphs after andalusite.

Sillimanite, although less common than kyanite, occurs in some abundance at limited places along the strike of the deposit. It too has formed from the replacement of andalusite. The sillimanite occurs as extremely fine fibrous masses (the variety fibrolite), the fibers of which are nearly parallel (Figure 10). Although individual fibers are too small to be traced, fibrous zones over 10 cm long are common. The sillimanite fibers are typically parallel to the andalusite *c* axis. Some of these zones occur in unaltered andalusite where they have only replaced portions of the large andalusite crystals, or less commonly they are in kyanite paramorphs after andalusite. The sillimanite is light tan with an obvious woodlike structure (probably somewhat weathered), or is gray to blue with a compact porcelaneous luster, showing a fibrous structure under magnification. Although large massive pieces of the mineral were found, sharp paramorphs, with remnant andalusite faces, are rare.

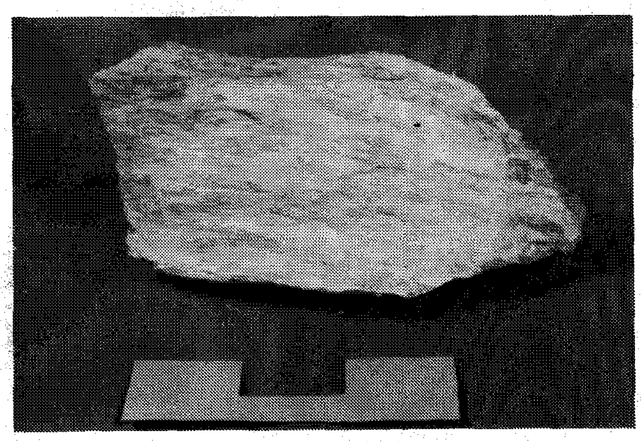

Figure 10. Fibrous sillmanite in the body of altered andalusite. Specimen is 4.5 inches long (photograph by T.M. Gathright, II).

Because andalusite, kyanite, and sillimanite have identical chemical compositions - Al_2OSiO_4 - but different crystal structures, they are said to be *polymorphs*. Theoretically, three different structures of one compound cannot form simultaneously in the same deposit unless they form within a very specific temperature and pressure environment termed an *invariant triple point*. This point, according to Holdaway (1971), is around 501° C and 3.76 kilobars. However, all evidence at this deposit indicates that these three minerals did not form at the same time, but in sequence.

Apparently, the original andalusite crystallized when the solutions from which quartz formed permeated the country rock (now schist, although it might have been any precursor pelitic rock). The country rock was the source of the aluminum that constitutes the andalusite. This thermal contact metamorphism apparently occurred at moderately low pressures and temperatures.

Both sillimanite and kyanite formed later as the environmental conditions changed. Sillimanite does not require high pressure, but it does appear to require higher temperatures than andalusite. Its occurrence as fibers within some of the large andalusite crystals indicates that the temperature increased after the andalusite formed. According to Deer et al. (1962), this transition is sluggish. There is also the possibility that the original andalusite formed close to the temperature transition boundary with sillimanite. Kyanite, on the other hand, generally forms in an environment of metamorphism involving high pressure, usually stress. The exact sequence of events is not clear, but it appears that after the andalusite crystals formed, higher temperatures initiated the formation of sillimanite; later, metamorphism with high stress (directed pressure) occurred, and much of the andalusite was converted to kyanite. Gates (1986) has recently studied the metamorphism of the schists in the Altavista area; his results are not summarized because the results were inconclusive.

The mutual occurrence of these three aluminum silicate minerals has been observed elsewhere. They occur together in a schist in Idaho, and Hietanen (1956) suggested that this resulted from a fluctuation of temperatures and stresses during complex regional and thermal metamorphism. Deer et al. (1962) discuss the possibility "that in such cases equilibrium has not been established and that one or more of these Al_2OSiO_4 minerals are present as metastable relics." Regarding the very large andalusite crystals from Delaware County, Pennsylvania, mentioned above, Wyckoff (1952) has observed that most are kyanite paramorphs. She suggests that stress has caused the conversion of the andalusite to kyanite, but she also says, "I would venture the hypothesis that the chemical nature of the circulating solutions — perhaps their content of alkalis or of 'acid' hyperfusibles such as HF or HCl — may determine the form in which Al_2OSiO_4 crystallizes."

OTHER MINERALS IN THE DEPOSIT

Chlorite, although relatively uncommon here, has been observed as micaceous aggregates and books (4 mm) as inclusions within unaltered andalusite. It occurs more commonly as plates (to 1 cm) in mica schist, adjacent to andalusite, where it is also associated with muscovite, paragonite, chloritoid, staurolite, and other minerals. The chlorite is grayish green with a pearly luster. X-ray diffraction studies indicate that it is in the clinochlore-chamosite series, possibly ferroan clinochlore, and has the IIb chlorite structure.

