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NAVAL PROVING GROUND
DAHLGREN, VIRGINIA

REPORT NO. 6-44

A METALLURGICAL INVESTIGATION OF THE UNIFORMITY OF 3" CLASS "A" ARMOR PLATE.

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APPROVED

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PREFACE

AUTHORIZATION

This study has been conducted under Naval Proving Ground Experimental Project APL-5 as authorized in Bureau of Ordnance letter NP9/A9(Re3) dated 9 January, 1943.

OBJECT

To determine the metallurgical characteristics of 3" Class A armor plates and to correlate these characteristics with ballistic performance.

SUMMARY

Ballistic limit determinations were made on eight 3" Class A ballistic test plates with 3" AP M61 projectiles at 20° obliquity. The plates were sectioned for metallurgical investigation including chemical composition, tensile properties, hardness distribution, macroexamination and microexamination.

A variation in ballistic quality was found to exist both between different plates and over the area of a single plate. The maximum difference in ballistic limit was 15% against 3" AP M61 projectiles.

An excellent correlation was obtained between ballistic limit and hardness distribution. It is shown that plates with high surface hardness and hard, deep chills have high limits against the 3" AP M61 projectiles.

CONTENTS

LIST OF FIGURES

I. INTRODUCTION.

For the past two years an increasing amount of work has been done on testing various 3" AP Projectiles against 3" Class "A" armor plate. Little information has been available concerning the metallurgical characteristics or the uniformity of these test plates. With this in view it was considered desirable to study several 3" Class "A" armor plates as to chemical composition, hardness distribution, depth of chill, depth of "hard" face, tensile properties, macrostructure and microstructure.

Plates were supplied as 12' by 9' Projectile Test Plates for acceptance test at the Plate Battery of the Naval Proving Ground. They were subsequently sectioned into plates 3' by 3' for tests at the Armor and Projectile Laboratory Range where the firing reported herein was carried out.

II BALLISTIC TESTS.

Test Conditions:

Gun:	3"/50 Cal. Mk. 19 No. 5523.
Projectiles:	3" M61 AP projectiles manufactured by Bethlehem Steel Co. (Beth. Dwg. No. DA-301).
Obliquity:	20°

The results of ballistic tests, which are given in detail in Appendix A, are summarized below. Penetration and effective limits are expressed as per cent of theoretical Class B plate limits given in Buord Sk. 78841.

APL Plate No.	Mfg.	Mfg. Plate No.	Penetration Limit		Effective Limit
278	Midvale	7226-2	105±1		105±1
209	Carn.-Ill.	EE630	107±1		107±1
275	Carn.-Ill.	JJ256	118±2	above	126
290	Carn.-Ill.	JJ256	116±2		120±2
279	Carn.-Ill.	JJ298	118±2		118±2
289	Carn.-Ill.	JJ298	112±2		112±2
280	Carn.-Ill.	JJ654	120±2	above	125
288	Carn.-Ill.	JJ654	115±2		117±1

The plate quality is specified in terms of two limits. The "penetration limit" is the minimum velocity at which all of the projectile penetrates the plate regardless of the condition of the projectile. The "effective limit" is the minimum velocity at which a complete penetration is obtained with the projectile in an effective bursting condition.

Photographs of the ballistic test plates and projectiles are included in Appendix B.

III METALLURGICAL STUDY.

HARDNESS DISTRIBUTIONS.

Appendix C contains hardness distribution curves for each of the plates tested. These show the variation of "R_C" hardness through the cross section from face to back.

The "chill" depth has been taken as the distance from the face to a point where the hardness distribution curve falls to a value of R_C - 35. Similarly the "hard face" depth, related to the manufacturers' "undrillable" depth, is the distance from the face to a hardness of R_C - 50 on the curve. These are more or less arbitrary selections of hardness, but experience has shown that the limits of the chill and the undrillable depths as determined by the manufacturers' drill tests are generally located at approximately these values.

MACROEXAMINATION.

Two cross-section samples of each plate were given different Macro-etches; the first, an ammonium persulphate etch to delineate the depth of carburization, the depth of chill and the flow lines in the metal; and the second, a hot-acid deep etch to show up any macro-segregation as well as flow lines. Photographs of these etched sections given in Appendix D show normal segregation and wavy flow lines indicating the difficulty of uniform forging on this gauge of armor. The depth of chill can be measured from the persulphate etched sections as a check on the results obtained by hardness measurements.

MICROEXAMINATION.

Photomicrographs are given in Appendix E which are representative of the microstructures of each plate. In all cases, the face consists of many undissolved carbides in a martensitic matrix. while the back shows a normal fine spheroidized structure with ferrite matrix.

CHEMICAL AND PHYSICAL PROPERTIES.

Chemical analyses were made on all plates as checks against the manufacturer's reported composition. Detailed results given in Appendix F show only minor differences between A. & P. Laboratory and reported analyses. The physical properties were obtained on each plate and reported in Appendix F. The results check quite closely the values given by the manufacturer.

The per cent "chill" and per cent "hard face" determined from the hardness distribution curves are included in Appendix F together with the chill and undrillable depths as determined by the manufacturer's drill test. It will be noted that in a single full size plate there is as much as 10% variation in per cent chill and 7% variation in per cent undrillable.

Appendix G contains schematic drawings of the manufacturer's plates showing method of sectioning for the small test plates. The positions from which metallurgical samples were taken are shown by cross hatched areas.

IV DISCUSSION.

All but one of the 3" Class A plates studied in this report were made by Carnegie-Illinois. They are all similar in chemical composition and have similar tensile properties and yet there is a maximum difference of 15% in "penetration" limit and of over 20% in "effective" limit against the 3" AP M61 projectile at 20° obliquity. This difference can be correlated directly with the hardness distribution introduced by the final water hardening heat treatment.

In the table below the plates are listed in the order of their "penetration" limit velocities. The per cent "chill", per cent "hard" face and maximum face hardness were obtained from the hardness distribution

curves shown in Appendix C. These curves are considered to be representative of the 3' x 3' plates from which the samples were taken.

