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EXAMINATION OF SLUGS FROM ARMOR PLATE SUBJECTED TO HIGH VELOCITY BULLET IMPACT

By

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[redacted]

June 30, 1937

WATERTOWN ARSENAL
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Report No. 710/201
Watertown Arsenal
[redacted]

June 30, 1937

EXAMINATION OF SLUGS FROM ARMOR PLATE SUBJECTED TO HIGH VELOCITY BULLET IMPACT

Reference: O.K.D. 472.9/40.1

Purpose

The purpose of this investigation was to determine the chemical analysis and microstructure of slugs blown from armor plate which was subjected to high velocity bullet impact.

Conclusions

1. Chemical analysis of the slugs is as follows:

C	Ni	Cr	Mo
.386	3.29	1.36	.69
.375	4.08	1.37	.66

2. The microstructure of the slugs consisted of relatively large grains composed of martensite and acicular troostite.

3. The Brinell hardness of the plate is reported as 420 - 450.

4. In superhigh velocity bullet impact, the energy of the bullet is not uniformly absorbed by the plate, failure

probably occurring along shear planes, which in this case appear to be white layer.

5. An increase in striking velocity, as in the case of superhigh velocity bullet impact, promotes an increase in the amount of white layer.

6. The observations obtained herein may be helpful in the study of failures in armor plate when subjected to fire with 37 mm. A.P. solid shot M39.

History of Samples

The samples were submitted on Reference O.K.D. 472.9/40.1.

Ballistic Data

Thickness of Plate	Angle of Indent	Caliber	Range	Ballistics	
				Velocity Average	LeBoulenge
.834"	70°	.519 A.P.	437	4588 4606	4560
				51583 p.s.i.	52200 p.s.i.

No buttons or spalls.

Plate, 1 meter x 1 meter

Hardness, 140 - 150 Kg/mm^2

Brinell 420 - 450

Method of Test

The samples were subjected to the following tests:

(a) Spectrographic analysis

(b) Chemical analysis

(c) Macro analysis

(d) Microscopic examination

(e) Hardness survey

Results of Test

1. The results of the spectrographic analysis are given in Table 1.

TABLE 1

Element	Slug S-1	Slug S-2
Nickel	Present	Present
Chromium	Present	Present
Molybdenum	Present	Present
Copper	Present	Present
Tin	Trace	Trace
Tungsten	Present (low)	Present (low)
Titanium	Nil	Nil
Zirconium	Nil	Nil
Vanadium	Nil	Nil

2. Chemical analysis of the slugs is given in Table 2.

TABLE 2

	C	Mn	Ni	Cr	Mo	Va	W
Slug S-1	.385	.46	3.29	1.35	.69	Nil	Nil
Slug S-2	.375	.49	4.08	1.37	.66	Nil	Nil

3. Macro and Microscopic examination of the slugs is shown in Figures 2 and 3.

4. Hardness surveys are illustrated in Figures 4, 5, 6, and 7.

Discussion

The appearance of the slugs as received is shown in Figure 1.

A macroscopic study of sections cut through the slugs shows the presence of dendritic segregation elongated in the direction of rolling, Figure 2. Also, faulting of the metal and white layer is evident near the face of impact and areas adjacent.

In high velocity bullet impact, the energy of the bullet is dissipated into heat which causes a local rise in temperature in the plate. In some cases, temperatures approaching melting temperatures occur along planes of greatest slip stress, known herein as white layer due to their characteristic properties of martensite. Local heating in the path of slip has caused a phase change.

As the energy of the high velocity bullet is not readily absorbed by the plate, it is believed failure occurs along shear planes which in this case are white layers.

An examination of the macrostructures in Figure 2 shows failure occurring along some of the white layers which are oriented in many directions with respect to the direction of impact. In a few cases, however, the white layers associated with crack systems partially follow the contour of the sheared surfaces of the slugs. This indicates that the shearing out of the slugs may have occurred along the white layers.

It has been observed recently that shearing of slugs in armor plate subjected to fire, using Cal .30 ball M1 bullets, occurs along white layers.

Furthermore, superhigh velocity bullet impact produces more white layer than an impact of Cal .30 armor piercing bullets.

Figures 3a, b, c, d, illustrate the microscopic study of the white layers and deformation of the slug at area of impact.

Small fragments of bullet core were attached to the slugs near the surface hit by the bullets, see Figures 2a-1, 2a-2. The structure of the fragments is typical of cold-worked medium high carbon steel, see Figures 3a, b, and d. The microstructure of the slugs in each case is typical of acicular troostite (see Figure 3c). The grain size is relatively coarse.

The hardness surveys of slugs S-1 and S-2 are given in Figures 4, 5, 6 and 7. It is evident that the metal was severely work hardened at the area of impact. Hardness surveys reveal the presence of the remnant of the medium high carbon bullet core stock at the surface of impact.

