THE CLEAVAGE SURFACES OF GALENA

M. J. BUERGER, *Massachusetts Institute of Technology*

ABSTRACT

This paper contains comments on certain conclusions drawn by Head in a recent article of the same title. Translation-gliding striae have been misidentified by Head as traces of cubic cleavage. Head has also applied the term "slip planes" to two different features which are really *tear lines* and linear voids. The former are markings on the cleavage surfaces of crystals due to the fact that separation does not take place over the whole area of the break on a single atomic plane, but rather along a single plane for a part of the area and then along another parallel plane for another part of the area, etc. The small surfaces connecting the various levels of actual cleavage are *tear lines*. They possess many of the properties of contour lines on maps.

The present article presents comments on some of the conclusions drawn by Head[1] in a recent paper of the same title. The writer entertains different ideas regarding the nature of some of the features described in the original article.

TRANSLATION STRIAE. The 90° lattice pattern observed on the cleavage surfaces and well pictured in Fig. 2 of the original article is not evidence of cleavage planes. On the contrary, it is evidence that the crystal did not cleave along the planes indicated by these traces, although subjected to stresses. The markings are translation-gliding striae indicative of the translation $T = \{100\}$, $t = [011]$. These are well known for galena[2] and very easy to obtain. In fact a piece of galena can not be cleaved without also subjecting it to sufficient stress to deform it by translation-gliding.

Anyone wishing to convince himself of the identity of the pattern illustrated need only repeat the classic experiments of Mügge on this mineral or devise simple variants of them. It is especially illuminating to observe the striations in the actual process of formation.

Translation-gliding striae are also known to occur on the natural external surfaces of otherwise normal galena crystals, indicating that the mineral has been deformed by natural processes. In fact crystals so marked first led Mügge to suspect the possibility of translation-gliding in galena and to prove it experimentally.

TEAR LINES. It appears that Head has used the term "slip plane" in two different senses and then possibly confused the two. In part,

[1] R. E. Head, The Cleavage Surfaces of Galena: *Am. Mineral.*, **16**, 1931, 345–351.

[2] An introduction on the literaturer relating to translation-gliding in galena is given in: M. J. Buerger, Translation-gliding in Crystals: *Am. Mineral.*, **15**, 1930, 64.

the term seems to have been used in the technical crystallographic sense of the physical metallurgist to mean "glide plane," but if this is the case this significance is immediately lost sight of in favor of a meaning close to "fault surface" in the geological sense, for Head contends that many of them are open passages, that gases and solutions may travel along them, and that in some cases the openings are closed by deposition. To complete the confusion, Head has applied this term, "slip plane," to at least two distinctly different features. To one familiar with galena, however, Head's photographs and descriptions leave little doubt as to his meanings in each case. In order to clear up the confusion, the two features will be redescribed separately:

The "tree-like surface indications" of Head's Fig. 2 and both the obvious and the more delicate straight and wavy lines of his Fig. 3 are tears between the cleavage levels which are parallel to the plane of the paper. For lack of a better name, these features will be designated *tear lines*. They are present on the cleavage surfaces of many minerals and other crystals having good cleavage and may be studied to advantage on muscovite where the supremacy of the single perfect cleavage eliminates confusion due to other features.

Tear lines owe their origin to the fact that cleavage does not take place along a single crystallographic plane of atoms even in crystals possessing such perfect cleavage as muscovite. Instead, the crystal cleaves along one plane over a certain area, then, due to a variety of possible causes, the cleavage continues on a parallel plane at a very slightly different level. The shear or tear connecting the two surfaces, making the entire break continuous, is the *tear line* under discussion. It follows that tear lines must be continuous, running from one boundary of the crystal or lineage[3] to another boundary, or else must close on themselves. In all features the tear lines as seen projected against the flat cleavage resemble contour lines except that there is possibly no necessity of their indicating regularly spaced levels.[4]

[3] M. J. Buerger, The Significance of "Block Structure" in Crystals; *Am. Mineral.*, **17**, 1932, 177–191.

[4] By this qualification I do not wish to imply that tear lines do not outline blocks or sheets of definite thickness. In fact, I have previously indicated my belief that crystals are periodically weaker at regularly or periodically spaced levels (M. J. Buerger, The Cause of Translation Striae and Translation Strain-hardening in Crystals: *Proc. of the Inst. of Metals Div., Am. Inst. Min. & Met. Engs.*, **1928**, 375–

traced liquid crystals

The contouring nature of tear lines is not evident, except on rather careful study. Casual examination might lead one to believe that they were surface markings which gradually die out. For example, in the photograph given as Fig. 2 of Head's article, the lines appear to be well-defined in the north and east quarters and to continue in a general south and west direction where they anastomose and die out in less striking lines. Apparently the lines do not close like contours in this instance. As a matter of fact, the clearness of the lines in the north and east is due to the fact that the tear lines in this region outline a truly cliff-like region by the coalescence of all of the connected lines (and probably more which are too delicate to photograph) from the south and west. Seen in cliff-like aggregates, tear lines are plainly visible; seen as individuals, they are easily overlooked. Furthermore, whether or not a delicate line will appear visible at all depends on the direction of the incident light. Thus, in the figure mentioned, the continuations of the finer lines may be brought into evidence, supposing a metallographic microscope is being used, by cutting off the normal illumination so that the surface of the galena appears black, and obtaining oblique illumination by means of an adjustable lamp. Under these conditions the tear lines stand out as brilliant threads with proper adjustment of the altitude angle of the lamp. Adjusting the azimuth of the lamp or rotating the specimen allows one to follow the lines to their destinations. The specimen may also be studied to advantage with the aid of a binocular microscope using a sharp source of light. Returning to Head's Fig. 2, the tear lines may be interpreted to mean that high[5] ground, as it were, occurs to the southeast with low ground on the northwest, and that the surface drops from high to low abruptly in two or three cliff-like monoclines near the northeast, but drops very gradually in the central and southwest regions.