Chloritoid, a sporadic mineral in the deposit, occurs both within andalusite and its kyanite paramorphs, and also at the contact of andalusite with schist. This micaceous mineral is greenish black, somewhat brittle, and occurs as plates and grains ranging to 3 mm across. When weathered, it is earthy and dark brown due to alteration to goethite. Within the andalusite crystals it can occur as veins (to 4 mm wide) in which the plates are arranged perpendicular to the vein walls. It also occurs as spotty inclusions in the bases of some of the andalusite crystals where they are adjacent to schist. Segregations (to 8 cm across) of granular chloritoid were observed in association with large, fanned-out muscovite books. It also occurs as tiny metacrysts (resembling a phenocryst, but metamorphic (1 mm and less) in white, fine-grained muscovite schist.

Corundum is present as blue aggregates within andalusite crystals and in kyanite paramorphs after these crystals (Virginia Department of Mineral Resources #R-8948). It is rather common, especially at some places along the strike of the outcrop. The clusters of corundum grains, which measure to 2 cm across, are composed of individuals measuring a few millimeters across (usually 1 to 2 mm, but to 7 mm), most of which are of irregular shape. Some euhedral crystals occur that are hexagonal to trigonal prisms or tapering, somewhat rounded, dipyramidal crystals, rarely wider than 2 mm. When broken, the mineral shows the typical parting planes for the mineral as well as crisscrossing striations. Some of the corundum shows color zoning with gray to light blue centers passing to deep blue or nearly black-blue at the surfaces. Many of the crystals have a beautiful sapphire color, but unfortunately they are too small to be cut for gems. In nearly ever instance the corundum clusters are intimately associated with paragonite. There is commonly a thin but distinct paragonite halo that resembles talc separating each aggregate from the enclosing andalusite or kyanite.

The occurrence of blue corundum in andalusite has been noted elsewhere. It is associated with andalusite in Patrick County, Virginia (Genth, 1890), and occurs with mica as inclusions in andalusite in pegmatites in Riverside County, California (Webb, 1943), and in Yosemite National Park, California (Rose, 1957).

Garnet is relatively rare and not obvious. In some of the muscovite schist associated with the andalusite a few small brownish red, rounded subhedral crystals (about 1 mm to 2 mm) occur. With a unit cell size of a = 11.56 A, determined by X-ray diffraction, the mineral is apparently almandine. Some of these garnets are altered to porous goethite masses.

Hematite, although rather sporadic, occurs in several ways within the deposit. Metallic, black, single-crystal plates are rarely embedded in andalusite crystals, both fresh and altered, as well as in massive quartz. These plates vary from 1 mm in thickness to about 1 cm across. Similar platy crystals more frequently occur in some of the associated schist, although these are considerably smaller (often microscopic) in size.

Hematite, often mixed with magnetite, occurs as granular massive reddish to brownish black specimens that appear to have once been large tabular crystals. The largest of these measures 8 cm across and about 2 cm thick and has planar surfaces where it is embedded in quartz and schist closely associated with andalusite. These granular masses appear to have once been large, single, tabular hematite crystals. There is a possibility that the environment that brought about the alteration of the andalusite to kyanite also granulated this original hematite. Tiny euhedral magnetite crystals (including martite) occur on the surfaces of some of these massive pieces.

Pseudomorphs of hematite after magnetite (martite), about 2 mm across, are common in some of the mica schist associated with this deposit. These have a subhedral octahedral shape but are soft and easily powdered to yield a brownish red earth.

Magnetite occurs with some of the hematite. Some of the large granular platy masses just described, that might at one time have been hematite crystals, are now composed of granular magnetite containing only minor hematite. The mica schist at the deposit occasionally contains magnetite metacrysts ranging from 1 to 2 mm across. Although some of these crystals are sharp octahedrons, most are distorted or have an etched appearance.

Muscovite is closely associated with the andalusite crystals. It occurs as fanned-out, radiating plates (to 5.5 cm across) with crested terminations, if open space allows euhedral faces. In one instance, single-crystal muscovite sheets are parallel to and cover each of the four prism faces of a relatively small andalusite crystal. The muscovite, vitreous and clear to light grayish, is not abundant in the deposit. Muscovite also may occur as an extremely fine-grained sericite on andalusite crystal surfaces. However, this fine-grained mica is more commonly paragonite. Likewise, muscovite is the usual white mica of the schist associated with the deposit. It also may form pseudomorphs after staurolite crystals in this schist. Paragonite is an abundant mica intimately associated with the andalusite and its altered crystals. Unfortunately, one cannot distinguish it easily from muscovite without specific tests, especially X-ray diffraction. As just mentioned, most of the thin sericitic coatings on the surfaces of the fresh and altered andalusite crystals are paragonite. These are typically about 0.5 mm thick and have micaceous plates arranged perpendicular to the andalusite crystal surfaces so they appear fibrous. This white mineral is soft and talc-like in appearance.

