students, to see the various parts of the projection retaining their original orientation, north always remaining in the north even during rotation of the net for the plotting of new data or auxiliary circles.

For classroom use a number of robust but simpler instruments were cheaply made using standard phonograph axes and turn-tables mounted on plywood. Here again, corks glued around the periphery serve as posts for the attachment of the tracing paper. Rubber shoes below the boards protect table tops from scratching.

THE AMERICAN MINERALOGIST, VOL. 49, MARCH–APRIL, 1964

MORPHOLOGICAL ANALYSIS OF HODGKINSONITE

L. A. HARDIE, JAMES L. MUNOZ, *The Johns Hopkins University, Baltimore, Md.*, GABRIELLE DONNAY, *Geophysical Laboratory, Carnegie Institution of Washington* AND J. D. H. DONNAY, *The Johns Hopkins University, Baltimore, Md.*

Hodgkinsonite, $MnZn_2(OH)_2SiO_4$, is monoclinic with $a:b:c=1.539:1:2.215$; $a=8.17\pm0.02$, $b=5.31\pm0.005$, $c=11.76\pm0.01$ Å, $\beta=95°28'\pm15'$; and space group $P2_1/a$ (Rentzeperis, 1958). Its morphology shows some striking anomalies to the first generalization of the law of Bravais (Donnay and Harker, 1937). It was therefore decided to analyze these anomalies to find whether they might give information concerning the bonding between atoms in the crystal structure, in accordance with the second generalization (Donnay and Donnay, 1961).

A theoretical list of interplanar distances for hodgkinsonite was computed on the IBM 7094 of the Johns Hopkins University Computation Center, by means of a program written by Charles W. Burnham. This program lists the d(*hkl*) values in decreasing order, using the correct multiple indices required by the space group. According to the first generalization of the law of Bravais, this theoretical sequence should closely correspond with the list of the forms arranged in decreasing order of observed morphological importance (frequency of occurrence and relative size).

The observed list was prepared from drawings and projections of measured hodgkinsonite crystals (Palache, 1935). The rank of a form was determined only by the number of times it occurs on the drawings. No discrimination among the forms that appear only once or twice was attempted. Although hodgkinsonite shows considerable variation in habit, attempts to treat the data in separate classes by recognizing several habits had to be abandoned. The Palache symbols were transformed to fit the structural cell, by multiplying *l* by 2: thus, Palache's *p*(111) becomes (112) and his *r*(221) becomes (111). A gnomonic projection (Fig. 1) shows the observed forms and their relative importances.