Respectfully submitted,

E. L. Reed,
Research Metallurgist

S. L. Kruegel,
Jr. Physical Sci. Aide.

Macro and Microstructures

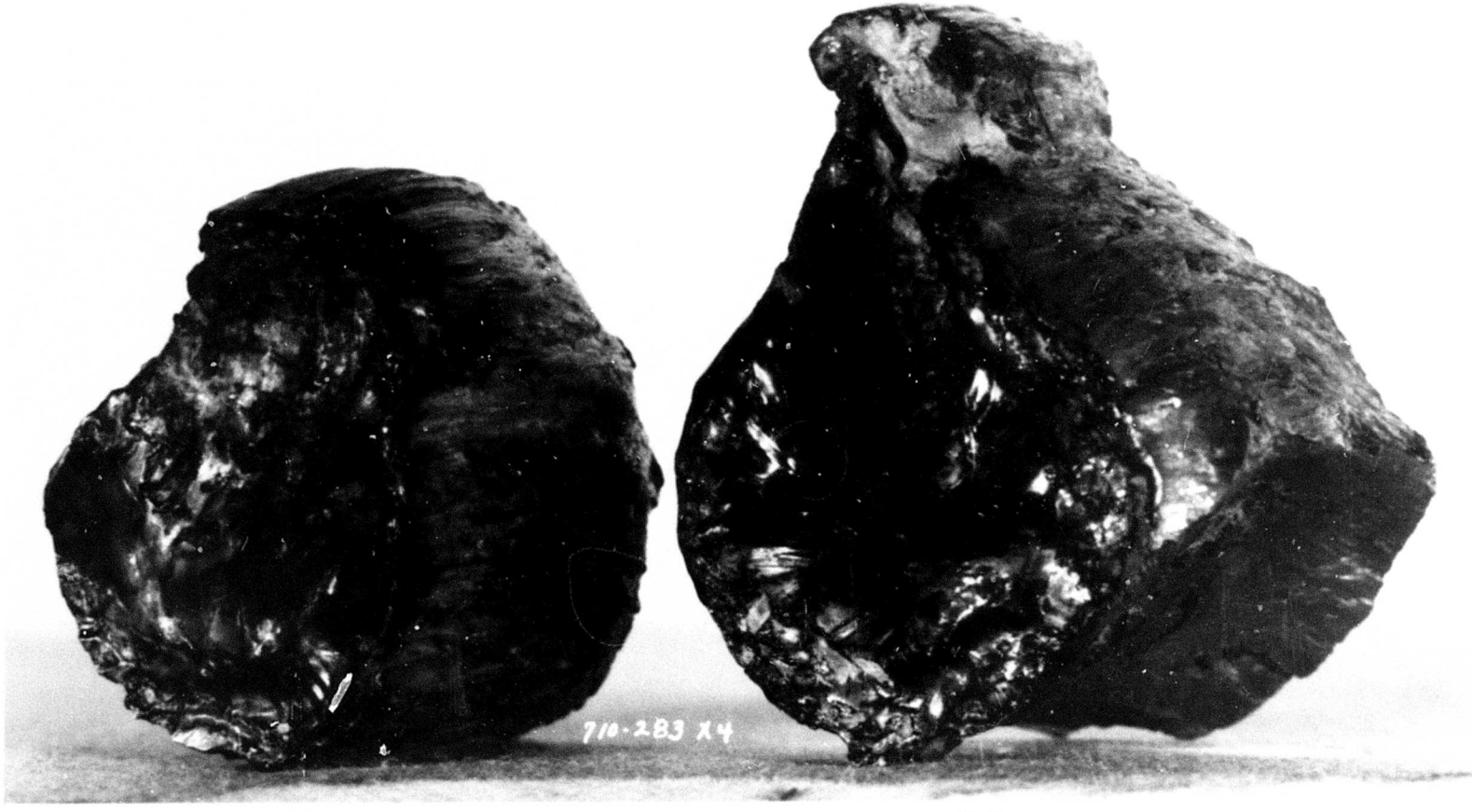
of

Punchings

Figure 1

Photographs of Slugs

Showing battered surface of slugs attacked by bullet.