Paragonite is intimately associated with kyanite throughout the body of the paramorphs. Dietrich (1956) also has found that paragonite is intimately associated with kyanite in altered andalusite at another locality in the same region. Where there are corundum inclusions, both in fresh and altered andalusite, paragonite forms distinctive aureoles around the corundum and is intimately intermixed with the corundum aggregates. Individual grains of paragonite here are white, pearly, soft and talc-like, and measure about 0.5 mm across.

Small crystals (7 mm across) of andalusite recovered from one of the trenches were almost completely replaced by fine-grained paragonite, with only traces of kyanite.

Although most of the schist in the vicinity of the andalusite deposit is composed of muscovite, there are some extremely fine-grained, somewhat silky zones, composed of paragonite. Paragonite has also replaced some of the staurolite crystals in the associated muscovite schist. In other instances, however, these are replaced by muscovite, or more rarely kyanite.

The abundance of paragonite (a sodium-rich mica) indicates that sodium was introduced into the deposit either nearly contemporaneous with or subsequent to the formation of andalusite.

Quartz at this locality is somewhat limited in its occurrence, although float quartz, along the general strike of the deposit defines the extent of the deposit rather well. Except for remnants of milky quartz that may occur between some of the large fresh or altered andalusite crystals, it generally is not intimately associated with the other minerals of the locality. It ranges from massive or saccharoidal nearly opaque milky types to rarer transparent varieties with opalescent or smoky zones. No quartz crystals were observed. The opalescent variety is an excellent stone for faceting.

Rutile, as light brown, sparkling, adamantine aggregates (fraction of millimeters across) of minute crystals, occurs with chloritoid in the bases of some of the andalusite crystals. Most of the rutile is at the centers of these chloritoid aggregates that occur in the andalusite as dark, pockmark-like inclusions about 2 mm across.

Staurolite, an abundant mineral in the schists at the site, is not directly related to the andalusite deposit. The writers' attention was originally directed to the andalusite by noting staurolite that had a frosted altered appearance in the vicinity. However, similar staurolite specimens also rarely occur at considerable distances from the andalusite. The frosted feature is due to the alteration of staurolite to either muscovite, paragonite, or more rarely kyanite. Some of the staurolite specimens are only partially altered to one of these minerals. One specimen of unaltered staurolite projecting into vein quartz was separated from the quartz by a thin sillimanite zone. Most of the staurolite at the deposit is in a fine- to medium-grained muscovite schist. Fresh staurolite here is dark brown to brownish black and occurs singly or very commonly as X-shaped twins. Twins that are +-shaped are relatively rare. Individual prisms usually range from 0.5 to 2 cm long, but altered crystals as long as 5 cm have been observed.

Tourmaline occurs as microscopic crystals in some of the schist that is closely associated with the andalusite. The brown, clear to vitreous, tiny euhedral, somewhat stubby prisms (0.2 to 1 mm long) are embedded in muscovite. Although an exact identification of the species was not made, X-ray data are close to the schorl-dravite series.

MINERALS FORMED BY WEATHERING

Florencite was observed on one specimen of andalusite as a thin, buff-colored, botryoidal coating. X-ray diffraction data showed the mineral to be in the crandallite group, and qualitative X-ray fluorescence indicated that Ce, La, Nd, Ca, and Ba are important constituents (Fordham, personal communication, 1987). Further work is needed to characterize the mineral more exactly.

Gibbsite occurs as sparse secondary crusts on the surfaces of some specimens. The crusts are less than 1 mm thick and range to 3 cm across. They are waxy, light yellowish orange and have irregular surfaces that are somewhat botryoidal in nature.

Other secondary minerals occur in the deposit. *Goethite*, especially in altered chloritoid and garnet, was observed. *Kaolinite* is a common secondary mineral coating andalusite that was uncovered during trenching operations. It also is a component of the soil that overlies the area. *Illite* likewise is an important constituent of the soil at the deposit. *Metahalloysite* (7Å-halloysite) occurs as reddish brown earthy coatings on andalusite crystals.

