TiO_2[6] present in mullite increases the refractive index of alpha 0.6%. In the case of augite approximately 5% TiO_2[7] has been found to increase the refractive index of alpha about 1%. The above considerations appear to indicate that titanium is generally present and if this is true the various colors of dumortierite can be explained by the presence of this element.

The specimens of schist studied consist chiefly of altered, fibrous material giving aggregate polarization effects and varies from nearly opaque to nearly transparent.

The dielectric constants were determined for the Nevada dumortierite and also for typical andalusite, and cyanite.

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

λ = infinite Error $\pm$ 1

It would be interesting to obtain data from other specimens since the determined values are not far apart. Dielectric constants obtained from some minerals which resemble each other very closely have been found to differ widely.

DUMORTIERITE AS A COMMERCIAL MINERAL

Albert B. Peck, *University of Michigan*

Introduction

About two years ago attention was called to the rapid rise in commercial importance of andalusite, as a result of the discovery of a large deposit of it in California.[1] One might assume that the development of a mineral of such great value from the ceramic standpoint, accompanied as it was by an almost revolutionary change in the composition of certain types of porcelains, would justify a pause in the search for better material. However, as a result of the fact that modern research is continually striving for the better, we are able at this time to add another hitherto rare and practically useless mineral to the list of those of real value. The mineral referred to is dumortierite. As in the case of the California andalusite, the present deposit of dumortierite is owned and has been developed by the Champion Porcelain Company of

[1] *Am. Mineral.*, **9**, 123–9 (1924).

Detroit, Michigan. A few notes dealing with the occurrence of this mineral and its use may therefore be of general interest to mineralogists.

Location and Occurrence

This deposit of dumortierite is located near what is known as Limerick Canyon, slightly west of the northwestern corner of what is ordinarily considered to comprise the Rochester Mining District of Nevada. A precise location can not be given, owing to the confusion of names existing to describe the various canyons of the region. Knopf[2] mentions the occurrence of dumortierite in an altered trachyte at Lincoln Hill, which is considerably to the southeast of the dumortierite of Limerick Canyon. The trachyte contains irregular areas of dumortierite and is profusely cut by veinlets up to six inches in width.

The dumortierite, which led to the discovery of the Champion mine, was first noted as veinlets cutting a large dike-like mass of andalusite and quartz, but in a canyon bottom to the west of this, some large boulders of dumortierite were found, one weighing probably 30 tons. Inasmuch as no masses that would weigh more than a ton could be observed in the andalusite-quartz mass, a prospect tunnel was started in the canyon to the west of the andalusite-quartz "dike" in an effort to locate the source of the large boulders. While this work was in progress, the main body of dumortierite was cut. For a considerable distance the width is fully 14 feet and the present development indicates a "vein" fully 250 feet long. This dumortierite is distinctly massive in character with a decided schistose structure and is rather vein-like in form.

Mineralogy

Physical properties. Thus far no perfect crystals are available. In one or two specimens, small crystals surrounded by quartz and andalusite have been observed, but they are not more than one quarter inch in length or over one thirty-second inch in width. The typical mode of occurrence resembles a schist. The masses exhibit a distinct cleavage and split rather easily into slabs, but these are exceedingly tough and resistant to transverse stresses. This accounts for the difficulty found in crushing it in practice, although it grinds with fair ease. In a few places veinlets composed of fibers perpendicular to the walls have been noted.

[2] *U.S. Geol. Sur. Bull.* 762.

The color of the schist varies from light to dark pink through lilac and lavender to medium blue. Some shade of pink is the most common color, a very unusual color for dumortierite. Some specimens show both pink and blue colors. The masses are hard as well as tough and will scratch glass. The specific gravity, although varying slightly, is generally near 3.30. All the crystals are microscopic in size and hence the other physical properties are relatively unimportant.

Microscopic properties. It is only when subjected to microscopic examination that the true nature of the rock is revealed. It is composed of very minute prismatic needles of dumortierite very intimately intergrown with muscovite. The intergrowth is so close that it is impossible to free one from the other. Frequently, numerous needles of dumortierite can be seen penetrating completely through some of the larger plates of muscovite. Muscovite usually comprises from 12 to 18 percent of the rock. Andalusite and quartz are also present in small and very constant amounts of less than 5 percent each. The only other constant associate is rutile. This is present as very minute grains evenly scattered through the rock. In this way it resembles the occurrence of rutile with the California andalusite.

Optical Properties. The optical constants for Nevada dumortierite do not appear to vary greatly for differently colored material, as is shown by the following indices of refraction:

	$alpha_{Na}$	$beta_{Na}$	$gamma_{Na}$	
pink massive	1.677	1.685	1.690	all ± 0.003
lavender massive	1.675	1.685	1.690	
light blue crystals	1.675	1.685	1.692	

In elongation $c=\gamma$; the optic angle in all cases is moderate, about 30–40°; the dispersion of the optic axes is $\rho > \nu$, but it does not appear to be unusually strong. Only alpha shows pleochroic colors and that varies from red violet to lavender blue, according to the color of the mineral.

Chemical composition. The chemical composition of this massive material on a loss-free basis is as follows:

SiO_2	37.05 Per cent	Equivalent to	
Al_2O_3	55.01	dumortierite	75.33 Per cent
TiO_2	0.63	muscovite	14.16
B_2O_3	4.65	excess SiO_2 (partly quartz)	8.53
Others	2.66	others	1.98

It is quite apparent from this that the massive rock is very high in dumortierite. Undoubtedly, part of the titanium is combined in the dumortierite, replacing Al_2O_3 or SiO_2. As is evident from the presence of microscopic rutile grains mixed with the dumortierite, one can not ascribe all of the TiO_2 present as the coloring agent of the dumortierite itself. For this reason the ordinary qualitative carbonate fusion test upon this material does not necessarily prove that the pleochroism of this dumortierite is due to TiO_2. Before an accurate quantitative investigation could be undertaken, some method would have to be devised to eliminate the rutile.