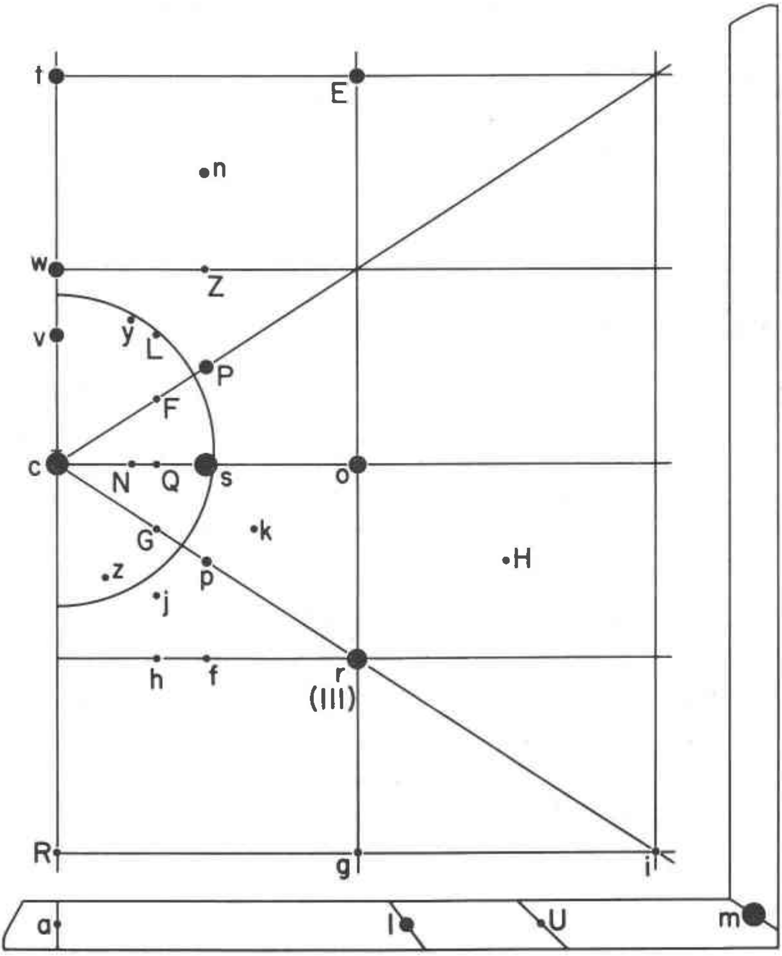

FIG. 1. Gnomonic projection of hodgkinsonite. Relative sizes of the poles indicate relative frequencies of occurrence of the crystal forms.

The form symbols (Table 1) are arranged in order of decreasing calculated d values. Each observed form is shown in the left-hand column by its form letter and the number of times it occurs. A dash in that column means that the form has not been observed. Several orders may have been calculated for some forms; examples: 001, 002, 003, 004; 200, 400.

TABLE 1. COMPARISON OF OBSERVED AND PREDICTED SEQUENCES OF FORMS FOR HODGKINSONITE

(a:b:c=1.539:1:2.215, β=95°28′, Rentzeperis, 1958)

Forms and frequencies	No condition *hkl*	*h* even *h*0*l*	No condition 0*kl*	*l* even 0*kl*	*k* even 0*k*0	*h* even *h*00 00*l*	Forms and frequencies	No condition *hkl*	*h* even *h*0*l*	No condition 0*kl*	*l* even 0*kl*	*k* even 0*k*0	*h* even *h*00 00*l*
c(17)						001	—		204				
(*c*)						002	—	$\bar{2}14$					
o(12)			011				—	$\bar{2}21$					
m(18)	110						—			023			
—	$\bar{1}11$						—	312					
r(15)	111						*i*(*rare*)	221					
a(*rare*)						200	—	$\bar{1}23$					
t(11)		$\bar{2}01$					—			015			
s(18)			012	012			—	$\bar{3}13$					
(*c*)						003	—		$\bar{2}05$				
R(2)		201					—	$\bar{1}15$					
P(6)	$\bar{1}12$						—	$\bar{2}22$					
w(9)		$\bar{2}02$					*k*(*rare*)	123					
p(6)	112						—	214					
l(10)	210						—		$\bar{4}01$				
—		202					(*a*)						400
E(8)	$\bar{2}11$						—	115					
Q(*rare*)			013				—		$\bar{4}02$				
g(2)	211						*h*(*rare*)	313					
F(2)	$\bar{1}13$						—	$\bar{2}23$					
v(8)		$\bar{2}03$					—		401				
(*c*)						004	—	$\bar{2}15$					
Z(*rare*)	$\bar{2}12$						—		205				
G(*rare*)	113						*y*(3)	$\bar{3}14$					
f(2)	212						—	$\bar{1}24$					
—		203					—	$\bar{4}11$					
—					020		—	410					
—			021				*U*(*rare*)	320					
L(*rare*)	$\bar{2}13$							·					
N(*rare*)			014	014				·					
—	120							·					
—	$\bar{1}14$						*A*(2)	$\bar{1}31$					
—		$\bar{2}04$						·					
—	$\bar{1}21$							·					
—	121							·					
(*o*)			—	022			*z*(4)	315					
—	310										·		
M(*rare*)	$\bar{3}11$										·		
J(*rare*)	213										·		
—	114						(*Q*)				026		
—	$\bar{1}22$											·	
(*c*)						005						·	
—	311											·	
n(5)	$\bar{3}12$						—					040	
—	122												

The following anomalies can be clearly seen (Table 1):

A. Forms anomalously absent:

1. Form ($\bar{1}11$) should be among the most important ones, but in fact it has never been observed.

2. The same remark applies to (202).
3. The pinacoid (010), which is symbolized (020) according to space group $P2_1/a$, has not been observed.

