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September 8, 1936

MICROSCOPIC EXAMINATION
(Made for Dr. Reed)
OF THE
"WHITE BANDS" CAUSED BY THE
PENETRATION OF ARMOR PLATE

I. Material Employed for Study

Two specimens were examined:-

A. - #614.5.8 which is one-half inch homogeneous armor plate manufactured by Watertown Arsenal and rolled by Henry Dieston & Sons Inc., W.A. Order 8542, Ingot 12-614.

Composition

<u>C</u>	<u>Mn</u>	<u>Si</u>	<u>S</u>	<u>P</u>	<u>Ni</u>	<u>Va</u>	<u>Cr</u>	<u>Mo</u>
.61	.42	.14	.013	.016	.09	.29	1.21	.56

Heat Treatment

Quenched from 1650°F in oil, drawn to 1150°F for two hours.

Brinell Hardness - Front 430, back 444

Striking velocity 2391 ft./sec., Height of bulge back .03"

Ammunition Cal. .30 M 1922 A.P. Weight core 87.5 grains.

Distance from muzzle to plate - 100 yards

Penetration - partial, Spec. 31

Angle of indent - normal

Bullet hole sectioned through axis of bullet.

B. - 614.5.5 - Same as 614.5.8 except as follows:

Striking velocity - 2495 ft./sec.

Penetration - partial.

Angle of indent - normal.

Bullet hole was sectioned to one side of axis of bullet.

Sample was tempered 1/2 hour at 300°C in tin bath, and cooled in air.

II. Object

The primary purpose of the study was the detection of the possible presence of metallographic structures in the "white bands" which had been observed by Doctor Reed in his work on the penetration of armor plate. They were, simply, regions in the metal which failed to respond to normal metallographic etching and hence, appeared as white streaks against the background of the etched plate material.

A customary survey of the unetched, polished surface, however, indicated the interesting nature of the main cracks caused by the penetration and the peculiar state of many of the nonmetallic elements. Consequently, a general examination of these conditions was first made.

III. Experimental Work

Specimen #614.5.8

A. Unetched

Three groups of photomicrographs were obtained, showing

1. The main crack systems at 50 diameters.
2. Portions of the main cracks at 1,000 diameters.

This was done to discover the possible existence of minute fractures which might occur as continuations of the cracks.

3. Typical groups of nonmetallic elements at 1,000 diameters.

These illustrations are presented in Folders #1 - #8. A more detailed record of observations accompanies each folder.

B. Etched

1. A 2% Nital etch revealed the structure of the plate metal and the presence of the "white bands" which were to be investigated. A complete view of the latter, which occur both alone and in conjunction with cracks, may be seen at 10 diameters in Folder #9.

They evidenced no metallographic structure and practically no detail when examined at 600 diameters. By using oblique illumination on the same surface, however, it was possible to observe definite flow lines which indicated metal movement and which occurred both adjacent to and within the white areas. Characteristic sections of the white regions were photographed at 1,000 diameters employing first normal illumination and then oblique illumination of the sample. Folder #10 contains these illustrations.

Folder #12 (105 and 106) shows the same material at 3,000 diameters. Cracks within the "white band" are more easily noted at this magnification.

2. Additional and prolonged etching of the same surface with 2% Nital produced apparent structure in the "white bands". It is illustrated at 1,000 diameters in Folder #11 (109, 108, 110) and at 3,000 diameters in Folder #12 (113). Due to lack of sharpness of the material within the white area, it was decided to make subsequent studies on a newly-cut surface of the sample.

3. After a very careful repolish the specimen was subjected to a prolonged etching with 5% Nital. Evidence of structure was observed even at fairly low magnifications. Photomicrographs showing it at 450 diameters are presented in Folder #9 (135, 136) and at 3,000 diameters in Folder #13.

The binocular eyepiece, which produced a three - dimensional effect, confirmed the presence of a multiplicity of small, though rounded, grains but a metallographic plate cannot record this appearance. Furthermore, the "white band" consisted not of one plane surface but of furrows. This condition, which was revealed by oblique illumination of the sample, would account for the absence of the well-defined outlines of orthodox metallographic structures. It was considered advisable, therefore, to make another at-

tempt to level down the "white bands".