The relation of titanium to the color of the mineral is a matter easier to speculate upon than to prove. One wonders if the state of oxidation of titanium may not influence the color of the resulting mineral. Whether, for example, if present as Ti_2O_3, a blue color may not result, and when replacing SiO_2 in the form of TiO_2, the red colors may not be formed. In this connection there is an interesting association to be observed in some of the veinlets which run through some parts of the andalusite "dike." These veinlets often show blue dumortierite next to the walls and grade into pink dumortierite at the center. It does not seem impossible to assume that under changing conditions as the veinlets were formed, the titanium first may have been in the form of Ti_2O_3, replacing the Al_2O_3 with the resulting blue color, and that under later conditions it was oxidized to the TiO_2 form and replaced the SiO_2, in which condition it imparted a pink color. On the other hand the possibility of the presence of manganese or other elements should not be entirely excluded. The presence of free rutile, however, also seems to indicate that the dumortierite has absorbed as much titanium as could be expected of it.

Behavior upon Firing

To the ceramist the most important property of a mineral is its behavior upon firing. An indication of the importance of this was briefly outlined in the earlier paper on andalusite.[3] Suffice it to say in the case of dumortierite that it breaks down gradually at a comparatively low temperature, beginning at cone 10 (approximately 1250°C) or a little lower. The result of this dissociation is similar to that of andalusite; namely, the formation of a very

[3] *Am. Mineral.*, **9**, 123–9 (1924).

intimate mixture of mullite crystals ($3Al_2O_3.2SiO_2$) in glass. When the breakdown first occurs there is no definite orientation of the mullite crystals with reference to the original dumortierite grain. The mullite crystals are exceedingly small and also lack definite form. Furthermore, they grow at a very slow rate as the firing temperature is increased.

When the dumortierite rock is fired it expands somewhat as it dissociates and decreases in specific gravity. At the same time it changes in color to a pure white and takes on a dull porcelain-like luster, the former being a highly desirable property from the ceramic standpoint.

Use

Although dumortierite dissociates into a mixture of mullite and glass at a rather low temperature, the resulting product is very refractory. This is due to the fact that its composition lies near that of mullite, according to the alumina-silica diagram of Bowen and Greig.[4] According to Dr. Fairchild[5] test cones formed from the powdered rock fuse sharply at 1810°C. At cone 36 half over (approximately 1800°C) the same material sintered somewhat but showed no signs of deformation and maintained even the sharpest edges without rounding due to fusion. It is apparent, therefore, that it has great possibilities from the standpoint of refractoriness.

The remarkably pure white color produced in this material when fired, is direct proof of the nearly complete absence of accessory metallic oxides, only two, Fe_2O_3 and TiO_2, being present. This is very important from the practical standpoint because comparatively small quantities of such compounds may impart a shade of color to the resulting ware; or still less desirable, they may produce small dark colored spots upon a white background. Thus, because of its white-firing property, this dumortierite could be used in even the very highest grade of porcelain, if it were desired to do so.

Although the use of dumortierite is still in the experimental stage, enough has been learned to show that it has other properties of great value for its use as a refractory and also as a constituent of porcelains. It is now being used experimentally, replacing a part of the andalusite used in special porcelains.

[4] *J. Am. Cer. Soc.*, **7**, 238–54 (1924).

[5] Unpublished data from U. S. Bureau of Standards.

As was the case for andalusite, this dumortierite rock is used in its original state without concentration; in fact, owing to its fine grain and intimate relation to the muscovite, concentration would probably be impossible.

ACKNOWLEDGMENT

Like andalusite, the discovery and development of this dumortierite deposit and its rise to the rank of a mineral of commercial importance, are both largely the direct result of patient and persistent search for the seemingly impossible thing, and too much credit in this connection can not be given Dr. J. A. Jeffery, President of the Champion Porcelain Company.

LITHIOPHILITE AND OTHER RARE PHOSPHATES FROM PORTLAND, CONNECTICUT*

J. F. SCHAIRER, *Yale University*

In studying the mineralogy and paragenesis of the pegmatite at the Strickland Quarry, Collins Hill, Portland, Connecticut, several lithium minerals associated with the manganese phosphates were found. The minerals occurring together are spodumene, lepidolite, manganapatite, lithiophilite, dickinsonite and hureaulite in albite and quartz. Only very small amounts of dickinsonite and hureaulite are found with the lithiophilite which is itself not abundant. W. G. Foye[1] has reported the occurrence of lithiophilite from this locality but gives no data.

Through the generosity of Professor Foye of Wesleyan University, the large specimen of lithiophilite (Wesleyan Museum No. 10615) was placed at the writer's disposal for chemical study. The specimen consists of a large mass of light orange colored lithiophilite without crystal form, in platy albite with muscovite, quartz and a very little dickinsonite as accessory minerals.

Pure material for analysis was separated very easily by hand picking and examining the fragments under the microscope to insure a homogeneous sample. Examination showed the indices of refraction to be between 1.66 1.67. The analysis follows:

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[1] W. G. Foye, *Am. Mineral.*, 5, 120 (1920).