

TRANSLATION-GLIDING IN CRYSTALS OF THE NaCl STRUCTURAL TYPE.

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ABSTRACT

The translation-gliding elements recorded for various crystals of the NaCl structural type display an unexpected lack of similarity for crystals of the same structure. New experiments indicate that the gliding elements recorded for NaF, NaCl, KCl, KBr, and KI. In addition, NaBr, NaJ and PbTe have been investigated for gliding. All of the NaCl-like crystals, NaF, NaCl, NaBr, NaI, KCl, KBr, KI, PbS and PbTe glide with $T = (001)$, $t = [1\bar{1}0]$. Of these, all but PbS and PbTe also glide with $T = (110)$, $t = [1\bar{1}0]$, as do also high-NH₄I, RbCl, and MgO; these are the usual halite gliding elements. The gliding is shown to be dependent on crystal structure; t is determined by rows of nearest like charged ions; T is dependent on ion radius ratio as well as on the polarizabilities of the ions involved. These factors influencing gliding are operative also in all other crystals for which both structural and gliding are sufficiently complete to allow of correlations.

INTRODUCTION

As early as 1902, Johnsen recognized the desirability of investigating translation-gliding in the simple alkali haloids as a step toward understanding this type of plastic deformation in more complicated crystals. To quote from his paper devoted to an extended investigation of these salts, Johnsen says, in translation:

“It appears of interest to investigate an entire series of chemically analogous substances for their translation capabilities; the isometric haloid salts of the alkalis are thus especially designated since crystals are, in part, easy to obtain, well cleavable, and besides, translation has already been demonstrated in NaCl and KCl by Mügge. Eventually a relation between gliding elements and structure will become known first of all for isometric substances; here all the relative distances of the lattice points for each of the three possible space lattices are known.”¹

Since these words were written, the structures of all of the simpler substances investigated by Johnsen have become known through the efforts of students of X-rays, but no great interest appears to have been taken in the possible relations of translation-

¹ A. Johnsen, Biegungen und Translationen: *Neues Jahrbuch f. Min., Geol., u. Pal.*, 1902, II, p. 145.

gliding to structure. Perhaps the simplest start on this problem is to investigate the gliding characteristics of a number of crystals having identical structures, differing only in the ions of which they are composed. The NaCl structural type is especially indicated in this research, not only because numerous substances known to translation-glide belong to this type, but because no less than four different sets of gliding elements have been recorded² for its various members, namely:

	<i>t</i>	<i>T</i>
PbS	{ [110]	(001)
	{ [100]	(001)
NaF	[001]	(110)
NaCl	}	[110] (110)
KCl		
KBr		
KI		
RbCl		
High-NH ₄ I		
MgO		

If mode of gliding is regarded as a function of crystal structure, as it must be, the different gliding behaviors of these structurally similar crystals appear to present an anomaly. Since, in several instances, the experimental methods upon which the above tabulated elements are based were not critical, a possible explanation of the anomaly is erroneous data, and it was considered desirable to repeat the investigation of gliding in all but RbCl, high-NH₄I and MgO, as well as to extend the data by investigating PbTe, NaBr and NaI.

It has proved fortunate that some of the earlier work has been repeated, not only because more desirable data have been obtained for some species, but because one error in previously deduced gliding elements (NaF) has been corrected and two entirely new sets of elements established for the NaCl-like alkali haloids.

THE GLIDING DATA

GALENA

The usual gliding elements of galena, $t = [1\bar{1}0]$, $T = (001)$, have been discussed in a previous paper.³ The unusual set of elements $t =$

² See tabulation of data in: M. J. Buerger, Translation-gliding in crystals: *American Mineralogist*, **15**, 1930, p. 64.

³ M. J. Buerger, The Plastic Deformation of Ore Minerals: Pt. I, *American Mineralogist*, **13**, 1928, pp. 6-11.

