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ON THE MINERAL

DUMORTIERITE



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## FOREWORD

This is the first of a series of bulletins to be issued by the Mackay School of Mines on live subjects of interest to the industry.

The bulletin is made up of articles by members of the school staff, each member contributing the portion which naturally falls in his department.

Our acknowledgment and thanks are due the following persons for information and specimens supplied:

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# THE MINERALOGY OF DUMORTIERITE

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## HISTORY AND OCCURRENCE

The history of dumortierite as a distinct mineral species dates back to November 13, 1879, when Ferdinand Gonnard (16)<sup>1</sup> checking up some of the mineralogic and petrographic observations of A. Drian in the vicinity of Lyon, France, chanced to see a beautiful fibrous blue mineral adhering to the feldspar of one of the gneissic blocks among a pile of stones used in repairing the road near Beaunan. At the time he thought that the mineral might be cyanite and made no attempt to collect more material or to trace it to its source. Later he submitted his small amount of material to Bertrand for determination. The intense pleochroism and other optical properties convinced Bertrand that this mineral was unlike any known and in his note of 1880 (1) he pronounced it a new species. This is the first published article on dumortierite. With the encouragement of having found something new, Gonnard (16) returned to the original locality and collected material which furnished the basis of his paper of 1881 in which he named the mineral dumortierite in honor of the Lyon palaeontologist, Eugène Dumortier. Gonnard's article was accompanied by Damour's (6) giving a chemical analysis and formula for the new mineral.

In the years which have followed the discovery of dumortierite, the mineral has been observed in many localities of world-wide distribution. It usually occurs in minor amounts as acicular, often radiating or fanlike inclusions in minerals contained in pegmatite or quartz veins which cut acidic aluminous rocks and it occasionally occurs in separate aggregates and in larger quantities. At Beaunan, southwest of Lyon, France, Gonnard found it in a pegmatite which cuts cordierite gneiss and later found similar occurrences near Oullins (17) and along the road to Francheville near Brignais (18). Websky (49) was the first to report dumortierite outside of France. He found it in pegmatite with corundum in the Riesengebirge of German Silesia, at Wolfshau, west of Schmiedeberg. Similar occurrences have been observed in the gneiss near Weitenegg (19) and in Switzerland. From the southern margin of the Bergeller massif of the Swiss Alps, Hugi and Hirichi (21) have described an occurrence of dumortierite in a quartz, rich muscovite pegmatite, and Linck (30), much earlier, described a similar occurrence in the pegmatite of the lower Val Donbastone in Upper Veltlin. Other southern European occurrences are located in Czechoslovakia. Rosler (40) has observed dumortierite in the kaolinized products of decay of a muscovite biotite granite at several places in Bohemia, namely, at Imligau near Chodeau, at Schobrowitz, near Karlsbad, and at Oberbriss, near Pilsen. Kratochvíl (24) records another Bohemian locality, Pelhřimov, near Putimov, where the dumortierite occurs in an aplite dike traversing granite and gneiss and in which the small prismatic grains of dumortierite are accompanied by andalusite. In Moravia bluish green fibers and prismatic aggregates of dumortierite

<sup>1</sup>These numbers refer to the numbered articles in the bibliography.

accompany sillimanite in small pegmatite veinlets which traverse a sillimanite biotite gneiss at Vymyslice, near Moravský, Krumlov (39).

Northern as well as southern Europe contains minor amounts of dumortierite. It is a microscopic constituent of a pegmatite which cuts garnet mica gneiss and such basic rocks as peridotite, pyroxenite, gabbro, and others on the Kyshtymask estate in the Uvildy Lake district of the Russian Urals (25). Inclusions of dumortierite in the cordierite gneiss of southern Norway have been described by Michael Lévy and Lacroix (32, 26) from the vicinity of Bamle, Tvedestrand, Kragerö, and Arendal. Mackie (33) recently has recorded the occurrence of the mineral in the gneiss, granite, and pegmatite of four localities in Aberdeenshire and Banffshire, Scotland, and in the granite of Cornwall, England.

Anfoka, near Soavina, 25 kilometers north of Ambalofinandrahana, Madagascar, is the only African locality in which dumortierite is known to occur. According to Lacroix (27), the mineral is disseminated in quartzite which is accompanied by other quartzites containing lazulite. In view of all other occurrences, one wonders if Lacroix's quartzite may not be veins of granular replacement quartz.

In the South American Continent dumortierite has been found in Argentina and in Brazil. It occurs as an accessory mineral in granite at Potrero, Province of Catamarca, Argentina (38), and as fibrous aggregates in pegmatites at Rio de Janeiro (12, 37). Riman (37) records two occurrences of dumortierite near Rio de Janeiro, one in the suburb of Copacabana where two pegmatite dikes intrude a garnet cordierite gneiss; the other at Ipanema in the south slope of the Morro de Cantagallo where six pegmatite dikes, four of which contain dumortierite, cut cordierite sillimanite gneiss. Ferraz and Roccati (12) more recently have recorded the occurrence of dumortierite in the diamond bearing sands at Diamantina, Riacho de Varras, Candonga, and Cachorra de Paraima.

North American dumortierite has been found in one locality in Canada, one in Mexico, and in several in the United States. In 1921 brief mention was made of the presence of dumortierite in the N $\frac{1}{2}$ , Lot 31, 14th Concession of Ashby Township, near Bancroft, Ontario, where a pegmatite vein one foot wide intersects a gneiss (53). In a later paper Walker (48) described this occurrence more fully. The dumortierite is included in muscovite, quartz, and microcline and coats joints in the pegmatite itself. The Mexican dumortierite of the Sierra de Guadalcázar in the State of San Luis Potosí forms the basis of the papers by Wittich and Kratzert (51, 52). It is associated with topaz in quartz boulders which the authors believe to be derived from pegmatite veins cutting the granite laccolith at Realejo, four kilometers northwest of Guadalcázar, because the streams carrying the boulders have their source in this granite mass. The presence of dumortierite with such fluorine minerals as topaz and fluorite makes this occurrence very much like those in Brazil.

Seven of the United States contain dumortierite: Arizona, California, Colorado, Nevada, New Mexico, New York, and Washington. The intense blue color of the mineral at Harlem, New York, attracted the attention of mineral collectors early in the Nineteenth Century but, lacking petrographic microscopes, they classified it as the blue

variety of tourmaline, indicolite. It is so recorded in Webster's (50) catalogue of the minerals of New York State, published in 1824, and was so called until 1887 when Riggs (36) had occasion to examine a specimen of this indicolite. His analysis showed that although the mineral contained boron, its composition was quite different from that of tourmaline. A subsequent hasty examination by Diller also showed that the mineral was not tourmaline but it was left for E. S. Dana (7) to suggest that the mineral might be identical with Gonnard's dumortierite. Subsequent analyses by Whitfield (9, 10) and further examinations and comparisons with the French material by Diller (9, 10) proved the correctness of Dana's suggestion. The New York mineral occurs as prismatic needles and fibrous radiating tufts, included primarily in the feldspar, and sparingly scattered through a pegmatitic portion of a biotite gneiss. Chamberlain (4) wrote that as early as 1865 it was observed by S. C. H. Bailey at Kip's Bay, near the upper end of Riverside Park, many other localities within New York City, including those previously listed by Chamberlain (4) and Hovey (20), are given by Schaller (44).

Dumortierite specimens from Clip, Arizona, were described and analyzed by Diller and Whitfield (9, 10) in 1889. Later, material from this locality was analyzed by Ford (14, 15) and further studied by Schaller (43, 44, 45), who described the mineral as occurring only in loose boulders of quartz rock associated with cyanite, magnetite, and muscovite. Clip has passed out of existence. It is not to be found on modern maps of Arizona and no longer is it listed in the Postal Guide. Information regarding its location has been supplied by Dr. W. F. Foshag,<sup>1</sup> who writes that old atlases show the location of Clip to have been on the Colorado River, near the present camp of Cibola. The place also has been referred to as Clipper Gap. He continues: "This is very close to the landmark called Picacho Peak and the two dumortierite localities are probably identical. Rolled boulders are sent us from time to time from Ogilby and specimens of cyanite that are similar to the cyanite associated with the dumortierite are in our collections from the American Girl Mine about 10 miles north of Ogilby, and others from three miles north of Ogilby. There is perhaps a belt of dumortierite and cyanite rocks in this district." Specimens in the Mackay Museum also show a striking similarity between the Clip dumortierite and that from Imperial County, California, in the vicinity of Picacho Peak. It is likely that the boulders at Clip actually had their origin in California.

According to Dean G. M. Butler,<sup>1</sup> dumortierite occurs in two other localities in the State of Arizona. One is the Patagonia Mining District, 12 miles northeast of Nogales, the other is in the northern part of the State; not far south of Quartzite.

Barring the above explanation of the source of the Clip dumortierite, the California mineral was first mentioned by Ford (14, 15) as occurring in a quartz dike, 30-40 feet wide which cuts a biotite-granite a few miles east of Dehesa, San Diego County, California. According to Schaller (44) the upper part of this dike is a fine-grained, whitish, or grayish schistose quartz containing sillimanite, a little muscovite, and

<sup>1</sup>Personal communication to Director Fulton.

no dumortierite. Downward the dike loses its schistosity, becomes coarser and dumortierite appears. Both dumortierite and muscovite become more abundant with depth.

The University of California recently supplied us with a specimen of dumortierite obtained by Charles Anderson four miles northeast of Corona in Riverside County, and other California occurrences in Imperial County have been called to our attention by Dr. Jeffery and by Dean Butler,<sup>1</sup> who sent us a specimen obtained six miles northwest of Picacho Peak, but no geologic reports have been published concerning these deposits.

The only account of dumortierite in Colorado is that published by Findlay (13) in 1907. He found the mineral associated with corundum and sillimanite along Grape Creek, seven miles southwest of Canyon City, Fremont County, Colorado. The parent rock is a pegmatite dike 40-80 feet wide which cuts through an epidote schist.

At the headwaters of the North Fork of the Washougal River in Skamania County, Washington, small spherulites of fibrous dumortierite occur in a fine-grained mass of muscovite, andalusite, and quartz. Specimens from this locality were first described by Ford (14, 15) and later by Schaller (44). A similar occurrence of dumortierite in New Mexico has been noted by Schaller (45). A quartzose sericite rock in the Tres Hermanas mountains of Luna County, 12 miles northwest of Columbus, contains blue spherulites of dumortierite.

Dumortierite is known to occur at four places in Nevada. Jones (22) observed the pink variety in the sericite schists of the Rochester Mining District of Pershing County, but in his hasty examination mistook it for rubellite. Knopf (23) later called attention to this mistake and published the first account of dumortierite in the State. He described the dumortierite veinlets in the Triassic (Koipato) sericite schist on the west slope of Lincoln Hill in the Rochester District. This work was published in 1924. In the next year R. H. Rowland discovered that his claims in Pershing County, in the Humboldt mountains just north of the Rochester District, contained a large deposit of dumortierite. This deposit lies in Humboldt Queen Canyon (sometimes referred to as Limerick Canyon, which is really to the south), six miles east of Oreana. Rowland's claims were purchased by the Champion Porcelain Company of Detroit, Michigan (subsidiary of the Champion Spark Plug Company of Toledo, Ohio), in October, 1925, and development work was begun. The highest grade dumortierite has been shipped to the Porcelain Company's plant at Detroit, Michigan, and used in the manufacture of spark plug porcelain, thus making the Humboldt Queen deposit the only commercial occurrence of dumortierite in the world. Fairbanks (11) and Peck (35) have already described the mineralogical properties of this dumortierite and, since it is the primary purpose of this bulletin to discuss this deposit quite fully, there is no need of further discussion here.