4. Final examination was made on a surface which had been prepared by a departure from current polishing practice in this laboratory, i.e. it was cut slowly and by hand on the abrasive papers rather than on the rapidly-rotating, paper-covered disc. The finishing procedure was unchanged since it is normally carried out slowly. The resulting surface, after a prolonged etch with 5% Nital, proved to be a duplication of the one described under (3) above. Although this condition vindicated the high-speed paper work, it indicated that metals can assume some structural arrangements which resist being cut to a level by ordinary methods and hence, prevent a sharply-defined presentation of their metallographic characteristics.

Photomicrographs, at 1,000 diameters, depicting the last surface obtained on specimen #614.5.8 are assembled in Folder #11 (142, 141, 140) and, at 3,000 diameters, in Folder #14. These show sections of a "white band" as they appear when illuminated first normally and then obliquely. Comparison of these illustrations should be made with those noted in paragraph 3 and found in Folder #13. In both cases the occurrence of structure within the band is obvious. To see fully the wealth of detail recorded in these prints it is recommended that they be examined by means of a hand glass.

Specimen #614.5.5

A. Unetched

The crack systems on this sample, which were more numerous than those on specimen #614.5.8, were photographed at 50 diameters (see Folders #15, #16 and #17).

Visual examination, but no photography was carried out at higher magnification. The appearance of cracks and of nonmetallic elements at X1000 is typified by the illustrations secured on specimen #614.5.8.

B. Etched

1. This metal, which had been tempered 1/2 hour at 300°C, responded more readily to etching attack. A treatment with 1% Nital revealed the structure of the plate metal and the presence of numbers of "white bands". Additional etching showed the occurrence of extremely fine detail within the bands. The latter condition is illustrated at 300 diameters in Folder #18 (54 and 53) and at 3,000 diameters in Folder #20 (47, 48, 49, 50, 51, 52). In addition, a study of the surface under oblique illumination showed the existence of flow lines, due to metal movement, similar to those described for specimen #614.5.8. A photomicrograph recording this state, at 1,000 diameters, may be seen in Folder #19 (45 and 46).

2. As in the case of specimen #614.5.8, it was believed that improved sample preparation might sharpen the appearance of the structure in the "white bands" of #614.5.5. Accordingly, it was carefully repolished by hand on the papers and finished slowly on the wheel. This time, prolonged etching was carried out with 2% Nital. The resulting exceedingly fine, rounded structure may be seen at 1,000 diameters in Folder #19 (57, 59, 58, 60) and at 3,000 diameters in Folder #20 (61, 62, 63, 64).

The photomicrographs confirm the presence of minute structural features within the band. The ones made with oblique illumination furnish evidence of the rough surface conditions to which must be attributed the lack of sharply-out characteristic metallographic outlines.

IV. Results

Results are presented in the form of illustrations bound together in "Folders". The latter are accompanied, where necessary, by detailed comments on individual prints. The story could be told just as effectively by means of a few carefully selected photomicrographs. The experimental results are, however, being given completely in order that Doctor Reed may, if he finds any of them useful, perform the final weeding-out process himself.

The following explanatory notes pertain to all folders:-

1. At the beginning of each folder is a photomicrograph at 10 diameters which serves as a map of the illustrations following it.

2. The number which occurs in the upper right-hand corner of each print is repeated on the map thus locating the area which has been photographed.

3. A number appearing in brackets under the number described in note 2 above, refers to another photomicrograph of the same spot made either at a different magnification or with a different type of illumination.

4. A letter "N" in the upper left-hand corner signifies that the photography was carried out with normal illumination.

5. A letter "O" in the upper left-hand corner signifies that the photography was carried out with oblique illumination.

6. Each print has the same orientation as that of the map.

7. It is recommended that the prints - particularly those depicting structures revealed by etching - be examined with the aid of a hand glass.