APL PLATE NO.	Mfg. Plate No.	Penetration Limit Vel. (% Sk.78841	% Chill Depth ("R_C"-35)	% Hard Depth (R_C-50)	Max.Face Hardness ("R_C")
Group A					
278	7226-2	105±2	33	9	53
209	EE630	107±2	32	12	52
289	JJ298	112±2	32	11	57
Group B					
288	JJ654	115±2	45	19	57.5
290	JJ256	116±2	34	17	58
275	JJ256	118±2	44	18	59
279	JJ298	118±2	41	18	58.5
280	JJ654	120±2	50	18	58

For ease in comparing the plates, they have been divided into two groups (A)-plates with low limit velocities, and (B)-plates with high limit velocities. In Group A, the plates have shallow chill (32% to 33%) and little "hard" face (9% to 12%). In Group B, the plates have varying depth of chill (34% to 50%), but all have a high percentage of "hard" face (17% to 19%) and all have a high face hardness (R_C 57 to R_C 59).

It is difficult to determine the relative importance of per cent chill depth, per cent "hard" depth, and maximum hardness because, in general, the deeper the chill, the higher the maximum hardness and the greater the per cent "hard" depth. However, from the results obtained on these eight plates the following generalities can be drawn.

Per Cent Chill does not appear to be a controlling factor. In Group B, the per cent chill varies 16%, while variation in limit is only 5%. Plate APL 290 with 34% chill has an 11% margin over plate APL 278 with 33% chill. On the other hand plate APL 290 has approximately the same limit as plate APL 288 which has a 45% chill.

Per Cent "Hard" is a very important factor and a high percentage of "hard" face is essential to obtain high ballistic limits. This is confirmed by these data and by the experience of the Naval Proving Ground on other gauges of Class A armor.

Maximum Face Hardness is important as shown by the results on plates APL 209 and APL 289. These plates have approximately the same per cent chill and per cent "hard" and have a 5% difference in limit. This difference can be ascribed to the higher face hardness of Plate APL 289. In all probability there is a critical hardness, dependent on the projectile hardness, to which the plate face must be raised in order for the plate to have a high ballistic limit. If the maximum face hardness is below this critical hardness, the plate will have a low limit. On the other hand, it is believed that variations in face hardness will not have marked effects on plate limits as long as the face is sufficiently hard to break up the projectile. The hardness of the cap and of the nose of 3" projectiles is approximately R_C 55 while the majority of 3" Class A plates obtained recently have a face hardness of about R_C 58.

V CONCLUSIONS:

The ballistic tests on 3" Class A plates against 3" AP M61 projectiles show a wide variation in limit between plates and between different areas in the same plate. The maximum variation in penetration limits in the eight plates investigated is 15% with a 6% variation in plates taken from a single large plate. The variation in "effective" limit, that is, in the minimum velocity at which a complete penetration is obtained with the projectile in an effective bursting condition, is over 21% between plates and over 8% in a single large plate.

The plates are quite similar in chemical composition, tensile properties and microstructure. The main variation in the plates is in the hardness distribution introduced during final water hardening. An excellent correlation can be obtained between the ballistic properties of the plate and the hardness distribution. A high per cent of "hard" face is required to obtain high limits.

The maximum face hardness is another important factor in obtaining high ballistic quality. A hardness

of at least RC 57 is required against 3" AP M61 projectiles.

The per cent chill is found to be relatively unimportant in determining ballistic quality. Wide variations in chill have little effect on the limits of the plates as long as the per cent "hard" and maximum face hardness are the same.

APPENDIX A

BALLISTIC RESULTS

SYMBOLS

"e" . . . . . .Plate thickness at impact in inches.

"θ" . . . . . .Obliquity.

S.V.,f.s . . . . . .Striking velocity, feet per second.

Pene. . . . . .Depth of penetration in inches.

Comp. . . . . .Complete Penetration. Projectile completely through the plate.

Inc.. . . . . .Incomplete Penetration. Projectile rejected.

SIP . . . . . .Projectile stuck in Plate.

Partial . . . . . .Part of projectile through plate.

% . . . . . .% empirical F(e/d,θ) value (Buord Sk. 78841).

F-. . . . . .Thompson F-coefficient defined by the relation:

$$F = \frac{41.57\ M^{1/2} V_L \cos \theta}{e^{1/2}\ d}$$

where V_L = limit velocity (minimum velocity for complete penetration)

BALLISTIC DATA

Projectile: 3" M 61 AP Projectiles manufactured by Bethlehem Steel Company (Beth. Dwg. No. DA-301) at 20° obliquity.

Plate: 3" Class "A" as cited.

Midvale No. 7226-2

B.I.No.	APL Plate No.	"e"	"θ"	S.V. f.s	Pene.	Proj.Cond.	% Sk. 78841
1737 APL	278	3".20	20°10'	1777	Inc.	Eff.Base dent. Nose intact.	103
1738 APL	278	3".20	20°20'	1807	1-3/4"	Ineff. Shattered.	104
1739 APL	278	3".20	20°10'	1834	Comp.	Eff. Base dent. Nose intact.	106
1736 APL	278	3".20	19°30'	1857	Comp.	Eff. Base dent. Nose intact.	108

Beth. M61 (Group D) Est.Limit F = 51,500±400(105±1%)

Carnegie-Illinois No. EE-630

1211 APL	209	3".22	19°45'	1771	Inc.	Ineff.Shattered	99
1212 APL		3".21	19°25'	1874	Inc.	Ineff.Shattered	106
1210 APL		3".23	20°10'	1924	Comp.	Eff.Whole	108
1209 APL		3".18	20°20'	2045	Comp.	Eff.Whole	116

Beth. M61 (Group D)Limit-F = 52,300±500(107±1%)

Carnegie-Illinois No. JJ256

1766 APL	275	3".21	19°40'	2014	Inc.	Ineff.Shattered	116
1767 APL		3".21	19°40'	2087	Comp.	Ineff. Nose broken	121
1768 APL		3".21	19°30'	2169	Comp.	Ineff. Split into cavity.	126

