LARGE AND SMALL GARNETS FROM FORT WRANGELL, ALASKA

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ABSTRACT

Measurement of 133 garnets from Fort Wrangell, Alaska, shows conclusively that there is an excellent correlation of habit with size. These garnets all show both {110} and {211}. The larger the garnet the more prominent {110}. Numerical and graphical methods for dealing with problems of this type are explained.

INTRODUCTION

It has been pointed out that garnets on the whole conform well to the Donnay-Harker law of crystal morphology[1] which requires that the order of importance of the forms shall be: {211}, {110}, {321}, {100}, {210}, {332}, ... So far as the writer has been able to determine, all garnet crystals show either {211} or {110}, or both, and one or the other is nearly always the dominant form. The predominance of these forms over all other forms is shown by the summary in Table 1, in which are included only the records of forms on garnets whose chemical composition was at least approximately known. Unquestionably the predominance of the two principal forms is much greater than indicated in the table, for, in many cases, the very occurrence of other forms has prompted mineralogists to examine garnets more closely and to report their results.

It seems not unreasonable to suppose that a variation in the habits of garnets might be correlated with variations in composition, and Table 1 shows that such a correlation does exist. For the ugrandite group {110} is definitely the most important form, no other form being known on uvarovite. Pyrope, which is found in ultrabasic rocks, at best shows only a poor suggestion of crystal form. Hintze lists only one "pyrope" for which crystal forms are given and this was excluded from the list because it contains less than 50% of the pyrope end-member. On almandite the two principal forms occur with about equal frequency. Almandite is mostly a constituent of crystalline schists, but some garnets in granitic and related rocks are also essentially almandite. Further distinctions on the basis of paragenesis might permit a finer correlation; for instance, garnets in glaucophane schist are always dodecahedrons.[2] The garnets listed as spessartite in the table include a few igneous and pegmatite garnets in which the spessartite end-member amounts to less than 50%,

[1] Donnay, J. D. H., and Harker, D., A new law of crystal morphology extending the law of Bravais: *Am. Mineral.*, **22** (Palache number), 446–467 (1937).

[2] Pabst, A., The garnets in the glaucophane schists of California: *Am. Mineral.*, **16**, 327–333 (1931).

TABLE 1. SUMMARY OF GARNET HABITS

		{211}	{211} {110}	{110} {211}	{110}	Other combinations	
8 Uvarovites							
	K				1		
	H				6		
	P				1		
	sum				8		
80 Grossularites							
	K	2	2	3	1	4	33%
	H	4	—	13	7	25	51%
	P	1	1	3	10	4	21%
	sum	7	3	19	18	33	42%
75 Andradites							
	K	1	1	2	3	4	36%
	H	6	1	14	11	15	32%
	P	2	—	2	11	2	12%
	sum	9	2	18	25	21	28%
Pyrope		Commonly in anhedral grains					
90 Almandites							
	K	6	4	2	4	—	—
	H	13	9	10	11	5	10%
	P	4	2	4	12	4	15%
	sum	23	15	16	27	9	10%
40 Spessartites							
	K	1	—	—	—	—	—
	H	2	2	2	2	1	11%
	P	14	5	4	3	4	13%
	sum	17	7	6	5	5	12%
293 Garnets		56	27	59	83	68	23%

K, recorded by Kokscharow in Materialien zur Mineralogie Russlands (**1858**).
H, cited by Hintze in Handbuch der Mineralogie (**1897**).
P, recorded in literature since 1897.

for instance, the Ely, Nevada, rhyolite garnet.[3] On spessartites, {211} definitely predominates and thus they show the best agreement with the Donnay-Harker law in this respect.

That garnet composition may be a controlling factor is suggested by the only two syntheses of garnet crystals, recently cited by Donnay.[4] Andradite has been synthesized in dodecahedrons[5] and spessartite in trapezohedrons,[6] the same forms which are dominant, respectively, on natural crystals of these varieties.

Table 1 also shows that combinations involving other forms besides {211} and {110} have been most frequently found on grossularite and andradite. From Table 2 it may be seen that these varieties also show the greatest number of forms. The reason is doubtless that these varieties, being mostly contact garnets, often found in calcareous rocks or vuggy situations, have a better opportunity for a rich development of forms. Hintze records that "the implanted crystals are comparatively richer in forms than the enclosed crystals," but does not point out that this gives rise to a correlation of composition with the richness in forms. Records for garnets lend no support to the view of "small crystals having a richer variety of faces which are less representative of conditions of growth."[7]

The forms are listed in Table 2 in order of their rank according to the Donnay-Harker law. The first seven forms in the list show frequencies in accord with this law, except for a slight preponderance of {110} over {211}. One cannot expect any correspondence for the remaining forms, most of which are very rare.