Another known locality of dumortierite in Nevada is at the southern end of the Granite Range in Washoe County, approximately eight miles northwest of Gerlach. R. M. Oliver, who has recently visited the locality, describes the pink dumortierite as occurring in segregations in the granite associated with quartz and muscovite. The fourth locality

<sup>1</sup>Personal communications to Director Fulton.

in the State is Round Mountain in Nye County. The mineral is a beautiful sodalite blue and, according to H. S. Clinton,<sup>1</sup> it occurs in a quartz replacement within a granite mass. Neither of the latter deposits have been investigated and much work remains to be done.

## MINERALOGICAL PROPERTIES

### A. Crystallographic Properties

No very good crystals of dumortierite have been found. Practically all the crystal forms of the mineral have been determined by Schaller (44). His work is based on six incomplete prismatic specimens: two from Dehesa, California, one from Clip, Arizona, and three from New York City. Dumortierite is orthorhombic with the following axial ratios: 0.8897 : 1 : 0.6871.

The forms observed by Schaller are:

- a. macro pinacoid (100)
- b. brachy pinacoid (010)
- m. Unit prism (110)
- l. brachy prism (120)
- g. macro prism (320)
- n. macro prism (210)
- d. macro dome (102)
- v. macro dome (203)

Schaller detected several other forms but the faces were too minute to determine with certainty. Dumortierite crystals are often vertically striated on the prism faces due to repeated pseudo-hexagonal twinning according to the laws obeyed by cordierite and aragonite (44, 48). Further crystallographic data may be obtained from Schaller's publication.

### B. Physical Properties

*Color.* Most frequently some kind of blue variously described as cobalt, azure, ultramarine, lilac, or sodalite-blue. Weathered surfaces of this blue variety are often nearly black. Notable exceptions to the most common color are: the pistacite green dumortierite of the Val Donbastone (30) and of Brazil (37), the lavender of Riverside County and of San Diego County, California (44) and Nevada (11, 23, 35), the rose of Nevada (11, 23, 35), and Madagascar (27). When heated for a few seconds above 800° C the mineral becomes permanently grayish or white (6, 3).

The cause of the color of dumortierite has been subject to some speculation. Damour (6) suggested that the color might be due to titanium. Schaller (44) failed to get a titanium test by the hydrogen peroxide method from blue Washington dumortierite free from rutile and titanite, whereas the California lavender dumortierite contains about 1.5% Ti<sub>2</sub>O<sub>3</sub>. From this it would seem that the blue dumortierite contains no titanium replacing aluminum, whereas the red does. Lacroix (27) does not agree with this, finding titanium in both the rose and lilac dumortierite of Madagascar, but one does not know whether the titanium which gave the test occurred as rutile or titanite, or as a partial replacement of the aluminum. Peck (35) found practically no difference between the refractive indices of pink dumortierite and those of lavender and light blue crystals and thus ruled out Fairbanks's

<sup>1</sup>Clinton, H. G., personal communication.

(11) suggestion that there might be some relationship between titanium content, color, and refractive index. As pointed out by Peck, the dumortierite usually contains inclusions of rutile which indicate that the dumortierite has absorbed its full amount of titanium, and hence it probably forms a part of the molecule of both the pink and blue varieties. This conclusion is further borne out by the fact that Peck has discovered some veinlets of dumortierite which are blue near the walls and pink at the center. Jones has found a similar gradation in the Nevada dumortierite while Walker (48) observed that the centers of some dumortierite crystals have a different pleochroism from their exteriors. Peck suggested that perhaps the color may be due to the state of oxidation of the titanium. In blue dumortierite it may be present as  $Ti_2O_3$  and replace a part of the alumina, in pink dumortierite it may be oxidized to  $TiO_2$  and replace a part of the silica. As further pointed out by Peck, however, the color effects of iron, manganese, and small quantities of other elements must not be overlooked, and one must keep in mind that "the color of the mineral is a matter easier to speculate upon than to prove."

*Streak.* A light tint of the color, nearly white.

*Luster.* Vitreous to mat (dull).

*Diaphaneity.* Transparent to translucent on thin edges or in crystals, but massive material appears to be opaque.

*Structure.* Fanshaped radiating masses, fibrous, acicular, prismatic crystals, occurring in masses, in spherulitic aggregates and as inclusions.

*Cleavage.* Distinct parallel to macropinacoid (100). Indistinct parallel to prism (110). Indistinct parallel to brachy pinacoid (010).

*Cleavage Angles—*

$$110 \wedge 110 = 124^\circ \pm (9, 10). \quad 100 \wedge 110 = 152^\circ \pm (9, 10).$$

*Fracture.* At right angles to the c axis.

*Parting.* Imperfect parallel to basal pinacoid.

*Hardness.* 7.

*Tenacity.* Very tough in massive aggregates.

*Specific Gravity.* Maximum is 3.36. Average 3.30. Variations in recorded specific gravities are largely due to variations in purity of material.

*Fusion Point.* On being heated, dumortierite decomposes to mullite which fuses at  $1810^\circ C(3)$ .

*Dielectric Constants.* Fairbanks (11) has determined the dielectric constants of Nevada dumortierite and two other aluminum silicates:

Dumortierite (violet) Nevada.....	17
Dumortierite (red) Nevada.....	17
Andalusite (bluish) California.....	8
Andalusite (bluish) Tyrol.....	12
Cyanite (blue) Nevada.....	7-9

X - infinite. Error  $\pm 1$

### C. Optical Properties

Interference figure, Biaxial.

Optic sign, Negative.

Index of refraction—

Investigator	Ref.	Locality	$\alpha$	$\beta$	$\gamma$
Fairbanks .....	11	Nevada	1.677 <sub>Li</sub>		
Larsen .....	29	California	1.670 <sub>Na</sub>	1.691 <sub>Na</sub>	1.692 <sub>Na</sub>
Lévy-Lacroix .....	31	Norway	1.650	1.712	1.728
Linck .....	30	Switzerland	1.678 <sub>Na</sub>	1.686 <sub>Na</sub>	1.689 <sub>Na</sub>
Peck .....	35	Nevada (pink)	1.677 <sub>Na</sub>	1.685 <sub>Na</sub>	1.690 <sub>Na</sub>
Peck .....	35	Nevada (lavender)	1.675 <sub>Na</sub>	1.685 <sub>Na</sub>	1.690 <sub>Na</sub>
Peck .....	35	Nevada (light blue)	1.675 <sub>Na</sub>	1.685 <sub>Na</sub>	1.692 <sub>Na</sub>
Walker .....	48	Canada	1.659 <sub>Na</sub>	1.684 <sub>Na</sub>	1.686 <sub>Na</sub>

Error =  $\pm 0.003$

Birefringence ( $\gamma - \alpha$ ) = 0.010 to 0.027.

*Dispersion.* Strong but indeterminate.  $\rho > v$  (25, 26, 32, 35)  $\rho < v$  (1, 11, 27, 29, 44). Lacroix gives both  $\rho > v$  (26, 32) and  $\rho < v$  (27). In view of Schaller's (44) work  $\rho < v$  seems to be correct.

Apparent optic axial angle (2E).

California (44) .....	33° <sub>Li</sub> , 37° <sub>Na</sub> , 42° <sub>Cu</sub> .
Canada (48) .....	95° $\pm$ .
Mexico (51, 52) .....	50° $\pm$ .
Uvildy Lake (25) .....	Small.

True optic axial angle (2V).

Canada (48) .....	52° $\pm$ .
France (44) .....	35° <sub>Na</sub> to 40° <sub>Na</sub> .
Madagascar (27) .....	35°40' <sub>Na</sub> .
Nevada (35) .....	30°-40°.
Norway (26, 32) .....	35° $\pm$ <sub>Na</sub> .
Switzerland (30) .....	Less than that of muscovite.

*Pleochroism.* Strong.

Locality	Ref.	$\alpha$	$\beta$	$\gamma$
Bohemia .....	40	<div>           Deep blue            Reddish brown            Olive green            Deep carmine            Light olive green         </div>	Colorless	Colorless
Brazil .....	37	<div>           Light to dark blue            Violet            Dark wine red            Bluish green            Greenish yellow            Dark green            Greenish brown         </div>	Colorless	Colorless

Locality	Ref.	$\alpha$	$\beta$	$\gamma$
California	44	Reddish purple	Colorless	Colorless
Canada	48	<div> <div>Berlin blue</div> <div>Some crystals show green interiors</div> </div>	Colorless	Colorless
France (Brignais)	44	Rose-salmon	Colorless	Colorless
Mexico	51, 52	Blue	Lilac red	Colorless
Moravia	39	Dark blue	Yellowish	Colorless
Nevada	11, 35	Blue, reddish, violet, lavender	Colorless	Colorless
Switzerland	30	Pistachio green	Colorless	Colorless
Other localities	1, 19, 26, 27, 32	<div> <div>Cobalt blue</div> <div>Light blue</div> </div>	<div> <div>Straw color</div> <div>Pale yellow</div> <div>Colorless</div> </div>	Colorless

*Orientation.* Z || a, X || c, Y || b.

Acute bisectrix is perpendicular to c axis.

*Elongation.* Parallel to c.

*Inclusions.* Diller (9, 10) observed liquid inclusions and long tubular cavities in dumortierite. Rutile and titanite inclusions are also common.

*Pleochroic Haloes.* Observed by Lacroix about inclusions of dumortierite in the cordierite of Norway.

#### D. Chemical Properties

Infusible before the blowpipe.

Loses color on strong ignition.

Yields a blue color when heated with cobalt nitrate on charcoal before the blowpipe.

Renders a salt of phosphorous bead slightly bluish and opaline.

Insoluble in acid including cold hydrofluoric acid. Quite resistant to weathering and hence found among detrital products.

Many specimens when fused with sodium carbonate will give a test for titanium with hydrogen peroxide.

When intimately mixed with potassium bisulphate and calcium fluoride and introduced into a colorless flame, the green flame of boron may be obtained, but this is a very delicate test and may fail.

The behavior of dumortierite on heating at high temperatures was investigated by Bowen and Wyckoff (3) who found that the mineral quickly turns white at 800° C and slightly turbid at 950°. The refractive index is slightly lowered and after 10 minutes heating at 1200° the average index becomes 1.61, the elongation becomes positive and the product shows characteristic X-ray spectrum lines of mullite [Vernadsky (47) had stated earlier that the decomposition product is sillimanite]. After two hours heating at 1400°, dumortierite completely breaks down to mullite ( $3\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$ ) and probably silica and boric oxide. Boric oxide and water are completely expelled in 4.5 hours at 1500° at which temperature sintering begins. Liquid first appears at 1550° due to the melting of the eutectic between mullite and silica (1545°). For all practical purposes dumortierite at high temperatures behaves like a material containing only alumina and silica, nearly if not actually, in the proportion  $4\text{Al}_2\text{O}_3 \cdot 3\text{SiO}_2$ , the formula which Damour originally assigned to the mineral.