Beth. M61 (Group D)Limit-F =58,000±1000(118±2%)

1805 APL	290	3".42	20°00'	1998	Inc.	Ineff. Shattered.	109
1802 APL		3".42	20°10'	2088	Par.	Ineff. Nose shattered.	114
1803 APL		3".42	20°00'	2157	Comp.	Ineff.Nose off	118
1804 APL		3".42	19°50'	2177	Comp.	Eff.Nose off.	119
1805 APL		3".42	20°00'	2226	Comp.	Prob. Ineff. Nose off.	122

Beth. M61 (Group D)Limit F = 58,000±100(116±2%)

Carnegie - Illinois No. JJ298

B.I.No.	APL Plate No.	"e"	"θ"	S.V. f.s.	Pene.	Proj.Cond.	% Sk. 78841
1740 APL	279	3".15	20°00'	1887	Inc.	Ineff.Shat-tered.	111
1742 APL		3".15	20°00'	1983	SIP	Ineff. Nose split into cavity.	116
1741 APL		3".15	20°00'	2050	Comp.	Eff.Intact	120
	Beth. M61 (Group D) Limit F= 57,000±1000(118±2%) (Effective Penetration at 120%)						
1801 APL	289	3".18	20°30'	1886	Inc.	Ineff.Shat-tered.	109
1800 APL		3".18	20°00'	1953	Comp.	Effective. Whole.	114
1799 APL		3".18	20°10'	1993	Comp.	Effective. Whole	116
	Beth. M61 (Group D) Limit -F = 54,500±1000 1(112±2%)						

Carnegie-Illinois No. JJ654

1769 APL	280	3".12	19°30'	1963	Par.	Ineff. Shat-tered.	116
1770 APL		3".11	19°50'	2032	CP	Not recovered	120
1771 APL		3".13	19°40'	2023	Par.	Ineff. Shat-tered.	120
1772 APL		3".12	19°30'	2113	Comp.	Ineff. Shat-tered.	125
	Beth. M61 (Group D) Limit F = 58,200±1000(120±2%)						
1798 APL	288	3".13	20°20'	1858	Inc.	Ineff. Shat-tered.	109
1794 APL		3".15	19°40'	1915	Par.	Ineff. Shat-tered.	113
1793 APL		3".15	19°40'	1973	Comp.	Ineff. Nose shattered.	116
1795 APL		3".15	19°40'	2003	Comp.	Eff.Nose broken	118
1796 APL		3".13	20°00'	2049	Comp.	Eff.Nose broken	121

Beth. M61 (Group D) Penetration Limit F = 55,800±800(115±2%)
Effective Limit F = 57,000±500(117±1%)

APPENDIX B

Photographs of Ballistic Test Plates

NPG PHOTO NO. 1048 (APL) - APL Plate No. 278 (Midvale 3" Class A No. 7226-2) vs. Beth. 14.99 lb. 3" M61 capped AP projectiles at 20° obliquity. FRONT VIEW. See NPG Photo No. 1049 APL for back view.

B.I.No.	"e"	"θ"	S.V., f.s.	%	Pene.	Proj. Cond.
1736 APL	3".20	19°30'	1857	108	Comp.	Eff. Base and body scarred. Nose intact.
1737	3".20	20°10'	1777	103	Inc.	Eff. Bent. Heavy base dent. Nose intact.
1738	3".20	20°20'	1807	104	Inc.	Ineff. Shattered.
1739	3".20	20°10'	1843	106	Comp.	Eff. Heavy base dent. Body scarred. Nose intact.

2-3 September 1943

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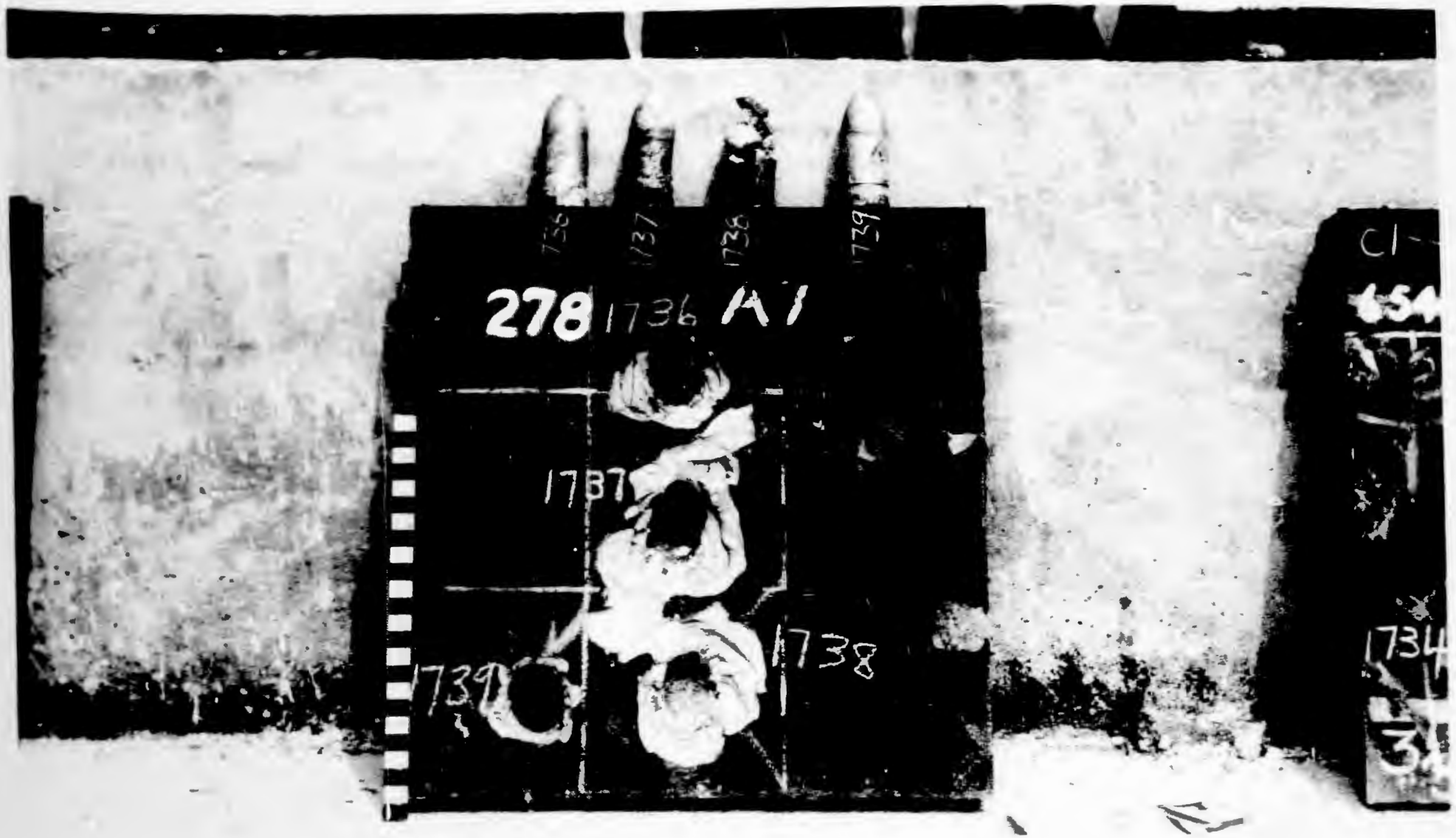