Folder #1

Specimen #614.5.8

Crack Systems

X50

Unetched

_____	No.
_____	Name
_____	Order
_____	Remarks
_____	Retouched
_____	Order Finished
_____	Reorder
_____	Reorder

Folder #2

Specimen #614.6.8

Crack At Side of Specimen

Opposite Penetration Cavity

X50

Unetched

_____ No.
_____ Name
_____ Order
_____ Remarks
_____ Retouched
_____ Order Finished
_____ Reorder
_____ Reorder

Folder #3

Specimen #614.6.8

Cracks Seen in Folder #1

X1000

Unetched

No.

Name

Order

Remarks

Retouched

Order Finished

Reorder

Reorder

See page 12.

Folder #3

56 - Crack offset.

Fine fracture between two parts.

57 - "Inclusion" at "a" on left of crack is swung around about 45° from its original location in the plate metal.

Fine fractures extend beyond a portion of main crack.

24 - Discontinuity of crack.

"Inclusion" on left of crack has been swirled around from its original horizontal position.

68 - End of main crack shown about center of print.

Fine faintly visible ruptures appear to right of it.

Folder #4

Specimen #614.5.8

Cracks seen in Folder #1

x1000

Unetched

No. _____
Name _____
Order _____
Remarks _____
Retouched _____
Order Finished _____
Reorder _____
Reorder _____

See page 14.

Folder #4

- 31 - Fine fracture running left from top of crack.
"Inclusion" above crack, moved out of position.
- 58 - Fine fractures extending from end of side arm
of crack in upper half of picture.
"Inclusions" above crack.
- 59 - Fine fracture above and to right of crack.
Fine fracture below crack extending to side
branch of main crack.
- 27 - Spherical "inclusion" at junction of main
crack and side one.
Fine fractures running out from small branches
on lower side of main crack.
- 28 - No apparent fracture extending beyond end of
main crack. Extreme end of crack appears to
have been caused by forces which were perpen-
dicular to those causing the main portion of
the crack.
- 29 - Fine cracks connecting discontinuous sections
of main crack.
- 30 - Main crack discontinuous.
"Inclusions" in right portion of the print are
swung out of their horizontal position.
- 76 - No evidence of fracture extending beyond ex-
tremity of main crack.
"Inclusion" below crack swirled out of its
original horizontal position.

Folder #6

Specimen #614.5.8

Cracks Seen in Folder #1

X1000

Unetched

_____ No.
_____ Name
_____ Order
_____ Remarks
_____ Retouched
_____ Order Finished
_____ Reorder
_____ Reorder

See page 16.

Folder #5

- 60 - Fracture at end of inclusion.
None at end of crack.

- 74 - Discontinuity of crack.

- 72 - Cracks near edge of penetration cavity.
Fine fractures extending between parts of
smaller cracks.

- 73 - No apparent fine fracture at beginning of crack.

- 70 - Crack offset. Fine fractures present in several
extremities.
Two straight lines at left of photomicrograph
are "inclusions".

- 71 - Fine fractures at ends of small cracks and also
between two "inclusions" which occur in lower
half of print.

- 55 - Fine fracture at discontinuous end of main crack.

Folder #6

Specimen #614.5.8

Cracks seen in folder #1

41000

Unetched

_____ No.
_____ Name
_____ Order
_____ Remarks
_____ Retouched
_____ Order Finished
_____ Reorder
_____ Reorder

See page 18.

Folder #6

- 61 - Faintly visible fracture extending beyond beginning of crack - another extends from very short rupture at left of main crack.
- 35 - Crack cutting through large "inclusion".
Fracture at left extremity of "inclusion".
- 73 - Discontinuity of crack.
Fine horizontal fracture extending from either side of small "inclusion" between two branches of crack.
- 34 - Discontinuity of crack.
Fine fractures extending from extremities of some branches.
- 36 - Crack discontinuous.
Fracture at left side of distorted spherical "inclusion".
- 62 - Crack discontinuous.
Small "inclusion" and fine fracture at beginning of middle section.
- 64 - Very faintly visible fracture extending well beyond end of crack toward bottom of print.
"Inclusions", not cracks, at upper left-hand corner.

Folder #7

Specimen #614.5.8

Cracks seen in folder 2

X1000

Unetched

_____ No.
_____ Name
_____ Order
_____ Remarks
_____ Retouched
_____ Order Finished
_____ Reorder
_____ Reorder

See page 21.

