1923

On the breakage of rock drill steel

Muir Luken Frey

ON THE BREAKAGE OF ROCK DRILL STEEL

By

Muir L. Frey.

- - - -

A

THESIS

Submitted to the Faculty of the

SCHOOL OF MINES AND METALLURGY OF THE UNIVERSITY OF MISSOURI

In partial fulfillment of the work required for the

DEGREE OF

MASTER OF SCIENCE IN METALLURGY

Rolla, Missouri.

1923.

Approved by Chas. Y. Clayton,
Professor of Metallurgy & Ore Dressing.

TABLE OF CONTENTS

ILLUSTRATIONS

ON THE BREAKAGE OF ROCK DRILL STEEL.

INTRODUCTION

Prior to 1920 there was little attention paid to the general problem of breakage of rock drill steel. Each locality had its problem and the matter was treated as a purely local one, independent upon conditions in that particular section. But in the above-mentioned year, there arose an interest of wider scope, from what causes it is impossible to determine accurately, and the matter is now the subject of a broad investigation in which the users of rock drill steel, the United States Bureau of Mines, and the United States Bureau of Standards are cooperating.[1] The response of the industry to this investigation indicates that in spite of the fact that the matter has not been regarded as serious in the past and that as a result, records do not show an inordinate amount of loss from the breakage of rock drill steel, the subject is now one of considerable moment in the mining industry.

There is, to date, no satisfactory method for tabulating results from drill steel and computing the amount of breakage therefrom. Consequently, available records are, probably, in error, and the conclusions drawn therefrom are not to be relied upon too much. The fact that the above-mentioned investigation is calling forth an hitherto undisplayed interest, made it seem advisable to investigate one case of rock drill steel breakage more fully than had been done before. It was realized that the case taken up was one peculiar to a restricted locality, and that in a large measure the results would be applicable only to that particular case, but at the same time it was hoped that from this one investigation some facts might come which would be applicable in general. This has been found to be true.

GENERAL THEORY

If we discard as requiring very little explanation the breaking of a piece of drill steel within a few minutes after being put into service, and take up the problem of failure after a considerable period of time, the matter links itself immediately with the more general problem of the fatigue of metals, since the term fatigue has come to be applied to failures in an apparently sound piece of metal after it has been considerable service. Furthermore, the generally accepted theory states that, even though apparently sound, such a piece of metal will, upon close examination, show certain physical or structural defects from which such failures start and, progressing with time, ultimately end in rupture. Obviously, if a piece of drill steel fails after a few minutes of service there is some glaring defect which will show up upon examination; but if the steel fails after some time, it is a case of fatigue. Such fractures show all the evidence of a progressive failure.

The phenomenon of the fatigue of metals has been under investigation ever since 1860 when Wöhler undertook his now classical work upon the relation between the so-called "fiber stress" and the ability of metals to resist fatigue under repeated stress. Though the cases of failure under consideration were those occurring in railway bridges and car axles (high-speed machine parts being then of no importance), nevertheless Wöhler's results are applicable to our present-day problems.

Briefly stated they are:[2]

> 1. A machine part or structural member may be ruptured by the repeated application of a load which produces a computed fiber stress less than the ultimate strength of the material as determined by static test.
>
> 2. The greater the range of stress, the lower the limiting fiber stress to insure against rupture after a very large number of repetitions.
>
> 3. To insure against rupture after a very large number of repetitions of loading causing complete reversal of stress, the limiting fiber stress is but little greater than one-half the limiting fiber stress for a very large number of repetitions varying from zero to the maximum.

From Wöhler's discussion of "fiber stress" there possibly arose the popular conception that metals were at first fibrous in structure. But when the surface of a fracture was examined it was found to be crystalline -- often coarsely -- and from that arose the popular idea that the fatigue of metals was due to a change in the structural state from fibrous to crystalline. This view is held even today by the layman, but has long since been discarded by the technician and the investigator since there is an ever increasing volume of evidence in favor of the view that all solid metals are crystalline in structure at all times, excepting such small amounts of amorphous material which, according to certain authorities, may exist within crystalline metal under certain conditions. The latest work by X-ray investigation has established the crystallinity of metals beyond doubt.

Following Wöhler came many elaborators and investigators, of whom Bauschinger[2] is the most noteworthy. He put forth the theory that under stress varying from zero to a maximum, it is possible for metals to acquire new elastic limits which for this range of stress may be anywhere between the original proportional limit and the yield point, and may in some cases exceed the latter. These "natural" elastic limits, as he called them, depend upon the number of cycles of stress to which the material is subjected, being higher for the greater number of cycles. This theory has received very little experimental confirmation and is at present nearly obsolete.

The generally accepted theory at present is that fatigue of metals is due to a localization of stresses in the member. It was first elaborated by Gilchrist, who, in discussing Wöhler's results stated:[2]

> 1. The average stress in the bars broken in Wöhler's machine did not reach the statical breaking load.
>
> 2. The fracture was caused by the statical breaking limit being exceeded at one point only, from which, when once started, rupture spreads, at first rapidly, then more slowly, sometimes continuing to complete separation of the two parts of the bar, but occasionally stopping short of complete rupture.
>
> 3. The raising of the stress at the point when fracture commenced was due to an irregularity in the bar. This might be an irregularity or discontinuity in the metal, either on the surface or in the body of the bar.
>
> 4. A bar of uniform strength whose surface was perfectly smooth with no sharp corners in the longitudinal configuration and the structure of which was perfectly homogeneous would endure, without breaking, an indefinite number of repetitions of a stress varying between zero and a value near to the breaking strength.

These statements have been the subject of investigation by several men in Europe, notably E. G. Coker, who published a series of articles in Engineering (London) from 1910 up to the present time. A similar series of articles by the same author appeared in the General Electric Review for 1920 - 21 and 22. In these articles is shown that in regions of abrupt change of cross section in a material under stress, there is a localization of stress that in many cases exceeds very considerably the actual load applied to the specimen.

All the work of modern investigators, then, serves to confirm Gilchrist's theory. Foremost among these confirmations may be cited the work of H. F. Moore[2] at Illinois Engineering Experiment Station, so often referred to in this paper. He is perhaps the foremost authority in the United States on fatigue of metals and we may therefore safely discuss the failure of rock drill steel upon the basis of Gilchrist's theory.

SPECIFIC THEORIES

There are at present three theories upon the cause of fatigue in rock drill steel. They are --

1. The nodal stress theory.[3]
2. The structural defect theory.[4, 1.]
3. The physical defect theory.[5]

The nodal stress theory was advanced by B. F. Tillson in a paper on the Breakage and Heat Treatment of Rock Drill Steel. He assumes that energy is transmitted through the steel from the hammer of the drill to the rock face in waves similar to sound waves but which travel at a higher velocity due to the greater density of steel. These waves may in turn be reflected through the steel from the rock face with or without a change of phase.

In addition the bar has a natural period of vibration which is, in all probability, not of the same frequency as the compressional waves through it. These waves of stress are subject to the following laws of wave propagation.[3]

1. When a longitudinal or compressed wave passes from one medium to another, a part of the energy is reflected and a part transmitted. The phase of that part reflected is changed one-half of a wave length when the reflection occurs in the denser medium. When the reflection occurs in the lighter medium the phase of the wave is altered.

2. Two waves of the same length, but differing in phase, combine to produce a wave of the same length but different amplitude and phase than either of the initial waves.

3. Two waves of the same period and amplitude, but differing in phase by a wave length, combine to produce a wave of the same length but double amplitude.

4. Two waves of the same period and amplitude but differing in phase by a half wave length mutually annul each other.

5. Two waves that differ slightly in length combine to produce a wave of varying amplitude. Its frequency is one-half the sum of its component frequencies. If both initial waves were of the same amplitude the amplitude of the resultant wave will vary from zero to twice the original amplitude as many times per second as the difference of their frequencies.

6. When two equal waves traverse in opposite direction, the resulting wave remains stationary. The node in the resultant wave occurs half way between the similar zero points of the original waves; and the points of greatest amplitude occur one-quarter of a wave length away. Therefore nodes occur at distances that are multiples of half wave lengths.

Mr. Tillson concludes that there may be stresses above the tensile strength of the steel set up at the nodes occurring throughout the length of a bar of drill steel. These nodes may occur from a single set of compressional waves or they may be the result of the combination of waves of different frequencies set up in the bar. This is most probably the case since when in operation, the bar will vibrate at its natural frequency in addition to carrying the compressional stresses set up by the action of the drill hammer. In such a case the nodes will represent greater stress than if just one wave is considered, since at a node the amplitudes of the two or more component waves are additive. Immediately the energy reflected into the bit from the rock face comes into play as do also the bending stresses which arise chiefly in stoping, and the torsional stresses which arise from the rotation of the bit in the hole.

It is evident then, that the problem of determining the magnitude of such stresses set up in a bar of drill steel is a very complicated one that would necessitate special apparatus. Stress nodes may be roughly detected, according to Mr. Tillson, by observing points along the bar at which the temperature arises when drilling is going on. However that may be, it would be absolutely necessary to determine the magnitude of the stress at such points if one were to determine whether or not the elastic limit of the steel was being exceeded. It must be borne in mind also that the statical proportional limit is not the criterion in this case as is shown first by Wöhler and later by others. Still further, the presence of inclusions in the steel or of minute cracks at the edges would serve as points for the further localization of such stresses.

The theory that the failure of rock drill steel might be due to either structural or physical defects is nothing more than the application of the general principles enunciated by Gilchrist and later elaborated upon by others. A structural defect in drill steel not infrequently takes the form of the "metallurgical break" or change in structure brought about by the heating of the end of the bar, first for upsetting and shaping, later for sharpening, and last for hardening. There will be at least four zones of structurally different material: First, the hot rolled condition of the bar; then the part heated for upsetting but not worked; next the part worked in shaping the bit; and last the part heated for hardening. All of these heatings involve a temperature above the critical temperature of the steel and so will produce at their upper limits a zone of very fine grains in close contact with a zone of relatively coarse grains. Undoubtedly these are regions of non-homogeniety in the bar and may be points from which, because of their inherent weakness, what is a first slip will eventually become a crack, which, in turn, spreads across the bar with time.