S1 S2

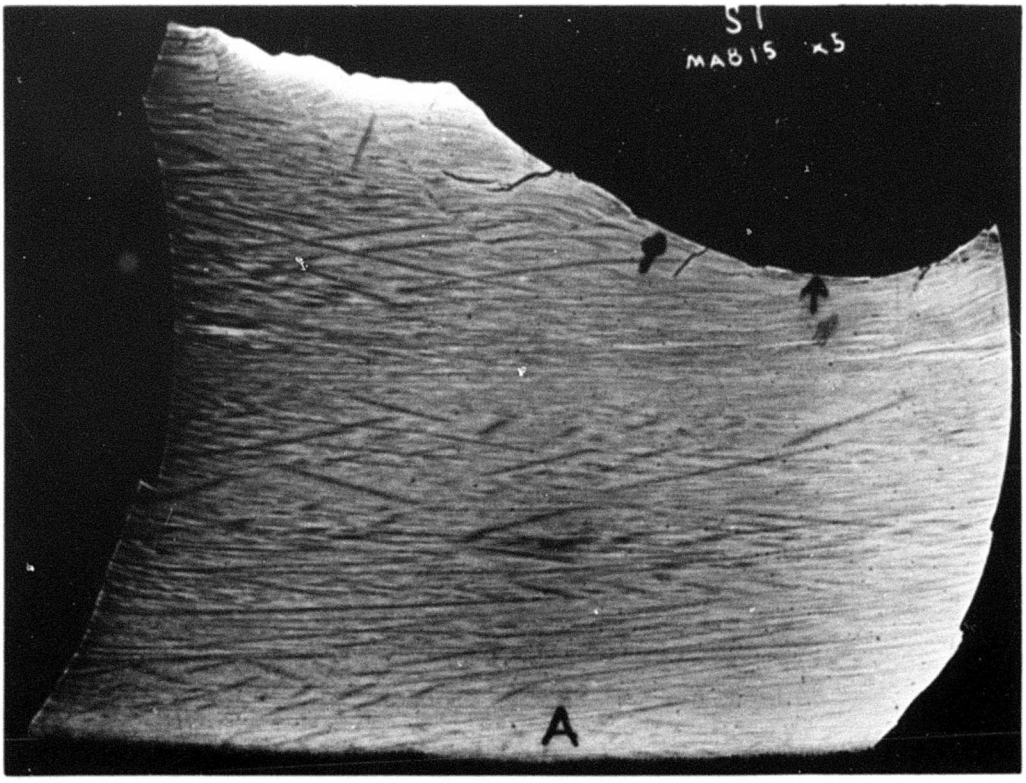
Fig. 1

Figure 2

(a) X5 Punching #S1. Etched Oberhoffer's Reagent.
MA 815

(b) X5 Punching #S2. Etched Oberhoffer's Reagent.
MA 816

In both samples, deformed dendritic segregation is evident in the direction of rolling. Also faulting of the metal and white layer is evident at area of impact. See arrows.