[100], $T = (001)$ were advanced by Taricco,⁴ and confirmed by Mügge⁵ as an explanation of a peculiar percussion figure ("Taricco's figure"). If a sharp needle is gently tapped, as with a pencil, on a broad, very thin, galena cleavage flake, a minute striated hole is produced with edges and striations parallel to the other two cleavages. On the opposite broad cleavage surface arises a corresponding elevation. The mechanism is interpreted as pushing through a set of coaxial square prisms, with faces parallel to (100) and (010), in the direction $[00\bar{1}]$. This gives gliding elements: $T = (100)$, $t = [00\bar{1}]$ or the equivalent $T = (001)$, $t = [100]$.

ALTAITE

Through the courtesy of Mr. A. C. Abbott, the writer was able to obtain altaite from the 800 ft. level of the Lake Shore Mine, Kirkland Lake, Ontario. It was possible to extract cleavage pieces of about a millimeter's length from the specimens.

It was observed that in attempting to break off cleavage pieces, the desired portion of the mineral became covered with striae parallel to cleavage traces on all cleavage faces, as well as on surfaces of conchoidal fracture, due to easy plastic deformation. Such striae can only result from gliding with elements $T = (001)$, $t = [hk0]$. The indices can be easily evaluated in this case by the pressure figure.

If a cleavage piece is placed upon a somewhat yielding surface, such as a blotter, and a thin needle with a rounded point is pressed against the upper cleavage surface with the force directed normal to this, a shallow, somewhat rounded, four-sided, pyramidal hole or pit is produced about the needle point, and a corresponding identical elevation is raised on the opposite cleavage face below. The sides of the pit have the attitude of pseudo faces ($h\bar{h}l$), and thus the border of the pyramid with the cleavage corresponds to four cube-face diagonals. Both pit and elevation are as free from striations as the original cleavage face, consequently only (001) can be the plane of slipping. The border of the pit with the undisturbed cleavage surface, (001), thus marks the folding direction, f , as $[110]$. Consequently $t = [1\bar{1}0]$. This pressure figure is identical

⁴ Michele Taricco, Solidi di scorrimento nella galena: *Atti della Reale Accademia dei Lincei*, 19, 1910, pp. 508-511.

⁵ O. Mügge, Über Translationen am Phosgenit und Bleiglanz: *Neues Jahrbuch*, 1914, I, pp. 48-51.

in origin with Bauer's pressure figure on galena⁶ as interpreted by Mügge,⁷ Altaite thus behaves precisely as galena, having elements, $T = (001)$, $t = [\bar{1}\bar{1}0]$, but is much more plastic.

Sufficiently large pieces of altaite were not obtainable to test for Taricco's figure.

PERICLASE

Mügge⁸ embedded periclase crystals in saltpeter within a steel cylinder and found that pressure produced striae on the cube faces only parallel to the cube edge, while on the octahedral faces only normal to a cube-octahedral edge. This places the attitude of the glide plane as $T = (110)$ and gives the glide direction $t = [\bar{1}\bar{1}0]$.

SODIUM FLUORIDE

Johnsen⁹ experimented with crystals of NaF derived from a water solution of this difficultly soluble and poisonous salt. The crystals were small octahedrons occasionally combined with cubes, having edge lengths of less than 1 millimeter. By pressing (normal to (111) ?) there resulted on $\{111\}$, striae parallel to the edge $[(111):(1\bar{1}\bar{1})]$, but no optical alteration appeared. Johnsen says:

"Accordingly T would apparently be either $= \{111\}$ or $\{110\}$.

"On cleavage faces, one obtains from pricks with a fine needle, four, somewhat faded, weakly birefringent striae which radiate from the prick point and run parallel to cleavage traces; X is parallel to their long directions. Since, for piezo-optical phenomena, the directions $[100]$ are axes of isotropy we must trace back these striae to the friction linked up with translation, and interpret their directions as traces of the plane T . Accordingly T is $= \{110\}$. Due to the gliding friction along T , the arising deformation allows the vibrations occurring to be regarded as if in the direction t ; this would only

⁶ Max Bauer, Beiträge zur Mineralogie; (5) Über das Vorkommen von Gleitflächen am Bleiglanz: *Neues Jahrbuch*, 1882, I, pp. 138-150.