Under physical defects may be listed, with particular reference to drill steel, inclusions and irregularities and small cracks along either the outside edges or the water hole of the steel. It has long been recognized that the presence of such defects makes the steel very susceptible to fatigue failures. This third source is undoubtedly the most potent cause of failure, but our work, as hereinafter described, discloses the presence of both the second and third.

SOURCE OF MATERIAL

The case chosen for this investigation was that occurring at the Homestake Gold Mines at Lead, South Dakota. This case is particularly noteworthy because 80% of the failures occur within six inches of the bit, whereas, in nearly all other cases, the major portion of the breakage is at the shank end of the steel.[1] The reports from the company, it being one of the few that keep extensive records of performance, show that the majority of failures occur in the 3, 4, and 5 foot lengths, the gages of which are 2-1/4, 2-1/8 and 2 inches respectively. Figure 1 is a reproduction of a curve drawn from data furnished by the company.

The steels are used in the following lengths and gages:

Length	Gage
Starter	2-3/8
3	2-1/4
4	2-1/8
5	2
6	1-15/16
7	1-13/16
8	1-11/16
9	1-9/16
10	1-7/16

The steel was regular 1 inch hollow quarter octagon, and did not vary from the usual type composition of rock drill steel, which is as follows:

C - - -	.85%	P - - -	.02%
Mn- - -	.60	S - - -	.02
Si- - -	.25		

with the exception that in some specimens there was vanadium not exceeding .20 per cent. Since the physical and structural rather than

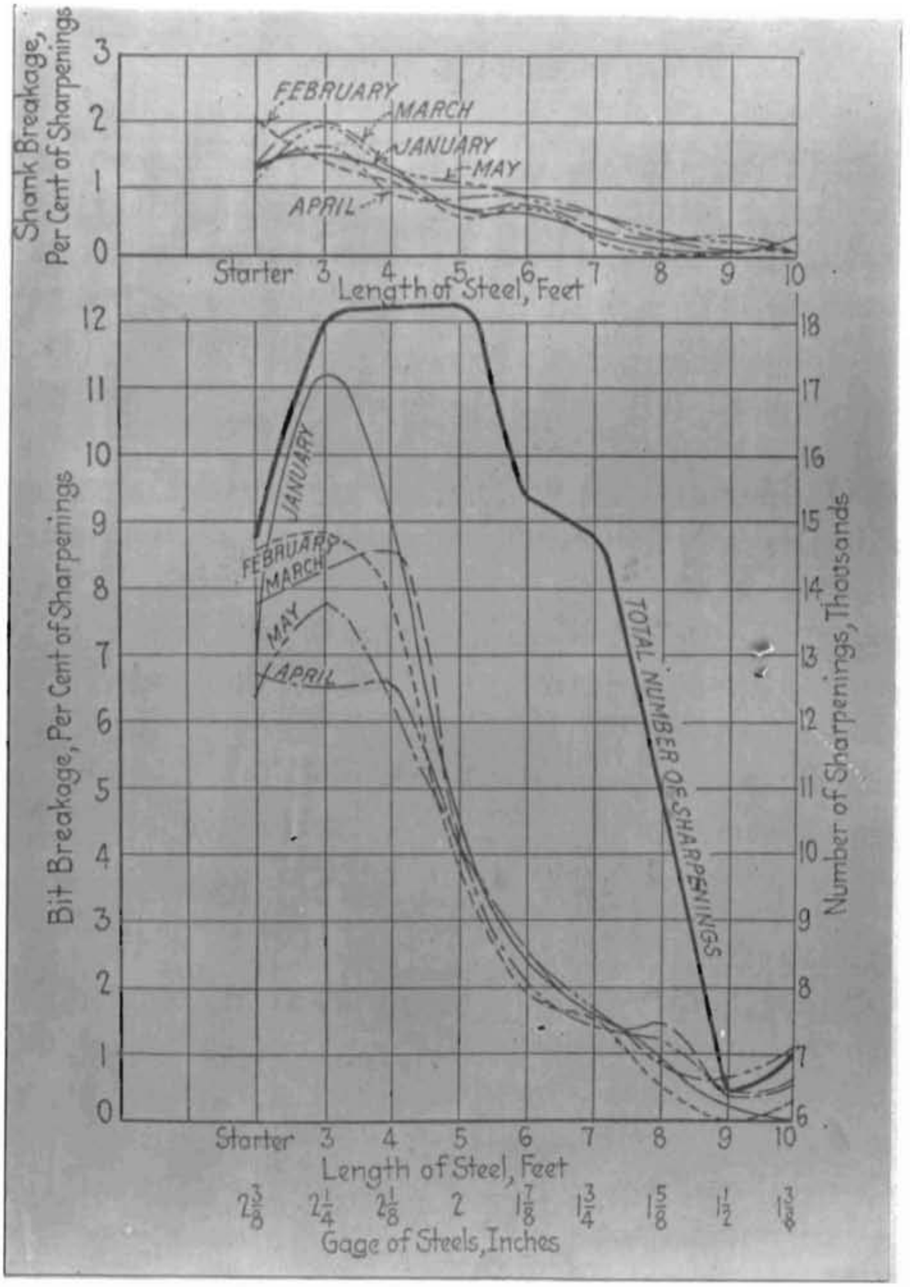


FIG. 1

Chart showing bit breakage as per cent of total sharpenings for the various lengths of drill steel, Homestake Gold Mines.[1]

the chemical properties of the steel were under investigation, the analysis is given only approximately and the presence of a small amount of vanadium is negligible. Tension, compression, torsion and impact tests were regarded as of little value because such could not be made upon the steel as it is in the drills and the work very soon showed that the physical and structural characteristics which affect the performance of the steel as drill steel do not depend upon those shown by the ordinary physical tests.

PROCEDURE

One bit end, about 12 inches long, was sent for each of the gages listed above, making nine samples in all. The samples were sent as forged so as to facilitate cutting into pieces for examination. These were first sawed longitudinally on a Browne & Sharpe milling machine and one half given a polish for a macro etch on the sawed face. These pieces were etched in a solution of 20% HNO_3 in water. The metallurgical breaks show up very well as can be seen from Figures 2, 3 and 4.

The other half of each bit was cut into pieces of convenient length and polished for microscopic examination. The finishing was done on felt with "levigated aluminum" as abrasive. This gave a surface entirely free from scratches, provided suitable reduction had been made on the previous polishing discs.

For the detection and measurement of the cracks, a metallurgical microscope fitted with a Bausch & Lomb 16 mm. objective and Filar micrometer eyepiece was used. The scale in the eyepiece was calibrated by means of a stage micrometer. Each division on the scale was found to be equal to .084 mm.

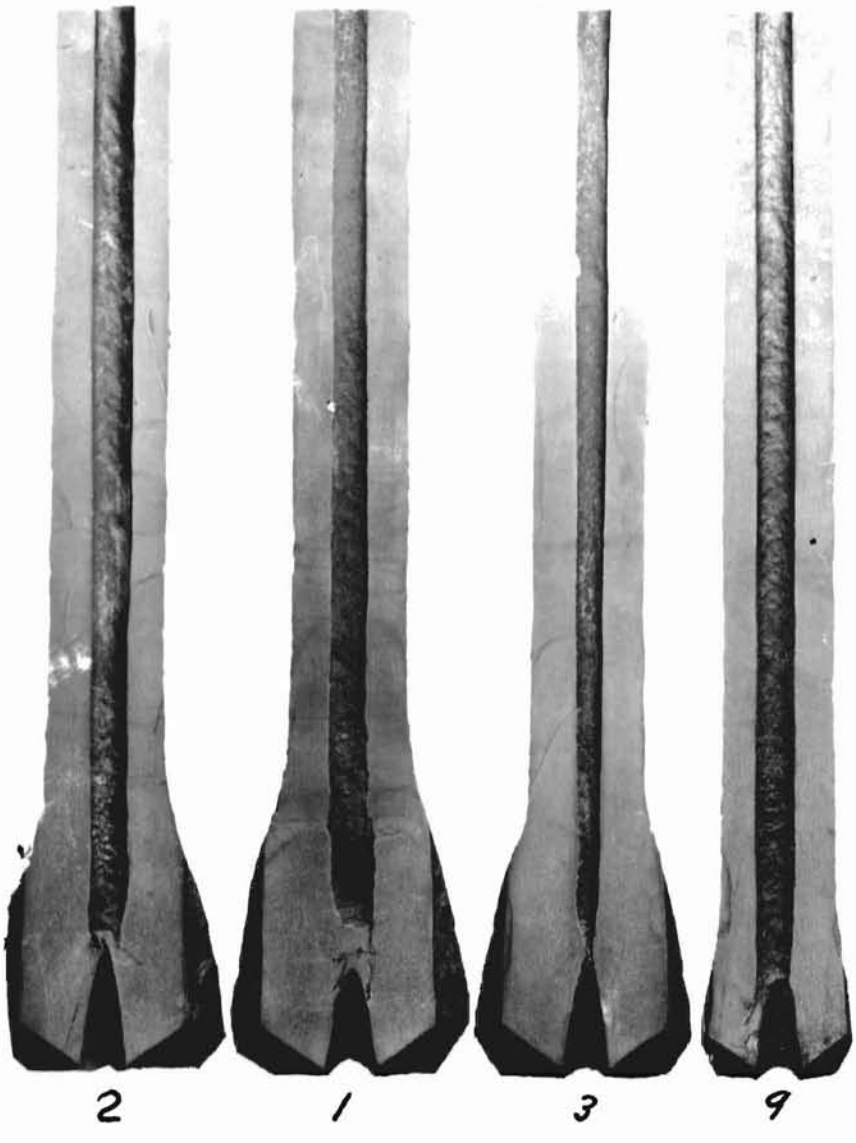


FIG. 2.

Bits 1, 2, 3, and 9. Macro etch, 7/10 actual size.

FIG. 3.

Bits No. 4, 5, 6, and 7. Macro etch, 7/10 actual size.

8

FIG. 4.

Bit No. 8. Macro etch, 7/10 actual size.