B. Forms that are present but out of place in the list:

1. *a*(200) is assigned much too great a theoretical importance.
2. The same remark applies, to a lesser degree, to *R*(201), *g*(211), and *F*($\bar{1}$13). These forms should go down the list.
3. *n*($\bar{3}$12), *y*($\bar{3}$14), *z*(315), and possibly *A*($\bar{1}$31) receive too little theoretical importance: one would expect to see them somewhat higher in the list.

Experience has shown that only the most frequent forms can be expected to obey the law of Bravais. The theoretical list for hodgkinsonite may cease to be significant beyond form *f*(212) or even beyond form *E*($\bar{2}$11). As regards ($\bar{1}$11), could it be that this form should be written ($\bar{2}$22), so that the linear projection of the structure onto the reciprocal lattice vector $L^*(\bar{1}11)$ would have its period halved for the bond assemblage?

It is known that faces in a zone can be compared (as to relative importances) more reliably than non-tautozonal faces. This is why the analysis of zones should accompany the calculation of the d values.

In the case of hodgkinsonite (Fig. 1) the three zones that intersect in *r*(111) are: *i*(221), *r*(111), *p*(112), *G*(113); *r*(111), *g*(211); *r*(111), *f*(212), *h*(313). As to frequencies, *r* is the most common (*hkl*), *p* comes ahead of *G*, *f* ahead of *h* (Table 1). These facts establish that all three central zones are of the simple type and, consequently, that the bond assemblage has the same primitive lattice as the crystal structure. In other words the structural cell and the morphological cell are identical. We note a glaring anomaly in the negative-*h* quadrant: the absence of form ($\bar{1}$11), in whose pole the central zones meet. Two of these zones are of the simple type: *P*($\bar{1}$12), *F*($\bar{1}$13); *E*($\bar{2}$11), *M*($\bar{3}$11); but the third one cannot be interpreted because of another absence, that of ($\bar{1}$21). Although these anomalies remain unexplained, they cannot invalidate the conclusion based on the zones in the first quadrant, namely the primitive mode of the morphological lattice.

Consider now the (*h*0*l*) faces, which are perpendicular to the symmetry plane. According to *x*-ray results the zone should be of the simple type with dominant forms (201) and ($\bar{2}$01), inasmuch as the *a* glide plane demands that *h* be even. In the negative-*h* segment, the zone is indeed simple: *t*($\bar{2}$01), *w*($\bar{2}$02), *v*($\bar{2}$03), in order of decreasing importance. In the positive-*h* segment only one form is known; it is *R*(201), as required. Although it is hard to see how (202) can be missing when *w* and *v* are observed (Fig. 1), the conclusion remains that the *a* glide plane governs both structure and morphology: in the planar projection onto *ca* the two-dimensional bond assemblage and the projected structure have the same mesh (*c*, *a*/2).

The (0*kl*) faces are not perpendicular to any plane of symmetry and should, therefore, be governed by the lattice. Since the latter is primitive, the zone should be simple with (011) dominant: *o*(011), *s*(012), *Q*(013), *N*(014). The relative frequencies of *o* and *s*, 12 against 18 (Table 1), would suggest that *s* should be taken as the dominant, *s*(012), with *N*(014) and *o*(022), while *Q* would become (026). (In this interpretation, *l* must be even.) The observed facts do not discriminate between *N* and *Q*: both forms are rare, and will fit either interpretation. If the second one be correct, then morphology would indicate that the period of the bond assemblage in the *bc* projection is (*b*, *c*/2). Consider the two columns headed 0*kl* (Table 1). The first interpretation ("no condition") is objectionable because *o*(011) comes ahead of *s* and (021), unknown, precedes *N*. The second interpretation ("*l* even") is unsatisfactory because *o*(022) is relegated far down the list among rare and unknown forms. It is hard to decide. As regards the total list of forms, the first choice may be the better one; as regards zone development, the second is preferable.

The zone of the (*hk*0)'s is definitely of the simple type, as required by the structural lattice: *m*(110) dominant, followed by *l*(210) common, and *U*(320) rare. Anomalous are the following unobserved forms: (120) and (310), which it is true occur among rare forms in the theoretical list (Table 1).