⁷ O. Mügge, Ueber Translationen und verwandte Erscheinungen in Krystallen: *Neues Jahrbuch*, 1898, I, pp. 123-138.

⁸ O. Mügge, Über Translationen am Schwefel, Periklas und Kupferkies und einfache Schiebungen am Bourmonit, Pyrrargyrit, Kupferglanz und Silberkupferglanz: *Neues Jahrbuch*, 1920, pp. 29-30.

⁹ A. Johnsen, Biegungen und Translationen: *Neues Jahrbuch f. Min., etc.* 1902, II, pp. 148-149.

perceptibly influence such rays, one of whose vibration directions coincided with t , and the other vibration direction of both polarized emerging ray bundles must lie normal to, or parallel with, t . Thus there results, then, $t = [001]$."

So far as the writer has been able to determine, the relations between birefringence and translation elements employed by Johnsen do not yield critical results. Both deformed sodium fluoride and deformed sodium chloride do show birefringence, but this is rather irregularly distributed. When $\{100\}$ planes are parallel with nicol directions, an irregular, patchy birefringence appears which gives an indistinct impression of being localized along $\{110\}$ planes, but if $\{110\}$ planes are parallel with nicol directions, the same phenomenon appears to localize itself along $\{100\}$ planes. The optical evidence is confusing and very indistinct, to say the least, and can not be relied upon; the evidence of striation distribution, however, is indisputable and should alone receive consideration.

In the writer's experiments, good crystals were obtained by evaporating a saturated water solution of sodium fluoride in a covered beaker within an autoclave held at $80^\circ \pm 2^\circ$ Centigrade. Crystals between a half millimeter and a half centimeter edge length were easily grown in this manner, the only form appearing being the cube. These displayed pseudo-monocrystallinity, made manifest by the mosaic on crystal faces and cleavage surfaces. All were very weakly birefringent in patches, a characteristic of natural villiaumite.

A series of preliminary tests were first made by pressing cubes in a vise, protected by sheet cork or blotting paper backing. The crystals were pressed parallel to $[001]$, $[110]$ and $[111]$. Only with pressure in the $[001]$ direction did striae appear, although all cubes showed some traces of plastic deformation in the form of very slight curvature of faces. The crystals pressed parallel to $[001]$ at times displayed faint striae running normal to the pressure direction on the unpressed cube faces. Greater pressure than required to produce these faint striae invariably produced shattering.

Very good results, however, were obtained by embedding crystals in sulfur within a steel cylinder of one centimeter bore. A piston load of 5,000 pounds was first applied to a cube in the $[001]$ direction. This produced two sets of striae on (001) and $(00\bar{1})$ parallel to the cube edges, and one set of striae normal to the pres-

sure direction on (100), (010), $(\bar{1}00)$ and $(0\bar{1}0)$. The (001) and $(00\bar{1})$ faces had taken on a convex curvature near their edges, while the other cube faces had acquired a concave curvature on their respective edges with (001) and $(00\bar{1})$, as shown in figure 1. The dis-

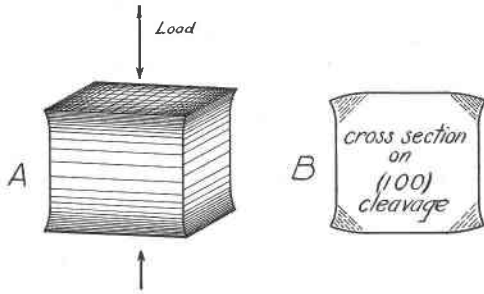


FIG. 1.

position of striae and the curvatures, taken together, indicate a translation $T = (hOl)$, $t = [\bar{l}Oh]$.

In order to confirm this conclusion, another experiment was performed as before, except that the load was applied parallel to $[110]$. The resulting striae and curvatures are indicated in figure 2.