Folder #7

- 78 - Fine fracture between main crack and section of crack to left of it.
"Inclusion" below crack is distorted.
- 77 - Fine fractures in plate material between two branches of crack.
- 81 - section of plate metal trapped in crack.
- 79 - Section of rupture disconnected from main crack.
- 80 - Cavities between section shown in 79 and main crack.

Folder #

Specimen #014.0.8

Typical articles of Nonmetallic
Elements

X1000

Untouched

_____ No.
_____ Name
_____ Order
_____ Remarks
_____ Retouched
_____ Order Finished
_____ Reorder
_____ Reorder

See page 23.

Folder #8

- 65 - Distorted "inclusions" - fine fractures extending from some of them.

- 62 - Fine fracture extending from right extremity of both "slag stringers".

- 64 - No evidence of fractures connected with these "inclusions".

- 65 - Very distorted "inclusions", fine fractures accompanying some of them.

- 63 - "Inclusions" distorted - evidence of fine fracture adjoining some of them.

- 82 - Fractures extending from spherical "inclusion" at right of print. Fine fracture extending from long "inclusion" in upper part of print.

- 84 - No evidence of fractures accompanying these "inclusions".

- 88 - Distorted "inclusions". Fractures at both sides of spherical particle at top of field. Fine fracture to left of "stringer" at bottom of print.

Folder #8

- 86) Fragmented "inclusions" typical of many
87) - found in area below penetration cavity,
83) some being well down in plate. Note actual
sharp breaks in the "stringers". Not found
in regions remote from penetrated section.
- 103 - Same "inclusion" shown in 53 after 2% Nital
etch. Lack of change in metallographic
structure immediately adjacent to it indicates
that the particle might have been shattered by
an elastic rather than by a plastic deformation
of the metal.
- 103 - A lighter print of the same photomicrograph
showing that the "inclusion" has not been lost
by etching.
- 104 - Another fragmented "inclusion" - not photo-
graphed before etching. Here, too, there is
no evidence around the "stringer" of a changed
metallographic structure which would be ex-
pected had the included material been moved
through plastic deformation. To the left of
and extending below it is the last remnant of
a "white band" as it merges into the plate
metal. For location of this "white band" see
photomicrograph of etched specimen at 10 di-
ameters in next folder.

* The possibility that this fragmentation
occurred during the rolling of the plate
should not be excluded.

Folder 19

specimen 614.6.8

"White Sand"

X10

5 Nitel

X450

5 Nitel

No. _____
Name _____
Order _____
Remarks _____
Retouched _____
Order Finished _____
Reorder _____
Reorder _____

see page 26.

Folder #2

Photomicrographs at 10 diameters show complete number of "white bands" on specimen. They also reveal the location of the bands with reference to the crack systems. The white areas which are associated with the cracks are not so easily seen as are those which extend beyond them.

- 136) - Structural detail, large cracks and fine
135) - cracks in "white band".

Hard material of the band is in relief - hence structure of plate metal cannot be focused at same time. From map at X10 it may be seen that this section of the "white band" is independent of the main cracks.

Note flow lines at outer edges of band.

Folder 10

specimen #614.5.8

"White Band"

x1000

2x Nitral

_____ No.
_____ Name
_____ Order
_____ Remarks
_____ Retouched
_____ Order Finished
_____ Reorder
_____ Reorder

see page 26.

Folder #10

- 101 - Deformed metal at lower edge of penetration cavity.
- 94 - "White band" in conjunction with a main crack. Fine cracks but practically no detail discernible.
- 92 - End of a main crack with "white band" extending beyond it. Cracks but no detail in band.
- 91 - Same as 92 but photographed with oblique illumination. Note flow lines in band.
- 90 - Beginning of crack at lower edge of penetration cavity. No detail in "white band" running parallel with one branch of crack. Fine detail in remainder of area which is deformed plate metal at edge of cavity.
- 89 - Same as 90 but photographed with oblique illumination. No detail in "white band" but flow lines are visible in region adjoining it as well as in the plate metal.
- 98 - Section of "white band" extending across plate between two main cracks. No detail within band.
- 97 - Same as 98 but photographed with oblique illumination. Flow lines adjacent to and within band.