A crack was first located by bringing it into the center of the microscope field, after which its depth was measured by means of the eyepiece micrometer scale. Then a measurement was taken along the piece of drill steel to the center of the illuminated spot and the location of the crack plotted on a full-size drawing of the piece of steel undergoing examination, proper allowance being made for the width of the saw cut between pieces of the half section so cut up. These drawings were afterward traced, and blue prints made. The term "angle" used in the drawings refers to the angle the crack makes with the center line of the piece of drill steel. These angles are by approximation only, since there was nothing to be gained by an exact measurement. The "depth" given is in all cases the actual length of the crack, regardless of the angle it made with the center line of of the bit.

The light, irregular lines on the blue prints are not cracks. They are the outlines of the regions differing in structural appearance as developed by the macro etch. The actual appearance of these regions is shown in Figures 2, 3, and 4, and by means of the lines in the blue prints the photographs and the blue prints can be correlated. For the purpose of bringing out the regions of structural change more clearly in the photographs, the lines of demarkation were traced on the steel with lead pencil

DISCUSSION OF RESULTS

When we study these drawings individually with the purpose of establishing a relation, if any should exist between the region of structural change and the location and depth of cracks, we obtain the following:

In bit No. 1 there are numerous crack areas a considerable distance above the metallurgical break but the deepest cracks occur in that latter region. Area No. 6, which is in the region of structural change, has the deepest cracks, two of which are 1.848 and 1.344 mm. deep and can be seen easily with the unaided eye.

In bit No. 2 there is apparently little relation between the cracks and the metallurgical break. This may be considered a relatively good piece of drill steel.

Bit No. 3 is very similar to No. 2 in that it has few cracks and may be considered relatively sound. Such unsoundness as exists is in the region of metallurgical break.

In bit No. 4 is found once more the semblance of a relation between the metallurgical break and the area of most cracks. However, the deepest cracks occur just beyond the region of structural change.

In bit No. 5, the worst condition with respect to cracks is in the region of structural change. There are five zones embracing areas in which there are numerous cracks, and four of these five zones are in that region. Practically all of the deepest cracks, also, are in this region. The bit is relatively in very poor condition. It may be cited as the poorest of the lot.

Bit No. 6 is poor but not as poor as No. 5. Here, too, the region of deepest and most numerous cracks coindide with the region of structural change.

As regards cracks, No. 7 is a fairly good specimen. There seems to be no connection between the metallurgical break and the location of the deepest crack. However, there are numerous small and incipient

FIGURE 5.

Representative Cracks from Bit No. 1.
X 140.

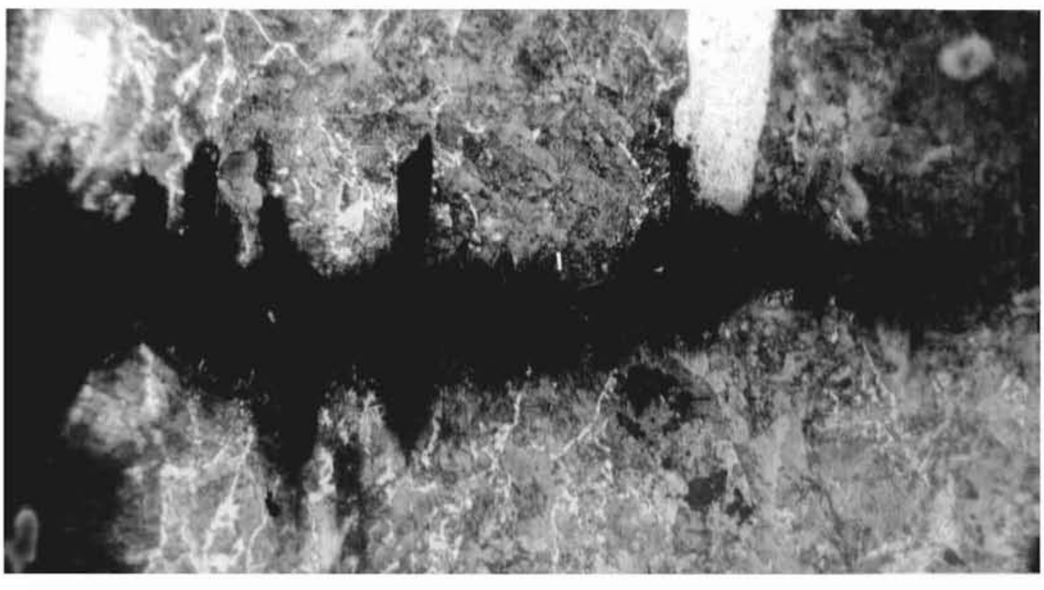
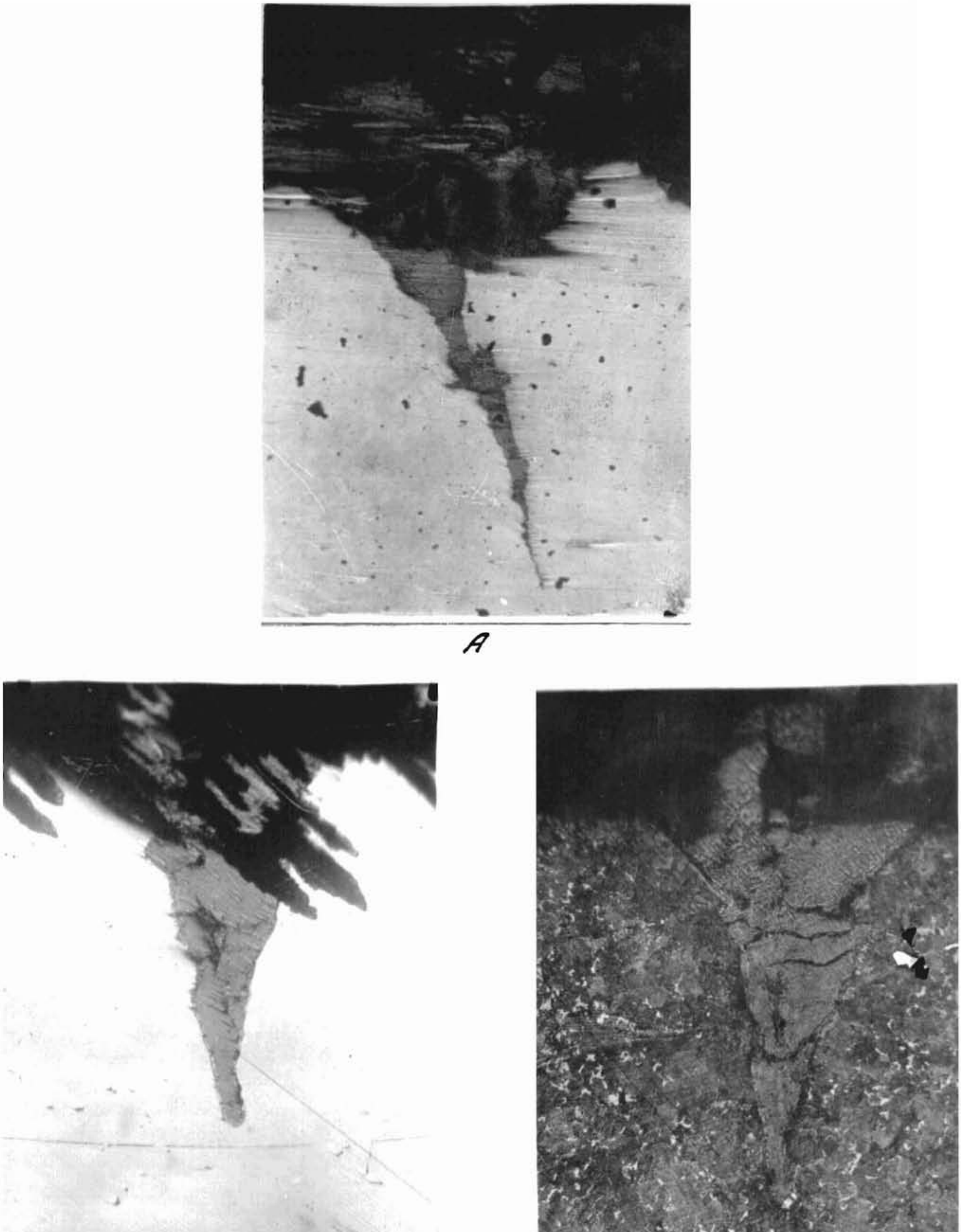


FIGURE 6.

A -- Deep crack from Bit No. 9, X 140, unetched.
B -- View of same crack etched, X 140. Etched with 10% HNO_3 in Amyl Alcohol.