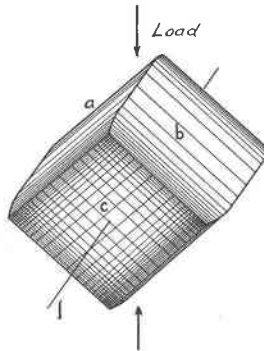


FIG. 2.

The absolute evaluation of h and l necessitates the trace of the glide plane being observed on some form other than the cube. While no determined effort has been made, as yet, to grow crystals with forms other than the cube, it appears quite likely that h and l are each unity from a correlation of curvatures on adjoining cube faces of deformed crystals.

After it had been ascertained that the other, softer, NaCl-like alkali haloids also glide on cube planes (see beyond), an attempt

was made to duplicate this behavior in sodium fluoride. A cube was pressed parallel to $[110]$ with the piston load increased to 15,000 pounds. The only striations which appeared were these indicated in figure 2, showing that the greatest part of the deformation took place with gliding elements as above, but there resulted a slight but very distinct alteration of the cube angles after the manner of those shown in figure 3, and new cleavages made slight angles with the

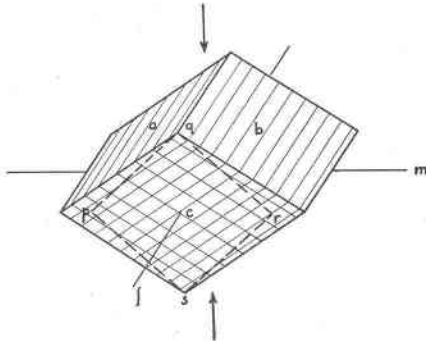


FIG. 3.

deformed cube faces. A further discussion of this effect will be found under sodium chloride. There is thus poor, but reasonable evidence that T' is (100) in sodium fluoride also.

HALITE

Reusch¹⁰ was the first to deduce gliding elements of any sort. He found that by pressing a cleavage piece of halite normal to (001) , it showed birefringent sheets making angles of 45° with the pressure direction when examined through (100) , (010) , $(\bar{1}00)$ or $(0\bar{1}0)$. On these surfaces he also observed striae all of which ran normal to the pressure direction. Thus he concluded that halite deforms in a plastic way by a slipping of $\{101\}$ sheets in $[10\bar{1}]$ directions.

Mügge¹¹ elaborated on Reusch's research and investigated in some detail the apparent bending of halite cleavage flakes about $[001]$. Johnsen,¹² working with artificial sodium chloride octahe-

¹⁰ E. Reusch, Ueber eine besondere Gattung von Durchgängen im Steinsalz und Kalkspath: *Ann. der Physik und Chemie*, **132**, 1867, pp. 443-444, and pp. 449-450.

¹¹ O. Mügge, Ueber Translationen und verwandte Erscheinungen in Krystallen: *Neues Jahrbuch*, **1898**, I, pp. 138-145.

¹² A. Johnsen, Biegungen und Translationen: *Neues Jahrbuch*, **1902**, II, p. 146.

drons precipitated from a urea-bearing solution, obtained similar translation elements.

The writer's experiments were performed both on cleavages of halite from an unknown locality, and on cleavages from artificial cubes precipitated by evaporating a saturated water solution of "C. P." sodium chloride at 80°C. The translation $T = (011)$, $t = [01\bar{1}]$ may be clearly demonstrated as follows: A binocular micro-

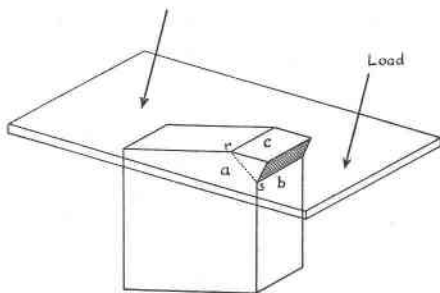


FIG. 4.