Folder #10

- 100 - Region of "white band" to right of area shown in 98. No detail in band. Structure of plate metal apparently unchanged near it.
- 99 - Same as 100 but photographed with oblique illumination. Flow lines visible within band and in adjoining territory.
- 96 - Same band shown in 98 and 100 as it crosses a main crack. It is offset by the crack. Practically no detail within the white area.
- 95 - Same as 96 but photographed with oblique illumination. Flow lines and cracks visible in "white band".
- 95 - Lighter print shows crack to better advantage. Also reveals flow lines in region adjoining "white band".

Folder 11

Specimen #614.5.6

"White Band"

X1000

(2% vital
(5% vital

No. _____
Name _____
Order _____
Remarks _____
Retouched _____
Order Finished _____
Reorder _____
Reorder _____

see page 31.

Folder #11

109 - "white band" running parallel with and to the left of a main crack - near area shown in Folder #10 - 94. Additional etching with 2% Nital has revealed considerable structure in band. This was overexposed in the present illustration which was made in order to show the detail in the isolated section of "white band" contained within the crack.

108 - Same area shown in Folder #10 - 91, 92. Additional etching with 2% Nital has developed pronounced evidence of structure.

110 - Same area shown in Folder #10 - 95, 96 after additional etching with 2% Nital.

Note intermediate metal structure between plate material and "white band".

142) sections of a "white band" which occurs independently of main cracks. This is the last surface to be polished and photographed - its preparation is described in the text.

140) -

141)

The effectiveness of a 5% Nital etch may be noted in the wealth of fine detail which is easily visible with ordinary illumination. An intermediate structure occurs between the band and the plate metal. The latter being at a lower level from that of the white material, its structure is not in focus.

Folder #12

Specimen #614.5.8

"White Band"

X3000

(2% Nital
(5% Nital

_____ No.
_____ Name
_____ Order
_____ Remarks
_____ Retouched
_____ Order Finished
_____ Reorder
_____ Reorder

see page 33.

Folder #12

106 - Section of "white band" (same etch) shown in Folder #10 - 99, 100. Higher magnification with ordinary illumination reveals no further detail than is seen at X1000.

105 - Same as 106, but photographed with oblique illumination. Flow lines which this type of illumination made visible at X1000 are more easily seen here.

Pronounced evidence of cracks within the band.

113 - Section of "white band" close to that shown in 106 and 105 after an additional etching with 2% Nitral. Structural details are visible with ordinary illumination. See text for comments concerning lack of sharp outlines. Note cracks.

Folder 13

Specimen 614.5.8

"White Band"

X3000

6" Nitral

No.

Name

Order

Remarks

Retouched

Order Finished

Reorder

Reorder

See page 38.

Folder #13

- 123 - Portion of one of isolated patches of "white band" material present at bottom edge of penetration cavity. Structure is self-evident. The black lower part of this illustration is the location of the plate metal which is at a different level.
- 124 - Section of "white band" attached to side of crack which begins at lower edge of penetration cavity. Contains structural details similar to those in 123.
- 126 - Section of a "white band" as it starts to extend away from a main crack. Structure like that in 123 and 124. Band at much higher level than plate. Latter is, therefore, out of focus - a condition existing in every illustration contained in this folder.
- 121 - Section of same "white band" as it appears in region to right of 126.

Finer detail evident.
- 122 - Section of same "white band" - to right of 121 - just before it crosses a main crack. Note fine cracks and detail within band.
- 127)
128) - Same "white band" after crossing the main crack mentioned under 122. Note presence of fine structure.

Folder #13

129 - Same "white band" in area to right of 127 and 128. Dark spots within band are not cavities. They are actually gray-colored inclusions which in this illustration are blackened by the length of exposure necessary to bring out details in the white material. Their smoothly spherical shape appears to have been undisturbed by the deformation of the metal. This is one of numerous instances in which such "inclusions" were observed in the bands. An explanation might be that the violent reaction which induced the formation of the "white bands" generated sufficient heat to melt any inclusions existing in the same regions. Upon subsequent solidification, the particles assumed their normal shapes and thus present the appearance of having been unaffected by the shock of penetration.