Though the most conspicuous anomalies with respect to the Donnay-Harker law are restricted to uvarovites and garnets in glaucophane schists, and though other correlations of habit with composition or paragenesis can be traced, this is no explanation of the departures from the law. There is no doubt but that all garnets belong to the space group *Ia3d* and they might all be expected to show the same order of importance of forms.

[3] Pabst, A., Garnets from vesicles in rhyolite near Ely, Nevada: *Am. Mineral.*, **23,** 101–103 (1938).

[4] Donnay, J. D. H., and Faessler, Carl., Trisoctahedral garnet from the Black Lake Region, Quebec: *Univ. Toronto Studies, Geol. Series*, **46,** 19–24 (1941).

[5] Michel, L., Sur la reproduction du grenat melanite et du sphene: *Bull. soc. franç. mineral.*, **15,** 254–257 (1892).

[6] Gorgeu, A., Sur la production artificielle de la spessartine: *Bull. soc. franç. mineral.*, **6,** 283–284 (1883).

[7] Buerger, M. J., The law of complication: *Am. Mineral.*, **21,** 702–714 (1936).

TABLE 2. FORMS RECORDED ON GARNETS OF KNOWN CHARACTER

	Rank after D-H	Grossularite				Andradite				Almandite				Spessartite				All
		K	H	P	Sum	K	H	P	Sum	K	H	P	Sum	K	H	P	Sum	
{211}	1	10	38	9	57	6	36	6	48	11	37	12	60	1	7	27	35	200
{110}	2	9	44	18	71	9	39	15	63	10	32	21	63	—	7	17	24	221
{321}	3	3	13	2	18	—	3	—	3	—	2	3	5	—	1	2	3	29
{100}	4	1	12	2	15	—	7	—	7	—	3	—	3	—	—	1	1	26
{210}	5	—	8	—	8	2	5	—	7	—	—	1	1	—	1	2	3	19
{332}	6	—	5	1	6	—	3	2	5	—	—	—	—	—	1	1	2	13
{431}	7	—	3	—	3	—	3	—	3	—	—	1	1	—	—	—	—	7
{310}	11	—	—	—	—	—	1	—	1	—	—	—	—	—	—	—	—	1
{541}	12	—	1	—	1	—	—	—	—	—	—	—	—	—	—	—	—	1
{111}	14	1	4	—	5	—	1	—	1	—	—	2	2	—	—	—	—	8
{320}	16	—	2	—	2	—	2	—	2	—	—	—	—	—	—	—	—	4
{432}		—	—	—	—	—	1	—	1	—	—	—	—	—	—	—	—	1
{520}		—	—	—	—	—	1	—	1	—	—	—	—	—	—	—	—	1
{433}		—	—	—	—	—	—	—	—	—	1	—	1	—	—	—	—	1
{530}		—	—	—	—	—	1	—	1	—	—	—	—	—	—	—	—	1
{221}		—	1	—	1	—	1	—	1	—	1	—	1	—	—	—	—	3
{610}		—	—	1	1	—	1	—	1	—	—	—	—	—	—	—	—	2
{540}		—	1	—	1	—	—	—	—	—	—	—	—	—	—	—	—	1
{311}		—	—	1	1	—	1	—	1	—	—	—	—	—	—	—	—	2
{322}		—	1	—	1	—	—	—	—	—	—	—	—	—	—	—	—	1
{331}		—	1	—	1	—	—	—	—	—	—	—	—	—	—	—	—	1
{511}		—	—	—	—	—	1	—	1	—	—	—	—	—	—	—	—	1
{533}		—	—	—	—	—	1	—	1	—	—	—	—	—	—	—	—	1
{722}		—	—	—	—	—	1	—	1	—	—	—	—	—	—	—	—	1
{744}		—	—	—	—	—	1	—	1	—	—	—	—	—	—	—	—	1
Number of forms					16				20				9				6	25

K—columns, summary of forms recorded by Kokscharow in Materialien zur Mineralogie Russlands (**1858**).