As to the side pinacoid, it is not observed. The space-group requires it to be symbolized (020). A large number of forms with smaller interplanar distances than *d*(020) have been observed (Table 1). Although most of them are rare forms, it may be necessary to call the side pinacoid (040). This would mean that, in linear projection onto the *y* axis, the bond assemblage has period *b*/4, whereas the crystal structure has *b*/2.

The *c* and *a* pinacoids are not essentially different from any other (*h*0*l*) pinacoid, since the choice of the coordinate axes in the plane perpendicular to *y* is not dictated by symmetry.[1] In view of its high frequency of occurrence, *c* could well be symbolized (001) as required by space group, although (002) or (003) would fit the facts just as well, but (004) would not be acceptable. Pinacoid *a* is rare: (400) would probably be a better symbol than (200), which is what the space group demands.

The results of the foregoing analysis (Table 2) are of various qualities. The 3-dimensional conclusion is definite: both the crystal structure and the bond assemblage have the same periodicity. The 2-dimensional conclusions are definite only as regards the planar projections onto *xz* and *xy*: in the former the period of the bond assemblage is (*a*/2, *c*); in the

---

[1] This truism obviously bears repeating: a paper has been written (and published!) whose only structural contribution is the proposal that Rentzeperis' axes *a* and *c* be interchanged (Roberts and Quodling, 1962). [Erratum: In that paper, p. 344, the transformation matrix should read $00 2/0\bar{1}0/100$ instead of $001/0\bar{2}0/200$.]

Table 2. Reciprocal-Lattice Periods for Structure and Bond Assemblage (Morphology)

	3-dimensional	2-dimensional			1-dimensional		
	hkl	$h0l$	$hk0$	$0kl$	$0k0$	$00l$	$h00$
Structural	a^*, b^*, c^*	$2a^*, c^*$	a^*, b^*	b^*, c^*	$2b^*$	c^*	$2a^*$
Morphological	a^*, b^*, c^*	$2a^*, c^*$	a^*, b^*	b^*, c^* or $b^*, 2c^*$	$4b^*$	c^*	$4a^*$

latter, it is (a, b). As to the yz projection, the period of the bond assemblage could be either (b, c) or $(b, c/2)$. The 1-dimensional conclusions are tentative: the periods of the linear projections on y, z, x, which are $b/2$, c, and $a/2$, for the structure, probably are $b/4$, and c, $a/4$, for the bond assemblage. (Note that, in the yz projection, the projection lines are parallel to the x axis; in the z projection, the projection planes are parallel to xy.) The morphological data of hodgkinsonite are not sufficient to warrant more definite conclusions.

Note added in proof: The structure of hodgkinsonite has now been published by Rentzeperis (*Zeit. Krist.* **119,** 117–138, 1963).

References

Donnay, J. D. H. and G. Donnay (1961) "Assemblage liaisons" et structure cristalline, *Compt. Rend. Acad. Sci. Paris,* **252,** 908–909; see also, **252,** 1982–1983, 1961; **253,** 291–292, 1961.

——— and D. Harker (1937) Généralisation de la loi de Bravais, *Compt. Rend. Acad. Sci. Paris,* **204,** 274–276.

Palache, C. (1935) The minerals of Franklin and Sterling Hill, Sussex County, New Jersey, *U. S. Geol. Survey Prof. Paper* **180.**

Rentzeperis, P. J. (1958) The unit cell and space group of hodgkinsonite, *Acta Cryst.* **11,** 448.

Roberts, W. M. B. and F. M. Quodling (1962) X-ray, optical, and morphological observations on hodgkinsonite from Franklin Furnace. *Mineral. Mag.* **33,** 343–346.

THE AMERICAN MINERALOGIST, VOL. 49, MARCH–APRIL, 1964

A CHROME-NICKEL PENNINE FROM SERPENTINITE, JAMBUR CHROMITE MINES, MYSORE STATE, INDIA

S. Varadarajan,[1] *Banaras Hindu University, India.*

The bluish green variety of chlorite occurring in the form of small veins in the serpentinite mass, adjacent to chromite veins, in the Jambur

---

[1] Present address: Dept. Geol., Central College, Bangalore, India.