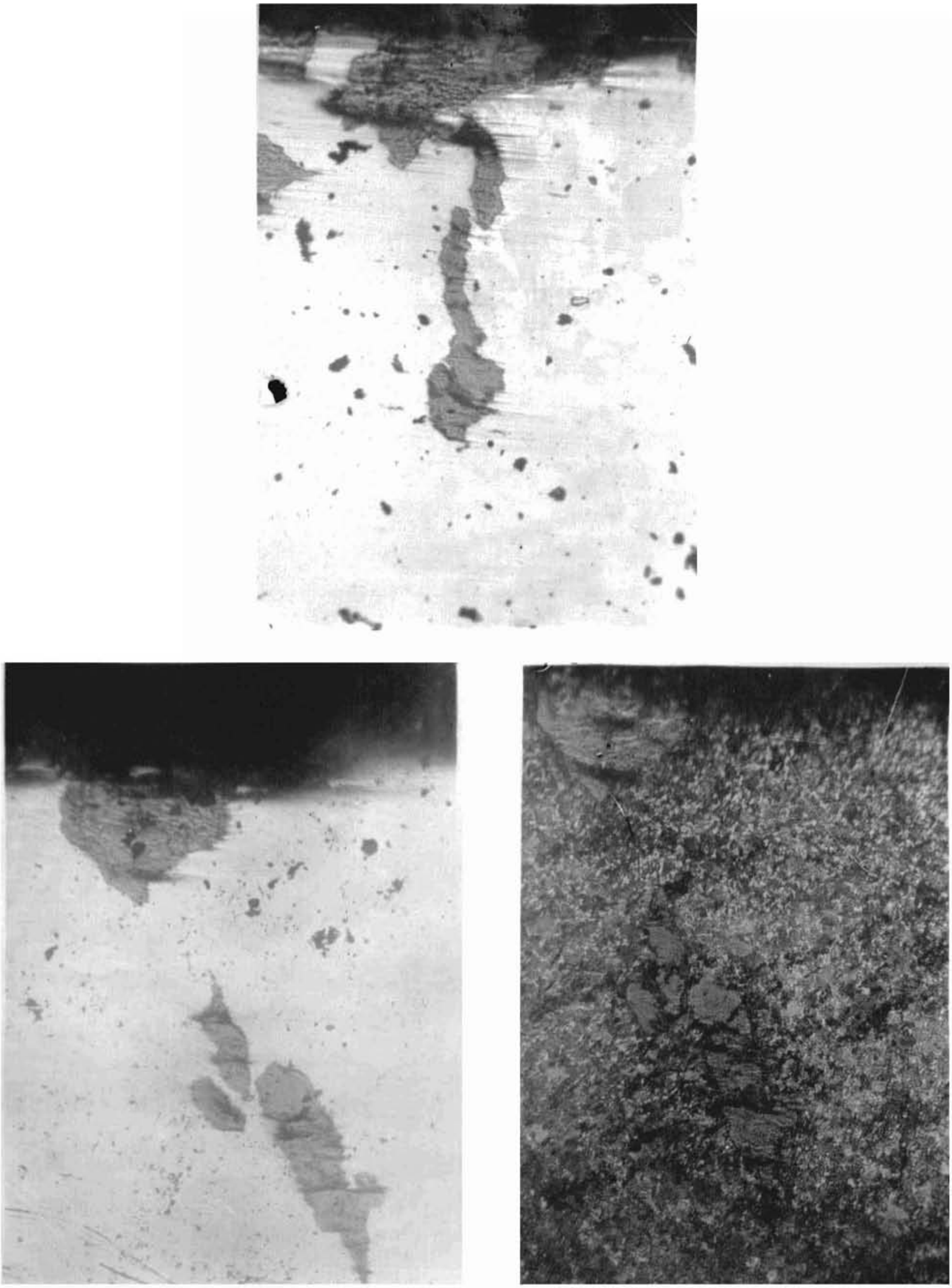
A

B

C

FIGURE 7.

A and B -- Two cracks from Bit No. 9, X 140.
C -- Etched view of B, X 140. Etched with 10% HNO_3 in Amyl Alcohol.



B FIGURE 8. *C*

A and B -- Inclusions near edge of drill steel, X 140.
C -- Etched view of B, X 140. Etched with 10% HNO_3 in Amyl Alcohol.

cracks within the area of structural change.

The most serious cracks in bit No. 8 are, generally speaking, not within the region of structural change, but are in the as-rolled section of the bar. The bit would be classed as poor.

A similar condition to that of bit No. 7 is found in bit No. 9. There are few deep cracks in any portion of the specimen. The deepest one, 0.924 mm., is distinctly in the as-rolled section. The bit may be classed as passable.

We find from the above that the bits divide themselves into two classes; Four of them, Nos. 1, 5, 6, and 8, being classed as poor to bad, and the remaining five, Nos. 2, 3, 4, 7 and 9, being classed as fair to good. In the former we find a definite relation between the region of structural change and that of the most prevalent and deepest cracks. In the latter five there are three in which no definite connection has been found, and one in which the author expresses a doubt. The remaining one shows an apparent relationship. From such an analysis the conclusion is that in those bits which are susceptible to cracking, the condition is aggravated by the change in structural condition brought about by the numerous heatings; and when the steel is relatively free from cracks, the condition brought about by the numerous heatings apparently does not have such a deleterious effect. Therefore, it seems reasonable to conclude that the structural change is not the primary cause of the cracks but is an accessory in the case of bad steel.

Taking as being basically right the statements of Gilchrist, we may say that rock-drill steel has a legitimate cause to fail. For the drawings show that even in the best pieces, numerous cracks are present and in the poorest pieces there is a truly amazing number of cracks. In fact, the author is not so much impressed with the fact that drill steel fails occasionally as he is with the fact that failures are not more frequent.

Figure 5 shows two shallow cracks from bit No. 1. These two cracks are representative of one of the two classes found -- the first being those not filled with any foreign material. A deeper crack of the same class is illustrated in Fig. 6, with both an unetched and an etched view.

The second class of crack, that filled with some foreign material, is illustrated in Fig. 7. The foreign substance may be either iron oxide, rock dust, or dirt and sediment from mine water. In all probability, rock dust and sediment is the filling material in most cases, since as will afterward be shown, such cracks form after the steel has been put into service. Such filled cracks are slightly more prevalent in the region heated for working and so the oxide filling, when such is present, could come from a slight oxidation of the steel when it is heated.

Figure 8 shows what are apparently inclusions near the edge of the steel, but which undoubtedly are cracks. In the first place, these "inclusions" are elongated at right angles to the direction of rolling of the bar. Any inclusion in the steel would necessarily show elongation in a direction parallel to that of rolling. Second, cracks in steel almost invariably follow a tortuous path. From these two facts it seems logical to conclude that what may at first sight appear to be inclusions are, in reality, cracks which have been filled with either oxide or mine water sediment and which have not been cut through in a plane that will show their continuity.

The edges of the bar, as viewed under the microscope, are seldom straight. They are in general undulating and in many cases serrated. Cracks as shown in Figs. 5, 6, and 7, most frequently occur in the undulating portion of the edges and always in the depressions in the serrated parts. This leads us to believe that even with irregularities of outline microscopic in proportions, there is sufficient localization of stress to cause rupture of the metal in those places. We conclude from that that nearly all of the cracks viewed started after the steel was rolled.

Other evidence points to the same conclusion. The steel, being so near eutectoid composition and in the troostitic state, showed uniformly dark under the microscope. Hence any decarburization could easily be seen since the ferrite present in decarburized areas showed white. There was a distinct decarburized skin along the outside edges and the water hole varying, in general, from 0.05 to 0.10 mm. in thickness. Since this skin was found in the as rolled as well as the worked part of the bars, it is logical to conclude that it was the product of hot rolling the metal. All of the cracks observed, provided they were deep enough, extended through the decarburized skin. In no instance did the ferrite network of decarburization follow the contour of the crack as seen at the time, nor did it show any undulation that would indicate that it had followed the contour of a smaller crack which might have existed at the time decarburization took place and from which the larger crack might have grown with subsequent service of the steel. The etched view shown in Figure 6 illustrates this point.

The presence of the cracks then, is due to the service done by the steel and cannot be attributed to the process of manufacture. But, more important than their presence is their cause, and this, we believe, is directly attributable to the method of manufacture, since first, as shown in the consideration of the location of the areas of cracks in regard to the metallurgical break, there are cracks in the as-rolled portion of the bar as well as in the worked portion; and, second, since, as brought out in the discussion of the place in which cracks occur, the surface of the steel is either undulating or serrated and so gives rise to points of localized high stress. As a result cracks occur at the bottom of the undulation and serrations. The rough outline of the surface is due to the process of manufacture.

As a check on this particular part of the work, the Homestake Mining Co. was asked to send some samples of their new steel for examination. In response they sent six specimens about four inches long. These were sawed in half longitudinally and one-half cut into short pieces for examination, just as had been done with the regular specimens. The microscope disclosed the presence of but three cracks along the water hole in all of the specimens, this showing that the cracks are nearly all developed in service. The outline of the water hole and on the outside edges, however, showed the usual irregularities noted in the specimens of used steel.

Figure 6 shows, in addition to the crack at right angles to the direction of rolling of the bar, several lateral cracks extending from the larger one at right angles, parallel to the direction of rolling. Such additional defects, though not common, are worthy of mention since they seem to show the action of another deteriorating factor. The presence of these cracks is most probably due to the corrosive action of mine water. Once admitted to the unprotected surface of a crack, the water will very readily attack certain segregated portions of the steel.

At the beginning of this work it was thought that perhaps some light might be thrown on the question of nodal stresses, but that hope was very soon abandoned, for in no case is there evidence that the accumulation of a very large number of microscopic cracks in small areas was regular enough to warrant the conclusion that anything like regularly spaced nodes were present in the bar. Neither is there evidence in favor of disregarding Mr. Tillson's theory for in the present case no more than an average of 12 inches, measured from the bit, of the drill steels were examined. And it is entirely probable that the nodes would be spaced farther apart than 12 inches. Mr. Tillson attempts to show in his paper that the wave length is 8.275 feet, but the author has been unable to check Mr. Tillson's quantitative considerations. As far as this present paper is concerned, Mr. Tillson's theory must remain merely an interesting theoretical consideration which may furnish the basis of a more thorough investigation. Should the nodal stress theory later be found to be on a firm footing it would add another powerful reason for the use of meticulous care in endeavoring to obtain drill steel free from physical and structural defects.

CONCLUSIONS

1. Physical defects in the form of cracks have been found to exist in great numbers along the water hole of hollow drill steel.

2. These defects are not caused by the method of heat-treatment of the drill bit.

3. Drill steel is pre-disposed to cracking by the presence along the exterior and water hole surfaces, of undulations and serrations produced in fabrication.

4. The stresses incident to service are localized by such irregularities of the surface to the extent of exceeding the breaking point of the metal, this causing the formation of microscopic cracks.

5. The heatings and coolings, to which the bit is subjected for sharpening and hardening aid in the formation of cracks starting from the bottom of the irregularities produced in rolling.

6. Mine water seeping into cracks around the water hole of the steel attacks the more impure metal, and produces tributary cracks parallel to the direction of working of the steel.

7. There is no evidence, such as the location of regularly spaced patches of cracks, in support of a nodal stress theory. Nevertheless, because of the shortness of the lengths of steel examined, the results of this work are not necessarily at variance with such a theory.

ADDENDUM

There is another aspect of the problem of drill steel breakage at the Homestake Mines, which is peculiar to that locality only. It is the excessive breakage which occurs within the bit itself. Since the preparation of the steel for examination for the previous work prepared it also for the investigation of this particular problem, it is deemed advisable to append this addendum which is not of general application.