#### ASSOCIATIONS OF DUMORTIERITE

Dumortierite commonly occurs as fibrous acicular, and fan-shaped inclusions in other minerals, chiefly in quartz, muscovite, feldspar, and cordierite. Occasionally, as in Humboldt Queen Canyon, Pershing County, Nevada, it occurs in large masses, but even here much of it is included in the quartz and muscovite.

The important minerals associated with dumortierite are indicated in the following table. Usually some other aluminum mineral is present, as andalusite, corundum, cyanite, pyrophyllite, sillimanite, or topaz. The common boron associate is tourmaline. While feldspar occurs with dumortierite in many localities, it is notably absent in some as in Madagascar, Mexico, Arizona, California, Nevada, New Mexico, and Washington. In some localities biotite and cordierite are present, chiefly as constituents of the country rock. Quartz, however, is an invariable associate, and muscovite is usually present either as a primary mineral or as an alteration product. In some places dumortierite has entirely altered to muscovite (sericite, or damourite). For example, spherulites in the Washington and New Mexico deposits have been observed by Schaller (44, 45) to be altered entirely into muscovite, and the same investigator has also observed pseudomorphs of muscovite after dumortierite in the French material (44). Sulphides are not commonly found accompanying dumortierite, but pyrite does occur in a few localities. Other minerals found with dumortierite are usually present in very small amounts as inclusions or as alteration products. (See table on pp. 16 and 17.)

Those minerals which have been found with dumortierite but which are not listed in the table are:

Brazil, Copacabana: beryl, graphite, monazite, pinite.

Ipanema: monazite, pinite, spinel.

France, Rhône: chlorophyllite and fahlunite as alteration products of cordierite.

Germany, Wolfshau: chlorite.

Madagascar, Anfoka: lazulite.

Mexico, Guadalcázar: axinite, fluorite, hematite.

Norway, Tredestrand: spinel and wernerite as inclusions in cordierite; aspasiolite, esmarkite, polychroite, and praseolite as alteration products of cordierite.

Switzerland, Veltlin: chrysoberyl and chlorite as an alteration product of biotite.

United States—

New York, New York City: xenotime and monazite as inclusions in quartz, monazite in orthoclase, torbernite (?), and autunite (?).

Nevada, Granite Range: leucoxene.

Humboldt Queen Canyon: chlorite, leucoxene.

Washington, Skamania County: leucoxene.





## CHEMICAL ANALYSES

Fifteen chemical analyses of dumortierite from ten different localities have been published by ten analysts. The following compilation of these analyses shows that no two of the ten analysts quite agree on the composition of the mineral. The causes of disagreement are: (1) small amount of material available for analysis, (2) difficulty of obtaining material of requisite purity, (3) difficulties inherent in methods of analysis, (4) failure on the part of some analysts to detect all constituents present, (5) the probability of vicarious replacement of aluminum by boron, hydrogen, iron and titanium.

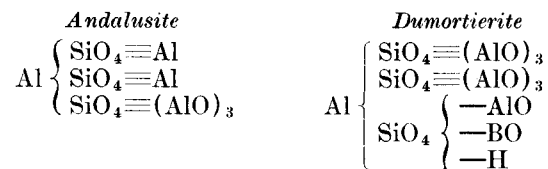
Dumortierite of all localities is so intimately associated with other minerals that material of sufficient purity for chemical analysis can be obtained only by employing special means of separation. Even then the material obtained may contain inclusions and therefore should be microscopically examined before it is analyzed. Often the amount of pure mineral obtainable is so small that considerable error is introduced in the analysis of the lesser constituent. Damour (6), in making the first analysis of dumortierite, introduced a method of purification which has since been used with modification by other analysts. Making use of the fact that dumortierite is not attacked by cold hydrofluoric acid while quartz and feldspar are, he treated his material with a mixture of hydrofluoric and sulfuric acids and obtained relatively pure dumortierite. This he further purified by drying, grinding and stirring in Thoulet's solution (potassium mercuric iodide). The dumortierite which sank in the solution was used for analysis. Ford (14, 15) reversed Damour's procedure. He crushed the mineral and first separated it from the lighter minerals by using Thoulet's solution and then barium mercuric iodide. Ford hand-picked the heavy concentrate and digested the selected material in cold hydrofluoric acid. Whitfield (9, 10) first used Klein's solution (cadmium borotungstate) and an electromagnet to get out the tourmaline but found the employment of Thoulet's solution and the digestion with hydrofluoric acid to be a better procedure. Schaller (42, 43, 44) used only heavy liquid separation but made a careful microscopic examination of the material to be analyzed. Todd (48) used Braun's solution (methylene iodide) as the separating medium.

According to Schaller (44), "an analysis of dumortierite is a difficult operation." He found (a) that the mineral must be fused with soda at least twice, (b) that the handling of large quantities of gelatinous aluminum hydroxide (plus those of iron and titanium) is cumbersome, (c) that a triple precipitation of the aluminum hydroxide is necessary, (d) that the Gooch method for the determination of boron is the best, providing all the known precautions are taken, (e) that the determination of water by ignition loss is not satisfactory.

Damour originally assigned the formula  $4\text{Al}_2\text{O}_3 \cdot 3\text{SiO}_2$  to dumortierite as a result of his analysis of Gonnard's material. He did not suspect the presence of boron. Subsequent spectroscopic analysis of a few hundredths of a gram of the French material indicated to Raoult (28) that the boron content of this material was much less than that obtained in American localities, but Ford (14, 15) had already pointed out that boron is not easily detected by qualitative tests. The difficulties involved in boron determinations are indicated by the wide range

of results on dumortierite from a single locality, Harlem, New York. Whitfield reported only a trace of boron; Riggs found 4.07%, but his material was not entirely free of tourmaline, while Ford found 6.14%. Similar discrepancies in the determination of the water content are illustrated by Ford's and Schaller's analyses of the Clip dumortierite. In the fifteen analyses only six indicate the presence of titanium, a few show an entire absence of iron, while other analyses indicating high percentages of calcium, magnesium, sodium, and potash show that the material analyzed was not pure.

Although admitting that titanium and iron may replace aluminum, Schaller (44) held that "it has not been proved that either boric acid and alumina or boric acid and hydroxyl may mutually replace each other in minerals as fluorine and hydroxyl are known to do. There is, then, no reason that the writer can see why the alumina, boric acid, and water in dumortierite should not be present in fixed quantities and that the variations shown in analyses are not due to isomorphous replacements, but to inaccuracy of analyses or impure material." Ford and others do not agree with this, but at the present time the formula for dumortierite which are considered best are Schaller's (44),  $8\text{Al}_2\text{O}_3 \cdot \text{B}_2\text{O}_3 \cdot 6\text{SiO}_2 \cdot \text{H}_2\text{O}$ , and Todd's (48),  $8\text{Al}_2\text{O}_3 \cdot \text{B}_2\text{O}_3 \cdot 7\text{SiO}_2 \cdot \text{H}_2\text{O}$ . These differ by only one molecule of  $\text{SiO}_2$ . Structurally Schaller has made his formula for dumortierite similar to that of andalusite:



# ANALYSES OF DUMORTIERITE

Locality	Analyst	Reference	SP.Gr.	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	FeO	Ti <sub>2</sub> O <sub>3</sub>	TiO <sub>2</sub>	B <sub>2</sub> O <sub>3</sub>	CaO	MgO	Na <sub>2</sub> O	K <sub>2</sub> O	P <sub>2</sub> O <sub>5</sub>	MnO	Ig. Loss	Total	Proposed formula
Argentina, Portrero	Jannasch	38	3.255	35.01	51.49	1.04			1.08	2.51	0.28	0.54	0.96	3.62			3.02	99.55	Impure
Canada, Ontario	Todd	48	3.309	30.46	60.80	1.08		0.08		5.37		0.77				0.11	1.32	99.99	8Al <sub>2</sub> O <sub>3</sub> .B <sub>2</sub> O <sub>3</sub> .7SiO <sub>2</sub> .H <sub>2</sub> O
France, Beaunay	Damour	6	3.36	29.85	66.02	1.01						0.45					2.25	99.58	4Al <sub>2</sub> O <sub>3</sub> .3SiO <sub>2</sub>
Madagascar, Anfoka	Raoult	27		30.34	61.24	0.71	0.29	0.59		5.00	0.36	0.18	0.18	0.05			1.29	100.23	(Al,B) <sub>8</sub> Si <sub>2</sub> O <sub>18</sub>
Switzerland, Veltlin	Schimpff	30	3.22	36.81	57.27					?	1.66	1.38					1.31	98.43	Impure
UNITED STATES:																			
Arizona, Clip	Ford	14, 15	3.319	29.86	63.56	0.23				5.26							1.41	100.32	(AlO) <sub>18</sub> (Al,B,H) <sub>4</sub> (SiO <sub>4</sub> ) <sub>7</sub>
	Whitfield	9, 10		27.99	64.49					4.94		Tr			0.20		1.72	99.34	3Al <sub>2</sub> Si <sub>2</sub> O <sub>18</sub> .AlB <sub>2</sub> O <sub>6</sub> .2H <sub>2</sub> O
	Whitfield	9, 10		31.52	63.66					2.62	Tr	0.52	0.37	0.11			1.34	100.14	Impure
California, San Diego County	Ford	14, 15	3.226	30.58	61.83	0.36				5.93							2.14	100.84	(AlO) <sub>18</sub> (Al,B,H) <sub>4</sub> (SiO <sub>4</sub> ) <sub>7</sub>
			3.43																
Nevada	Schaller	42, 43, 44		28.68	63.31	0.23		1.45		5.37							1.52	100.56	8Al <sub>2</sub> O <sub>3</sub> .B <sub>2</sub> O <sub>3</sub> .H <sub>2</sub> O.6SiO <sub>2</sub>
	Peck	35		37.05	55.01				0.63	4.65	All	others	2.66				Loss free basis		
New York, Harlem	Ford	14, 15	3.211	31.24	61.26	0.10				6.14							2.09	100.83	Impure material
			3.302																
	Riggs	36		34.82	55.30					4.07		0.57	1.72	1.04			2.96	100.52	(Na,K) <sub>7</sub> O.10Al <sub>2</sub> O <sub>3</sub> .B <sub>2</sub> O <sub>3</sub> .10(SiO <sub>2</sub> ).3HO <sub>2</sub>
	Whitfield	9, 10		31.44	68.91					Tr								100.35	
Washington, Skamania County	Schaller	42, 43, 44		28.51	59.75	2.48			0.95	5.54	0.68						2.12	100.03	Impure

## THE GEOLOGY OF THE DEPOSIT OF DUMORTIERITE IN HUMBOLDT QUEEN CANYON, PERSHING COUNTY, NEVADA

### GENERAL GEOLOGY

By J C. JONES

*Professor of Geology and Mineralogy, Mackay School of Mines*

While dumortierite is a rare mineral, yet it has been found practically the world over associated with granites, pegmatite dikes, high temperature quartz veins, and contact metamorphic deposits. With the recent discovery that an addition of dumortierite makes an unusually tough and valuable porcelain the search for suitable deposits has been stimulated. It is essential, aside from a sufficient quantity and accessibility, that a deposit be practically free from quartz and other associated minerals, though such minerals as andalusite and muscovite can be tolerated in considerable amounts.