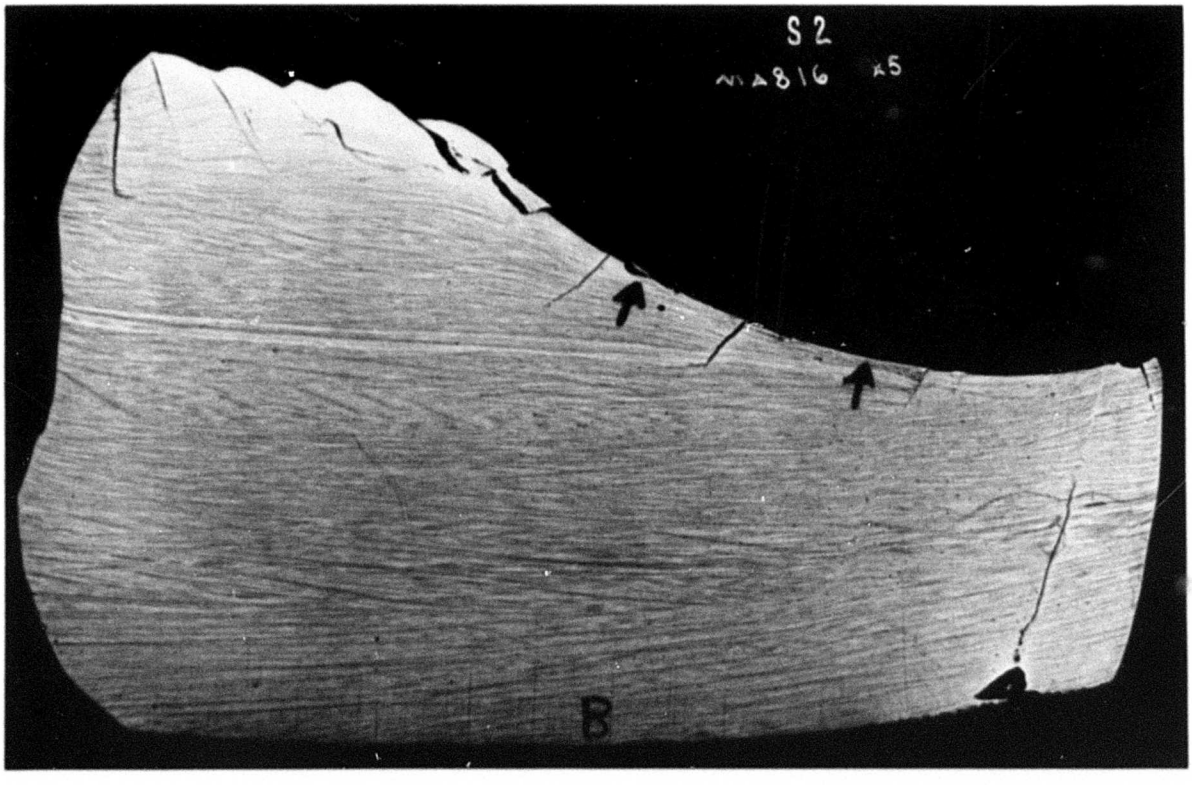


FIG. 2

W.A. 639 - 731

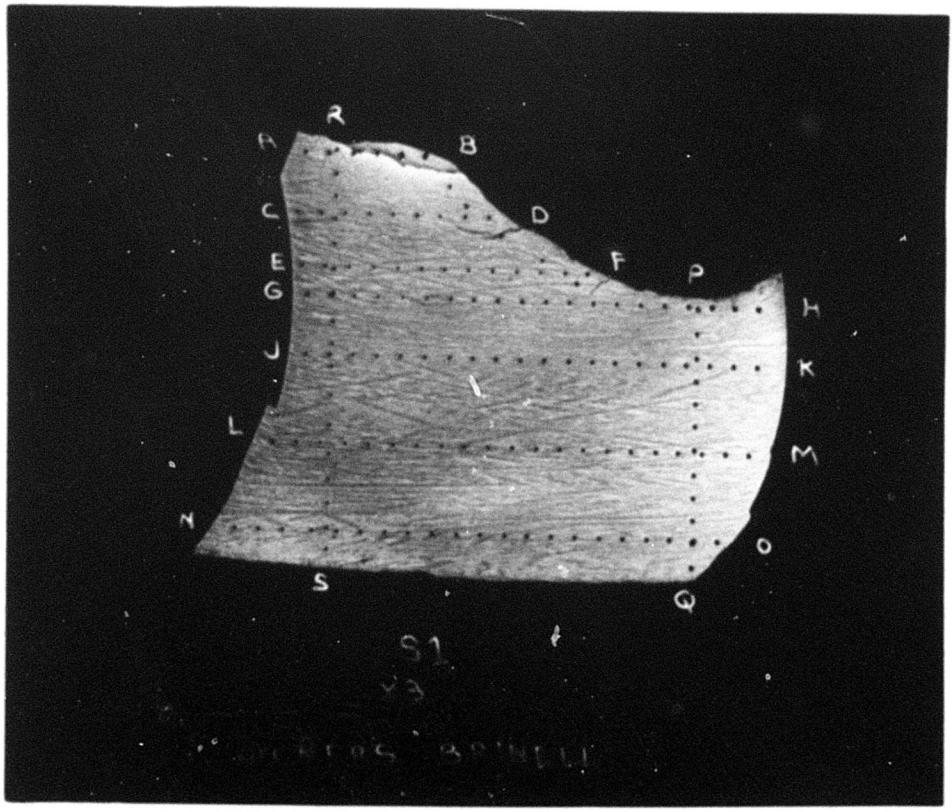
Figure 2a

(1) X3 #S1. Showing hardness surveys, results of which are given in Figures 6 and 7. Also remnant of bullet core shown at R-B.

Etched in 1% Nital

(2) X3 #S2. Showing hardness surveys, results of which are given in Figures 7 and 8. Also remnant of bullet core shown at T-B.

Etched in 1% Nital



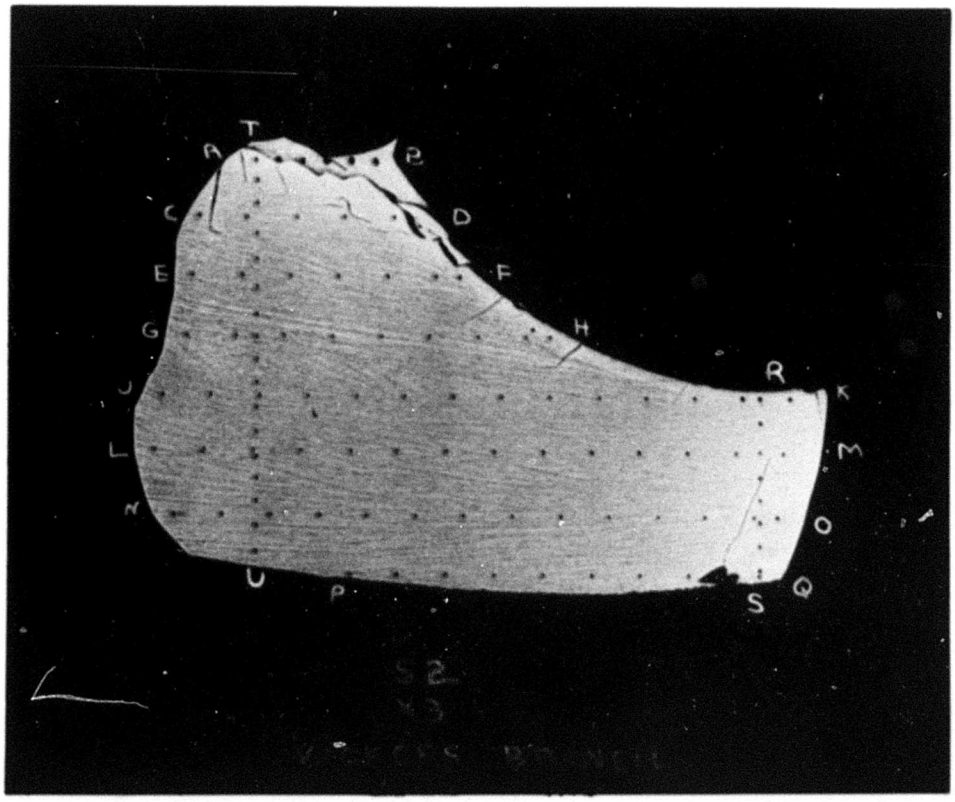


FIG. 2A

WA.639-732

Figure 3

(a) X100 #S1. Base metal of slug to right of white layer, with layer branching into it. At the left, a foreign matter coating parts of the penetration, and not shown in Figures 1a and b, because of etching difficulties. We assume this material to be part of the bullet core which adhered to the plate.

MA 818

(b) X100 #S2. Base metal of slug at left, bullet to right.

