THE AMERICAN MINERALOGIST
JOURNAL OF THE MINERALOGICAL SOCIETY OF AMERICA

Vol. 17 NOVEMBER, 1932 No. 11

THE IDENTIFICATION OF JADE BY MEANS OF X-RAY DIFFRACTION PATTERNS

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INTRODUCTION

Jade is one of the oldest of mineralogical materials used by primitive man. It was used in the construction of hatchets, chisels, and ornaments. Such articles have been found in many localities in North America, Asia, Europe, and New Zealand. The source of the jade found in Europe was for many years unknown, a fact which caused extended controversy concerning the methods of commercial intercourse of pre-historic man. Jade has long been a much prized mineral both for ornamental and religious purposes among the Chinese, its use dating back at least as far as 2852 B.C. Objects, some of which undoubtedly required a life time to carve with a hand drill, have found their way into several large collections. The most notable collection available to the American public is the Bishop Collection in the Metropolitan Museum of Art, New York City.

The historical and archeological aspects of jade have been fully reviewed by Laufer.[1] He has furnished an extensive bibliography dealing with various phases of the subject. An extensive examination of jade has also been made of the Bishop Collection.[2]

Jade has recently shown increasing popularity in the jewelry trade and is now frequently used for necklaces and ornaments of various kinds. In commercial usage the minerals jadeite, chloromelanite, and nephrite are usually included under the name of jade. The characteristic fine grained, dense, or compact nature of these minerals, together with the fact that the specimens may not consist entirely of one mineral, involves problems in identification not always easily solved by ordinary routine methods.

[1] Laufer, Berthold, Jade: *Field Museum of Natural History*, Publication **154.** *Anthropological Series*, vol. **X,** 1912.

[2] Bishop, Heber R., Investigations and Studies in Jade. *New York*, **1906.** Privately printed. Two Volumes. 98 copies. (Available at the Metropolitan Museum of Art, New York City.)

In view of the extensive advances in x-ray diffraction technique that have been made during the last few years, it is possible, in many instances, to identify fine grained crystalline minerals by comparing their x-ray diffraction patterns with standard patterns. The present investigation is an attempt to utilize such methods of mineral study in an effort to overcome a few of the difficulties involved in the identification of jade. The first problem in such an x-ray diffraction study is to make up a set of standard patterns of known specimens with which the unknown material may be compared. In order to make the study cover a wider range of practical application, several imitations of jade should also be included. A number of specimens of jadeite, chloromelanite, and nephrite as well as imitations such as vesuvianite (californite), serpentine (williamsite), and agalmatolite have been examined by means of x-rays in an attempt to establish a standard set of diffraction patterns. The usual specific gravity and optical determinations have also been made on the specimens. Optical study has included examination of both thin sections and crushed fragments. Several specimens previously analyzed chemically have also been studied optically and by means of x-rays.

The writer is indebted to Professor Paul F. Kerr of Columbia University for suggesting this problem as well as for his assistance and advice during the course of the investigation and the preparation of this paper.

Physical Properties

Complete physical data on jade are given in Dana's *System of Mineralogy*. Only a few of the properties especially useful in identification are referred to in this discussion.

Except in the case of those who have unusual experience, the sight identification of jade is often inaccurate because of the extreme variation in texture, color, and quality of the material. The ordinary differences in appearance existing between hand specimens of jadeite and nephrite were pointed out by Clark and Merrill.[3] As a rule, jadeite and its dark green variety chloromelanite are somewhat granular in texture whereas nephrite is more inclined to be compact and fibrous throughout. Such a distinction between the jade minerals, however, is not always reliable.

[3] Clark, F. W. and Merrill, G. P., On Nephrite and Jadeite: *Proc. U. S. Nat. Mus.*, vol. **XI**, 1888, pp. 115–130.