The statistics given in the fore part of this paper are that more than 80 per cent of the breakage of rock drill steel at the Homestake Mines occurs at the bit end. This amount of breakage at the bit can be partly explained by the fact that the shanks of this steel do not have lugs or a collar formed on them, since the steel is quarter octagon and auxiliaries for rotation are unnecessary. The only heat-treatment that the shanks receive is a heating about one inch back for hardening. Consequently, there is but one line of structural change and that point is within the chuck during drilling. Since the regions of structural change are regions which add to the possibilities for failure of a drill, the number of breaks at the shanks is decreased.

The examination of the specimens showed the bits to be poorly formed. It is understood that the drill sharpener used is not a standard machine but rather one designed by the company. Though such does not, in itself, detract from the value of the machine as a drill sharpener, nevertheless, the bits show that the machine does not do its work properly. Figures 9 to 14 are photographs of

FIGURE 9

Bit No. 1 as polished.

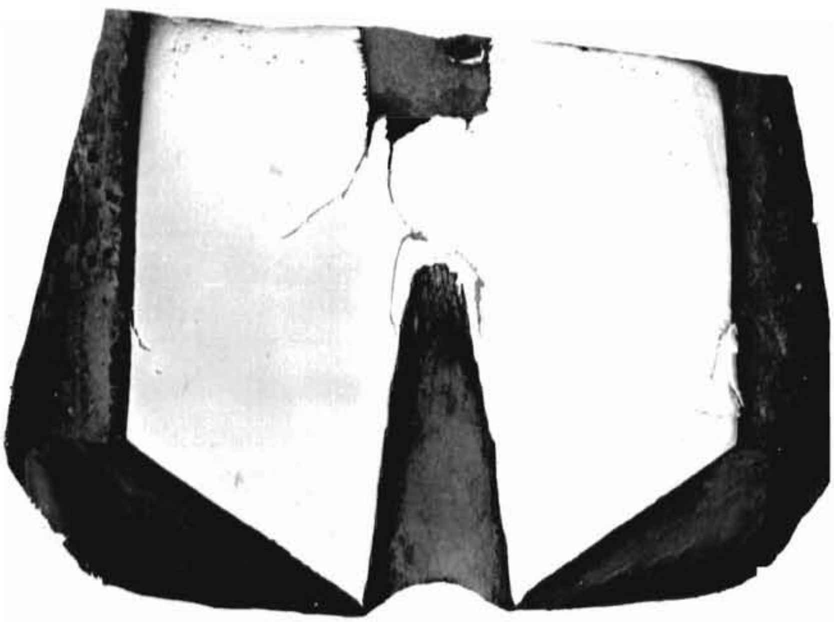


FIGURE 10.

Bit No. 2 as polished.

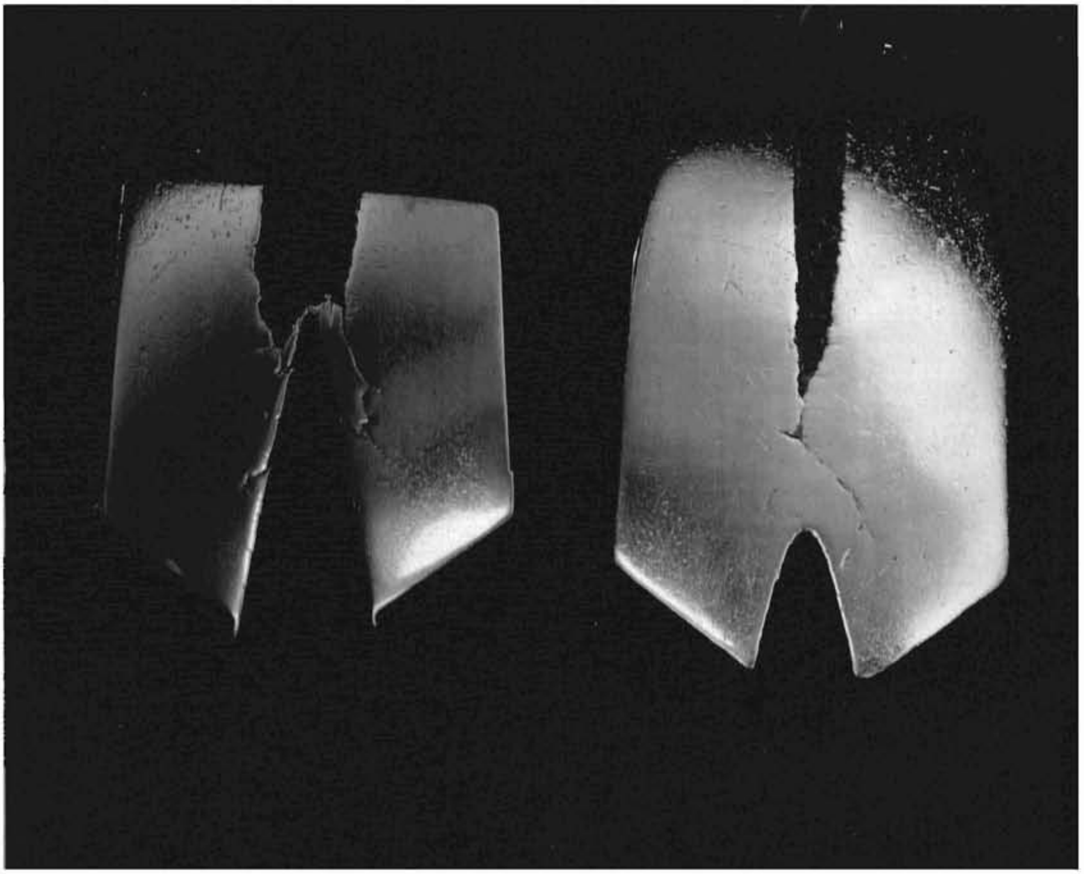


FIGURE 11

Bits No. 4 and 5 as polished.

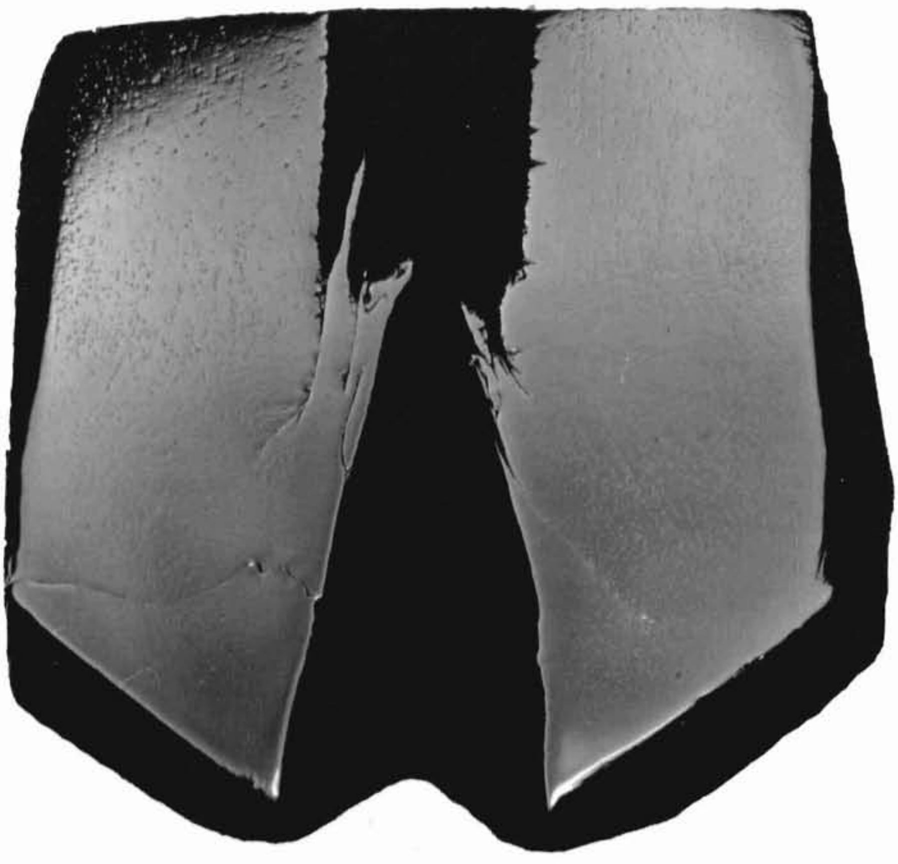


FIGURE 12.

Bit No. 7 as polished.

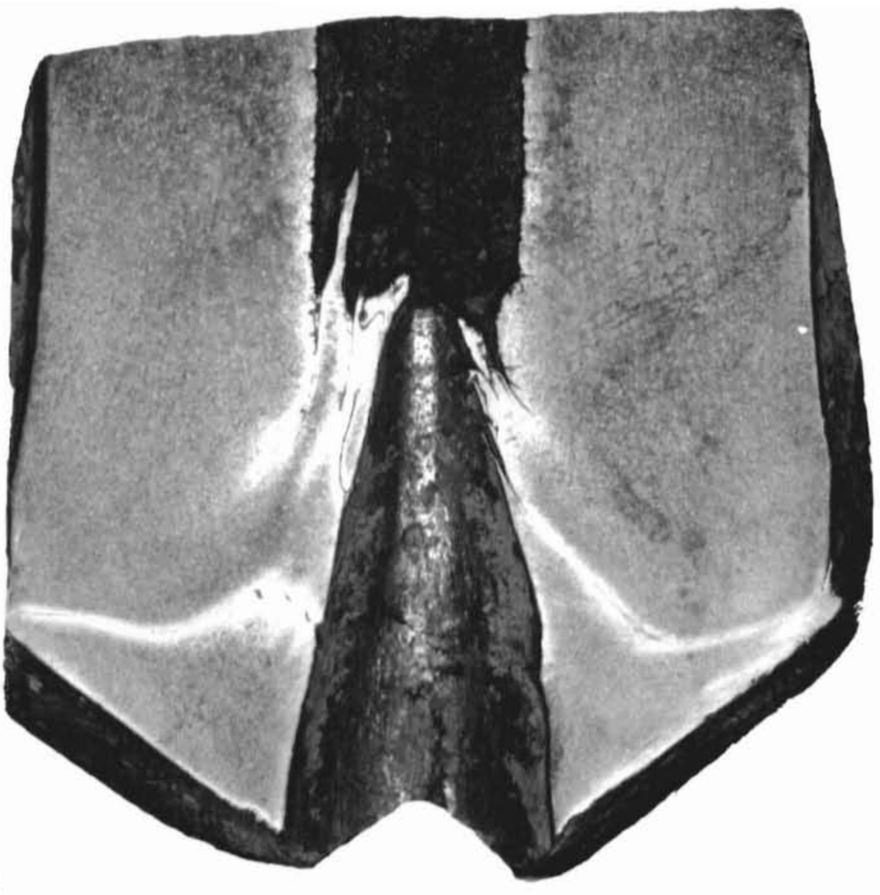


FIGURE 13.