scope is focused upon the upper surface of a small cleavage cube. A microscope object glass is then placed on the upper cleavage, tilted slightly about a cube edge, and pressure applied to the object glass (fig. 4), while the process is watched through the glass with the aid of the binoculars. The crystal is sufficiently plastic to flow and make true optical contact with the object glass; meanwhile a portion of the crystal in the vicinity of the cube edge is displaced as shown in figure 4. Due to the ease of flow, pseudo-face c is an accurate cast of the glass surface and thus remains striationless. Face a is also striationless since this is in the zone t , while b is quite concave and covered with horizontal striae near the edge $b:c$. Looking directly at the face a , the disturbed part of the crystal can be seen in profile, and the more or less distinct limit of the disturbance, rs , has an approximate slope of 45°. This demonstration that T is (011) and t is $[01\bar{1}]$ is not rigorous, since the same effect would also be brought about by slipping along two planes symmetrically situated about the edge $c:b$. Nevertheless, it is the best that can be obtained from the cube form alone, and has been used in obtaining the gliding elements of the other NaCl-like alkali haloids from their cleavage cubes. The method has the advantage over others in that only one set of (011) planes function at once, and thus confusion is avoided.

Since galena has the same structure as halite, it was thought possible that it also might have gliding elements $T = (011)$, $t = [01\bar{1}]$, as yet unsearched for, as well as its more usual elements $T = (001)$, $t = [1\bar{1}0]$. Tested as above, however, galena shows an inability to glide with the usual halite elements.

On the other hand, these usually quoted gliding elements for halite are not the only ones it may display; there are at least two others. This was discovered in the application of a simple criterion for distinguishing the two sets of gliding elements:

$$(a) T = (110), t = [\bar{1}\bar{1}0]$$

$$(b) T = (001), t = [1\bar{1}0]$$

If a cube is loaded normal to (110), the elements (a) give rise to the striae and shape distortion pictured in figure 2, elements (b) give rise to those of figure 3. Several halite cleavage cubes thus oriented, were embedded in sulfur within steel cylinders and pressure applied. The crystals, however, proved to be so plastic that the individual sulfur grains left their impressions on all previously lustrous cleavage faces and roughened them to such an extent that there was no possibility of discerning the delicate striae. Nevertheless, this important fact was noticed; instead of elongating in the direction l , figure 2, as would be expected if (110) alone functions as T , the deformed crystal was remarkably elongated in the direction of m , figure 3, and of practically the original dimension along l . The cube angles were strongly altered, as shown in figure 3. New cleavage surfaces followed along pq , qr , rs , and sq , figure 3, at an angle to the attitude of the erstwhile cube surfaces. Now, such a condition can not result from gliding along $\{110\}$ alone with the load as shown, but must result, at least in greater part, from gliding along cube planes if planes of index numbers greater than unity are excluded.

It appeared very desirable to see the actual striations produced by this sort of deformation in order to check this conjecture in a more accurate manner. Since the striations were rendered invisible by reason of the destroyed luster of the faces, a number of very soft embedding media were experimented with, including raw rubber, powdered talc and paraffin, but all these spoiled the originally smooth surfaces. A degree of success was attained by mounting a cleavage cube in concavities between two large cork stoppers. The corks were pressed normal to their surface of joining, within a vise. After removal from the corks it was seen that some parts of the

crystal surfaces had not received a heavy load, due to irregularities in the cork. On these spots striae were visible. Striae were disposed as in figure 2, especially near the edges $c:a$ and $c:b$, but away from these on faces a and b some striae were seen after the manner of distribution shown in figure 3.

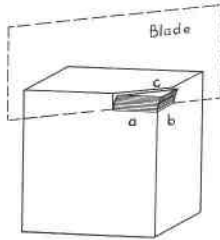


FIG. 5.

The best method of demonstrating translation along cube planes is shown in figure 5. If a razor blade is impressed near the corner of (001) with the blade parallel to (110), it sinks in rather easily, pushing aside the small portion of the crystal shown in the figure.