H—columns, summary of forms cited by Hintze in Handbuch der Mineralogie (**1897**).

P—columns, summary of forms recorded in the literature since 1897.

DESCRIPTION OF MATERIAL

The excellent garnet crystals occurring in great abundance in the crystalline schist near the mouth of the Stikine River, not far from Fort Wrangell, Alaska, have found their way into most mineral collections. Sometime ago the writer noticed that crystals from this locality show a curious correlation of size and habit. With the encouragement of Dr. Donnay, he decided to make a quantitative study of this correlation in the hope that it may throw some light on certain factors affecting habit.

Through the courtesy of Dr. W. F. Foshag, 120 loose crystals and one matrix specimen were borrowed from the United States National Museum for study. This material was supplemented by 15 loose crystals and numerous matrix specimens in the collections of the University of California. All but two of the loose crystals were suitable for measurement.

The occurrence of these garnets has been repeatedly described.[8] They are disseminated through certain beds in schist lying close to intrusive quartz diorite. Buddington[9] now regards them as "probably dynamothermal metamorphic." The crystals measured, and those usually described, are one to three centimeters in diameter, but a large slab in the collections of the University of California is studded on one side with similar garnets only a millimeter or two in diameter. The garnet crystals are very easily separated from the groundmass which consists largely of quartz and mica. As far as could be determined the rock contains no garnet other than the prominent porphyroblasts under discussion.

All of the larger crystals show {211} and {110}. No other forms were seen and none have been reported. Vicinal development is not conspicuous. Striations on both forms, where present, are in the {111} zone. According to Kalb,[10] who ignored the Law of Bravais in his speculation, such garnets belong to Niggli's dodecahedral type and are "minerogenetically older."

All the garnets are deep red and they show little if any variation in color. They are generally fractured but not altered. A thin section through the center of a large crystal shows no birefringence, color, or alteration, and not even a trace of zoning. The crystal shows numerous minute inclusions of quartz. These are arranged in lines and groups by sectors as if governed by garnet growth.

Composition and Properties

An analysis of these garnets by A. F. Kountze was published long ago[11] together with a brief description. With it appears a crystal drawing that corresponds closely to the appearance of the largest of these crystals.

[8] Wright, F. E., and Wright, C. W., The Ketchikan and Wrangell Mining Districts, Alaska: *U. S. Geol. Sur., Bull.* **347** (1908).

Buddington, A. F., Mineral deposits of the Wrangell District: *U. S. Geol. Sur., Bull.* **739,** 51–75 (1923).

Buddington, A. F., and Chapin, Theodore, Geology and mineral deposits of Southeastern Alaska: *U. S. Geol. Sur., Bull.* **800** (1929).

[9] Personal communication, August 12, 1941.

[10] Kalb, G., Vizinalerscheinungen auf den Hauptflächen isoharmonischer Kristallarten: *Zeits. Krist.*, **75,** 311–322 (1930).

[11] Dana, E. S., System of Mineralogy, 6th ed., 442 (**1892**) the last of the "almandite" analyses.

TABLE 3

SiO_2	39.29%		$RO : Al_2O_3 : SiO_2$
Al_2O_3	21.70		2.89: 1.00:3.18
Fe_2O_3	*tr.*		
FeO	30.82		Al=69.6
MnO	1.51		Sp= 3.5
MgO	5.26		Py=21.2
CaO	1.99		Gr= 5.7
	100.57		

The calculation of the end-members is slightly at variance with that of Ford,[12] as is also the determination of the indices given below, but it is in agreement with the end-member composition given by Eskola.[13]

The properties given in Table 4 were all determined on the crystal represented by the spot farthest to the right in Figs. 3 and 4.

TABLE 4

	Calculated[14]	Observed
Lattice constant	11.50Å	11.50±0.01Å
Specific gravity	4.12	4.10
Refractive index	1.797	1.806

The agreement is such as to leave little doubt but that the garnet examined has approximately the composition reported by Kountze for garnets from this locality. The lattice constant was determined from 23 alpha lines on a powder pattern kindly prepared by Mr. W. H. Dore. The specific gravity was determined on the Berman balance. The refractive index was interpolated for the *D* line from measurements on two prisms by the minimum deviation method, using a mercury arc for illumination. They gave the values:—

6234Å	5780Å	5461Å	4358Å	4046Å
1.8025	1.8071	1.8102	1.8261	1.836

To check the uniformity of composition of the garnet, two prisms with angles of about 50° were cut from a large crystal in such a way that the prism edge was a line running from the surface approximately through the center. The indices of refraction were determined at various points along these prisms. No variations exceeding the limits of error were found. The specific gravity of large garnets, small garnets, and chips is

[12] Ford, E. W., A study of the relation existing between the chemical, optical and other physical properties of the members of the garnet group: *Am. Jour. Sci.*, **40,** 33–49 (1915).