The jade minerals may be separated more or less satisfactorily on the basis of specific gravity. However, if quartz, albite, various pyroxenes or amphiboles and alteration products, as well as numerous other minerals are present they will materially alter the specific gravity determinations of the three jade minerals. The average specific gravity of 107 samples of jadeite, with a few specimens of chloro melanite, in the Bishop Collection at the Metropolitan Museum of Art was reported by Hallock to be 3.3202.[4]

The average specific gravity of nephrite from the Egleston Museum at Columbia University was determined in this study to be 2.992. Chloromelanite has been reported by Damour to vary from 3.36 to 3.43 in specific gravity.[5] In general, providing the material is pure, the three jade minerals may be distinguished from each other by this method, although some of the imitations might easily be confused. The following table includes determined and reported values of specific gravity for the jade minerals and their imitations.

TABLE I.

	Specific Gravity
Jadeite	3.296
Chloromelanite[6]	3.36–3.43
Nephrite	2.992
Vesuvianite (californite)	3.284
Serpentine (williamsite)	2.638
Agalmatolite	2.631
"South African Jade" (grossularite)[7]	3.33–3.52

OPTICAL PROPERTIES

The most reliable optical constants available for the identification of the jade minerals and their imitations are the indices of refraction. The following table includes values determined during the course of the investigation as well as several determinations recorded in the literature:

[4] Hallock, W., in H. R. Bishop's Jade Book, vol. **I,** 1906, p. 116.

[5] Damour, A., Nouveaux essais sur la Cholormelanite: *Soc. Fr. de Min.*, Bull. **16,** 1893, pp. 57–59.

[6] Damour, A., Nouveaux essais sur la Cholormelanite: *Soc. Fr. de Min.*, Bull. **16,** 1893, pp. 57–59.

[7] Hall, A. L., On "Jade" (Massive Garnet) from the Bushveld in the Western Transvaal: *S. A. Geol. Soc., Trans. and Proc.*, **27,** 1924, pp. 39–55.

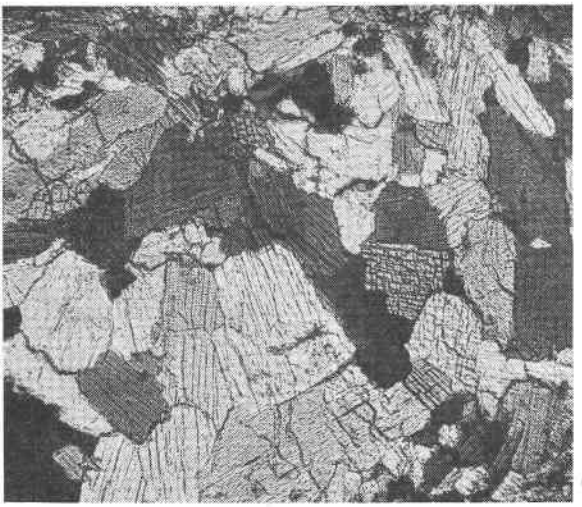

FIG. 1. Photomicrograph of jadeite illustrating the prismatic habit and cleavage, and the granular structure. Crossed nicols. ×27.

FIG. 2. Photomicrograph of nephrite illustrating the occurrence in long, bladed, radiating fibers. Crossed nicols. ×27.

TABLE II

	α	β	γ	$\gamma-\alpha$
Jadeite (China)	1.650		1.664	.014 (±.003)
Chloromelanite (Burma)	1.653		1.685	.032 (±.003)
Diopside-jadeite[8] (Tuxtla statuette)	1.666	1.674	1.688	.022
Soda Jadeite[8] (Thibet)	1.655	1.659	1.667	.012
Nephrite (Jordansmühl, Silesia)	1.600		1.625	.025 (±.003)
Nephrite[9] (Bahia, Brazil)	1.597		1.625	.028
Tremolite[10] (Lee, Mass.)	1.5992	1.6132	1.6246	.0254
Actinolite[11] (Krageroe, Norway)	1.636		1.660	.024
Serpentine (williamsite) (Texas, Pa.)	1.566		1.574	.008 (±.003)
Vesuvianite (californite) (Siskeyou Co., Calif.)	1.699		1.708	.009 (±.003)
Agalmatolite (China)	1.550		1.578	.028 (±.003)
Grossularite[12] (Western Transvaal)	1.72–1.73 (sometimes doubly refracting)			

Although the examination of jade in thin section is not a practical method of identification, thin sections were examined in order to ascertain the purity of the specimens examined by x-ray diffraction methods. Several specimens of each of the jade minerals as well as of the imitations were sectioned and only those samples which proved to be composed of a single mineral were later photographed by x-rays. (See Figures 1 and 2.)