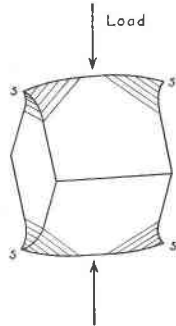


FIG. 6

Striae are absent on c but present parallel to the edge $a:c$ on a and the edge $b:c$ on b of the displaced part.

Clearly halite may glide with T as (001) and t as $[hkO]$. The direction of displacement of the deformed part of the crystal, figure 5, is not a rigorous demonstration that t is $[110]$, but is the best that can be obtained from cleavage cubes.

Another set of gliding elements was noticed in the previously mentioned experiments with cork stoppers as an embedding medium and the load parallel to $[110]$. The four cube corners located with respect to the load as s , figure 6, were markedly bent toward

the center, and in these regions, rather widely spaced striae parallel to the cube face diagonals could sometimes be made out. Probably this indicated gliding on $\{111\}$ but the direction and character of the movement are undetermined. Attempts to reproduce this mode of gliding by pressing a corner with a microscope object glass were fruitless, because of confusion with gliding on (110). Apparently it is a phenomenon which only takes place under a relatively great load.

SODIUM BROMIDE

Water solutions of sodium bromide precipitate the monoclinic sodium bromide dihydrate when evaporated below approximately 50°C .¹³ Accordingly, the anhydrous crystals were prepared by slow evaporation of a saturated solution at $80^{\circ} \pm 2^{\circ}\text{C}$ using "C. P." sodium bromide as raw material. Crystals a centimeter along an edge or larger could easily be prepared, but these were hollow and irregular, and small perfect pieces had to be cleaved from them for use. The crystals were filtered within the oven, thus preventing hydration. No forms other than the cube were obtained.

Sodium bromide is very sensitive to moisture. In handling it the moisture from the imperceptible perspiration on the hand tarnishes its surfaces. Fresh cleavages must be continually prepared, and cleaving can be accomplished only while the crystal is wrapped in a towel or other protecting envelope.

Sodium bromide behaves like sodium chloride but is more plastic. Tests identical with those mentioned under halite were made, and with the same results, so will not be detailed here.

SODIUM IODIDE

Like the bromide, sodium iodide crystallizes from a water solution as the dihydrate at ordinary temperatures. Above approximately 65°C the anhydrous salt separates out.¹⁴ Rather tabular, water-clear cubes a centimeter or more long were easily obtained by slowly evaporating the water solution of "C. P." sodium iodide at $80^{\circ} \pm 2^{\circ}\text{C}$. To avoid inversion, the mother liquor was decanted within the oven. Sodium iodide is even more sensitive to moisture than the bromide, and extreme care must be exercised in its manipulation. It is more plastic than the bromide, but otherwise behaves the same.

¹³ Arthur Messinger Comey and Dorothy A. Hahn, A dictionary of chemical solubilities, inorganic. 2d Ed., *New York*, 1921, p. 836.

¹⁴ Comey and Hahn, *op. cit.*, p. 854.

SYLVITE

Mügge¹⁵ states that sylvite behaves in a manner similar to that of halite under pressure, except that translation is somewhat more difficult.

The writer experimented with cleavage cubes of a very homogeneous crystal of sylvite from Stassfurt, as well as with cleavages obtained from cubes precipitated by the evaporation of a saturated solution of C. P. potassium chloride between 80°C and 90°C. These were found to behave precisely as sodium chloride, giving the new gliding elements, as well as those recorded by Mügge. The writer, however, regards potassium chloride as slightly more plastic than sodium chloride, especially with regard to gliding along $T = (001)$.

POTASSIUM BROMIDE

Johnsen¹⁶ pressed cleavage pieces of commercial potassium bromide, but obtained no visible striations. He claims, however, that with the naked eye, diagonal sheets of varied refractive index appeared through four unpressed cleavages, and that between crossed nicols these sheets showed birefringence. He claims, further, that the percussion figure is the same as for NaCl and KCl. Ritzel¹⁷ also observed birefringent striae under similar conditions.