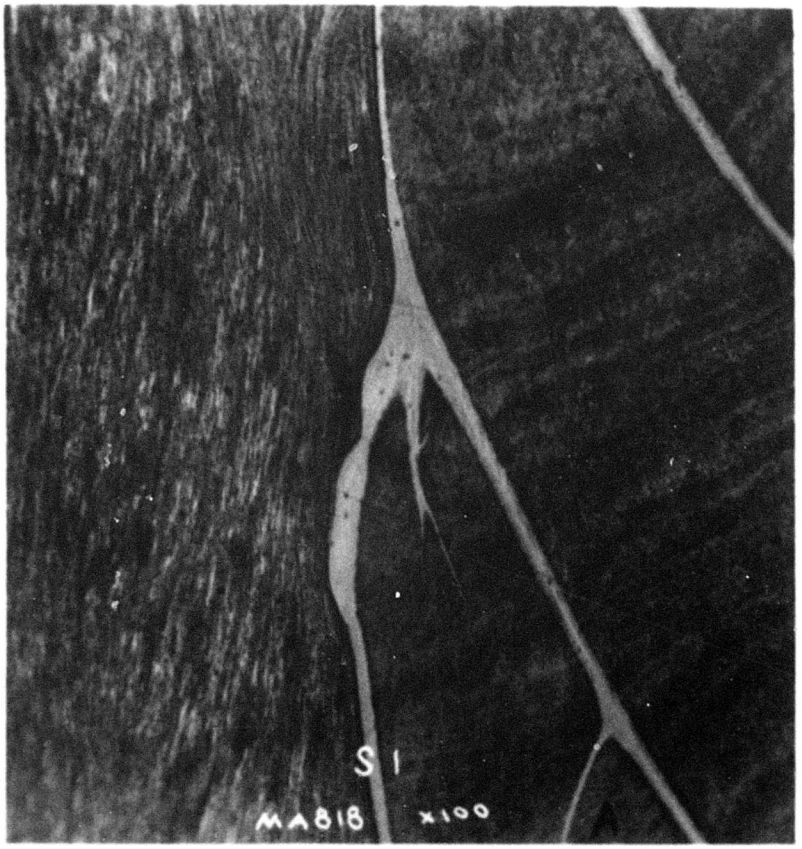
MA 817

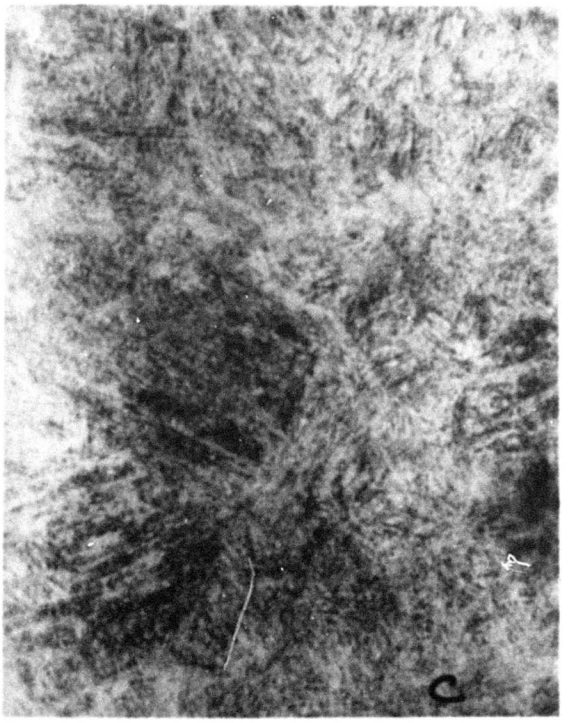
(c) X1000 #S1. Structure of slug is troostito-sorbite with a tendency to martensite. Typical of both specimens.

MA 822

(d) X1000 #S1. Bullet core, badly distorted by cold work. Lower carbon, possibly poorly heat treated because of the considerable ferrite areas present in the sorbite. Scattered nonmetallic inclusions. This is typical of both specimens.

MA 821





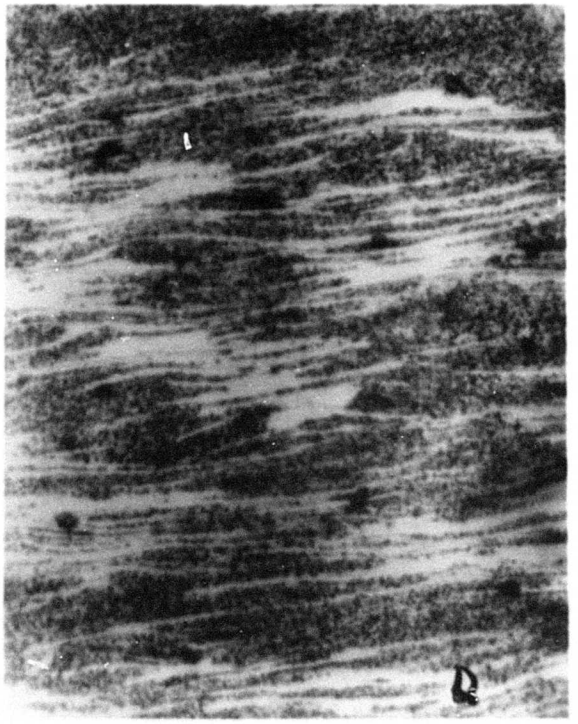
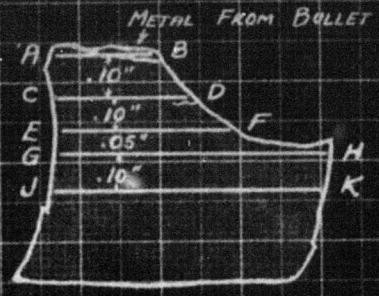