NPG PHOTO NO. 1301 (APL) - APL Plate No. 209 (Carn.-Ill. 3" Class "A" No. KE630) vs. Beth. 14.2 lb. 3" M61 capped AP projectiles at 20° obliquity. FRONT VIEW. See NPG Photo No. 615 (APL) for back view and NPG Photo No. 614 (APL) for previous impacts.

B.I.No.	"e"	"θ"	S.V., f.s.	%	Pene.	Proj. Cond.
1209 APL	3".18	20°20'	2045	116	Comp.	Effective - Whole.
1210	3".23	20°10'	1924	108	Comp.	Effective - Whole.
1211	3".22	19°45'	1771	99	7/8"	Ineffective - Shattered.
1212	3".21	19°25'	1874	106	1-1/4"	Ineffective - Shattered.

15-16 January 1943

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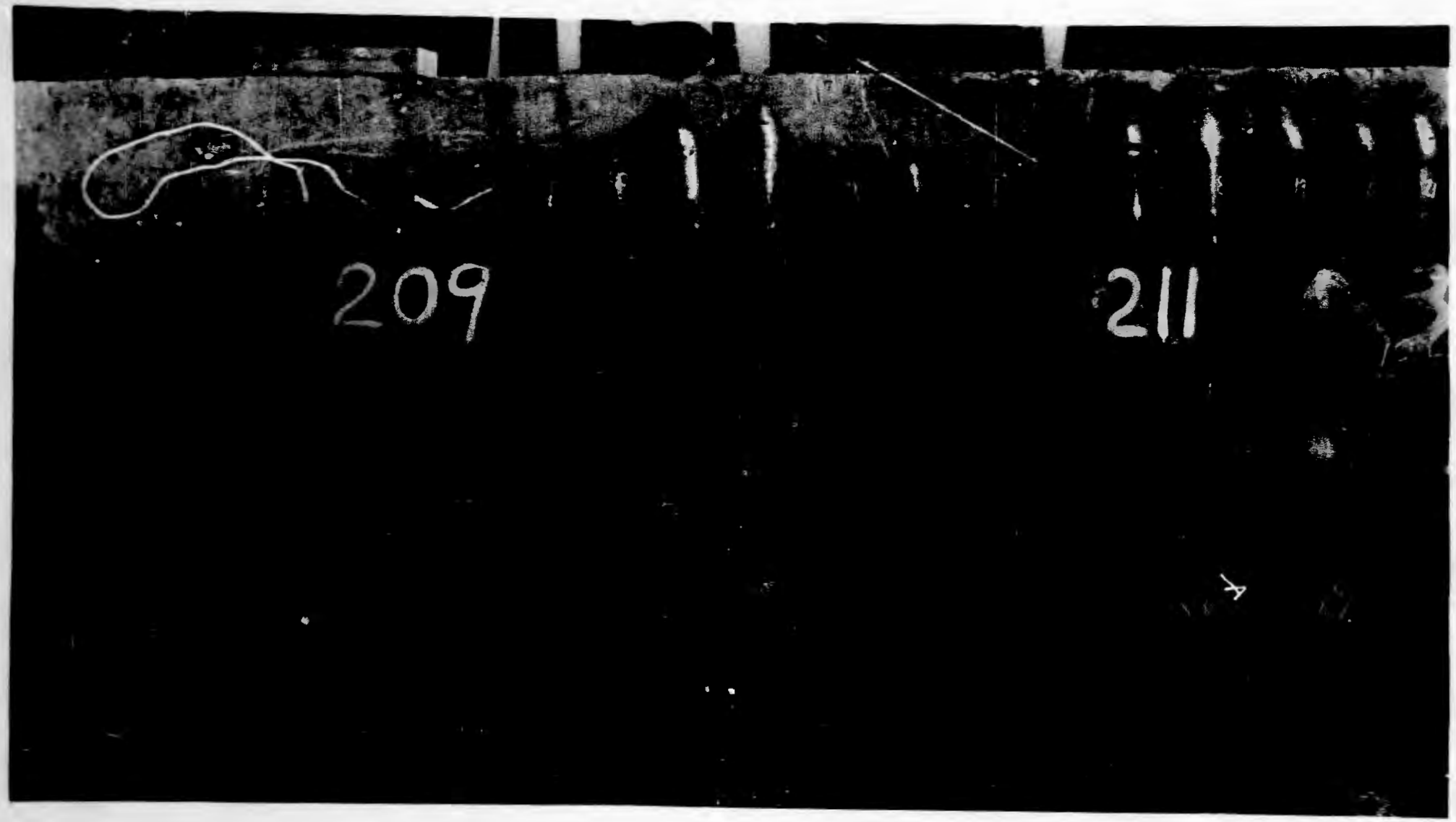

NPG PHOTO NO. 1060 (APL) - APL Plate No. 275 (Carn.-Ill. 3" Class "A" No. JJ256) vs. Beth. 14.99 lb. 3" M61 AP projectiles at 20° obliquity. FRONT VIEW. See NPG Photo No. 1061 APL for back view and NPG Photos Nos. 1025-26 APL for previous impacts.