[13] Eskola, P., On the eclogites of Norway: *Videns. Skrifter*, I. No. **8,** Christiania (1921).

[14] For a garnet of the composition given in Table 3, from the properties of end-members given by M. Fleischer, The relation between chemical composition and physical properties in the garnet group: *Am. Mineral.*, **22,** 751–759 (1937).

nearly the same. This, together with the thin-section observations, indicates that these garnets vary little, if at all, in composition.

MEASUREMENTS

133 crystals were measured in order to establish the correlation of habit and size among the Fort Wrangell garnets. The crystals were selected solely to cover the maximum range of sizes conveniently measurable and without regard to the habit displayed.

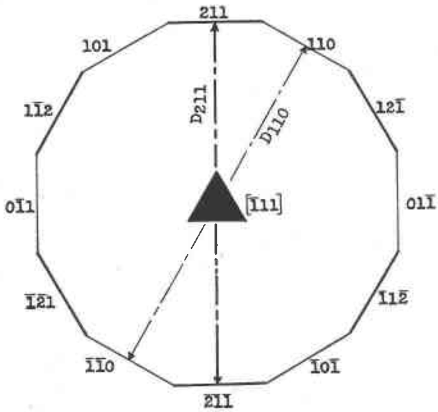


FIG. 1. Cross-section through a garnet crystal normal to a trigonal axis.

The manner in which the garnets were measured may be seen from Fig. 1. Any isometric crystal has 4 trigonal (or hexagonal) zones. The faces of both forms present on these garnets lie in these zones, each (110) face lying in two such zones. The relative sizes of the faces of several forms on a crystal are connected in a simple way with the distances between opposite like faces. The smaller this distance for a given form, relative to the distance for other forms on the same crystal, the larger the faces of the given form. The relations in the present case may easily be seen from Fig. 1. When the distances between opposite faces, $D_{\{110\}}$ and $D_{\{211\}}$, are alike the widths of the faces of both forms are the same. Let $D_{\{110\}}$ and $D_{\{211\}}$ be the mean values of all the D_{110}'s and all the D_{211}'s, respectively, for a given crystal. Let $D_{\{110\}}/D_{\{211\}}$ be called the habit ratio, H. The faces of $\{110\}$ will get relatively narrower as H increases, and vice versa. The limiting values $2/\sqrt{3}$ and $\sqrt{3}/2$, or 1.155 and 0.866, represent the ratios at which $\{110\}$ and $\{211\}$, respectively, disappear. For all crystals showing faces of both forms this ratio must lie between these limiting values. In this way a numerical expression can be given to the habit variation of these garnets. A sample calculation is shown in Table 5.

TABLE 5. MEASUREMENTS OF A GARNET FROM FORT WRANGELL, ALASKA, TO ESTABLISH HABIT AND MALFORMATION

D_{110} $D_{\{110\}}$	$\lvert D_{\{110\}}-D_{110}\rvert$	D_{211} $D_{\{211\}}$	$\lvert D_{\{211\}}-D_{211}\rvert$
1.71 cm.	0.007 cm.	1.64 cm.	0.088 cm.
		1.71	0.018
1.71	0.007	1.82	0.092
		1.69	0.038
1.73	0.027	1.79	0.062
		1.67	0.058
1.75	0.047	1.74	0.012
		1.62	0.108
1.65	0.053	1.79	0.062
		1.75	0.022
1.67	0.033	1.76	0.032
		1.76	0.032
Mean 1.703	Mean 0.029	Mean 1.728	Mean 0.052

Habit: $H=\frac{1.703}{1.728}=0.985.$

Malformation: $M_{\{110\}}=\frac{0.029}{1.703}\times 100=1.64,\qquad M_{\{211\}}=\frac{0.052}{1.728}\times 100=3.00.$

Measurements of distances between opposite faces were made to 0.1 mm. with vernier calipers. From duplicate measurements of half a dozen crystals it was concluded that the average error of H, determined in this way, is well under one per cent.