FIG. 3

WA 639-733

HARDNESS SURVEY OF SLUGS SHOT FROM ARMOR PLATE

SLUG No. S1



SCALE - 2 To 1

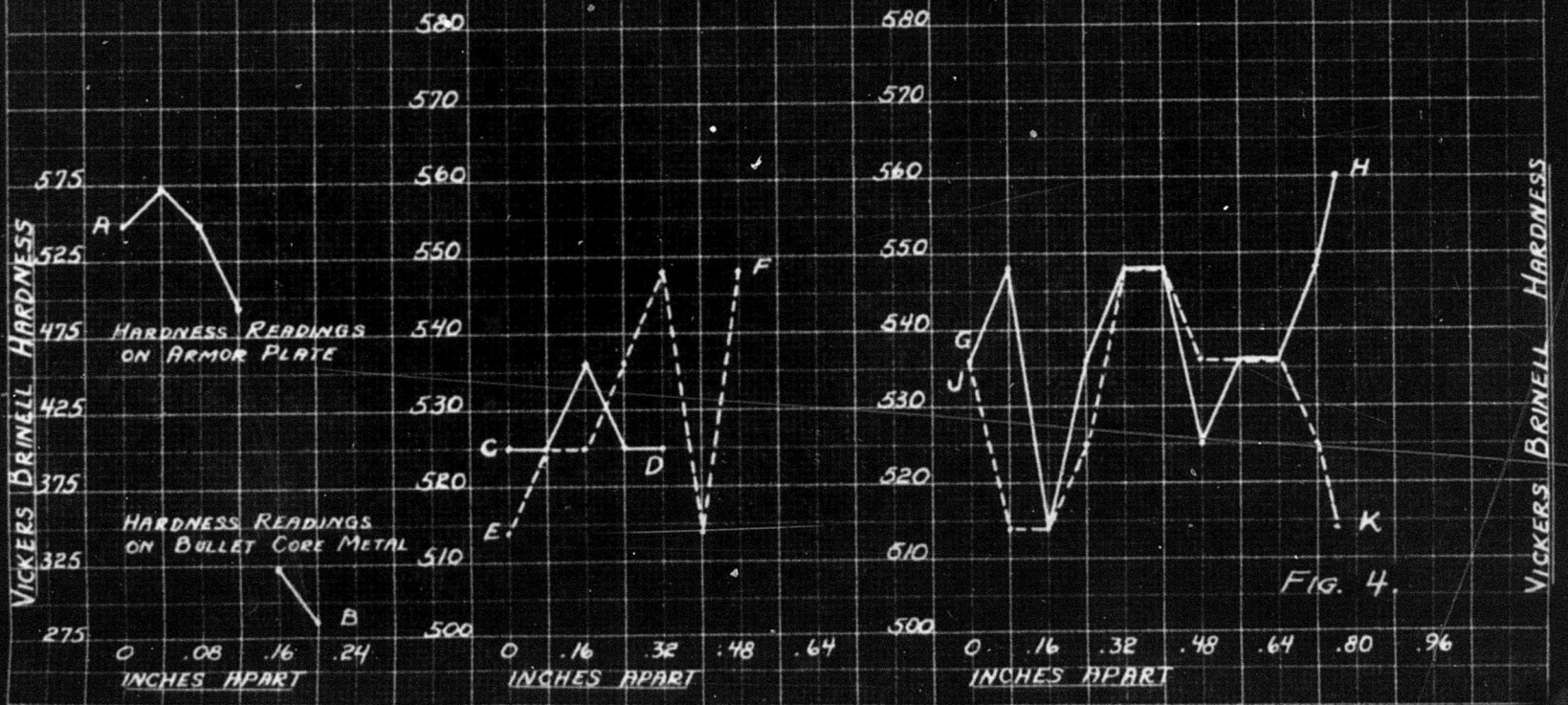


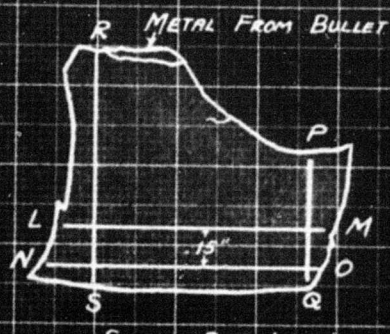
FIG. 4.

SK. NO 719/60 - AP NL 710/207

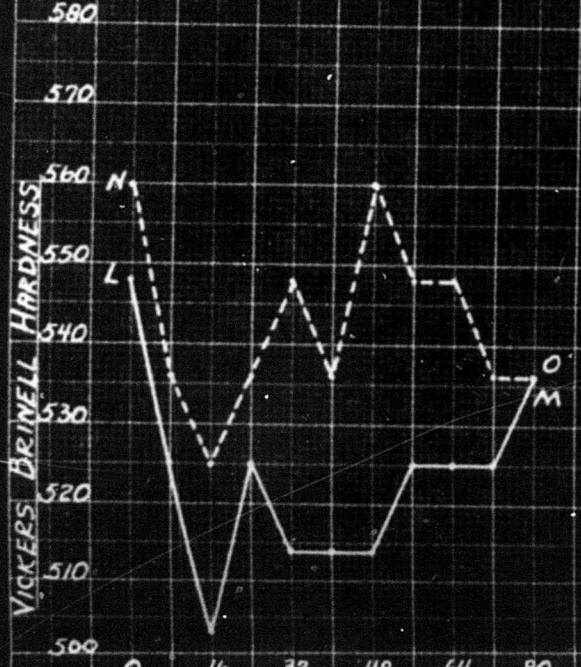
KEUFFEL & ESSER CO.