Jadeite is colorless in thin section and occurs in granular crystals characterized by distinct prismatic cleavage. Basal sections display two cleavages at nearly right angles. Frequently the material is partially altered to serpentine and uralite. Chloromelanite is similar to jadeite except that it has a distinct greenish cast even in thin section. Nephrite, on the other hand, is composed of fine, compact, frequently radiating aggregates and bundles of fibers and scale-like crystals.

[8] Washington, H. S., The Jadeite of the Tuxtla Statuette: *Proc. U. S. Nat. Mus.*, vol. **60,** 1922.

[9] Washington, H. S., Nephrite Celt from Bahia, Brazil: *Pan-Am. Geol.*, vol. **37,** 1922, pp. 198–202.

[10] Washington, H. S. and Merwin, H. E., Note on Enstatite, Hypersthene, and Actinolite: *Am. Mineral.*, vol. **8,** no. 4, pp. 63–67.

[11] Ford, W. E., A Contribution to the Optical Study of the Amphiboles: *Am. Jour. Sci.*, 4th series, vol. **37,** 1914, pp. 179–193.

[12] Hall, A. L., On "Jade" (Massive Garnet) from the Bushveld in the Western Transvaal: *S. A. Geol. Soc., Trans. and Proc.*, **27,** 1924, pp. 39–55.

X-Ray Diffraction Study

Standard samples of jade were first established by optical and physical means, then x-ray diffraction patterns were taken. The samples were ground to about 350 mesh, from 50 to 100 milligrams of material or even less being found sufficient to give a good pattern. In the case of very fine, granular material it is possible to secure a pattern by reflection from a straight line edge entirely avoiding even slight damage to the specimen. It was found that a sufficient amount of material for x-ray examination could be readily removed from the under side of the base of a carved object with a small drill, resulting in but little damage to the specimen.

The general problems of the pyroxene and amphibole groups materially affect the x-ray study of the jade minerals. Previous x-ray studies of the pyroxenes and amphiboles have been of considerable assistance in establishing standard patterns. A number of crystal structure studies on the pyroxenes and amphiboles are on record which have been carried on by utilizing Laue, x-ray spectrometer, and x-ray diffraction photographs.[13]

An x-ray examination of the pyroxenes by Wyckoff, Merwin and Washington indicated that nearly all of the minerals usually classed as pyroxenes could be classified in four general groups according to their similarities in x-ray diffraction patterns. In the first group were placed diopside, hedenbergite, acmite, jadeite, and augite. The size of the unit cell and the arrangement of the atoms in the lattice were determined from a study of the Laue photographs of single oriented crystals. Wyckoff gives the following measurements for diopside:[14]

$$a = 9.71\text{Å};\ b = 8.89\text{Å};\ c = 5.24\text{Å};\ \beta = 74°10'.$$

[13] Wyckoff, R. W. G., Merwin, H. E., and Washington, H. S., X-ray Diffraction Measurements upon the Pyroxenes: *Am. Jour. Sci.*, 5th series, vol. **10,** 1925, pp. 383–397.

Wyckoff, R. W. G., and Merwin, H. E., The Space Group of Diopside: *Am. Jour. Sci.*, 5th series, vol. **9,** 1925, pp. 379–394.

Warren, B., and Bragg, W. L., The structure of Diopside Ca $Mg(SiO_3)_2$: *Zeit. f. Krist.*, **69,** 1928, pp. 168–193.

Warren, B. E., The Crystal Structure and Chemical Composition of the Monoclinic Amphiboles: *Zeit. f. Krist.*, **72,** 1930, pp. 493–517.