See also the fine cracks which seem either to start or to end at the "inclusions".

Folder #14

Specimen #614.5.8

"White Band"

X3000

5" Nitel

_____ No.
_____ Name
_____ Order
_____ Remarks
_____ Retouched
_____ Order Finished
_____ Reorder
_____ Reorder

See page 38.

Folder #14

- 143) Sections of "white band" shown at X1000
146) - in Folder #11 - 142, 141, 140.
147) Fine detail and occasional cracks are present.
- 144) Identical with 143, 146, and 147 but photo-
146) - graphed with oblique illumination.
148) Fine detail still apparent. Here, however, is evidence of the furrowed condition of the surface which prevents the presentation of well-defined structural characteristics.
- 149 - A narrow portion of a "white band" as it merges into the plate metal. The latter is at a different level from the hard white material and consequently not in focus.
- 150 - Same as 149, but photographed with oblique illumination.

Note fine cracks.
- 130 - Another part of same "white band" shown in 143, 146, 147, for which there is no corresponding photomicrograph made with oblique illumination. Note "inclusion", fine cracks and very evident "structure".

Folder #16

Specimen #614.5.5

Main Crack Systems

60

Unetched

No. _____
Name _____
Order _____
Remarks _____
Retouched _____
Order Finished _____
Reorder _____
Reorder _____

Folder #16

Specimen #614.6.6

Main Crack Systems

X50

Unetched

No. _____
Name _____
Order _____
Remarks _____
Retouched _____
Order Finished _____
Reorder _____
Reorder _____

Folder #17

Specimen #614.5.5

Main Crack Systems

150

Unetched

_____ No.
_____ Name
_____ Order
_____ Remarks
_____ Retouched
_____ Order Finished
_____ Reorder
_____ Reorder

Folder 18

Specimen #614.5.5

"White Sand"

X10

1² Nital

X300

1² Nital

No. _____
Name _____
Order _____
Remarks _____
Retouched _____
Order Finished _____
Reorder _____
Reorder _____

See page 43.

Folder #16

Photomicrographs at 10 diameters show complete number of "white bands" on specimen. They reveal, too, the location of the bands with reference to the main crack systems. More numerous and finer "white bands" exist in this sample than in specimen #614.5.8.

54 - Region directly below bottom of penetration cavity showing a "white band" making a complete turn, and distorting the plate metal. No evidence of lack of structure within band.

53 - Branching of a "white band" immediately below penetration cavity.

Cracks and fine detail quite evident within the band.

Folder #19

Specimen #614.5.5

"White Band"

X1000

(1% Nital
(2% Nital

_____	No.
_____	Name
_____	Order
_____	Remarks
_____	Retouched
_____	Order Finished
_____	Reorder
_____	Reorder

See page 45.

Folder #19

- 45 - A "white band" directly below penetration cavity. Fine detail visible.
- 46 - Same as 45, but photographed with oblique illumination. Flow lines may be seen both within the band and adjacent to it.
- 57 - "white band" directly below penetration cavity as it appeared after repolishing and an etch with 2% Nital.

Extremely fine detail and cracks are evident.
- 59 - A "white band" as it makes a turn in region below penetration cavity. Pronounced fine structure.
- 58 - A "white band" as it crosses between two main cracks. At the top of this illustration is the normal plate metal. Then follow: the band containing very fine detail and an undisturbed "inclusion", a region of intermediate structure and finally the distorted structure of the plate.
- 60 - Section of another "white band" with its further evidence of structural detail. This photomicrograph, as do all the others in the present folder, serves to illustrate the striking difference between the extremely fine detail within the "white bands" and the relatively coarse structure of the plate metal.

Folder #19

60 - The comparison is made possible by the
Cont'd.) fact that the white material in this
specimen, unlike that in specimen #614.5.8,
could be cut down more nearly to the level
of the plate. The more favorable response
to the polishing action indicates a state
of lesser hardness than that of the bands
in specimen #614.5.8 - due, probably, to
the effect of the tempering to which the
sample was subjected.