HARDNESS SURVEY OF SLUGS SHOT FROM ARMOR PLATE

SLUG No. S1



SCALE - 2 TO 1.



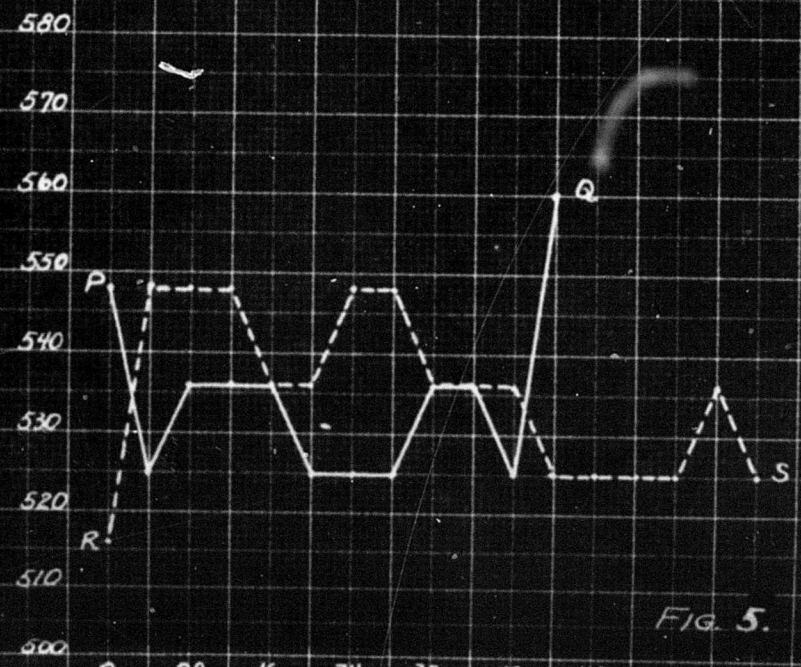


FIG. 5.