HABIT VARIATION

The habit variation of these garnets is well exhibited in Fig. 2, which shows that the habit differences of large and small garnets are not connected with any difference in environment. As stated above, there seems to be no compositional variation of the garnets to which the habit differences might be attributed.

The correlation of habit with size can be shown by plotting the habit ratio, H, against $D_{\{211\}}$. This is done in Fig. 3, on which are plotted the values for all 133 garnets measured. The correlation is very good and the distribution of the 14 points representing the "UC specimens" shows that measurement of this small number would have sufficed to indicate the trend.

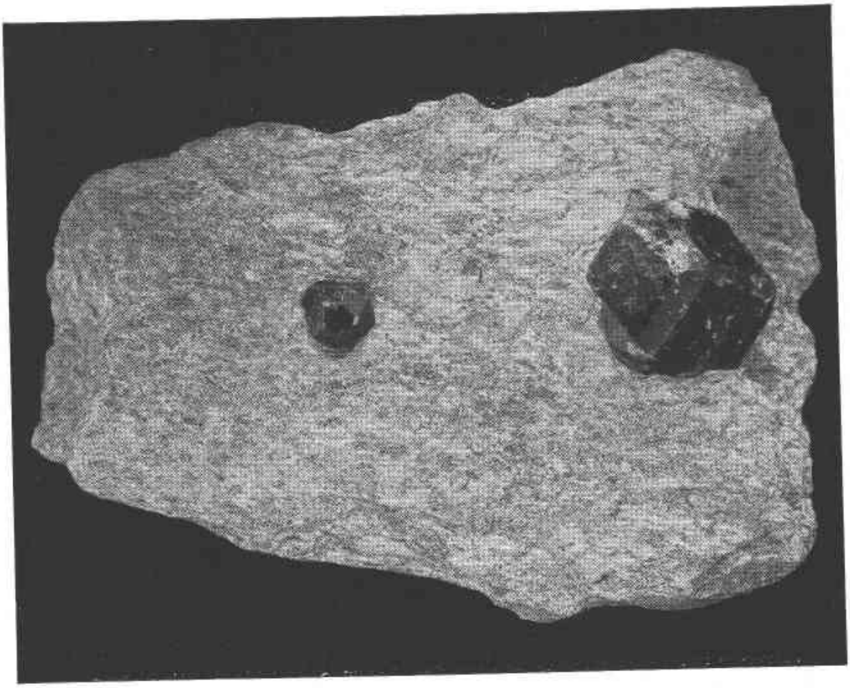


FIG. 2. Two garnets in matrix from Fort Wrangell, Alaska, illustrating variation of habit. Natural size. Specimen lent by the United States National Museum.

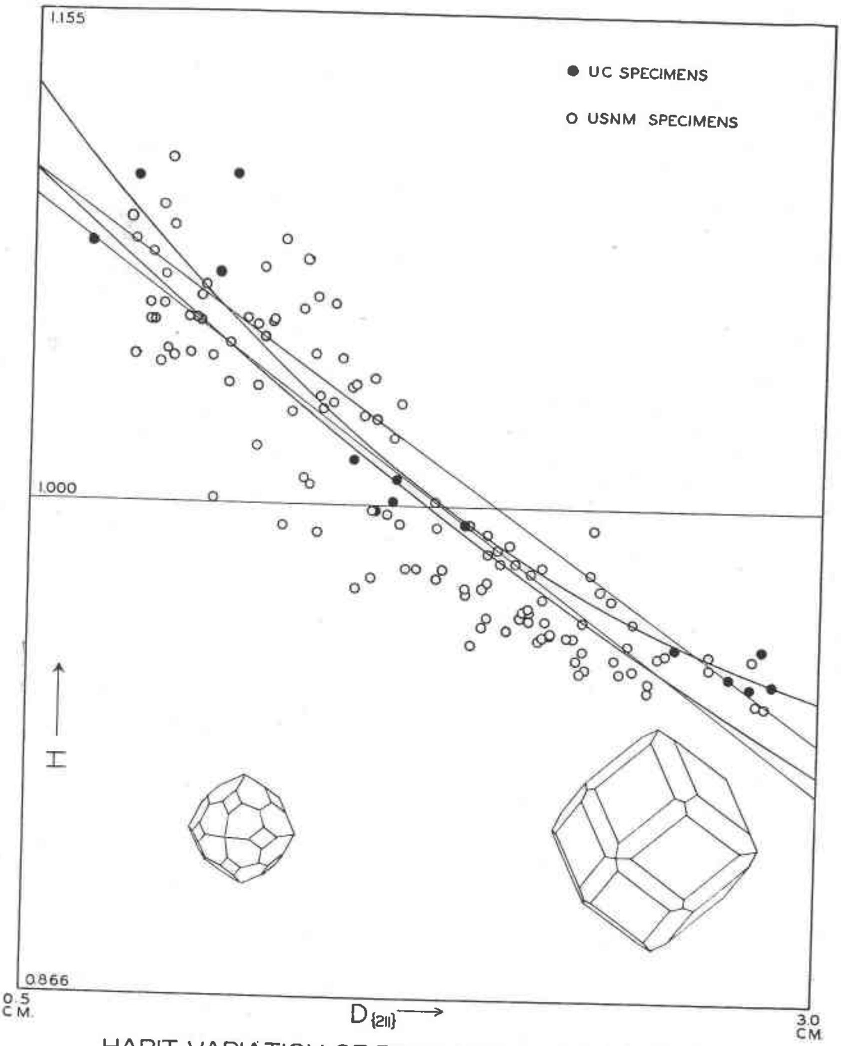
The mean value of H for the UC specimens is 1.008. The equations:—