Bit No. 7, etched with 10% HNO_3 in Amyl Alcohol.

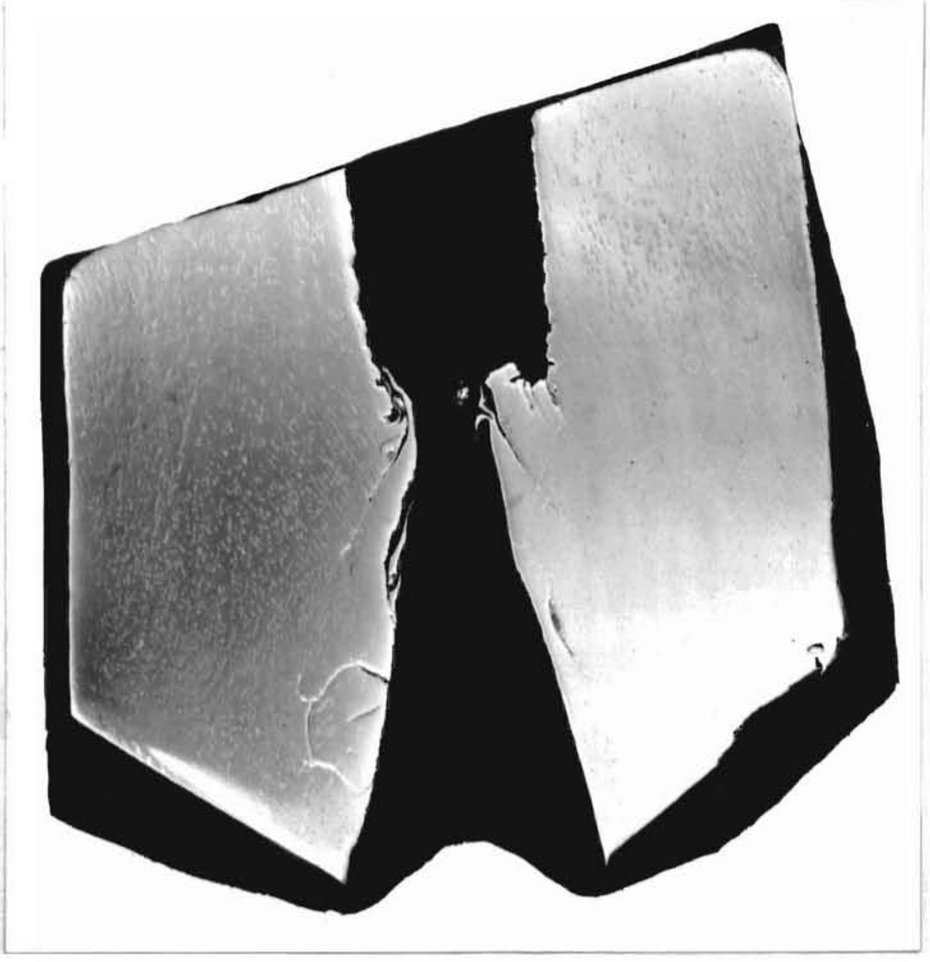


FIGURE 14.

Bit No. 8 as polished.

half-sections of the different bits. Figure 9 shows bit No. 1. In this case the water hole is completely plugged with metal forced into it during the process of upsetting and shaping the bit and punching the water hole. This bit shows no cracks that may be considered of a very serious nature. Figure 10 shows bit No. 2, the water hole of which is also completely plugged. This bit has one large crack which would undoubtedly in time cause rupture. Figure 11 shows bits Nos. 4 and 5. The water hole of No. 4 is not completely plugged, but there are no doubt some cracks which would in time become detrimental to the bit. It is impossible to tell from the photograph of No. 5 whether or not the water hole was closed, but some cracks of a serious nature are in evidence.

Figures 12 and 13 respectively show unetched and etched views of bit No. 7, which bit may be considered worthless from the start. In this bit the water hole remains open but there are cracks extending entirely through each wing of the bit. The white on the photograph of the specimen etched shows that there is decarburization all along the crack. The microscope showed that in general the crack was filled with oxide.

Figure 14 shows bit No. 8. The water hole in this bit is not plugged but there are cracks which, with another upsetting of the end, would produce the condition shown in Figures 12 and 13. There is also a large defect near the lower end of the bit.

The major portion of the trouble seems to come from the method of maintaining the water hole through the bit during shaping and sharpening. In the ordinary drill sharpener a mandrel the exact size of the water hole is inserted a suitable depth several times during upsetting and sharpening. Such does not seem to have been the practice with these bits. All of the photographs show that the water hole was apparently punched with a tool resembling the ordinary machinist's punch. In some cases, Figures 9 and 10, the tool was not driven deep enough to open the water hole.

That in itself, is a defect of some consequence in the method but there is another still more potent. The punch, being of the shape it was, had a tendency to carry up with it tongues of metal which, upon subsequent heating, were decarburized and later oxidized so that they would not weld to the walls of the water hole. Upon a second upsetting or sharpening of the bit, these cracks which at first were in the form of an inverted V with nearly vertical legs, spread, increasing the angle between the legs of the V. This process continued until the extreme case illustrated in Figures 12 and 13 was the result.

It would seem, then, that were the Homestake Mines to revise their method of maintaining the water hole in the bit, much of their trouble from breakage within the bit itself would be removed.

BIBLIOGRAPHY

1. F. B. Foley, Chas. Y. Clayton, Henry S. Burnholz. Review of Present Status of Drill Steel Breakage and Heat Treatment. Trans. A. I. M. & M. E., 1206-M.

2. H. E. Moore and J. B. Kommers. An Investigation of the Fatigue of Metals. University of Illinois Bulletin Vol. 19, No. 8, Oct. 24, 1921.

3. B. F. Tillson. Breakage and Heat Treatment of Rock drill Steel. Trans. A. I. M. & M. E. 1072-M.

4. F. B. Foley. Analysis of Some Drill Steel Tests. Trans. A. I. M. & M. E. 1076-M.

5. Rosenhain. Introduction to Physical Metallurgy, Chapt. XI., p. 253 et. seq.

6. General Electric Review. Vols. 23, 24, 25, and 26. Articles by E. G. Cohen, D. Sc.

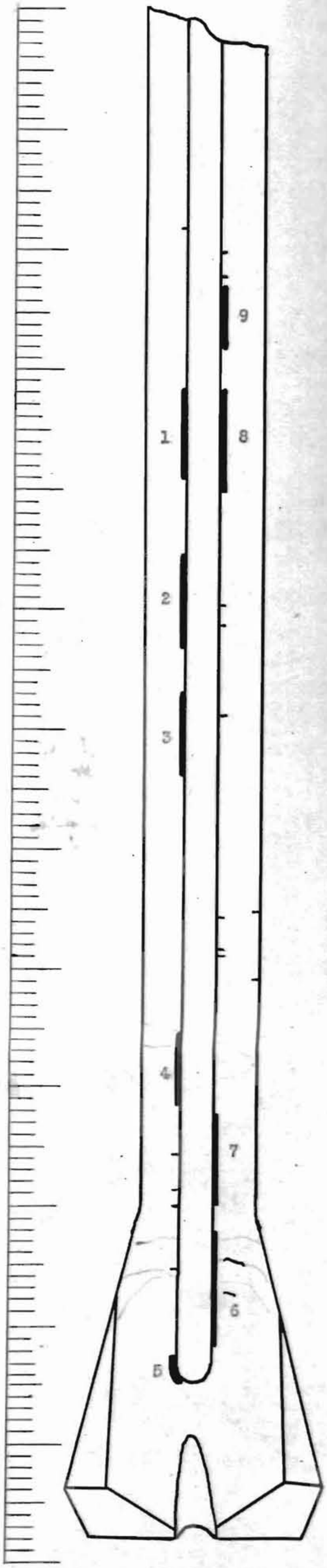
ACKNOWLEDGMENT

The author wishes to express his appreciation to Prof. Chas. Y. Clayton of the Department of Metallurgy and Ore Dressing, of the School of Mines and Metallurgy of the University of Missouri, and to Francis B. Foley, Metallurgist, Mississippi Valley Experiment Station, U. S. Bureau of Mines, for their valuable aid in organizing the work and for their constructive criticism of the report; and also to Mr. Noel Hubbard, Principal Clerk of the Mississippi Valley Experiment Station, for transscribing the manuscript.

BIT No. 1.
Gage--2 3/8 in.