Gossner, B. and Spielberger, F., Chemische und röntgenographische Untersuchungen an Silikaten: *Zeit. f. Krist.*, **72,** 1930, pp. 111–142.

[14] Wyckoff, R. W. G. and Merwin, H. E., The Space Group of Diopside Ca Mg $(SiO_3)_2$: *Am. Jour. Sci.*, 5th series, vol. **9,** 1925, pp. 379–394.

The size of the unit cell for the other pyroxenes has not been calculated but has been compared with that of diopside, the latter being taken as 1.000.[15] The relationship between the relative sizes of the unit cells of jadeite, diopside, and acmite were thus brought out as follows:

TABLE III

Film No.	Acmite	Jadeite
1.	.995	.976
2.	.995	.971
3.	.994	.976
4.	.994	.972
	.9945	.974

Washington has shown that jadeite from the Tuxtla statuette is not a simple jadeite but rather a mixture of the jadeite molecule and the diopside molecule in almost equal proportions. He notes that the jade of Middle America, in contrast to most of that from the Orient, is especially characterized by the presence of diopside in varying but usually large amounts.

It has been pointed out that jadeite occurs in isomorphous mixture with acmite, the ferric iron replacing a portion of the alumina.[16] Chloromelanite is probably a very complex mineral consisting of an isomorphous mixture of jadeite, diopside and acmite.

X-ray diffraction photographs were taken of several samples of jadeite and chloromelanite from the Egleston Museum at Columbia University. All the specimens examined were from China, Thibet or Burma. In order to compare jadeite with the minerals with which it occurs in isomorphous mixtures, *x*-ray diffraction patterns were also made of diopside from Zillerthal, Norway, and acmite from Norway (Fig. 3). The interplanar spacings of the atoms for these minerals were calculated in Angstrom Units ($\times 10^{-8}$ cm.) and corrected by comparison with patterns of sodium chloride. The patterns given by jadeite and chloromelanite proved to be identi-

[15] Wyckoff, R. W. G., Merwin, H. E., and Washington, H. S., *X*-ray Diffraction Measurements upon the Pyroxenes: *Am. Jour. Sci.*, 5th series, vol. **10**, 1925, pp. 383–397.

[16] Doht, R. and Hlawatsch, C., Über einen ägirinähnlichen Pyroxene und den Krokydolit vom Mooseck bei Golling, Salzburg: *Wein Geol. Reich.*, **1913**, pp. 79–95.