388) and more recently Zwicky has independently come forward with the same suggestion from a different viewpoint (F. Zwicky, On Mosaic Crystals: *Proc. Nat. Acad. Sci.*, **15**, 1929, 816–822). By this qualification I merely wish to indicate that I have not studied the distribution of functioning cleavage planes indicated by tear lines in a quantitative way, and therefore, wish to imply no necessary regularity in their spacing as yet.

[5] The words "high" and "low" may have to be interchanged in this sentence, for one can not distinguish high ground from low ground on the map of a surface with which he is not familiar unless the altitudes of the contour intervals are marked. In maps of the earth's surface, of course, we are familiar with the action of drainage and can obtain our clue from this in its various influences.

In the case of galena, three varieties of tear lines are encountered. First, there is a type of line of indefinite direction and no highly developed regularity which may be resolved into alternations of the 0° and 90° cubic cleavages (both at right angles to the cleavage surface being examined). Second, there is a gracefully curved, to an almost straight line of irrational direction. The central line of Head's Fig. 2, the prominent curved line some half inch from the left edge of his Fig. 3, and the faint curved line about an inch from the right edge of his Fig. 3, for example, are of this type. Third, this second type often connects with, branches into, or becomes, a regular straight line running in the rational crystallographic direction [110], i.e., at 45° to the cleavage directions. This type of line indicates either a true {110}, (vertical) cleavage or {111}, (inclined) cleavage. Goniometric studies fail to reveal the angle of inclination because of the diffraction effects from such small surfaces. Tear lines of this variety are clearly indicated at the extreme left of Head's Fig. 2, and faintly in the center of his Fig. 3.

Head's photographs admit of no doubt that what has just been described is one of the things he means by slip planes, for his explanation attached to Fig. 2 runs:[6]

> "Shows . . . *tree-like, surface indications of "slip planes,"* which in come cases are open and whose surfaces may be etched and non-reflective or smooth as in slickensides."

And in the text, he says (347–348):

> "*There are areas in which the preceding characteristics are well defined but in additon show another set of lines not so strongly marked, but clearly visible, extending diagonally across the cleavage lines* [i.e. referring to the translation-gliding indications discussed above] *at an angle of approximately 45°.*"

Further, on page 348, he says:

> "*Reference to Figure 2 shows, in addition to the block cleavage, two sets of irregular, tree-like striations that are equally as well marked as the regular cube face outlines* [meaning translation-gliding striae again]. Close examination of these forms suggests that they indicate planes along which slippage may have taken place and through which solutions or gases may have penetrated the cube mass. In some cases these channels are still open and when exposed by dissection show surfaces that present a pebbly

[6] All italics are mine and are used to distinguish the two features included by Head under the term, "slip planes." Italics refer to tear lines, the rest to other features, M.J.B.

appearance indicative of corrosion. Where these channels have "healed," i.e., been filled or cemented, they present surface irregularities similar to those of the cube blocks."

VOIDS. In the unitalicized portions of the quotations just given from Head's paper, the author refers to a feature which is quite different from the tear lines just described. Tear lines can only occur on the cleavage surfaces since they arise simultaneously with the cleaving process. If the sense of the preceding discussion has been grasped, it is evident that tear lines are not major breakage features of the mineral but are essentially minor rents; that they are dependent on the major cleavage and can not exist independently of it. There is, therefore, no possibility of their ever existing as, or developing into, open channels or of having been etched. Head has certainly confused tear lines with some other feature.

This second feature appears to be elongated negative crystal cavities. Negative crystals are of common occurrence in galena, especially in the Joplin galena. The nature of these voids is discussed in some detail in another paper.[7]

The writer submits that in the following passages, Head refers to various sorts of negative crystal cavities, usually to cavities of tabular shape (i.e. tabular openings where an ordinary lineage boundary would be present if the two lineages had ever grown together again after once separating slightly[8]): Page 348:

"Close examination of these forms suggests that they indicate planes along which slippage may have taken place, and through which solutions or gases may have penetrated the cube mass."

and (legend, Figure 2):

". . . which in some cases are open and whose surfaces may be etched and non-reflective or smooth as in slickensides."

and page 350:

"In some instances the surfaces were smooth and highly reflective, approaching the condition of block cleavage surfaces. In others, the surface of the slip plane was dull and lusterless and had the appearance of having been etched or corroded."

[7] M. J. Buerger, The Negative Crystal Cavities of Certain Galena and their Brine Content: *Am. Mineral.*, **17**, 1932, 228–233.

[8] Lineage boundaries usually run more or less radially from the center of the crystal, and there is a decided tendency, in many instances, for the trace of the lineage boundary in the region of the cube diagonals to run at about 45° to the traces of the two cleavages. In this way, the courses of the lineage boundary traces somewhat mimic the courses of the tear lines.