Angle	Depth mm.	Angle	Depth mm.
Area No. 1.		Area No. 6.	
90	.252	90	1.848
90	.146	90	1.344
90	.146	90	.146
90	.252	90	.420
90	.252	90	.252
90	.168	90	.084
Area No. 2.		Area No. 7.	
90	.146	90	.252
90	.168	90	.336
90	.252	90	.168
90	.252	90	.420
90	.336	90	.084
90	.210	90	.084
90	.210	90	.084
90	.210		
90	.840	Area No. 8.	
Area No. 3.		90	.168
		90	.252
90	.084	90	.146
90	.168	90	.084
90	.294	90	.420
90	.168	90	.168
90	.146	90	.168
90	.146	90	.252
Area No. 4.		Area No. 9.	
90	.252	90	.084
90	.210	90	.084
90	.252	90	.084
90	.168	90	.084
90	.064	90	.146
90	.294	90	.168
		90	.146
Area No. 5.		90	.084
		90	.084
90	.420		
90	.756		
90	.568		

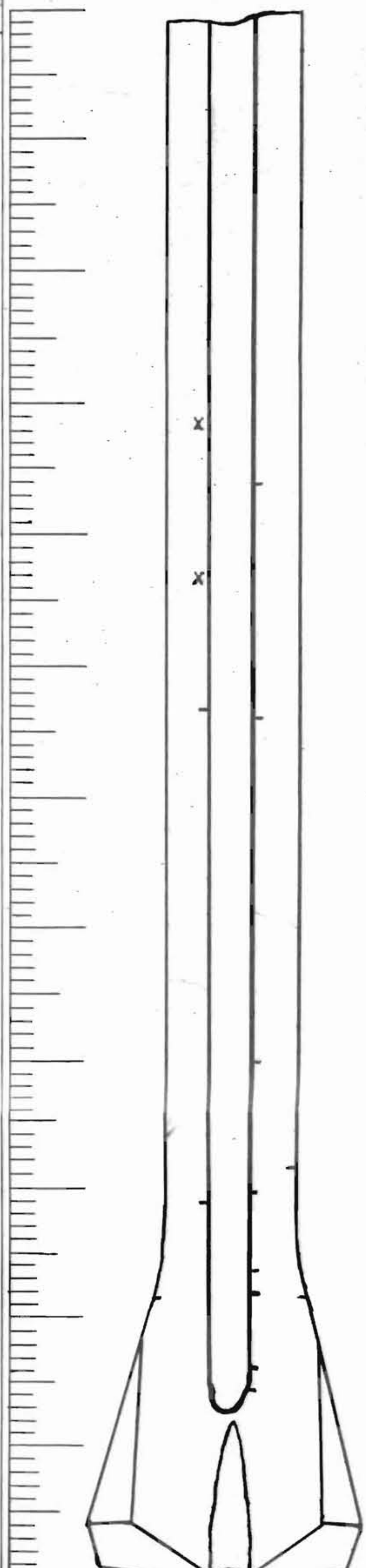
X indicates where photographs were taken.



INSIDE		OUTSIDE	
Angle	Depth mm.	Angle	Depth mm.
90	.146		
90	.294		
90	.084		
90	.146		
90	.146		
90	.420		
90	.168	30	.252
90	.168		
90	.168		
		45	.146
90	.168		
90	.084		
90	.840		
		Internal	
90	.252	90	.294
		90	1.344

BIT No. 2.
Gage-- 2 1/4 in.

Outside		Inside	
Angle	Depth mm.	Angle	Depth mm.
		90	.084
		90	.126
90	.126		
90	.378		

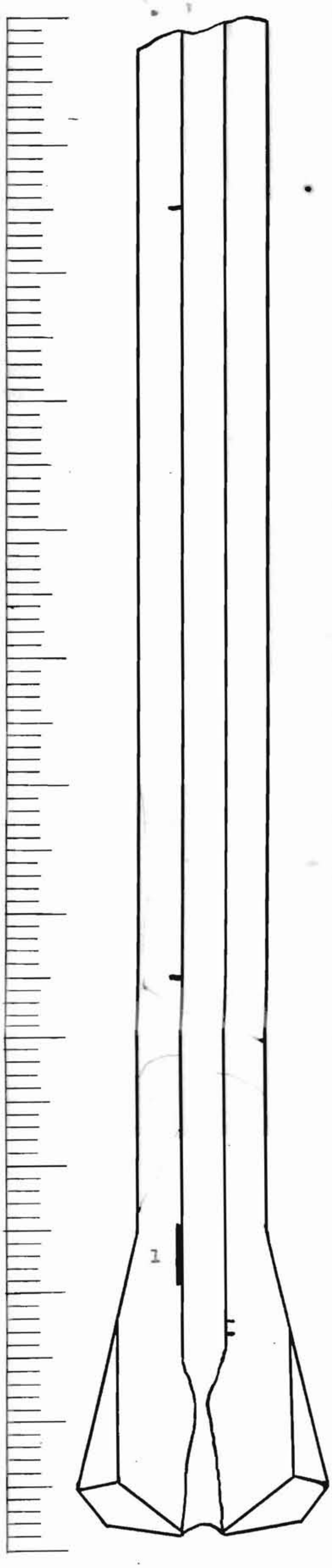


Inside		Outside	
Angle	Depth mm.	Angle	Depth mm.
90	.042		
60	.060		
60	.084		
60	.168		
		90	.126
90	.126		
90	.084		
90	.504	45	.126
90	.084		
90	[illegible]		

X indicates where photographs were taken.

BIT NO.3.
Gage---2 1/8 in.

Angle	Depth mm.
90	.042
90	.042

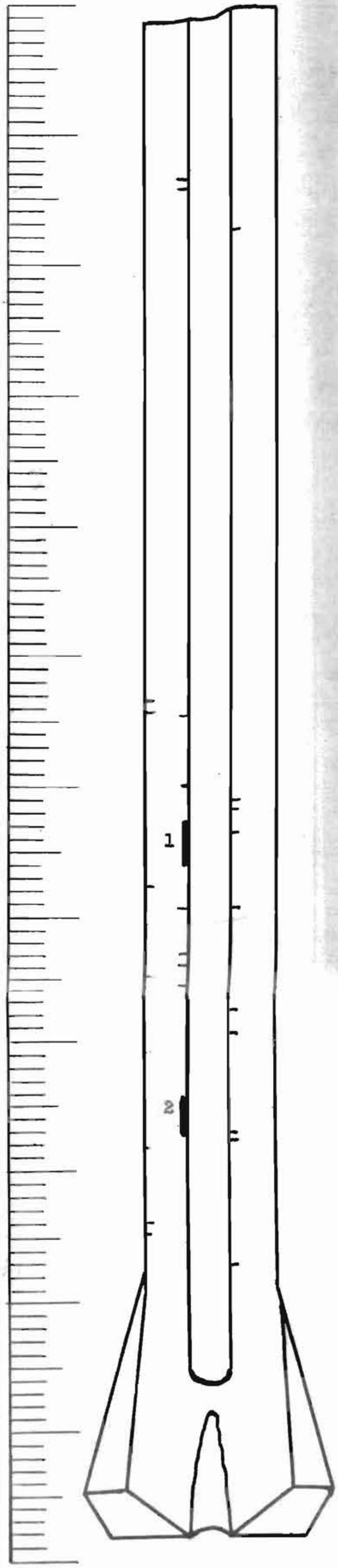


Angle	Depth mm.
90	.336
90	.084

Angle	Depth mm.
Area No. 1.	
90	.084
90	.420
90	.168
90	.084
90	.210
90	.084
90	.126
90	.084

OUTSIDE		INSIDE	
Angle	Depth mm.	Angle	Depth mm.
		90.	.084
		90	.168
90	.168		
90	.588	90	.084
		90	.252
90	1.680		
		90	.084
		90	.084
		90	.084
		90	.168
90	.840		
90	.504		

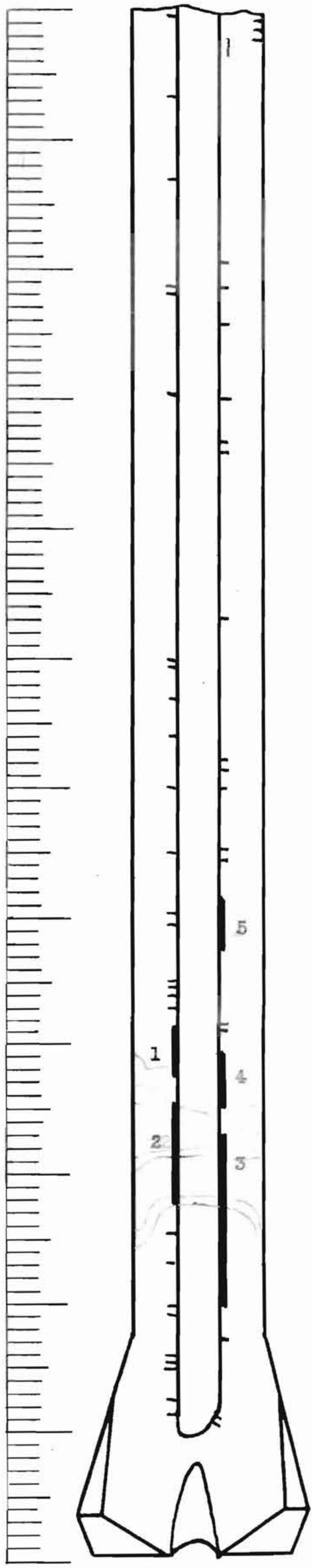
BIT NO. 4.
Gage--2 in.



Angle	Depth mm.	Angle	Depth mm.
90	.042		
		Area No. 1.	
		90	.336
		90	.252
		90	.210
		90	.168
		90	.252
		Area No. 2.	
90	1.008	90	.084
90	.168	90	.084
90	.168	90	.084
		90	.084
90	.252	90	.168
90	.210		
90	.084		
90	.168		
90	.168		
90	.084		

BIT NO. 5.
Gage—-1 15/16 in.