GEOLOGIC SETTING

The Precambrian schist in which the vein quartz and its associated andalusite occur has been assigned diverse formational names and is still a topic of argument. The schist was once considered to be equivalent to the Wissahickon Formation (Furcron, 1935; Stose, 1928) that occurs in Maryland and

Pennsylvania. It should be noted that the large andalusite crystals mentioned above from Delaware County, Pennsylvania, are in the Wissahickon. Later, Espenshade (1954), Redden (1963), and Gates (1986) assigned Evington Group names to rocks in the Altavista area. More recently, Conley (personal communication, 1987) has suggested that rocks here are equivalent to Precambrian schists exposed in Franklin County, Virginia, that have been named informally the Fork Mountain Formation (Conley and Henika, 1973).

In the area around the andalusite deposit, the rock is a silvery white to gray (often stained light brown), fine- to medium-grained muscovite schist typically with conspicuous dark brown staurolite metacrysts, many of which are replaced by muscovite (sericite) or paragonite. Other minerals, such as garnet, are less common. Thin sections show that some of the schist is nearly quartz-free, while other specimens are fine-grained mixtures of muscovite and quartz; tiny hematite plates and minute tourmaline crystals are also common. As mentioned above, the nature of the schist differs considerably where it is in direct contact with the andalusite and quartz deposit; it is here that chloritoid, chlorite, sillimanite, kyanite, and many of the other minerals described above occur.

The andalusite-rich material is situated in a relatively level, long-time forested area that recently was cleared of trees. At the surface there are both large and small masses of rock composed entirely of andalusite crystals and their related minerals. Although the minerals are relatively resistant to weathering, the crystal faces long exposed to the atmosphere are generally etched. The trend of this zone of andalusite-quartz residuum is slightly east of north, and the zone extends for a distance of over 280 feet. From the distribution of surface materials, it was originally assumed that the quartz vein was at least 10 feet wide. In an attempt to determine more about the vein, six trenches were cut through the deposit. From this it has been concluded that instead of a single quartz vein, the deposit consists of quartz veins *en echelon*, perhaps an original vein that has undergone displacement. Trenching also showed that the quartz veins range from 1.5 to 3 feet wide with zones of andalusite from 1 to 3 feet wide, typically on each side. The veins dip from between 75° to 80° SE. The prismatic andalusite crystals are either at an angle to or nearly parallel to the quartz, and most of their bases generally are anchored in altered schist.

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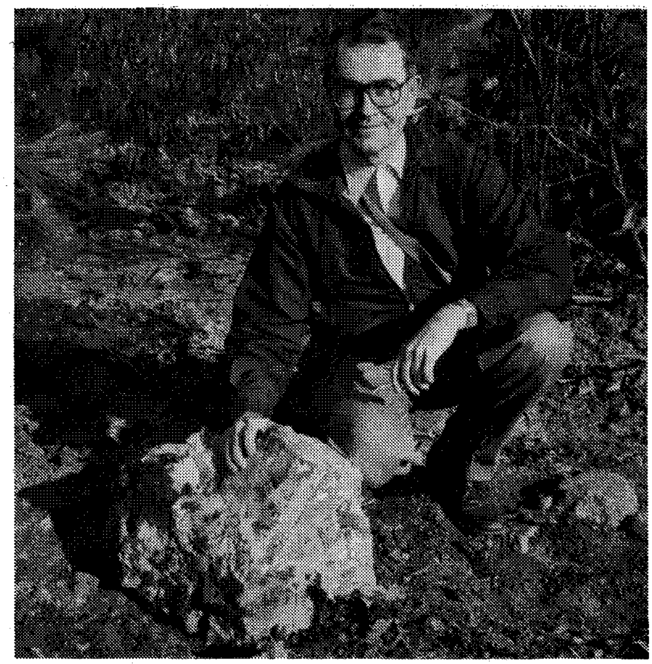
The writers wish to express their appreciation to Donal (now deceased) and Nancy Dinwiddie (associated with the Avoca Museum at Altavista, Virginia) and to Dr. Mary Dearing Lewis for their help and encouragement in this study. The Dinwiddies' knowledge of staurolite in the area led us to the discovery of the deposit. We are also grateful to David Woolley, District geologist with the Virginia Department of Transportation (Lynchburg District), who coordinated the use of the backhoe; and to Roy Owen East, backhoe operator — also with the Department of Highways and Transportation (Yellow Branch Office) — for his expertise in the field. Our appreciation goes to Oliver M. Fordham, Jr., formerly of the Division of Mineral Resources, for chemical analyses of the florencite; and to T. M. Gathright, II, also of the Division of Mineral Resources, for taking some of the photographs. Our gratitude is extended to Prof. Lance E. Kearns, James Madison University, who shared with us some of the unusual specimens he collected at the deposit; and to Dr. Robert C. Milici, former State Geologist of Virginia, for his support and assistance with the project.



Richard S. Mitchell (deceased) with a large cluster of andalusite crystals (photograph by W.F. Giannini).

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