The writer also experimented with cleavage cubes from coarse crystals of C. P. potassium bromide. The bromide behaves exactly as the chloride, but is much more plastic. It shows a tendency to glide even more easily on cube planes than does sylvite or halite.

POTASSIUM IODIDE

Johnsen¹⁸ also pressed potassium iodide as he did the bromide, and states that they behave the same. Ritzel¹⁹ reports birefringent striae as seen through (100) and sloping at 45° to the pressure direction when this is normal to (001).

The writer used cleavage cubes of coarse C. P. potassium iodide. It is the most plastic of the alkali haloids personally investigated, and glides in quite the same manner as the bromide.

¹⁵ O. Mügge, Über Translationen und verwandte Erscheinungen in Krystallen: *Neues Jahrbuch*, 1898, I, p. 145.

¹⁶ *Op. cit.*, p. 146.

¹⁷ Albert Ritzel, Translationen und anomale Doppelbrechung bei Steinsalz und Sylvit: *Zeit. f. Krist.*, 52, 1912-1913, pp. 275-276.

¹⁸ *Op. cit.*, p. 146.

¹⁹ *Op. cit.*, pp. 275-276.

RUBIDIUM CHLORIDE

Johnsen²⁰ crystallized RbCl from a water solution and obtained small cubes of about 2 millimeter edge length. Pressed normal to a cube face, all cube faces showed striae parallel to the horizontal edges. A face was ground parallel to (110) on one crystal, and after pressing the crystal normal to (001), this ground face displayed striae parallel to the traces of (101) and (011). This gives: $T = (110)$, $t = [\bar{1}\bar{1}0]$. Data on gliding along (001) are lacking.

HIGH-AMMONIUM IODIDE

Johnsen²¹ precipitated small cubes of high-NH₄I of about 3 millimeters edge length from a urea-bearing solution. Pressed between cube faces, Johnsen says they behaved as RbCl. Data on gliding along (001) are lacking.

COLLECTED DATA

The new data obtained, as well as those already recorded, may be summarized in the following form:

CRYSTAL	Translation-gliding elements			Order of Increasing general plasticity and of increasing ease of gliding with $T = (001)$
	$T = (110)$ $t = [\bar{1}\bar{1}0]$	$T' = (001)$ $t' = [\bar{1}\bar{1}0]$	$T'' = (001)$ $t'' = [100]$	
NaF	+	+	-	↓ (Less plastic series)
NaCl	+	+	-	
NaBr	+	+	-	
NaI	+	+	-	
KCl	+	+	-	↓ (More plastic series)
KBr	+	+	-	
KI	+	+	-	
RbCl	+	?	-	
High-NH ₄ I	+	?	-	
MgO	+	?	-	
PbS	-	+	+	↓
PbTe	-	+	?	

²⁰ *Op. cit.*, p.147.

²¹ *Op. cit.*, pp.147-148.

The following points should be noted:

(1) The evaluation of indices of the form (hkO) to (110) , for the alkali halides, depends, in most cases, on the experiments illustrated in figures 1, 2, 4, and 5, and previously discussed.

(2) Gliding of alkali haloids along (111) ? has not, as yet, been sufficiently investigated to warrant inclusion in the table.

(3) No data for gliding on (001) are available for MgO, RbCl and high-NH₄I, and the conclusions regarding gliding on (001) for NaF, depend upon shape, not striations.

(4) The absence of gliding with elements $T'' = (001)$, $t'' = [100]$ for the alkali haloids and periclase is deduced from inability to produce the Taricco figure on their cleavage flakes. These crystals yield figures of the halite type.

(5) Haloid for haloid, the sodium salts are less plastic than the corresponding potassium salt.

(6) For both sodium and potassium series, the plasticity, especially gliding with $T' = (001)$, increases from fluoride to iodide.

(7) Altaite is more plastic than galena.

(8) Disregarding the third set of translation elements, $T'' = (001)$, $t'' = [100]$, which has an unusual explanation, the translation direction is $[\bar{1}10]$ regardless of what plane functions as T .

(To be continued)