Angle	Depth mm.
90	.084
90	.168
90	.084
90	.336
90	.336
90	.252
90	.126
90	.168
90,	.168
90	.672
90	.420
90	.252
90	.378
90	.084
90	.252
90	.252
90	.336
90	.336
90	.084
90	.420
90	.588
90	.252
90	.084
90	.252
90	.252
90	.588
90	.672

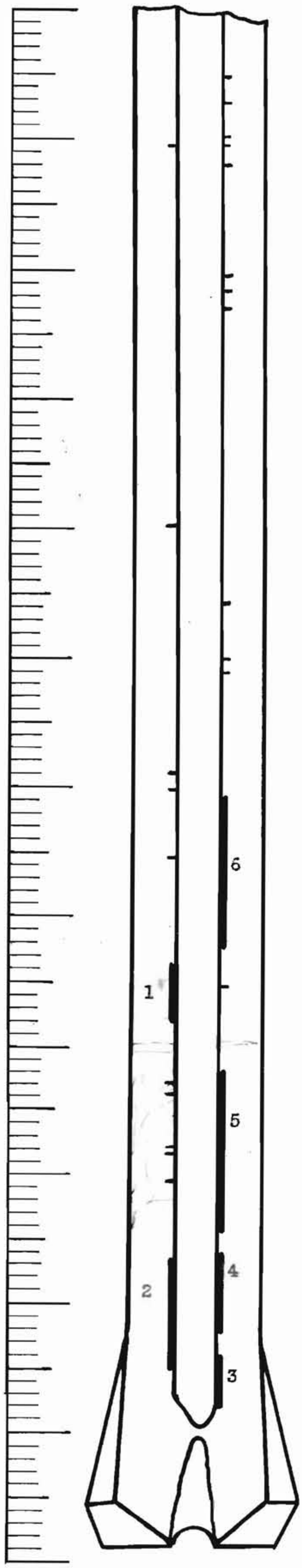


Angle	Depth mm.
Internal	2.100
"	.840
"	.672
90	1.092
90	.126
90	.126
90	.126
90	.084
90	.588
90	.252
90	.336
90	.336
90	.420
90	.420
90	.588
90	.126
90	.336
90	.504
90	.252
90	.252
90	.420

Angle	Depth mm.
Area No. 1.	
90	.084
90	.042
90	.042
90	.021
90	.063
90	.908
90	.420
90	.126
90	.168
Area No. 2.	
90	.084
90	.168
90	.504
90	.084
90	.084
90	.336
90	.084
90	.084
90	.672
90	.336
90	.336
90	.294
90	.252
Area No. 3.	
90	.084
90	.672
90	.504
90	.168
90	.588
90	.252
90	.252
90	.252
90	.252
90	.252
90	.084
90	.084
90	.756
90	.336
90	1.008
90	.336
90	.252
90	.084
Area No. 4.	
90	.210
90	.336
90	.084
90	.084
90	.084
90	.420
Area No. 5.	
90	.252
90	.252
90	.252
90	.294
90	.084
90	.084
90	.210
90	.336
90	1.008

BIT NO. 6.
Gage—1 13/16 in.

Angle	Depth mm.
90	.084
90	.126
90	.168
90	.252
90	.084
90	.084
90	.504
90	.168
90	.252
90	.252
90	.252

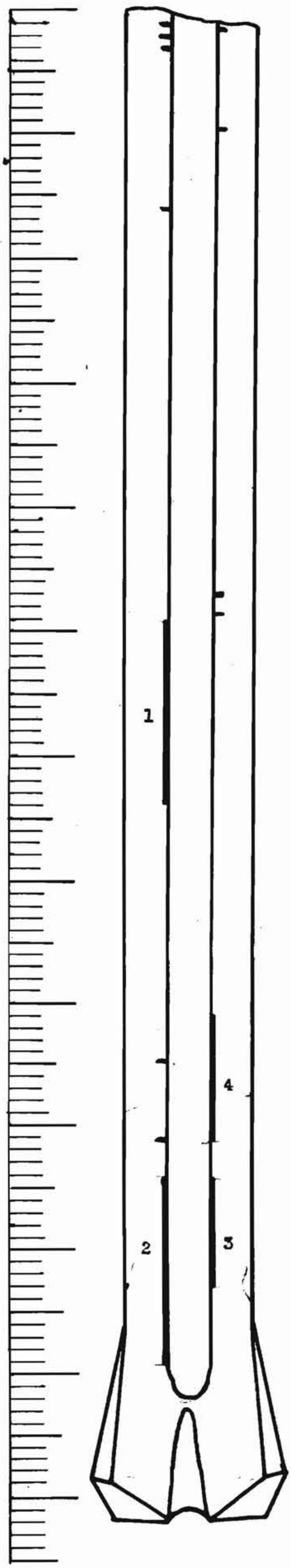


Angle	Depth mm.
90	.084
90	.168
90	.168
90	.084
90	.168
90	.084
90	.126
90	.336
90	.168
90	.168
90	.252
90	.168

Angle	Depth mm.
Area No. 1.	
90	.084
90	.084
90	.168
90	.168
Area No. 2.	
90	.420
90	.504
90	.210
90	.336
90	.210
90	.420
Area No. 3.	
90	.504
90	.420
Four incipient	
Area No. 4.	
90	2.520
Five Incipient	
Area No. 5.	
90	.084
90	.126
90	.294
90	.084
90	.084
90	.336
90	.420
Area No. 6.	
90	.084
90	.084
90	.084
90	.084
90	.084
90	.084
90	.084
90	.126

Angle	Depth mm.
Area No. 1.	
90	.084
90	.084
90	.084
90	.084
90	.084
90.	.168
90	.168
90	.168
90	.252
90	.168
90	.168
90	.168
90	.084
90	.084
90	.336
90	.084
90	.168
90	.168
90	.084
90	.084
90	.084
Area No. 2.	
90	.084
90	.084
90	.084
90	.084
90	.085
90	.084
90	.126
90	.168
90	.084
90	.084
Area No. 3.	
90	.168
90	.084
90	.168
90	.084
90	.168
90	.084
Area No. 4.	
Incipient cracks	

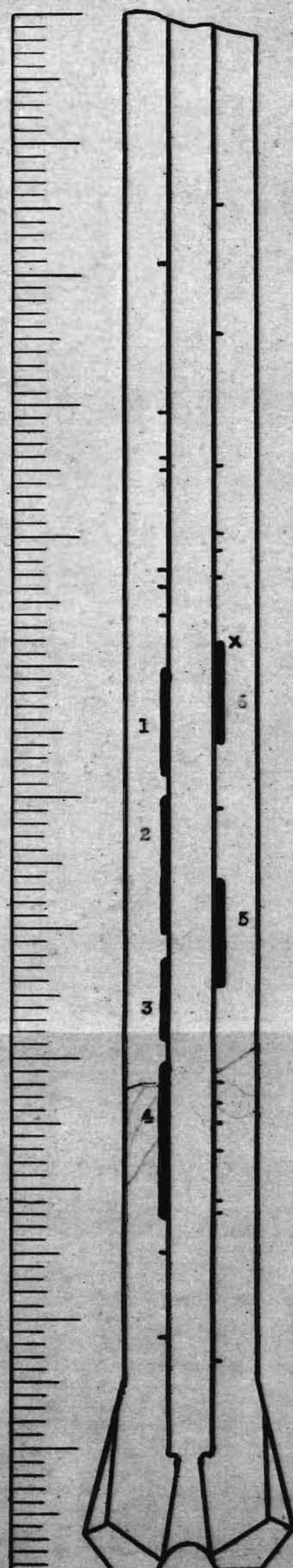
BIT NO. [illegible]
Gage— 1 11/16 in.



LEFT-HAND		RIGHT-HAND	
Angle	Depth mm.	Angle	Depth mm.
90	.252	90	.210
90	.126		
90	.042		
		90	.252
90	.840		
		90	.084
		90	.084
90	.084		
90	.084		

BIT No. 8.
Gage—1 9/16 in.

Angle	Depth mm.
90	.126
90	.126
90	.084
90	.168
90	.252
90	.252
90	.420
90	.168
90	.504



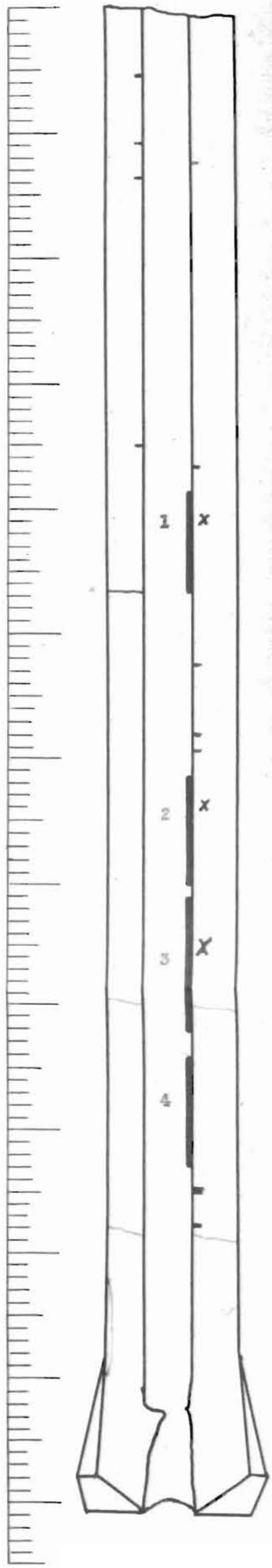
Angle	Depth mm.
60	.168
90	.168
90	.504
90	.252
60	.252
90	.252
90	.168
90	.210
90	.252
90	.336
90	.210
90	.084
90	.084
90	.168

Angle	Depth mm.
Area No. 1.	
90	.084
90	.084
90	.168
90	.504
90	.126
90	.252
90	.252
90	.168
90	.252
Area No. 2.	
90	.462
90	.336
90	.588
90	.084
90	.252
90	.336
90	.336
90	.294
Area No. 3.	
90	.504
90	.126
90	.126
90	.126
90	.252
Area No. 4.	
90	.168
90	.252
90	.126
90	.252
90	.084
90	.126
90	.158
90	.168
90	.378
90	.504
90	.168
90	.672
Area No. 5.	
90	.504
90	.420
90	.168
90	.168
90	.394
Area No. 6.	
90	.504
90	.420
90	.504
90	.252

X indicates where photographs were taken.

Bit No. 9.
Gage--1 7/16 in.

Angle	Depth mm.
Area No. 1.	
90	.168
90	.168
90	.084
90	.252
90	.336
Area No. 2.	
90	.336
90	.210
90	.336
90	.336
90	.336
90	.504
90	.336
Area No. 3.	
90	.336
90	.420
90	.084
90	.252
90	.210
90	.168
90	.294
90	.252
90	.084
Area No. 4.	
90	.084
90	.168
90	.294
90	.126
90	.252
90	.168
90	.126



Inside Angle	Inside Depth mm.	Outside Angle	Outside Depth mm.
* 90	.168		
* 90	.252		
* 90	.168		
90	.042		
* 90	.064		
90	.924		
90	.168		
90	.252		
90	.168		
90	.504		
90	.084		

indicates cracks on left-hand side of bit.

X indicates where photographs were taken.

Below place marked ** only one-half of the section was available for examination.