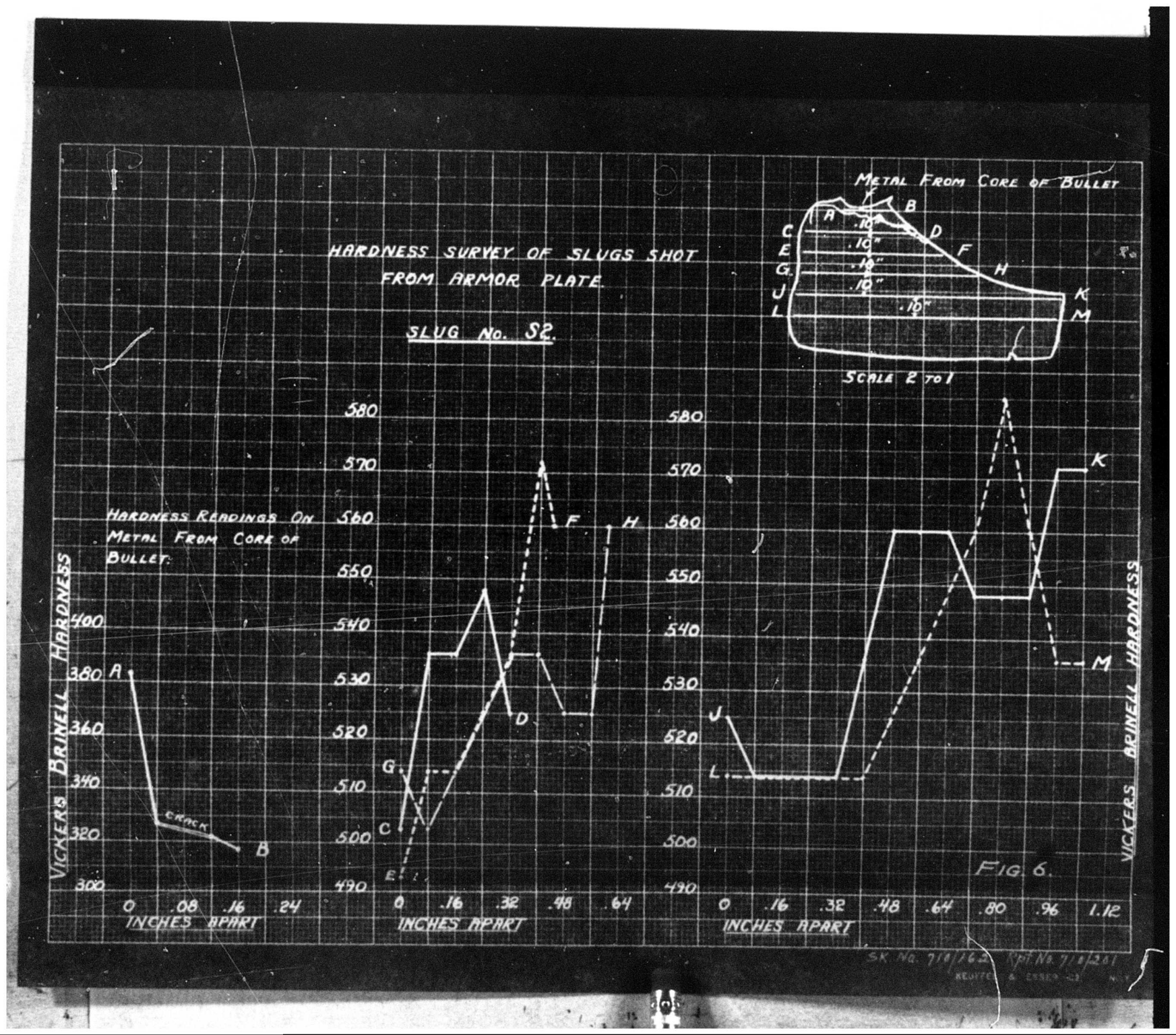
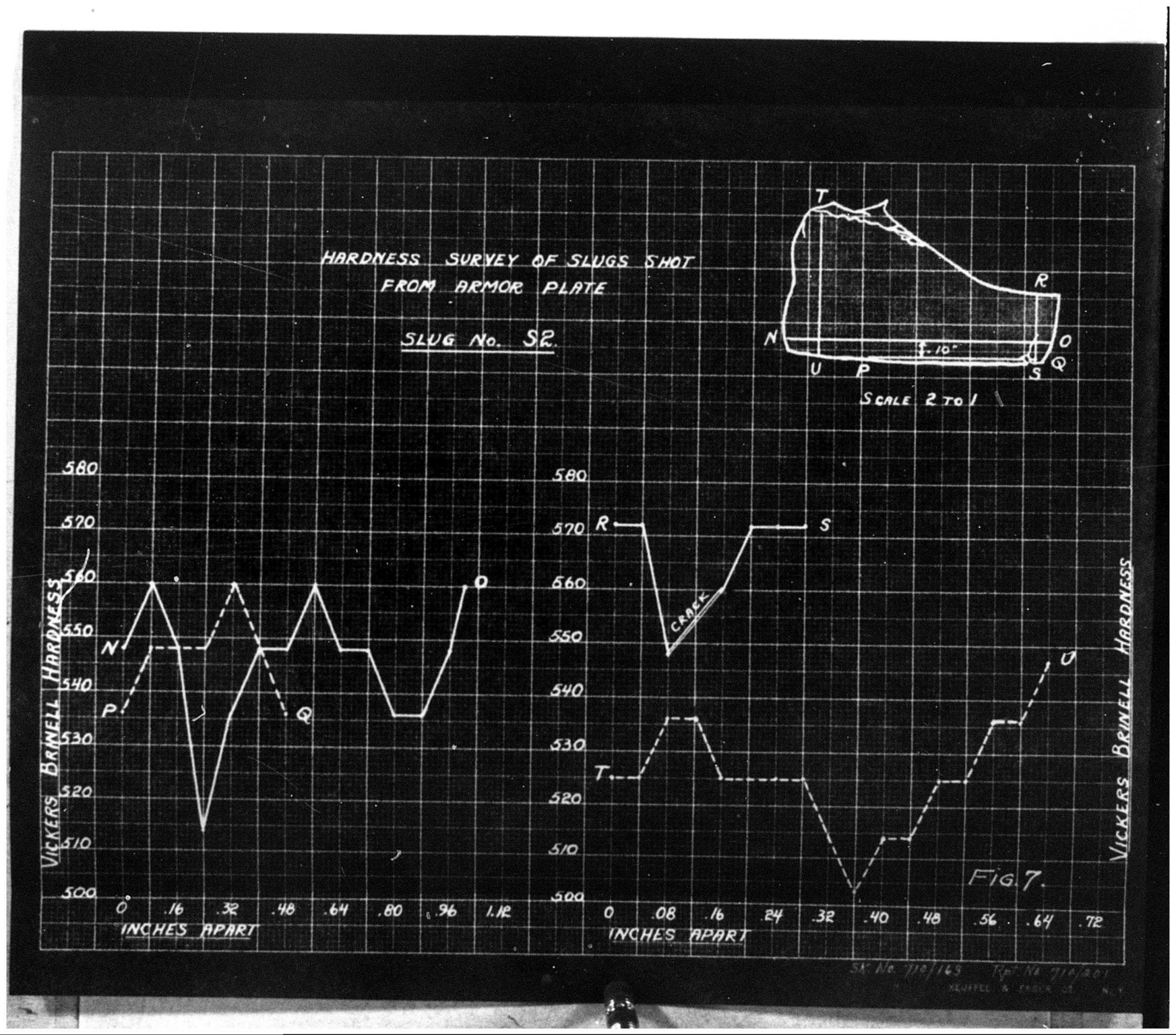


FIG. 6.

SK No. 710/162 Rpt No. 710/261


HARDNESS SURVEY OF SLUGS SHOT FROM ARMOR PLATE
SLUG No. S2.
T
R
N
O
Q
U
P
S
.10"
SCALE 2 TO 1
VICKERS BRINELL HARDNESS
580
570
560
550
540
530
520
510
500
N
P
Q
O
0 .16 .32 .48 .64 .80 .96 1.12
INCHES APART
R
S
CRACK
T
U
0 .08 .16 .24 .32 .40 .48 .56 .64 .72
INCHES APART
VICKERS BRINELL HARDNESS
FIG. 7.
SK No. 710/165 Rpt No 710/201
KEUFFEL & ESSER CO N.Y.