At present only one suitable deposit has been found, the deposit on the west slope of the Humboldt Range near Oreana, Nevada, owned and operated by the Champion Porcelain Company, of Detroit, Michigan. The chief geological problems suggested in a study of this deposit are the determination of the mode of occurrence and origin that determines the suitability of the dumortierite of this locality in contrast to the unsuitability of other known occurrences of the desired mineral.

Summarizing the results of the present study, it may be stated that the dumortierite used from this locality is won from lenticular masses occurring in zones formed by solutions originating in a granitic magma that intruded the region. While dumortierite also occurs in quartz veins as in other known localities, yet the lenticular masses originated through the replacement of pre-existing lenses of andalusite formed during an earlier stage in the metamorphism of the rocks by the granitic magma. During the period of replacement of the andalusite little quartz was deposited, the quartz-dumortierite veins forming later. Thus the lenses contain only the tolerated minerals and can be utilized, while the veins are worthless.

The deposit operated by the Champion Porcelain Company is located six miles due east of Oreana, Nevada, a station on the transcontinental line of the Southern Pacific railroad. The area is just beyond the northwest corner of the geologic map (23, plate 1)<sup>1</sup> of the Rochester District and about three and a half miles northwest of Lower Rochester. The deposit lies near the head of a small canyon locally known as Humboldt Queen Canyon located between Limerick Canyon to the south and Sacramento Canyon to the north. On the map of the Fortieth Parallel Survey<sup>2</sup> Limerick Canyon is designated as Sacramento Canyon, but at present the large canyon two miles north is known as Sacramento Canyon.

The geology of the Humboldt Range has been well summarized by Knopf (23) in a description of the geology of the Rochester District.

<sup>1</sup>The numbers refer to the articles listed in the Bibliography.

<sup>2</sup>Wing, Clarence. Geol. Surv. 40th Par. Atlas, Map V, east half.

The Humboldt Range is largely composed of a thick series of lavas, volcanic tuffs and breccias in part interbedded with sediments chiefly limestones, shales, and sandstones of middle and upper Triassic age. As the igneous rocks largely lie below the sediments the Fortieth Parallel Survey<sup>1</sup> separated the Triassic rocks into two groups, naming the lavas the Koipato, the sediments the Star Peak Formation. During the close of the Mesozoic Era these were intruded by granites and folded. In the Rochester District the structure is a broad anticline that pitches to the south. The rocks forming the western limb of the anticline have a general strike of N. 30 deg. W. and dip 30 deg. westerly. Accompanying the intrusion of the granitic rocks were heated solutions that introduced the ore and mineral deposits found in the Rochester District.

During the following geologic periods erosion was active denuding the mountain range and depositing the débris in the valleys. Towards the close of the Tertiary Era extensive faulting began to reelevate the mountains and continued to the present, as is evidenced by recent fault scarps at the base of the range and the steep walled canyons that notch the range. This latest movement has been accompanied at times by the outpouring of basaltic lavas.

The greater part of the rocks exposed in the Rochester District are Triassic lavas belonging to the Koipato group. Knopf (23, p. 23) estimates their thickness as between 10,000 and 15,000 feet. In Limerick Canyon the rocks are chiefly trachytes and keratophyres intruded by irregular areas of aplite and dikes of granite porphyry.

The trachyte, as described by Knopf, comprises a series of lavas, tuffs, and volcanic breccias; light colored, felsitic, and usually containing inconspicuous phenocrysts of microcline only, although a few quartz phenocrysts occur in the upper layers of the series. While the lavas are usually massive, the tuffs and breccias are more or less schistose.

Near the head of Limerick Canyon an area of the trachyte was but little altered and Knopf found in a study of the darker colored rock that it had numerous slender phenocrysts of microcline in a sperulitic ground mass, the spherulites dusted with minute specks of iron oxide. In addition, minor amounts of apatite, titanite, and zircon were found. A small amount of secondary quartz occurred as veinlets and partial replacement of some of the microclines. A fresh specimen of this rock was analyzed by R. C. Wells (23, p. 16) with the following results:

SiO <sub>2</sub> .....	67.01%
Al <sub>2</sub> O <sub>3</sub> .....	15.97%
Fe <sub>2</sub> O <sub>3</sub> .....	2.54%
FeO .....	.44%
MgO .....	Trace
CaO .....	.19%
Na <sub>2</sub> O .....	1.92%
K <sub>2</sub> O .....	11.42%
H <sub>2</sub> O .....	.28%
TiO <sub>2</sub> .....	.39%
Total .....	100.16%

<sup>1</sup>U. S. Geol. Explor. 40th Par. Rept. vol. 1, p. 269, 1878.

The extremely high percentage of potash and relatively low percentage of silica indicates that the rock is a trachyte.

On the west slope of Lincoln Hill a considerable area of the trachyte has been profoundly altered and replaced by quartz, sericite, andalusite, and dumortierite. The underlying breccias strike N. 20 deg. W. and dip 25 deg. westerly. The dumortierite occurs as lavender to pink splotches in the schist and as a network of quartz-dumortierite veins. The original texture of the trachyte has been completely obliterated and the rock consists of the four minerals mentioned. Knopf (23, p. 19) believes the alteration of the trachyte is due to the action of gases containing boron that escaped from the underlying granitic magma as it cooled and solidified.

The keratophyres are dark colored tuffs, breccias, and lavas, with phenocrysts of albite, chlorite pseudomorphs after pyroxene, and some quartz. Due to metamorphism the keratophyres are largely schistose with an abundance of black tourmaline and biotite. The contact of the keratophyres and trachytes is somewhat uncertain as they are interbedded through a transition zone of from 500 feet to one thousand feet in thickness.

Three types of intrusive rocks were recognized, a meta-diorite of Triassic age, aplites and granite-porphyrries of post-Triassic age. The porphyries are believed to be responsible for the solutions that deposited the dumortierite and metalliferous veins.

The deposits of dumortierite in Humboldt Queen Canyon occur near the head of the canyon at an elevation of approximately 5,500 feet above sea level and about 1,000 feet above Oreana. The road from Oreana leads across the flat floored Humboldt Valley to the foot of the mountains, then rises rapidly due east through the steep-walled canyon. At the property of the Champion Porcelain Company, the canyon branches, the main canyon turning south, with a branch to the north and a minor saddle continuing east.

The dumortierite occurs in two parallel zones striking east of north and dipping west. The western zone, located at the fork of the canyon, is marked by a bold outcrop of massive quartz several hundred feet long, fifty feet wide, striking N. 20 deg. E., and dipping 55 deg. westerly. Little development work has been done upon it as yet. The eastern zone is about 600 feet east from the western zone and continues up the northern branch of the canyon. This zone is 75 feet wide, strikes N. 15 deg. E., dips 50 deg. W., and has furnished the bulk of the dumortierite obtained up to the present time. North and south of the saddle, the zone is marked by bold outcrops of massive quartz through which are numerous stringers and veins of quartz and dumortierite. At the saddle, however, the zone is inconspicuous and large boulders of nearly pure, massive dumortierite were found along and below the zone. The greater part of the production has come from these boulders and lenses found in and near the saddle. It is evident that the saddle has formed due to the somewhat softer character of the rocks in this portion of the zone.

The deposits have been explored by numerous open cuts and shallow tunnels in the zone as it crosses the saddle and by about 1,000 feet of work in the lower tunnel driven to intersect the zone at depth. The surface workings follow the zone up the gulch to the north and it is apparent that the masses of high grade dumortierite are most

abundant in an elongate area or shoot pitching about 35 deg. to the south. This shoot lies on the southern end or toe of the large outcrop of massive quartz to the north.

The lower tunnel cut the dumortierite zone about 160 feet from the portal and at 180 feet intersected a diabase dike that at the time seemed to be the footwall of the zone. The tunnel then was turned to the north and followed the dike for 300 feet. At this point it became apparent that the dike had crossed the zone at a low angle and a crosscut was driven east through the zone behind the dike. This crosscut is under the southern end of the massive quartz outcropping up the northern branch of the canyon. For the first few feet the crosscut is in altered schist that soon changes to massive quartz which continues for 75 feet to the schist that forms the footwall of the zone. While the massive quartz contains numerous stringers and small lenses of dumortierite, muscovite, and quartz, yet none of the large masses of pure dumortierite were encountered.

A second crosscut was then driven where the tunnel first encountered the dike and on breaking through, a large lense of dumortierite was found. This lense was spindle shaped and about 38 feet long, 15 feet high, and 7 feet wide, tapering at both ends. The longer axis pitched 35 deg. to the north lying across the general pitch of the shoot as disclosed in the surface openings. The lense lay on massive quartz with schist hanging walls and stringers of dumortierite leading from the lense. This seems to be the common mode of occurrence of the lenses found in place near the surface in the saddle.

The course of the diabase dike varies from N. 10 deg. W. in the southernmost exposure in the tunnel, then turns on an arc parallel to the zone for 125 feet, then again turns N. 10 deg. W. cutting across the zone. At the northern end of the tunnel the dike again turns a few degrees east of north and follows parallel to the zone. It is probable that the dike follows more or less closely the hanging wall of the massive quartz but not so closely but that occasional pockets of the softer altered schist and dumortierite lenses are included between the dike and the quartz as in the area where the recent mass of dumortierite was found. Unfortunately the surface is deeply covered with debris and the dike does not outcrop. The westerly dip of the dike varies from 45 deg. to 70 deg., and the width from 20 to 35 feet. As the dike has numerous apophyses cutting across the schistosity and the dumortierite veins and lenses it is evident that the dike was injected after the dumortierite had formed and that its approximate parallelism to the zone is due to the relative weakness of the zone offering a readier avenue of flow than the surrounding rocks.

## MEGASCOPIC MINERALOGY

By O. R. GRAW

The dumortierite in Humboldt Queen Canyon shows a diversity of characteristics because of its various modes of occurrence. These may be classified as three main types:

(1) Nearly pure dumortierite of shipping grade, occurring in lenses within sericite schist and as residual surface boulders in the alluvium above the schist.

(2) Dumortierite in veins and stringers cutting quartz or as fibrous inclusions in the quartz.

(3) Dumortierite in veins and stringers in sericite schist or as fibrous inclusions in the sericite.

For practical purposes it may be feasible to further subdivide classes 2 and 3 in accordance with the specific manner of occurrence of the dumortierite, its associations and abundance.

No regular arrangement of dumortierite is apparent in the quartz. It fills fractures in the quartz and quartz fills fractures in the dumortierite. Much of the dumortierite is included in the quartz as fine, inseparable hair-like fibers which give their color to the gangue material. Andalusite is associated with dumortierite and quartz in such an intimate way that very often the andalusite can only be distinguished from the quartz with the aid of a microscope. Mica is a minor associate in this mode of occurrence except where this mode of occurrence grades into the third type.

Mica and dumortierite occur together in a variety of ways. Granular intergrowths of the two range from a microscopic texture to that containing grains of granular aggregates up to a half centimeter in diameter. In many instances dumortierite veins cut the sericite, in others dumortierite apparently has replaced the sericite along the planes of schistosity, producing an interlamination of dumortierite and sericite. Where subsequent movement has taken place the two have been crenulated and compressed together so that the rock takes on a talc-like appearance. Dumortierite also is found intimately mixed with a matrix of sericite, quartz, and andalusite and as fibrous inclusions in the mica, coloring the mica as it does the quartz. Pyrite is a rare associate but is found with dumortierite in the schist.