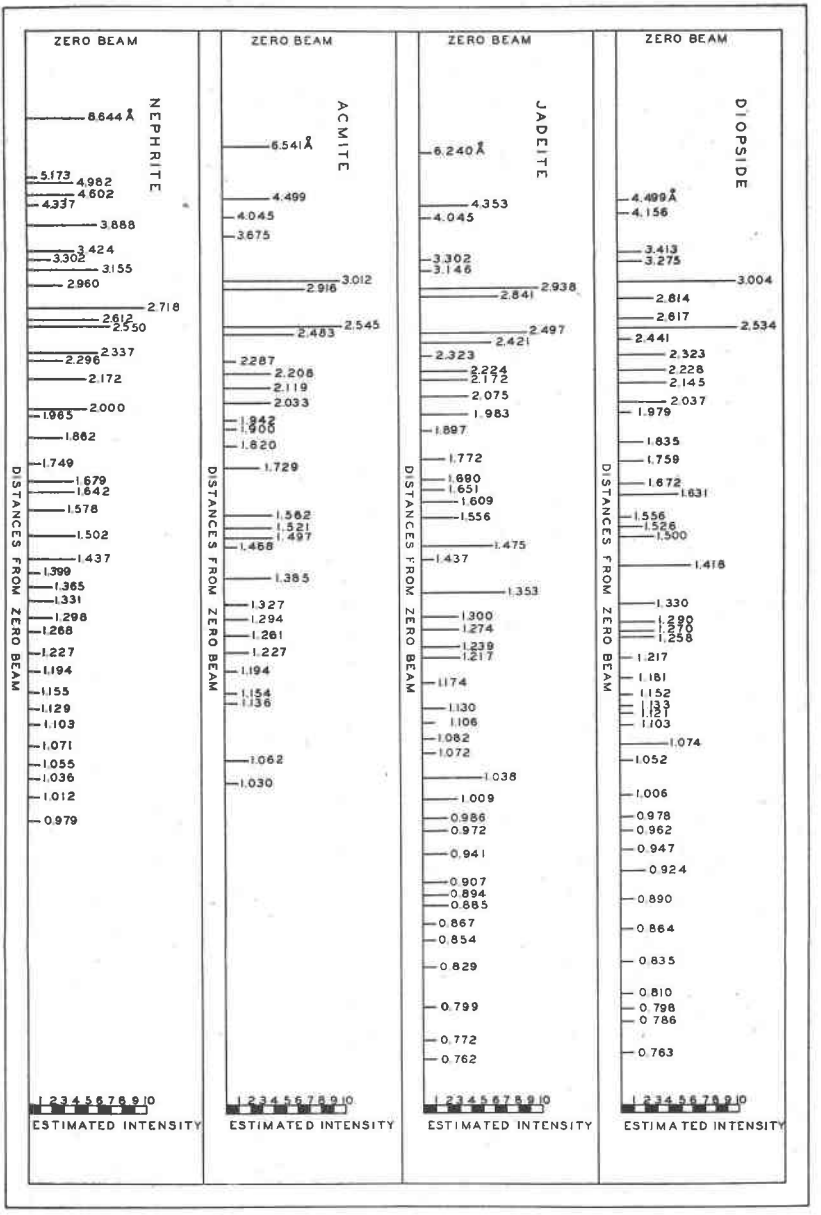

FIG. 3. Chart showing the *x*-ray diffraction lines of diopside, jadeite, acmite, and nephrite.

cal, but quite distinct from either diopside or acmite, although there is apparently a certain similarity. Sufficient analyzed material was not available for an x-ray diffraction study of the effect of the addition of varying amounts of the diopside and the acmite molecules on the interplanar spacing of jadeite.

In the case of the amphibole group, the position of the atoms in the space lattice of tremolite and actinolite have been calculated by Warren from Laue and x-ray spectrometer photographs.[17] He calls attention to the close similarity between the size of the unit cells of tremolite and diopside. The unit cells of actinolite and tremolite are practically identical in size.

TABLE IV

Diopside	Tremolite	Actinolite
$a=9.71$Å	$a=9.78$Å	$a=9.8$Å
$b=8.89$Å	$b=17.8$Å	$b=17.9$Å
$c=5.24$Å	$c=5.26$Å	$c=5.27$Å
$\beta=74°10'$	$\beta=73°58'$	

In the case of the amphibole, tremolite, and the pyroxene, diopside, a, c, and β are said by Warren to be nearly identical. In the case of b, however, the value for diopside is about one-half the 17.8Å of tremolite.

X-ray diffraction photographs were taken of several samples of nephrite from New Zealand, China, and Jordansmühl, Silesia. In addition, patterns were obtained of tremolite from Gullsjo, Sweden, and actinolite from Greiner, Tyrol. The patterns given by all of these minerals proved to be identical.

[17] Warren, B. E., The Crystal Structure and Chemical Composition of the Monoclinic Amphiboles: *Zeit. f. Krist.*, **72**, 1930, pp. 493–518.

Warren, B. E., The Structure of Tremolite $H_2Ca_2Mg_5(SiO_3)_8$: *Zeit. f. Krist.*, **72**, 1929, pp. 42–57.