Folder #20

Specimen #614.5.5

"White Band"

X300C

(18 Nital
12 Nital

_____ No.
_____ Name
_____ Order
_____ Remarks
_____ Retouched
_____ Order Finished
_____ Reorder
_____ Reorder

See page 48.

Folder #20

47 - Same area as shown in Folder #19 - 45. More detail is visible here than at X1000, illustrating the observation that the structure within the "white bands" of specimen #614.5.5 seems to be of an even finer order than that present in the "white bands" of specimen #614.5.8.

48 - Another portion of area seen in Folder #19 - 45. This illustration, too, exemplifies the necessity of using magnifications greater than X1000 in order to resolve the fine details occurring in the "white bands" of specimen #614.5.5.

49) Sections of "white band" shown at X300 in
50) - Folder #18 - 54.
51)

49 and 51 are at points where the band makes a turn.

All three photomicrographs testify to the presence of minute structural details. The bands in every case are so wide that the plate metal is excluded from the print. They are slightly in relief with respect to the plate material but not to the same extent as are the bands in specimen #614.5.8.

52 - A "white band" which occurs in conjunction with a main crack. The band, with its fine structure, appears at the left of the crack and the plate metal is visible at the right.

51 - Portion of area shown in Folder #19 - 57. Abundance of minute but not sharply-defined detail.

Folder #20

- 62 - Same as 61 but photographed with oblique illumination. Reveals furrowed condition which is much less severe than that of specimen #614.6.8 but which is sufficient to account for the lack of sharply-defined metallographic characteristics in 61 and in all the photomicrographs of this folder.
- 63 - Portion of area shown in Folder #19 - 68. Very fine, but rounded, structural detail present.
- 64 - Same as 63, but photographed with oblique illumination.
Wavy appearance of surface again evidenced.

V. Summary of Observations

1. Main Crack Systems

Specimen #614.5.8 was photographed unetched at X50 and X1000. The main cracks caused by the penetration of the bullet were seen to be very discontinuous. Offsetting was frequent. Many continued as very fine fractures which were visible at X1000. Although "inclusions" occurred in conjunction with some of them, there was no evidence that the cracks were greatly influenced by the presence of the nonmetallic elements in the plate.

Specimen #614.5.5 was photographed unetched at X50 only, the conditions illustrated for #614.5.8 being common to both samples.

2. "Inclusions"

Specimen #614.5.8

Study of the unetched metal revealed that particles of nonmetallic elements were very numerous. Many of them showed evidence of having been swung out of their original positions (some to the extent of 45°) through the movement of the plate metal which occurred when it was penetrated by the bullet. In some cases tiny cracks appeared at one or both ends of the particle.

A number of "inclusions" in the region below the penetration cavity exhibited a peculiar effect in that they were fragmented - offset into cleanly cut blocks. When etched, the metal around them failed to show signs of plastic deformation. It was concluded, therefore, that the particles might have been jarred by an elastic*movement in the metal.

Other "inclusions" in the plate failed to reveal cracks or distortion of any kind.

The nonmetallic particles of specimen #614.5.5 were not photographed but they were generally similar to those of #614.5.8.

3. Etching

A. Specimen #614.5.8

<u>Etch</u>	<u>Effect</u>
Normal	1. Plate structure revealed.
2% Nital	2. "White bands" visible.
	3. Normal illumination: no detail in "white bands".
	4. Oblique illumination: flow lines present in "white bands".
Prolonged	1. Detail in "white bands" which occurred in conjunction with main cracks.
2% Nital	
Prolonged	1. Maximum detail in "white bands" which did not coexist with main cracks.
5% Nital	

*The possibility that this fragmentation occurred during the rolling of the plate should not be excluded.

B. Specimen #614.5.5

<u>Etch</u>	<u>Effect</u>
Normal 1% Nital	: 1. Plate structure brought out. : : 2. "White bands" visible. : : 3. Normal illumination: no detail in : "white bands". : 4. Oblique illumination: flow lines : present in "white bands".
Prolonged 1% Nital	: 1. Detail in "white bands" which oc- : curred in conjunction with cracks.
Prolonged 2% Nital	: 1. Maximum detail in "white bands" : which did not coexist with main : cracks.