From the pure mineralogical standpoint it was considered best to select four type specimens of the purest dumortierite and describe them. In general this dumortierite is like previously described material showing a wide range of colors from intense blue to deep pinkish lilac. The luster of the massive material is mat or dull and the streak is nearly white. The hardness is between 6 and 7 and the massive material is very tough due, no doubt, to the close intergrowth of many fibers. An aggregate of transparent prismatic crystals without terminal faces was observed in the schist but, because of their incompleteness, these crystals were not studied in detail. They are dull violet blue and match best the Ridgway color 53 V-B. Other properties of dumortierite from the vicinity of Humboldt Queen Canyon have been described by Fairbanks (11) and by Peck (35).

In the following table certain variable properties of the selected dumortierite specimens are tabulated together with analyses of the

material as determined by C. W. Davis of the Rare and Precious Metals Experiment Station of the U. S. Bureau of Mines.

The colors of the hand specimens were determined by comparing the samples with the Ridgway color chart. No tint photometer readings could be made because of lack of suitable material in pieces large enough for the purpose. The streaks were determined both by comparison with the Ridgway chart and by analysis by means of the Ives Tint Photometer according to the method described by the distributors of the instrument and according to the suggestions made by the present writer (Science, n. s., Vol. LXVI, pp. 61, 62, 1927). Material for the determination of the streak was prepared by grinding selected fragments of the mineral in an agate mortar to pass a 1/16 mm. screen. This fine powder was poured on a piece of cardboard approximately 4 square inches in area and rolled smooth under a four kilogram weight, a second piece of cardboard being inserted between the weight and the material during the rolling. This insured a uniform compactness to all specimens analyzed. The cardboard covered by the compressed powder was then placed on the magnesia block of the photometer and color readings were taken in the usual way. The readings tabulated are the mean of five. Specific gravity determinations recorded in the table represent the average Jolly balance determinations of five samples of each specimen.

Davis analyzed three specimens of the dumortierite described above. The material was ground to pass a 200 mesh screen and, in accordance with instructions, no attempt was made to purify it. The general method of analysis was that for silicate rocks outlined by W. F. Hillebrand (U. S. Geol. Survey Bull. 700, 1919) but modified to take into account the precautions of Schaller (44). Titanium was determined colorimetrically, boron according to the Gouch-Low method as modified by Chapin (J. Am. Chem. Soc. Vol. 30, pp. 1691-1701, 1908), and the alkalis were determined by the J. Lawrence Smith method.

From the chemical analyses the theoretical mineral compositions of the analyzed materials were calculated. These computations are based on the minerals observed by Jones in his study of the thin sections of the material analyzed. The following assumptions were made:

- (1) That all the  $K_2O$  is contained in muscovite ( $Al_3KH_2Si_3O_{12}$ ), av. sp. gr. 2.85.
- (2) That all the  $Na_2O$  is contained in paragonite ( $Al_3NaH_2Si_3O_{12}$ ), av. sp. gr. 2.90.
- (3) That all the  $B_2O_3$ ,  $Ti_2O_3$  and  $Fe_2O_3$  is contained in dumortierite, av. sp. gr. 3.30.
- (4) That all  $Al_2O_3$  in excess of that needed to form micas and dumortierite produced andalusite ( $Al_2SiO_5$ ), av. sp. gr. 3.18.
- (5) That all excess  $SiO_2$  formed quartz ( $SiO_2$ ), av. sp. gr. 2.65.

No account was taken of the  $MgO$  which may form some colorless phlogopite. The calculated specific gravities are the sums of average specific gravities of the theoretical minerals weighted according to their abundance.

The first set of mineral analyses is based on Schaller's formula for dumortierite,  $8Al_2O_3 \cdot B_2O_3 \cdot H_2O \cdot 0.6SiO_2$ , in which titanium and iron may replace aluminum. The results based on this formula are at fault because the calculated percentage of andalusite for specimen 1 is far

greater than that actually observed in the thin section, which shows only 1-2% of andalusite. The per cent of dumortierite is too low. The most serious objection, however, is apparent in the analyses of specimens 2 and 3. Here there is a notable excess of boron, an excess sufficient to make itself apparent in the thin sections in some mineral other than dumortierite, but such a mineral was not observed by Jones. Calculations based on Todd's formula,  $8Al_2O_3 \cdot B_2O_3 \cdot H_2O \cdot 0.7SiO_2$ , lead to similar results. For specimen 1 the following mineral composition was determined:

Muscovite .....	6.45%
Paragonite .....	2.72%
Dumortierite .....	59.96%
Andalusite .....	12.51%
Quartz .....	13.01%
Total .....	94.65%

Sp. gr. 2.99

Since these computations did not agree very well with the microscopic study, other computations were made based on Ford's formula,  $(AlO)_{16}(Al,B,H)_4(SiO_4)_7$ , which makes allowance for the possible replacement of aluminum by boron and hydrogen, and of course the replacement of aluminum by titanium and iron is not ruled out. This formula has the advantage that all the boron can be calculated as being in dumortierite. Further, much more of the water can be calculated as combined in the known minerals. The per cent of dumortierite is increased in specimen 1 and not notably changed in the other two. While the calculation shows the absence of andalusite whereas the mineral is actually known to be present, the error made is smaller in this case than in those based on the formula of Todd and of Schaller. Moreover, if Schaller is correct in saying that the determination of water by the ignition loss method yields high results, then it is possible by reducing the water content to have  $Al_2O_3$  in excess of that required by the Ford formula and such  $Al_2O_3$  could be calculated as andalusite. The calculated specific gravities are not notably different, those based on Ford's formula being slightly better. The total mineral compositions as calculated on the basis of Ford's formula for dumortierite are also better than those based on the formulas of Todd and of Schaller.

In summary, then, it may be stated that the mineral composition of the specimens of dumortierite as computed from chemical analyses agree best with observed facts when the percentage mineral composition is based on Ford's formula for dumortierite.

## ANALYSES OF DUMORTIERITE FROM GYPSY QUEEN CANYON, NEVADA

Number of sample Color of hand specimen (Ridgway)	1 Tourmaline pink 67 <sup>a</sup> V-R b Pale rhodonite pink 71 <sup>a</sup> V-RR f	2 Light vinaceous purple 65 <sup>iii</sup> RR-V b Pale vinaceous lilac 69 <sup>iii</sup> RV-R f	3 Dark lavender 61 <sup>iii</sup> VR-V b Vinaceous lavender 65 <sup>iii</sup> RR-V f	4 Grayish violet-blue 53 <sup>a</sup> V-B1 Grayish lavender 57 <sup>iii</sup> VB-V f
Color of streak (Ridgway)	Red Yellow Green Blue violet Peacock blue	82.5 77.0 71.0 67.0 67.0	72.0 67.0 65.5 62.0 60.0 60.0	67.0 65.5 63.0 62.5 62.0
Streak color as determined by the Ives Tint Photometer		26.86	36.30	39.01
Percent admixture of black as calculated from photometer readings		2.99	3.26	3.13
Specific gravity (Jolly Balance)		40.83 47.67 53.63 0.14 0.65 3.15 None 0.13 0.22 0.76 0.38 6.13	37.10 53.63 0.16 0.72 4.80 None 0.15 0.22 0.35 0.17 2.65	33.24 57.42 0.18 0.75 5.40 None 0.11 0.24 0.34 0.11 2.31
Chemical analysis Results in per cent				
Mineral analysis calculated from chemical analysis using Schaller's formula for dumortierite				
Results in per cent				
Calculated sp. gr.				
Mineral analysis calculated from chemical analysis using Ford's formula for dumortierite				
Results in per cent				
Calculated sp. gr.				

\*These analyses were made by C. W. Davis of the Rare and Precious Metals Experiment Station of the U. S. Bureau of Mines, Reno, Nevada.

## PETROGRAPHY

By J. C. JONES

A number of thin sections of the dumortierite and associated rocks were made and studied under the microscope. In the material analyzed by Davis and studied megascopically by Grawe the dumortierite occurs as a felt of minute, elongate crystals, one-quarter to one-half millimeters in length and one to fifteen microns in width. These are embedded in plates of muscovite up to a millimeter in diameter. A few minute crystals of rutile and titaniferous magnetite occur sparsely distributed through the felt. A small amount of iron stain occurs in splotches in the vicinity of the titaniferous minerals together with a little leucoxene. Occasional clear spaces are present, filled with fine grained quartz and sericite. The dumortierite crystals projecting from the felted ground mass into the clear spaces have rounded terminations that occasionally resemble low angled domes. Aside from the variation in the relative proportions of the minerals the only essential difference in the three specimens is that in the blue material the clear spaces contain crystals of topaz intergrown with quartz which are absent from the other specimens.

The second grade material offered a greater variety of minerals and gave a clew to the mode of origin of the deposits. Quartz occurs for the most part as areas of irregular outline or in mosaics of intimately intergrown crystals with irregular boundaries, a "jasperoid" structure typical of quartz that has replaced pre-existent minerals and rocks. In the veinlets, on the other hand, the quartz crystals are euhedral although there is no relationship between the orientation of the crystals and the walls or comb structure.

The dumortierite had four microscopic phases or modes of occurrence:

(1) As a felt of sheaves or rosettes of minute crystals as in the high grade material.

(2) As capillary crystals in and through the quartz, muscovite, and sericite. Sometimes these fine crystals of dumortierite were bunched as sheaves and rosettes or in brushes when they progressed from the matrix out into the veinlets of quartz, but for the most part they were irregularly arranged as spots and individual crystals in the ground-mass. One instance was noted where three lines of crystals were oriented parallel to the walls in a small quartz vein dividing it into four equal parts.

(3) Rarely as large crystals usually blue and violet in color in contrast to the usual lavender and pink shades of the finer crystals. Occasionally the large crystals had both blue and pink colors irregularly distributed in the same crystal.

(4) As powdery masses of submicroscopic particles dusting the quartz and muscovite crystals.

Muscovite occurred in large foils and plates frequently colored pink by capillary crystals of included dumortierite. Dumortierite occurred sometimes as fairly large flakes but for the most part as minute foils of sericite. There is the usual uncertainty that some of the sericite may be pyrophyllite but none of the latter mineral occurred in large enough crystals to be recognized in the hand specimens.



Andalusite was observed as large grains up to several millimeters in diameter and in all stages of replacement by the minerals mentioned previously. The replacement proceeded along the cleavage cracks or started in isolated areas within the crystals and progressed by stages. The preliminary stage was generally a granulation of the andalusite in which the borders of the crystals broke into a dusty aggregate of grains that extinguished in harmony with the unaltered crystal indicating that there had been no movement of the individual grains during the period of granulation. Then needles of dumortierite accompanied by sericite penetrate the granular mass eventually changing it to a mixture of dumortierite and muscovite as observed in the high grade material. Later quartz, sericite, and dumortierite were deposited in irregular patches and in veinlets replacing to some extent the earlier formed minerals. Finally quartz veins with a minor amount of dumortierite and sericite cut through the replaced mass as the last deposit from the solutions causing the alteration of the andalusite.

Minute grains of andalusite the same size as the granules in the granulated andalusite occur in the quartz and in a number of instances they were clearly dragged from the original borders of the large crystals by the solution as it deposited the quartz veinlets.