B.I.No.	"e"	"θ"	S.V., f.s.	%	Pene.	Proj. Cond.
1766 APL	3".21	19°40'	2014	116	Inc.	Ineff. Shattered.
1767	3".21	19°40'	2087	121	Ineff.	Nose gone.
1768	3".21	19°30'	2169	126	Ineff.	Split in two.

9-10 September 1943

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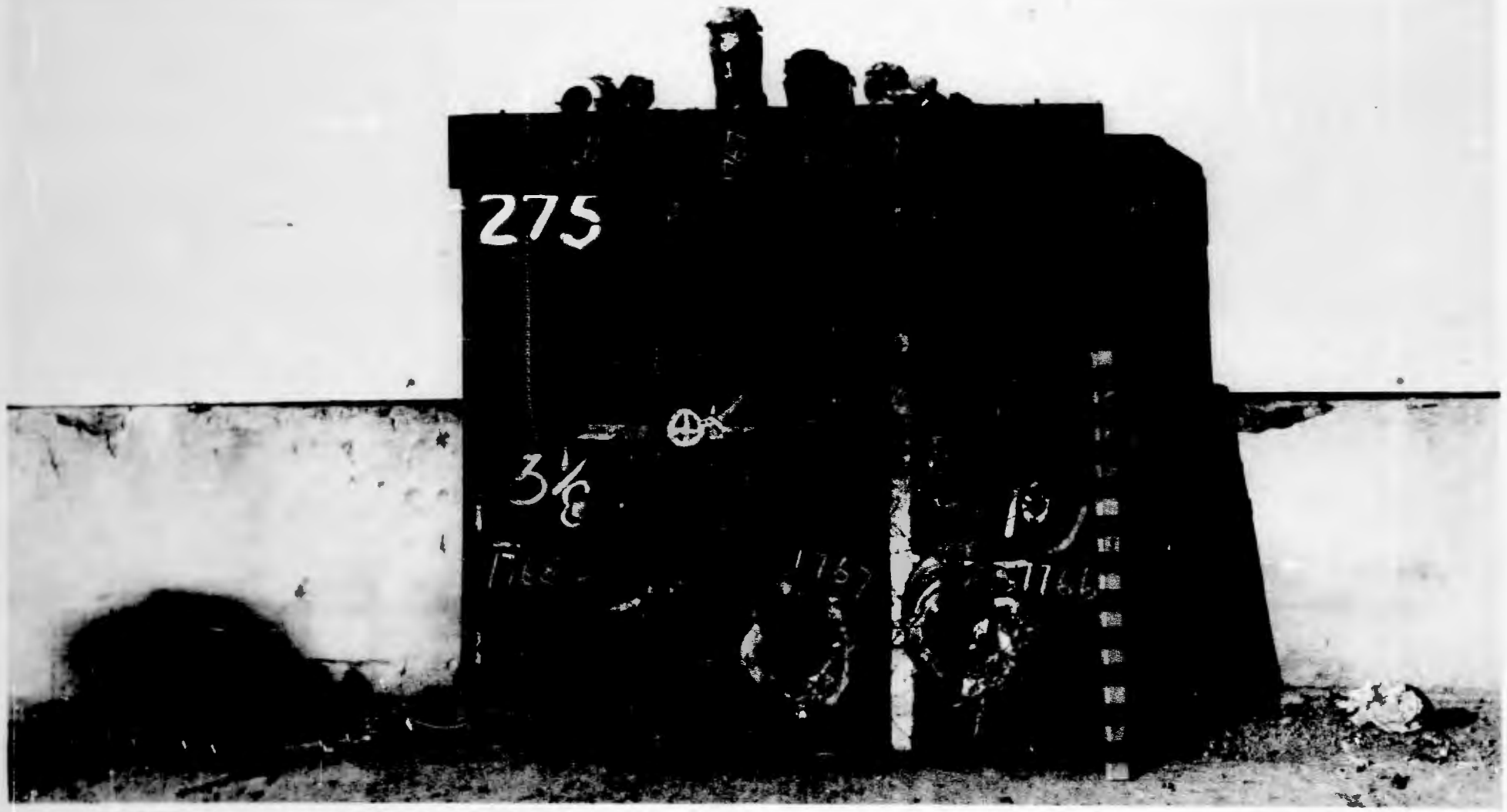

NPG PHOTO NO. 1076 (APL) - APL Plate No. 290 (Carn.-Ill. 3" Class "A" No. JJ256) vs. Beth.14.99 lb. 3" M61 AP capped projectiles at 20° obliquity. FRONT VIEW. See NPG Photo No. 1077 APL for back view.

B.I.No.	"e"	"θ"	S.V.,f.s.	℘	Pene.	Proj. Cond.
1802 APL	3.42	20°10'	2088	114	Partial	Ineff.Nose shattered. Body cracked into cavity.
1803	3.42	20°00'	2157	118	Comp.	Ineff. Nose wiped off. Cavity exposed.
1804	3.42	19°50'	2177	119	Comp.	Eff. Nose wiped off.
1805	3.42	20°00'	1998	109	1-3/4"	Ineff. Shattered.
1806	3.42	20°00'	2226	122	Comp.	Probably ineff. Nose wiped off. Body cracks.