$$H=1.1395-0.07109\ D_{\{211\}}, \text{ and}$$
$$H=1.196-0.143\ D_{\{211\}}+0.0192(D_{\{211\}})^2,$$

calculated by least squares, represent the trend for the UC specimens and determine the upper line and curve, respectively, in Fig. 3. The mean value of H for all specimens is 1.0063. The equations:—

$$H=1.1336-0.0746\ D_{\{211\}}, \text{ and}$$
$$H=1.1509-0.0968\ D_{\{211\}}+0.00635(D_{\{211\}})^2,$$

calculated in a similar manner, represent the trend for all specimens and determine the lower line and curve, respectively in Fig. 3. An extrapolation is best made from the last equation. Since the first constant is just under the limiting value of H at which {110} disappears, it indicates that very small garnets belonging to this group would still show traces of that form. This is borne out by observation. It was not feasible to make caliper measurements on these very small specimens, but of 15 crystals between 1 and 2 mm. in diameter, examined under a binocular microscope, each showed {211} as the dominant form and some faces of {110}, corresponding to a habit ratio just under 1.155. On these small crystals the (110) faces are very bright and show no vicinal development, whereas the (211) faces are not so bright and are roughly striated parallel to [111].



HABIT VARIATION OF FORT WRANGELL GARNETS

FIG. 3

Extrapolation from the curve based on UC specimens alone would have indicated that garnets under about 3 mm. in diameter would show only {211}. This is not in accord with observations and, of course, the lower curve based on all of the data is a better representation of the trend.

Extrapolating towards the larger values of D one may calculate that, if the trend in the measured range continues, the crystals would show the dodecahedron only when $D_{\{110\}}$ exceeds 3.5 cms.

It may seem arbitrary to handle the data in the manner shown in Fig. 3. One might, for instance, plot H against $D_{\{110\}}$. This gives much the same sort of diagram, as is shown by the equations:—

$$H = 1.1549 - 0.0805\, D_{\{110\}}, \text{ and}$$
$$H = 1.2249 - 0.1685\, D_{\{110\}} + 0.0240(D_{\{110\}})^2,$$

corresponding to the line and curve, respectively, indicating the trend for the 14 UC specimens in such a diagram. The constants in these equations are quite similar to those for the corresponding equations for $D_{\{211\}}$.