TABLE V

X-RAY DIFFRACTION MEASUREMENTS

d in Å

Diopside	Jadeite	Acmite	Nephrite
4.499	6.240	6.541	8.644
4.156	4.353	4.499	5.173
3.413	4.045	4.045	4.982
3.275	3.302	3.675	4.602
3.004	3.146	3.012	4.337
2.814	2.938	2.916	3.888
2.617	2.841	2.545	3.424
2.534	2.497	2.483	3.302
2.441	2.421	2.287	3.155
2.323	2.323	2.208	2.960
2.228	2.224	2.119	2.718
2.145	2.172	2.033	2.612
2.037	2.075	1.942	2.550
1.979	1.983	1.900	2.337
1.835	1.897	1.820	2.296
1.759	1.772	1.729	2.172
1.672	1.690	1.562	2.000
1.631	1.651	1.521	1.965
1.556	1.609	1.497	1.862
1.526	1.556	1.468	1.749
1.500	1.475	1.385	1.679
1.418	1.437	1.327	1.642
1.330	1.353	1.294	1.578
1.290	1.300	1.261	1.502
			1.437
1.270	1.274	1.227	1.399
1.258	1.239	1.194	1.365
1.217	1.217	1.154	1.331
1.181	1.174	1.136	1.298
1.152	1.130	1.062	1.268
1.133	1.106	1.030	1.227
1.121	1.082		1.194
1.103	1.072		1.155
1.074	1.038		1.129
1.052	1.009		1.103
1.006	0.986		1.071
0.978	0.972		1.055
0.962	0.941		1.036
0.947	0.907		1.012
0.924	0.894		0.979
0.890	0.885		
0.864	0.867		

TABLE V (*Continued*)
X-RAY DIFFRACTION MEASUREMENTS
d in Å

Diopside	Jadeite	Acmite	Nephrite
0.835	0.854		
0.810	0.829		
0.798	0.799		
0.786	0.772		
0.763	0.762		

Figure 4 is included in order to show the *x*-ray diffraction patterns of the various imitation jade minerals compared with those of jade. It is apparent that all of the patterns are easily distinguished from each other.[18]

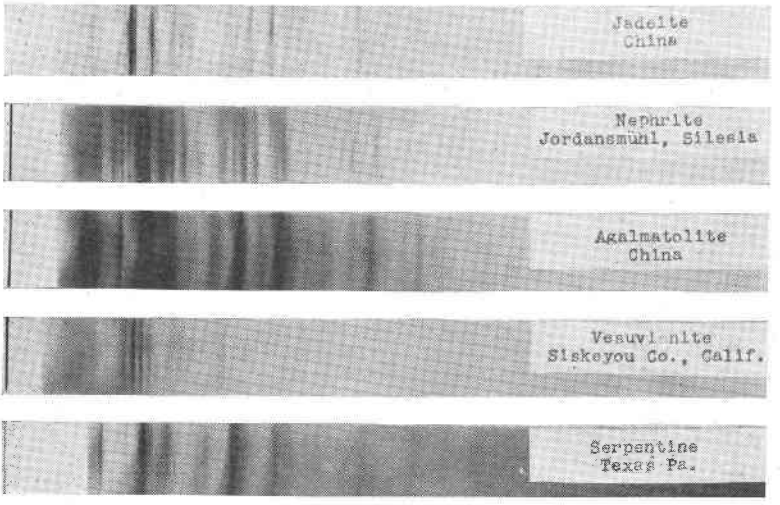

FIG. 4. *X*-ray diffraction patterns of the jade minerals and their common imitations.

[18] Complete *x*-ray diffraction data on grossularite garnet are given by Agar and Krieger. (*Am. Jour. Sci.*, vol. **24**, July, 1932). Garnet, however, is seldom a convincing imitation of jade even in the case of the well known South African variety.

Summary

Physical, optical, and chemical criteria have heretofore been relied upon exclusively in the identification of the jade minerals and their imitations. The identification is often either uncertain or unduly complicated when limited to these methods. It is suggested therefore, that *x*-ray diffraction patterns might be of assistance in identification. A number of *x*-ray diffraction photographs have been taken for comparative purposes to be used in the identification of jade and the more common imitations. The interplanar spacings of the atoms have been calculated for jadeite, the closely related pyroxenes, diopside and acmite, and also for nephrite. In addition to providing criteria for use in identification, comparison of the *x*-ray diffraction measurements agrees with previous *x*-ray work in pointing toward a more consistent classification of pyroxenes and amphiboles when *x*-ray criteria are employed.