17-18 September 1943

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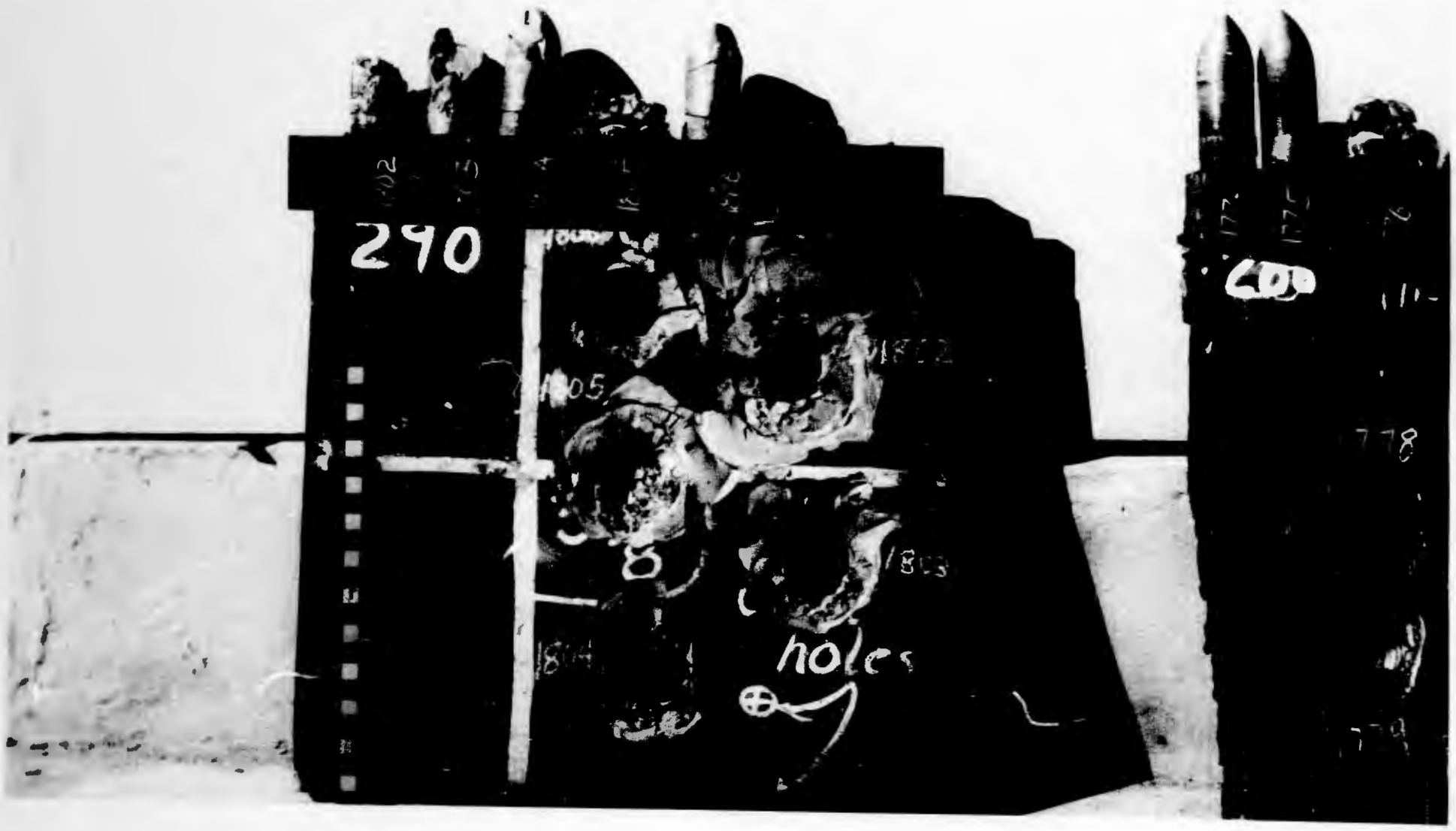
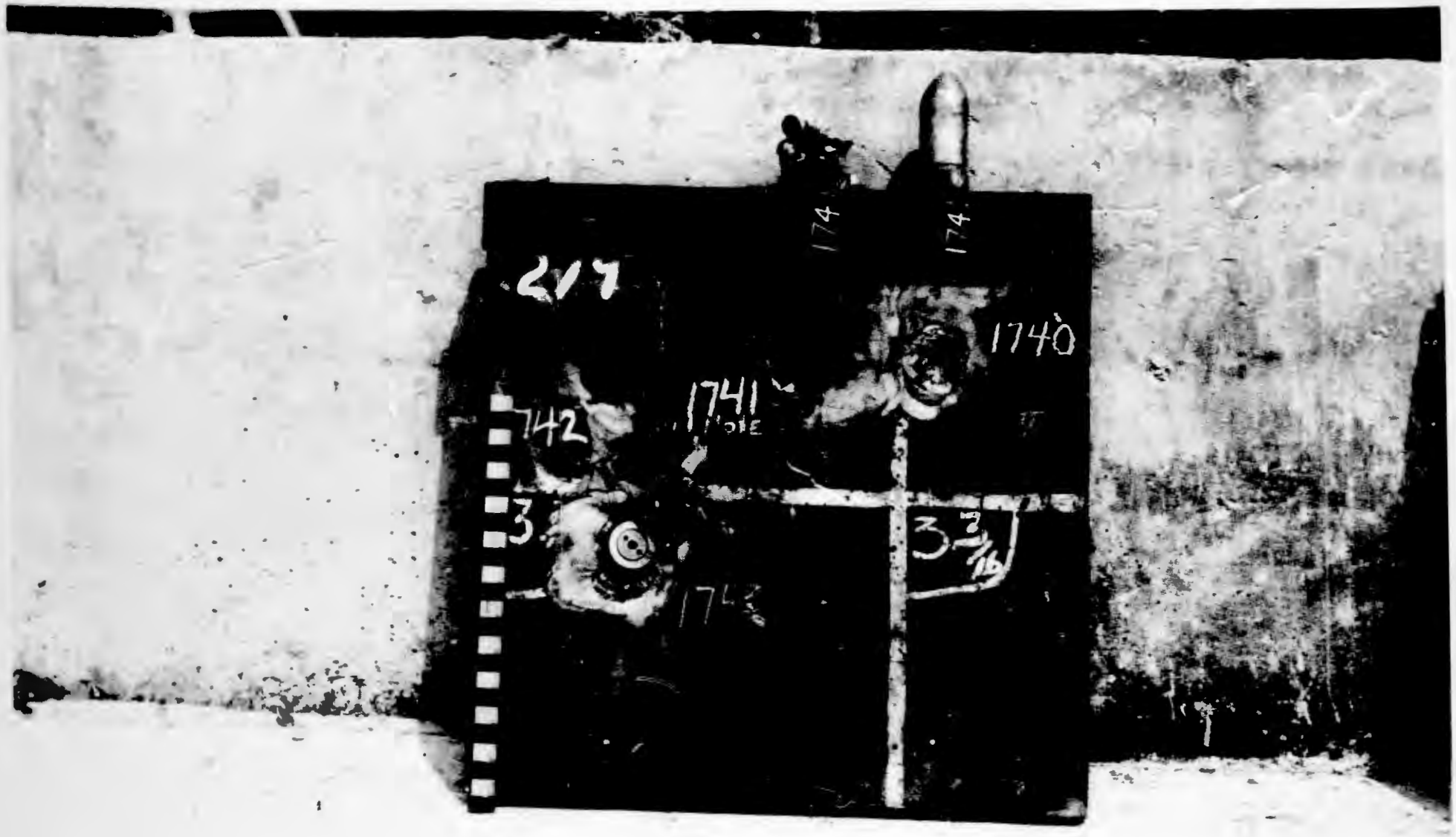