Specimen #614.5.5 was much more responsive to etching than was specimen #614.5.8. It was noted, too, that the "white bands" which were intertwined with the main cracks were, in general, more easily etched than those bands which extended away from the cracks.

4. "White Bands"

A. Cracks

In both specimens the bands contained a very great number of cracks, some of which were visible at X300, others of which were just discernible at X3000. In all cases these cracks were seen to much better advantage when the sample was studied with oblique illumination.

B. Flow Lines

When viewed with oblique illumination the bands in both specimens were found to possess evidence of metal movement in the form of lines of flow. These occurred also in the metal adjacent to the white regions. They became visible with much less etching than that which was required to produce structural details.

C. "Inclusions"

Many clearly-cut, undeformed particles of non-metallic elements were observed intact within the "white bands" of both samples. Their occurrence was considered noteworthy since the bands themselves bore witness to the drastic reactions which must have taken place at the moment of penetration. The undisturbed appearance of these "inclusions" was particularly striking when they were compared with those found scattered through the plate metal beneath the penetration cavity. It has already been pointed out that some of the latter were greatly distorted while others were shattered to sharply-defined fragments. The presence of undeformed particles within the "white bands" was, therefore, inconsistent with the existence of badly mutilated ones throughout the plate.

As a probable explanation of this inconsistency it is suggested that the forces which induced the formation of the "white bands" generated enough heat to melt any

"inclusions" occurring in the same regions. The subsequent solidification of such particles would account for the fact that, apparently, they were unaffected by shock of the penetration.

D. Structure

Normal etching appeared to have no effect on the "white bands". Prolonged etching with 5% Nital in the case of specimen #614.5.8 and with 2% Nital in the case of #614.5.5 revealed quantities of fine though rounded detail within the bands. The almost complete absence of characteristic well-defined structural outlines was noted and explained with the aid of oblique illumination, through the use of which it was possible to photograph the real surface conditions of the white regions. The latter, as has been shown in the illustrations, were hard enough to resist the cutting action of the specimen-polishing. They presented to the microscope, therefore, not flat, smoothly-finished faces but rather irregular, cracked, furrowed ones, the structural features of which could not possibly be seen as normal metallographic outlines.

The difficulty of wearing down the "white bands" to a proper level was further attested to by the fact that they stood out in great relief from the plate metal. Those in specimen #614.5.5 exhibited this effect to a less degree

than did the bands in specimen #614.5.8 - a circumstance which was attributed to the probable softening action of the tempering treatment to which this sample had been subjected. It was believed, too, that the slightly lower resistance to abrasion - i.e. softness - might explain the greater fineness of structure observed in the "white bands" of specimen #614.5.5. In other words, although their surfaces were far from being flat, the details within them were cut more effectively and hence were seen in a truer light than were those in the rougher bands of specimen #614.5.8. This supposition was supported by the fact that the white regions of specimen #614.5.5, when observed with oblique illumination, did not appear to be as extensively furrowed as did those of specimen #614.5.8.

On the basis of the foregoing observations, therefore, the following statements concerning the nature of the "white bands" are offered:

1. THEY CONTAIN MASSES OF FINE DETAILS WHICH INDICATE THEIR CRYSTALLINITY.
2. THEY ARE HARD AND RESISTANT TO ABRASION. HENCE, THEIR STRUCTURAL FEATURES ARE VISIBLE AT VARIOUS LEVELS AND NOT ON ONE PLANE SURFACE - A CONDITION WHICH ACCOUNTS FOR THE LACK OF WELL-DEFINED OUTLINES AND EXPLAINS WHY THE TINY GRAINS MIGHT APPEAR TO BE OUT OF FOCUS IN THE PHOTOMICROGRAPHS.

3. THEIR FAILURE TO EXHIBIT ACICULAR STRUCTURE IS NO PROOF THAT THEY LACK THE CHARACTERISTICS OF HARDENED STEELS SINCE SUCH STEELS DO NOT NECESSARILY HAVE TO ASSUME ONE DEFINITIVE TYPE OF STRUCTURAL ARRANGEMENT.

Respectfully submitted,

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