Small grains of rutile and titaniferous magnetite, with the accompanying oxidation products leucoxene and iron oxides, were scattered sporadically through the rock. A few instances were noted where pyrite had been deposited in altering andalusite along with the sericite, quartz and dumortierite.

A slide of the rock forming the hanging wall of the east dumortierite zone disclosed residual phenocrysts of microcline and rare quartz, a few grains of titanite, needles of tourmaline, and angular fragments of tuffaceous inclusions with spherulitic texture in a schistose groundmass of granular quartz and sericite. The rock corresponds closely to the trachyte as described by Knopf.

The footwall rock is somewhat darker in color and is essentially a quartz-sericite schist containing veins of quartz and black tourmaline. The microscope disclosed crystals of titaniferous magnetite and titanite with leucoxene, biotite foils and patches of chlorite, and outlines of feldspar crystals and tuff fragments replaced by a fine-grained aggregate of secondary quartz and sericite. No residual quartz phenocrysts were noted. The rock is similar to the keratophyres.

The rock in the face of the crosscut under the massive quartz is an altered quartz-sericite schist with a few quartz phenocrysts as the only representatives of the minerals in the original lava. Along the hanging wall of the diabase dike occasional thin streaks of dark colored schist occur which have quartz residuals and outlines of feldspars now completely replaced with a fine grained aggregate of quartz and sericite. Euhedral crystals of black tourmaline are abundant that cut across the planes of the schistosity and have evidently been formed after the development of the schist.

As nearly as can be judged the zone has formed in the transition zone between the trachytes and the keratophyres where the two types of lavas are interbedded. While no definite statement can be made at present as to the attitude of the different beds, it is probable that the zone dips somewhat more steeply than the beds and cuts them at a low angle.

## ORIGIN OF THE DEPOSIT

By J C. JONES

Frequently in a study of rocks metamorphosed through contact with an invading magma several stages can be identified and a sequence in the process of alteration be recognized. The data at hand indicates the following history of the deposits in Humboldt Queen Canyon:

(1) The interbedded series of trachytes and keratophyres forming the transition zone between the two types of lavas were altered to quartz-sericite schists by the increased temperature and differential pressure incident to the intrusion of the granitic magma.

(2) Zones of weakness developed cutting the beds at a low angle and offering channels for the transmission of fluids escaping from the cooling and solidifying magma below.

(3) These fluids at first were probably liquid and changed the schists in the channels to massive, elongate bodies of quartz with subordinate lenses of andalusite.

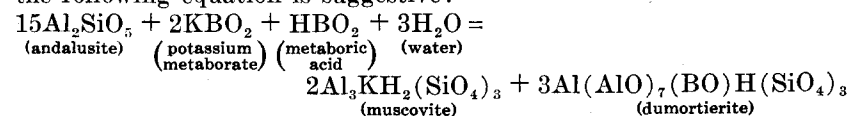
(4) Solutions, probably gaseous, next introduced potash, boron, and water that replaced the andalusite forming the high grade dumortierite as mined and the isolated crystals of black tourmaline found in the keratophyres.

(5) The final solutions, probably liquid, introduced the quartz, dumortierite, sericite veins found in the zones and quartz, black tourmaline veins found elsewhere. These final solutions eventually deposited the metalliferous veins found in the vicinity.

This history as sketched does not imply any sharp demarcation of the stages but rather the changing conditions under which the solutions reacted during the slow cooling of the magma. Our knowledge of the physical-chemical laws governing the processes of solidifying magmas with the attendant alteration of the invaded rocks is so scanty that conjecture only is possible.

A very suggestive study of the reactions of water, potash, and silica at temperatures between 200° C. and 1000° C., was accomplished by Morey.<sup>1</sup> In discussing his results he states that the solubility of silica in water is very slight and not enough to appreciably affect the critical point of water. If silica is melted in an atmosphere of water vapor a certain amount of the water will dissolve, depending on the pressure, and lower the freezing point of the silica. As the pressure is increased more water will enter into the solution and the freezing point of the silica be depressed until a second critical point probably at 550° C., and zero concentration of silica is reached. At this point both phases are practically pure water. The addition of potash causes immediate disappearance of the critical field and the pressures must be enormous. He also found that at temperatures above 500° C. potash was volatile but that no evidence of silica could be found in the vapor phase.

As the evidence obtained with the microscope indicated that the andalusite was replaced with a mixture of dumortierite and muscovite the following equation is suggestive:



<sup>1</sup>Morey, Geo. W., Jour. Am. Chem. Soc. Vol. 39, pp. 1173-1220, 1917.

As the components introduced into the andalusite are known to be volatile at temperatures above 500° C., and to be present in the emanations given off by solidifying magmas it is probable that these solutions were gaseous at the time of the formation of the high grade dumortierite. The latter introduction of the quartz veins would be delayed until the solutions had cooled below the critical temperature of water (365° C.) as is indicated by a slight replacement of the dumortierite and muscovite. It is possible that most of the andalusite grains found in the quartz veins are residuals though some may have been deposited with the quartz.

The dumortierite then was formed in two distinct stages; one as a replacement of pre-existent andalusite, probably by gaseous solutions at temperatures above 500° C.; the other by liquid solutions below the critical temperature of water in the vicinity of 365° C., as a component of the quartz veins. An examination of specimens from about a dozen other localities indicated that in every instance the dumortierite was deposited with quartz, and the first mode of deposition was absent.

As an excess of silica is undesirable in the manufacture of the porcelain sought and as the deposit near Rochester is the only occurrence known at present that furnishes suitable material, the inference is clear that only such deposits as have formed through the replacement of andalusite are of present commercial value.

Prospecting for deposits of dumortierite should be confined to the areas in the vicinity of granites and other acid magmas in contact with aluminous rocks. Such rocks are present in the Triassic lavas of Northern Nevada and have been intruded in a number of localities by granites. As the lavender color of the dumortierite is distinctive it will probably be first noted in quartz veins associated with light colored mica schists. If in addition bodies of andalusite occur in the vicinity it is probable that a suitable deposit of dumortierite will be found indicated by large boulders and masses of the purer material on the surface.

## THE MINING OF DUMORTIERITE

By JAY A. CARPENTER

*Professor of Mining, Mackay School of Mines*

At the present time the mining of dumortierite in the United States is confined to one mine and that is the mine of the Champion Porcelain Company, about six miles east of Oreana, Nevada. Oreana is the station on the Southern Pacific serving the Rochester Mining District, and is 14 miles north of Lovelock, Nevada.

At the present time the actual mining of dumortierite at this mine is limited to simple open-cut work on a hillside. The dumortierite being mined is in the form of small and large boulders occurring either in the overburden of a few feet in thickness above the schist or projecting out of the enclosing schist formation. For a detailed description of the deposit the reader is referred to the section of this bulletin devoted to the geology of the deposit. For the purpose of describing the mining of the material it is sufficient to say that the dumortierite of present commercial value occurs as segregated lenticular masses in a schistose rock that is probably of a metamorphosed igneous origin. The boulders outcrop on the western slope of a hill over a width of about 100 feet and a length of 600 feet, the length conforming with the planes of schistosity in having a general north-south course. The dip of the schistosity is about 45 degrees to the west which may also indicate the dip of the ore zone. The dumortierite occurs in this schist much as plums do in a plum pudding. It is interesting to note also that the dumortierite has a minor schistosity conforming with that of the schist.

The first mining of dumortierite for shipment consisted merely of bulldozing outcropping boulders along lines of weakness or in short hand-drill holes, using 60% dynamite. The rock was broken just small enough to load on pack horses to take it down the steep gulch to where the freighting wagons of R. H. Rowland could then transport it to Oreana for rail shipment to Detroit.

This particular outcrop of violet or purplish colored boulders was included by chance in a location made in 1917 by R. H. (Slim) Rowland on account of narrow silver-bearing quartz veins occurring in the schist just over the brow of the hill from the outcropping boulders. It was not the large boulders that interested Mr. Rowland but rather the narrow veinlets of a blue mineral that brought to mind the usual prospector's hope that his blue mineral might be the elusive silver bromide. Later Mr. Rowland "found out that the mineral was dumortierite through a party gathering specimens and after that found out that it was of no commercial value." Years later stirred to action by the publicity given to the mining of "spark plug mineral" near Bishop, California, by the Champion Porcelain Company, Mr. Rowland sent samples of the dumortierite to that company early in 1925. Dr. Joseph A. Jeffery, the president of the company, visited the property in April, and with a growing appreciation of the size of the deposit and the value of the mineral as a refractory, the property was purchased in October of that year. The first carload shipments were made from "grass roots" or more strictly speaking from the boulders sticking above the sparse sagebrush.

Due to the high hardness and toughness of these boulders, small fragments of this pretty colored and attractive looking mineral now salt the hillsides for a quarter of a mile around the main outcrop as a result of the blasting of the boulders. A tenderfoot, even today, might wonder how such a promiscuously mineralized area could have lain undiscovered for so long a time.

By October, 1926, the wagon road had been extended as far as practical up the gulch and at this point a neat compressor plant was installed. The compressor is an Ingersoll-Rand portable gasoline engine driven unit of the 10" x 8" type "Twenty," capable of running two or three jackhammers and the No. 33 Leyner sharpener. The oil forge for the sharpener is lined with a refractory brick of exceptional qualities made for experimental purposes by the Champion Porcelain Company from the dumortierite of this property.

A 3-inch pipeline of several hundred feet in length transmits the compressed air to the lower tunnel and surface workings. A string of pack mules packs up the mining supplies and brings down the ore.

The mine foreman acts both as mechanic and shift boss. After sharpening the steel he spends his time at the mine workings, with an eye and ear on the compressor. The reliability of this type of unit is shown by the fact that in over a year's operation it has given steady service with only a few cup leathers for repairs.

The dumortierite is a very slow drilling rock because of its combination of hardness and great toughness. A well-tempered machine-made bit dulls in three to five inches of drilling. It is also a difficult rock to break with sledge hammers.

Short tunnels and open cuts soon disclosed the fact that most of the large boulders were part of an unconsolidated surface overburden ten to twelve feet deep, but a few of the boulders were still partly encased in the schist formation, and one prospect tunnel encountered dumortierite in place in the schist.

To date the surface boulders have been the main source for the ore shipments, which now totals close to fifteen hundred tons. These boulders varied in size from a few pounds to a couple that furnished one hundred to two hundred tons each. Lately a main open cut has been started, with the idea of removing and sorting the overburden, and disclosing an area of the mineral-bearing schist to obtain an idea if the lenticular masses of dumortierite occur frequently enough in the schist to justify mining as an open cut over a considerable area.

At the present time the separation of shipping material is determined by the color and its "heft" checked occasionally by the use of the Jolly balance. By breaking with sledges and cobbing, any adhering schist is discarded and a very pure product made, having an average minimum gravity of 3.05 compared with 3.2 to 3.4 for the pure dumortierite. With the shipment of this pure product there will accumulate a much larger tonnage of second-class material in which the dumortierite occurs as narrow ribbons in schist or as mixed crystalline masses of dumortierite and quartz.

The possible utilization of this material is ably discussed under the section of this bulletin dealing with the ore dressing of dumortierite.