Malformation

Table 5 also shows how a measure of the malformation, M, may be obtained from the measurement of distances between opposite like faces on each crystal. For instance, the ratio of the average difference, $|D_{\{211\}} - D_{211}|$, to $D_{\{211\}}$ times one hundred, may be thought of as the percentage of malformation, $M_{\{211\}}$. On an ideal crystal the values of D_{211} would be the same for all parallel pairs of faces, the departure from the mean would be zero and the malformation zero. This sort of measurement can be made independently for each form, or combined for all forms

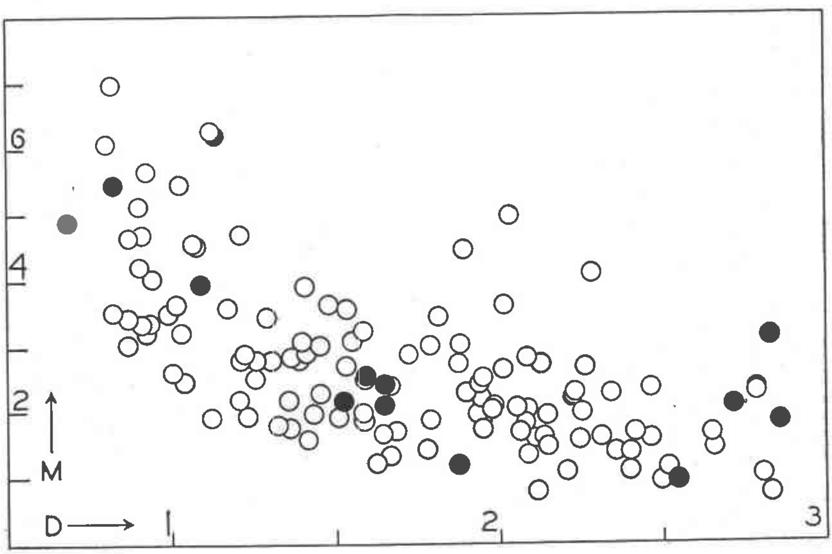


FIG. 4. Malformation of {211} on garnets from Fort Wrangell, Alaska. Open circles—USNM specimens, solid circles—UC specimens.

on a crystal. No additional measurements beyond those previously described are needed.

As noted by several earlier observers, the malformation of these crystals is very slight. Figure 4 shows the malformation of {211} plotted against the diameter. The correlation is not quite so good as for the habit variation, but there is a definite decrease in malformation with increase in size.

A graph similar to Fig. 4 is obtained if $M_{\{110\}}$ is plotted against $D_{\{110\}}$. Since the malformation of {110} is, on the average, considerably less than that of {211}, its variation with size is not as pronounced, but the trend is the same. {110} also tends to show less malformation on the larger crystals.

Since error in the caliper measurements might make a contribution to M and since this contribution would vary inversely with the dimensions, one might suspect that the correlation seen in Fig. 4 is due largely to this cause. To check this point the five smallest of the UC specimens were remeasured after an interval of half a year with the following results:—

H		$M_{\{211\}}$	
First measurement	Remeasurement	First measurement	Remeasurement
1.014	1.021	2.15	2.36
1.072	1.067	3.96	3.74
1.103	1.110	6.22	6.08
1.102	1.100	5.45	5.62
1.081	1.082	4.90	4.45

The near duplication of the original results shows that, at the worst, the error of measurement makes but a slight contribution to M and does not affect the correlation of malformation with size in any important degree.

A further check on these relations may be obtained from the distribution of M with respect to H, shown in Table 6. Comparison of columns 1 and 2 in this table leaves no doubt that {110}, as well as {211}, tends to show greater malformation when H is greater than unity, that is, on the smaller crystals. The table also shows clearly that {211} tends to be more malformed than {110}, regardless of the value of H, but this tendency is slightly stronger on those garnets on which it is the more prominent form.

TABLE 6. CORRELATION OF MALFORMATION WITH HABIT

		$H>1$	$H<1$	All
	Number of garnets	61	72	133
	Percentage of total	46%	54%	
	Average $M_{\{211\}}$	3.41	2.16	2.73
	Average $M_{\{110\}}$	2.48	1.80	2.11
$M_{\{110\}}<M_{\{211\}}$	Number of garnets	47	49	96
	Percentage of group	77%	68%	
	Percentage of total			72%
	Average $M_{\{211\}}$	3.73	2.24	2.97
	Average $M_{\{110\}}$	2.41	1.53	1.96
$M_{\{110\}}>M_{\{211\}}$	Number of garnets	14	23	37
	Percentage of group	23%	32%	
	Percentage of total			28%
	Average $M_{\{211\}}$	2.33	2.01	2.13
	Average $M_{\{110\}}$	2.72	2.36	2.50

CONCLUSION

It seems that as they grow the shapes of these garnets tend to approach more closely to the ideal crystal forms while the departure from the Donnay-Harker law increases.