NPG PHOTO NO. 1052 (APL) - APL Plate No. 279 (Carn.-Ill. 3" Class A No. JJ298) vs. Beth. 14.99 lb. 3" M61 AP projectiles at 20° obliquity.
FRONT VIEW. See NPG Photo No. 1053 APL for back view.

B.I.No.	"e"	"O"	S.V., f.s.	%	Pene.	Proj. Cond.
1740 APL	3".15	20°00'	1887	111	Inc.	Ineff. Shattered.
1741	3".15	20°00'	2050	120	CP	Eff. Base chipped. Body scarred. Nose intact.
1742	3".15	20°00'	1963	116	SIP	Ineff. Nose split into cavity.
1743	3".15	20°10'	(est)1920	118 (est.)	SIP	Prob. Eff. Nose chewed off.

3 September 1943 - CONFIDENTIAL -



NPG PHOTO NO. 1080 (APL) - APL Plate No. 289 (Carn.-Ill. 3" Class A No. JJ298) vs. Beth. 14.99 lb. 3" M61 AP projectiles at 20°. FRONT VIEW. See NPG Photo No. 1081 APL for back view.

B.I.No.	"e"	"θ"	S.V., f.s.	ϕ	Pene.	Proj. Cond.
1799 APL	3".18	20°10'	1993	116	Comp.	Eff. Nose slightly cracked.
1800	3".18	20°00'	1953	114	Comp.	Eff. Nose cracked.
1801	3".18	20°30'	1886	109	Inc.	Ineff. Shattered.

16 September 1943

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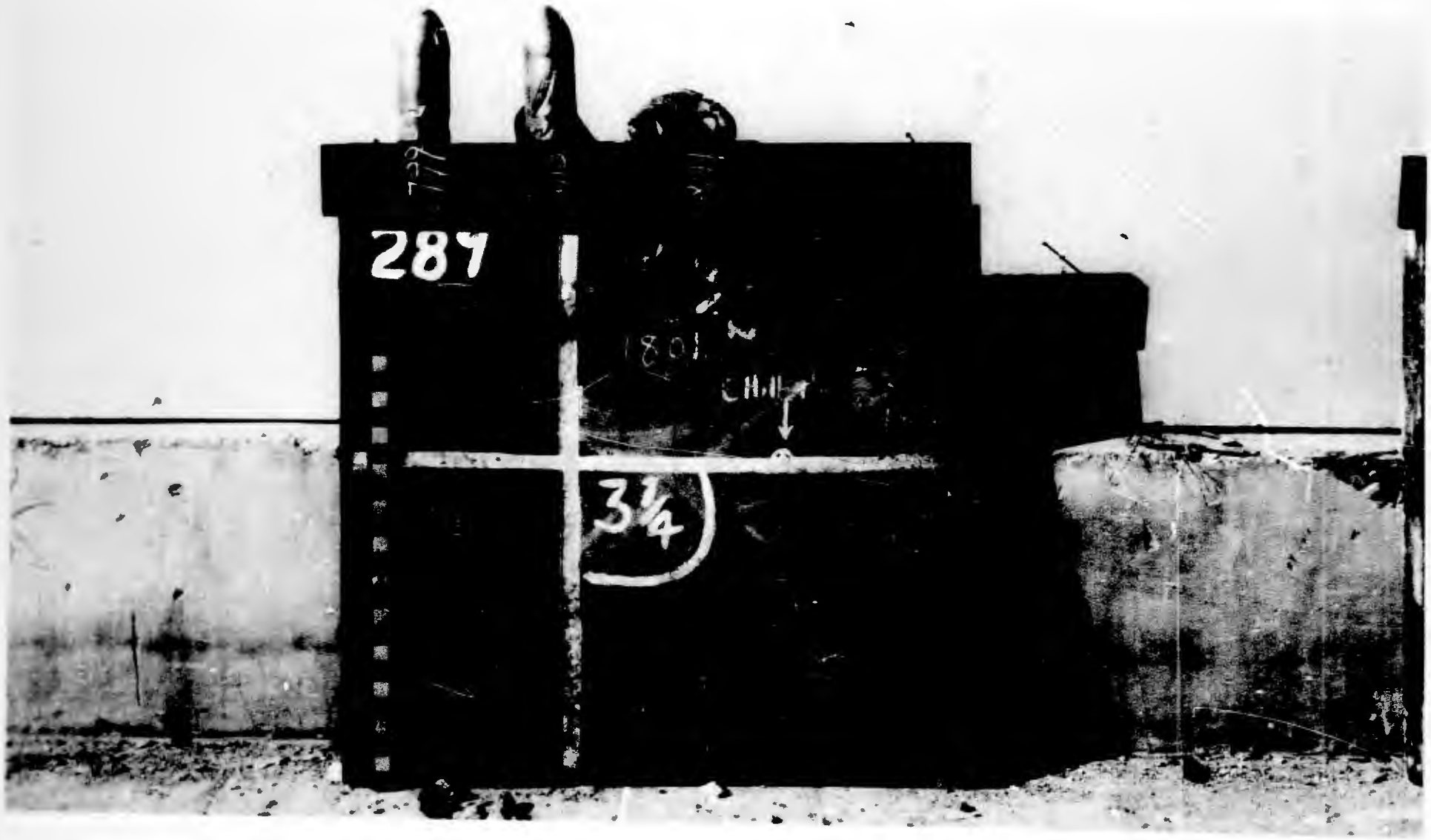