The development of this occurrence of dumortierite at a depth of about 200 feet below its outcrop is being carried on in a lower tunnel

known as Tunnel No. 3. About 1,000 feet of work in this tunnel has disproved the theory that the dumortierite occurred in a possible vein formation along the hanging wall of a diabase dike encountered in the driving of the tunnel, but that it did occur in the schist formation on the dip of the schistosity below its outcrop, and in the same large lenticular masses of pure mineral as on the surface. Development work will be continued to determine if the dumortierite masses occur frequently enough over large enough areas at this depth to justify stopping operations.

#### PROSPECTING FOR DUMORTIERITE

Dumortierite is a silicate of aluminum of less common occurrence than the better known similar minerals, andalusite and sillimanite which are commonly known as "spark plug minerals" because of their use in that industry.

It differs from these minerals in that beside the elements aluminum and silicon, it also contains a small percentage of boron.

The natural occurrence of these three minerals is with highly siliceous igneous rocks. The main characteristics by which they might be detected in prospecting is their dull or greasy luster in massive form, their specific gravity which is higher than that of quartz, their hardness which is equal to that of quartz, and lastly, by their color which in andalusite and sillimanite is generally enough different from quartz or feldspar to excite curiosity, while in the case of dumortierite color is a distinctive characteristic. Dumortierite has color but is not limited to a single color. It varies from a deep blue to pink with shades between, as purple, lavender and lilac. These three minerals as a whole can be classed as uncommon minerals not easily identified without laboratory facilities.

The prospector who believes he has made a discovery of one of these so-called "spark plug minerals" should try to ascertain for himself if it be just an interesting occurrence of no commercial value or if there be a possibility of sufficient quantity to be profitably mined. He should send samples of the mineral and enclosing formations for determination to a State Mining Laboratory such as, for instance, is maintained by the State of Nevada at the Mackay School of Mines. There is no charge for such determinations, but the State expects in return as good a description of the mineral occurrence as the prospector can give in order to intelligently catalogue the mineral resources of the State.

The prospector naturally wants to know or should know the approximate value of these spark plug minerals and how nearly pure mineral the shipment must be in order to size up the value of his discovery or the effort he can put forth to retrace his steps to a mineral occurrence or favorable locality that he has in mind. The use of these minerals is too recent and restricted to have reached the point of a steady open market quotation. The Arizona Mining Journal has quoted andalusite at \$50 per ton f. o. b. Philadelphia. This would correspond to approximately \$30 a ton f. o. b. for points west of the Rocky Mountains. This tentative price for "spark plug" minerals in general is sufficient to indicate that it is not in the class with rare minerals sold in small lots and shipped by express, but more in the class with the higher priced nonmetallic minerals such as magnesite, sulphur, short fiber asbestos, or small size sheet mica.

At the present time a high percentage of purity is demanded. The mineral as it occurs or as it is mined, is apt to be contaminated with quartz intercrystallized or mechanically held in it, and the section of this bulletin dealing with the metallurgical treatment points out how serious this impurity is in high class refractory work. At the present time the purity of these minerals, such as dumortierite for instance, is judged commercially by its specific gravity. The pure mineral has a specific gravity of 3.2 to 3.4, and carload shipments are required to average close to 3.1 in gravity. With a more extended use of these minerals for less exacting requirements than that of spark plugs, it may be possible that much more impure mineral may be used but probably at a correspondingly lower price. As a whole, dumortierite and its kindred minerals offers, at the least, a very interesting additional chance of gain to the prospector searching for the more common metallic and nonmetallic minerals.

## ORE DRESSING TESTS

By WALTER S. PALMER

*Professor of Metallurgy, Mackay School of Mines*

From an ore testing standpoint there are at least six distinct types of dumortierite ore in the deposit in Humboldt Queen Canyon, and two types of ore have been sent to the Mackay School of Mines from the deposit at Lincoln Hill near Rochester. Both of the types found at Lincoln Hill are similar in general to ores found in Humboldt Queen Canyon.

These six types of ores can be described as follows:

*Type 1.* This type of ore is the high grade material which can be shipped directly as mined, with perhaps a little cobbing and hand sorting. All material coming in lump form and running over 3.05 in specific gravity is considered first-class ore.

*Type 2.* Consists of pieces composed of dumortierite surrounded or partly coated with coarse muscovite or with sericite schist.

*Type 3.* Consists of veins of dumortierite, some of which is distinctly crystalline in hand specimens, occurring in both sericite schist and in the material which has been described as type six.

*Type 4.* Consists of dumortierite closely associated and intergrown with quartz varying from fairly pure dumortierite to quartz only stained by dumortierite. Examination of thin sections of this quartz under the microscope shows fine needle like crystals of the dumortierite running through the quartz, giving it its color.

*Type 5.* Consists of dumortierite, both blue and pink varieties, with andalusite and some quartz and sericite.

*Type 6.* Consists chiefly of a mixture of quartz and andalusite with very little dumortierite.

### ORE DRESSING TESTS

Since ore having a specific gravity of 3.05 is considered of shipping grade, such tests as have been made up to the present time on these ores have had for their object the producing of a concentrate running better than 3.05 gravity.

The associated minerals are dumortierite with a gravity of 3.26 to 3.42; andalusite, gravity 3.16 to 3.20; muscovite, gravity 2.86; sericite, gravity 2.82; and quartz, gravity 2.65. There are traces of pyrite in some of the ore which might have to be taken into account before an acceptable concentrate was produced. Several methods could be used to remove it from the concentrate.

High grade ore similar to Type 1 requires only a little hand sorting with perhaps a little cobbing to produce shipping ore.

Most of the ore of Type 2 can be raised to the required grade by simply grinding the lump ore on itself in a ball mill and washing. The dumortierite is quite tough while the sericite is quite soft and is easily crushed, while the coarse muscovite is dislodged from the dumortierite. It is understood that a little sericite or muscovite is not detrimental but is actually of some value in the final product when it is used for making spark plugs.

The first problem in the treatment of ores of Types 3 and 4 appears to be one of so crushing the ore as to liberate the dumortierite, or the dumortierite and andalusite, from the associated minerals of which quartz is the most important. The quartz and the dumortierite crystals are so intergrown and some of the dumortierite occurs in such fine hair-like crystals that it is practically impossible to crush the ore fine enough to liberate all of the dumortierite. Some idea as to the fineness of these crystals is given by the fact that whole networks of them will be composed of crystals less than 0.01 m.m. in diameter, some crystals having a diameter of only 0.001 m.m. Tyler Standard sieves of 300 mesh have an opening of 0.043 m.m. These fine crystals have produced two effects which are of importance in concentrating the ores; they tend to raise the gravity of the quartz grains in the crushed product and they also give an apparent color to the quartz, both of which complicate the operation of concentration to produce a clean dumortierite product.

Ores of Type 3 appear to separate into the individual minerals on crushing very much better than those of Type 4 and when such action results, a concentration of the dumortierite to a high gravity product is easily done. In some of the preliminary tests a concentrate running 3.26 has been made by gravity concentration and it is probable that even higher concentrates can be produced. A microscopic examination of the concentrate so produced shows that it consists quite largely of crystals of dumortierite free from adhering minerals. In fact the extent to which the dumortierite, andalusite, and other minerals can be physically separated, especially above 200 mesh in size, will indicate in general the extent to which the material can be successfully concentrated. At the present time only a few tests have been run on minus 200 mesh material. Fine material produced from Type 3 gave successful results but ore similar to Type 4 give inconclusive results on the minus 200 mesh material. More tests are to be run on this type of material.

No definite data is as yet available indicating what grade of concentrate will prove acceptable, and concentrates running 3.07 in gravity are now being experimented with by the Champion Company. If concentrate of this gravity can be used it will make possible the utilization of the low grade material which is found at Lincoln Hill near Rochester.

Tests were run using a high gravity pulp in an endeavor to separate a product running over 3.05 in gravity. Galena was used for this purpose because of its high gravity and the fact that we had enough of the mineral for the test. While it was possible to make some separation in this way and raise the product to 3.05 or better in gravity, it was decided that other and simpler methods could be used with equally good results.

Flotation has been tried on these ores but up to the present time the method is only partially successful in raising the grade of the final material. Reagents tried have removed fairly clean quartz but none have been found which would remove a clean dumortierite or, on the other hand, remove both the quartz and the material containing part quartz and part dumortierite.

Woolf<sup>1</sup> has found that there is little possibility of making a separation of the quartz and dumortierite by heating, quenching, and screening.

#### USES

Dumortierite is used with andalusite in the manufacture of porcelain for spark plugs. As has been stated the Champion Porcelain Company is shipping high grade dumortierite from its mine in Pershing County, Nevada, to the plant of the Champion Porcelain Company of Detroit, Michigan. The mineral forms a good basis for refractory material because of its high alumina content. It has important advantages (3) over sillimanite, andalusite, and cyanite. Dumortierite burns to a practically pure white product. Dr. J. A. Jeffery informed the writer that it increases the toughness and electrical resistivity of porcelain and allows a greater temperature range in burning than does andalusite. It has a high fusion point, and porcelain made from a mixture of dumortierite and andalusite has a very low coefficient of expansion. Experimental ware made by the Champion Porcelain Company indicates that if sufficient dumortierite can be obtained its applications would multiply many fold. Greatly improved pyrometer tubes, chemical porcelain ware, and dishes have been made of it. The pyrometer tubes do not become porous or brittle after over a year's use in a kiln. The porcelain ware resists both mechanical shock and sudden changes in temperature much better than does the porcelain now in general use. By using the proper mixture of andalusite and dumortierite a high grade refractory brick has been made by the Champion Company for use in their own kilns. Bricks made of dumortierite alone gradually swell and those made of only andalusite sag so that a proper mixture of the two yields a brick of just the right quality. The present known occurrence of commercial dumortierite is too limited to permit its employment in any field other than in the manufacture of spark plug porcelain.

Schaller (45) has suggested that dumortierite bearing rock might be used for ornamental stone if large enough pieces are obtainable. Certainly there is material in Pershing County, Nevada, which is valueless as porcelain ore but which might well be used for decorative purposes.

Schaller (45) and Knopf (23) both suggest a possible use of dumortierite as a semiprecious gem material. The quartz associated with dumortierite in Nevada often contains minute hair-like fibers of dumortierite which give the quartz a beautiful rose color, rendering it of gem quality.

#### USE OF DUMORTIERITE IN SPARK PLUGS

• Due to the fact that the use of dumortierite as a commercial mineral is only carried out by one company, the Champion Porcelain Company of Detroit, who control the only known workable deposit, a brief description of its use and the making of spark plugs would probably be interesting to some readers of this bulletin.

The following description has been given the writer in conversation and in correspondence with Dr. J. A. Jeffery, President of the Champion Porcelain Company:

<sup>1</sup>Tests made by J. A. Woolf, U. S. Bureau of Mines Rare and Precious Metals Experiment Station, Reno, Nevada.

The material as mined is hand sorted if necessary at the mine and then shipped to the Detroit plant of the Champion Porcelain Company. Upon arriving at the plant it is bedded in lots of 2,000 tons by a system of parallel rows, each carload being laid out in a long row parallel to and beside or above the previous carload. In drawing the material for use cuts are taken across the ends of the rows giving a good average lot of the material.

The coarse ore is first crushed in a jaw crusher to about one-half inch in size and is then crushed dry in a ball mill, using chrome steel balls, to minus sixteen mesh in size. It then passes over a magnetic separator to remove any iron from the ball mill and passes to a second ball mill where it is ground with sillimanite porcelain balls, and the mill is lined with sillimanite porcelain liners. Crushing is to such a fineness that all will pass a 100 mesh screen and 70% will pass 300 mesh. The material is then sampled and stored.

In preparing the body the ground dumortierite is mixed with ground andalusite, kaolin, and water and the grinding continued in a special mill having a capacity of about two tons. Here the grinding is done in batches, and a charge will be ground for about seventeen hours. The slip or ground body will then pass a 300 mesh screen. The material then passes to filter presses where the excess water is removed. The cakes from the presses are stored in an aging cellar for ten days. This aging develops plasticity and gives time for each batch of material to be tested.

From the aging cellars the material passes through two pugging mills before being formed into the blanks from which the spark plugs are made. After thorough drying the blanks are turned down on special lathes and given their final form. The tolerance allowed is one three-thousandth of an inch. The cores are then glazed and are ready for burning.

The cores are burned in a continuous kiln 300 feet long, at a temperature of 2700 degrees Fahrenheit. It takes four days for the cores to pass through the kiln.

The cores are next stamped with the trade mark "Champion" or "Champion X" and then passed through an electrically heated furnace to fix the stamping, by burning the name into the glaze.

The cores are now ready to have the metal parts attached.

## SAMPLES OF DUMORTIERITE SOLICITED

The Mackay School of Mines wishes to gather as complete a collection of specimens of dumortierite as possible and will very much appreciate the receipt of any samples the readers of this bulletin may have available and which they care to send in.

The School will reciprocate by supplying any information about dumortierite it may have to anyone requesting the same.

## BIBLIOGRAPHY

By O. R. GRAWE

*Instructor in Mineralogy, Mackay School of Mines*

1. *Bertrand, Émile*, Sur un minéral bleu de Chaponost, près Lyon: Bull. Soc. Min. de France, vol. 3, pp. 171-172, 1880.
2. *Bertrand, Émile*, De l'application du microscope à l'étude de la minéralogie: Bull. Soc. Min. de France, vol. 4, p. 9, 1881.
3. *Bowen, N. L., and Wyckoff, R. W. G.*, A petrographic and X-ray study of the thermal dissociation of dumortierite: Wash. Acad. Sci. Jour., vol. 16, pp. 178-179, 1926.
4. *Chamberlain, B. B.*, The minerals of New York County, including a list complete to date: New York Acad. Sci. Trans., vol. 7, p. 230, 1888.
5. *Clarke, F. W.*, The data of geochemistry: U. S. Geol. Survey Bull. 770, p. 416, 1924.
6. *Damour, A.*, Analyse de la dumortierite: Bull. Soc. Min. De France, vol. 4, pp. 6-8, 1881.
7. *Dana, E. S.*, Review of Riggs' "The so-called Harlem indicolite": Zeitschr. Kryst., vol. 15, p. 127, 1889.
8. *Dana, E. S.*, A system of mineralogy, 6th ed., p. 558, 1900; Appendix II, p. 37, 1914, John Wiley & Sons.
9. *Diller, J. S., and Whitfield, J. E.*, The dumortierite from Harlem, N. Y., and Clip, Arizona: Am. Jour. Sci., ser. 3, vol. 37, pp. 216-219, 1889.
10. *Diller, J. S., and Whitfield, J. E.*, Dumortierite from Harlem, N. Y., and Clip, Ariz.: U. S. Geol. Survey Bull. 64, pp. 31-33, 1890.
11. *Fairbanks, E. E.*, Dumortierite from Nevada: Am. Mineralogist, vol. 11, pp. 93-96, 1926.
12. *Ferraz, Jorge Palmiro de Araujo and Rocatti, M. Alessandro*, Notes sur la minéralogie du Brasil: Bull. Min. Soc. de France, vol. 80, p. 34, 1927.
13. *Findlay, G. I.*, On an occurrence of corundum and dumortierite in pegmatite in Colorado: Jour. Geology, vol. 15, pp. 479-484, 1907.
14. *Ford, W. E.*, On the chemical composition of dumortierite: Am. Jour. Sci., ser. 4, vol. 14, pp. 426-430, 1902.
15. *Ford, W. E.*, Über die chemische Zusammensetzung des Demortierite: Zeitschr. Kryst. vol. 37, pp. 417-421, 1903.
16. *Gonnard, Ferdinand*, Note sur l'existence d'une espèce minérale nouvelle, la dumortierite, dans le gneiss de Beaunan au-dessus des anciens aqueducs galloromains de la vallée l'Iseron (Rhône): Bull. Soc. Min. de France, vol. 4, pp. 2-5, 1881.
17. *Gonnard, Ferdinand*, Sur un nouveau gisement de dumortierite à Brignais (Rhône): Bull. Soc. Min. de France, vol. 11, pp. 264-265, 1888.
18. *Gonnard, Ferdinand*, Sur un nouveau gisement de dumortierite dans le Rhône: Bull. Soc. Min. de France, vol. 15, p. 230, 1892.

19. *Hlawatsch, D.*, Dumortierite von Weitenegg : Min. pet. Mitt. (Tschermak's, Wien), vol. 30, pp. 140-141, 1911.
20. *Hovey, E. O.*, Notes on some specimens of minerals from Washington Heights, New York City : Am. Mus. Nat. Hist. Bull. 7, pp. 341-342, 1895.
21. *Hugi, E., and Hirschi, H.*, Dumortieritvorkommen aus den südlichen Schweitzer Alpen : Schweiz. Min. Petr. Mitt., vol. 5, pp. 251-252, 1925. (Reviewed in Neues Jahrb. Min., vol. 2A, pp. 333-334, 1926.)
22. *Jones, J. C.*, Geology of Rochester, Nevada : Mining and Sci. Press, vol. 106, pp. 737-738, 1913.
23. *Knopf, Adolph*, Geology and ore deposits of the Rochester District, Nevada : U. S. Geol. Survey Bull. 762, pp. 18-19, 1924.
24. *Kratochvíl, Josef*, Minerály Pelhřimovska (Minerals from near Pelhřimov) Časopis Musea Českého (Jour. Bohemian Mus.) Praha, vol. 95, pp. 112-118, 1921. (Reviewed in Min. Abstr., vol. 2, p. 118, 1923-1925.)
25. *Kuznetsov, E. A.*, The rocks of the Uvildy Lake District, Ural Mts. : Trans. Inst. Econ. Min. Petrogr. "Lithogaea" (Moscow), 1923, No. 2, pp. 1-40. (Reviewed in Min. Abstr. vol. 2, p. 397, 1923-1925.)
26. *Lacroix, Alfred*, Contributions à l'étude des gneiss à pyroxene et des roches à wernérite : Bull. Soc. Min. de France, vol. 12, pp. 219-221, 1889.
27. *Lacroix, Alfred*, Minéralogie de Madagascar, vol. 1, pp. 401-403, 1922. (Augustin Challamel, Rue Jacob 17, Paris.)
28. *Lacroix, Alfred, and de Gramont, A.*, Sur la recherche spectrale du bore et sur sa présence dans quelques silico-aluminates naturels : Bull. Soc. Min. de France, vol. 44, pp. 67-77, 1922.
29. *Larsen, E. S.*, The microscopic determination of the non-opaque minerals : U. S. Geol. Survey Bull. 679, pp. 70, 263, 1921.
30. *Linck, G.*, Die pegmatite des oberen Veltlin : Zeitschr. Naturwiss. (Jena), vol. 33, pp. 345-360, 1899.
31. *Lévy A. Michel, and Lacroix, Alfred*, Réfringence et biréfringence de quelques minéraux des roches : Compt. Rend., vol. 106, p. 777, 1888.
32. *Lévy, A. Michel, and Lacroix, Alfred*, Sur un nouveau gisement de dumortiérite : Compt. Rend., vol. 106, pp. 1546-1548, 1888.
33. *Mackie William*, Dumortierite in British rocks : Edinburgh Geol. Soc. Trans., vol. 11, p. 352, 1925.
34. *Niggli, P., and Faesy, K.*, Silicates : Zeitschr. Kryst., vol. 56, p. 338, 1921-1922.
35. *Peck, A. B.*, Dumortierite as a commercial mineral : Am. Mineralogist, vol. 11, pp. 96-101, 1926.
36. *Riggs, R. B.*, The so-called Harlem indicolite : Am. Jour. Sci., ser. 3, vol. 34, p. 406, 1887.
37. *Rimann, Eberhard*, Über ein neues Vorkommen von Dumortierite : Centralbl. Mineralogie, pp. 615-620, 1914.

38. *Romberg, J.*, Petrographische Untersuchungen an argentinischen Graniten : Neues Jahrb. Beilage Band 8, p. 340, 1893.
39. *Rosicky, Vojt.*, Mineralogické Zpravy z Moravy (Mineralogic communications on Moravia) : Časopis Moravského Musea Zemského, (Bull. Moravian Museum), vol. 22, pp. 138-158, 1926. (Reviewed in : Min. Abstr., vol. 3, p. 123, 1926. Neues Jahrb. Min., p. 337, 1926. Revue de Geologie, VIII. année fascicule, 1927.)
40. *Rosler, H.*, Über Hussakit (xenotim) und andere seltene gesteinsbildene Mineralien : Zeitschr. Kryst., vol. 36, p. 262, 1902.
41. *Saslawsky, J. J.*, Die Kontraction der Minerale : Zeitschr. Kryst., vol. 59, p. 176, 1924.
42. *Schaller, W. T.*, Dumortierite : Am. Jour. Sic., ser. 4, vol. 19, pp. 211-224, 1905.
43. *Schaller, W. T.*, Über Dumortierite : Zeitschr. Kryst., vol. 41, pp. 19-47, 1905.
44. *Schaller, W. T.*, Dumortierite : U. S. Geol. Survey Bull. 262, pp. 91-120, 1905.
45. *Schaller, W. T.*, Gems and precious stones : U. S. Geol. Survey Min. Resources, 1916, pt. 2, p. 893, 1919.
46. *Schrader, F. C.*, The Rochester Mining District, Nevada : U. S. Geol. Survey Bull. 580, pp. 325-372, 1914.
47. *Vernadsky, W.*, Sur la reproduction de la sillimanite : Bull. Soc. Min. de France, vol. 13, p. 258, 1890.
48. *Walker, T. L.*, Dumortierite from Ashby Township, Addington County, Ontario : University of Toronto Studies, Geol. Ser. No. 14, pp. 80-83, 1922.
49. *Websky, A*, note, Sitzungsab. der niederr. Gesell. (Bonn) vol. 42, p. 202, 1885.
50. *Webster, M. H.*, Catalogue of the minerals which have been discovered in the State of New York arranged under the heads of the respective counties and towns in which they are found, 32 pp., Albany, N. Y., 1824.
51. *Wittich, Ernesto, and Kratzert, I.*, Contribuciones a la mineralogia mexicana : Soc. Cient. "Antonio Alzate" Memorias, vol. 39 (1920-1921), pp. 651-655, 1921.
52. *Wittich, Ernesto, and Kratzert, I.*, Über ein neues Vorkommen von Dumortierite im Granit bei Guadalcázar, Nordmexico : Centralb. Mineralogie, pp. 648-650, 1921.
53. *Anonymous*, Notes on Canadian minerals : University of Toronto Studies, Geol. Ser. No. 12, p. 69, 1921.