NPG PHOTO NO. 1066 (APL) - APL Plate No. 280 (Carn.-Ill. 3" Class "A" No. JJ654) vs. Beth. 14.99 lb. 3" M61 capped AP projectiles at 20° obliquity. FRONT VIEW. See NPG Photo No. 1067 APL for back view.

B.I.No.	"e"	"θ"	S.V.,f.s.	%	Pene.	Proj. Cond.
1769 APL	3".12	19°30'	1963	116	Partial	Ineff. Shattered.
1770	3".11	19°50'	2032	120	Comp.	Not recovered.
1771	3".13	19°40'	2023	120	Partial	Ineff. Shattered.
1772	3".12	19°30'	2113	125	Comp.	Shattered.

10 September 1943

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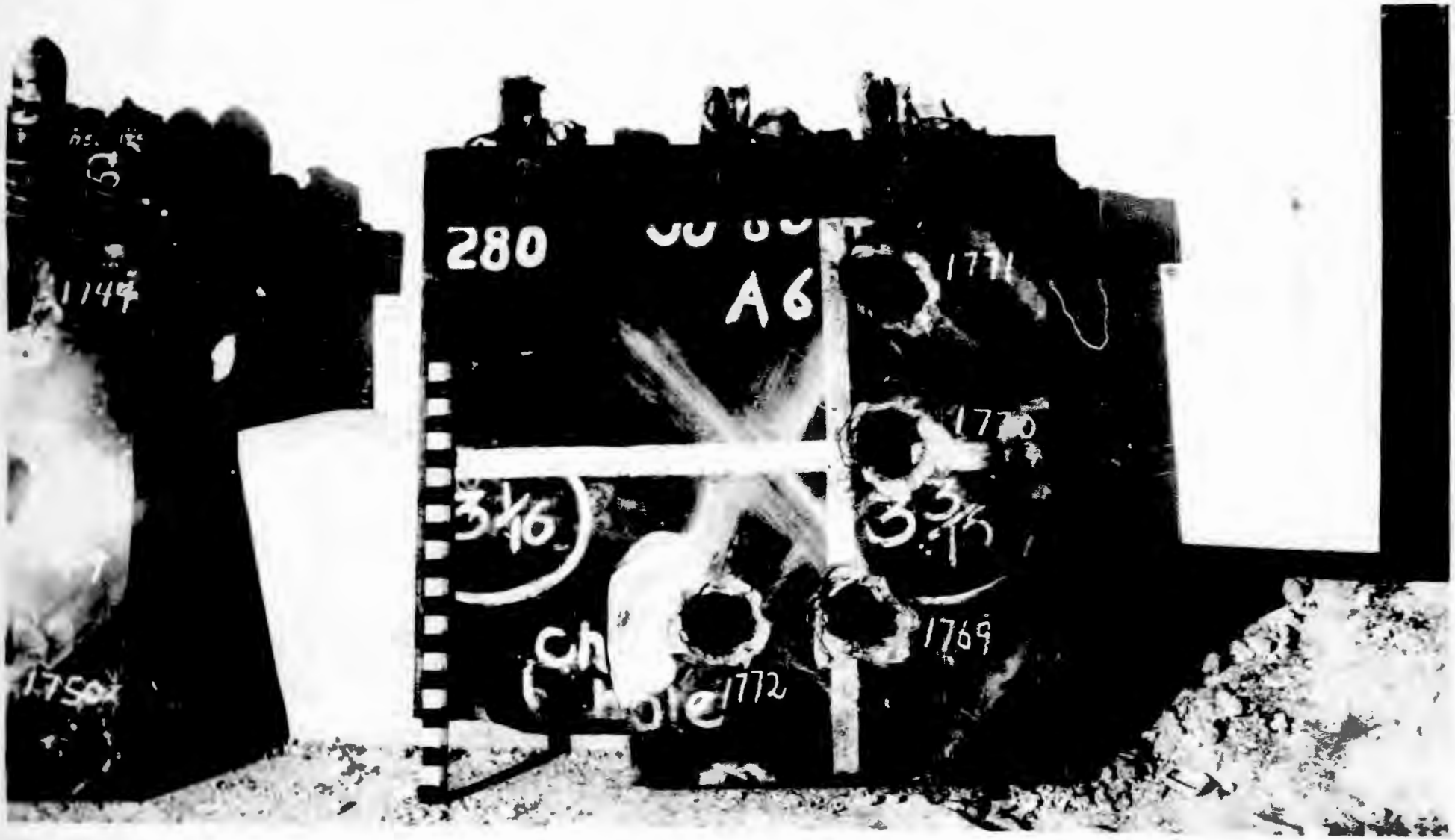

NPG PHOTO NO. 1084 (APL) - APL Plate No. 238 (Carn.-Ill. 3" Class A No. JJ654) vs. Beth. 14.99 lb. 3" M61 capped AP projectiles at 20° obliquity. FRONT VIEW. See NPG Photo No. 1085 APL for back view and data on impacts 1796-8 APL.

B.I.No.	"e"	"θ"	S.V.,f.s.	ϕ	Pene.	Proj.Cond.
1793 APL	3°15	19°40'	1973	116	Comp.	Ineff. Nose shattered. Split into cavity.
1794	3°15	19°40'	1915	113	Partial	Ineff. Shattered.
1795	3°15	19°40'	2003	118	Comp.	Eff. Nose chipped. Body cracked.

15-16 September 1943

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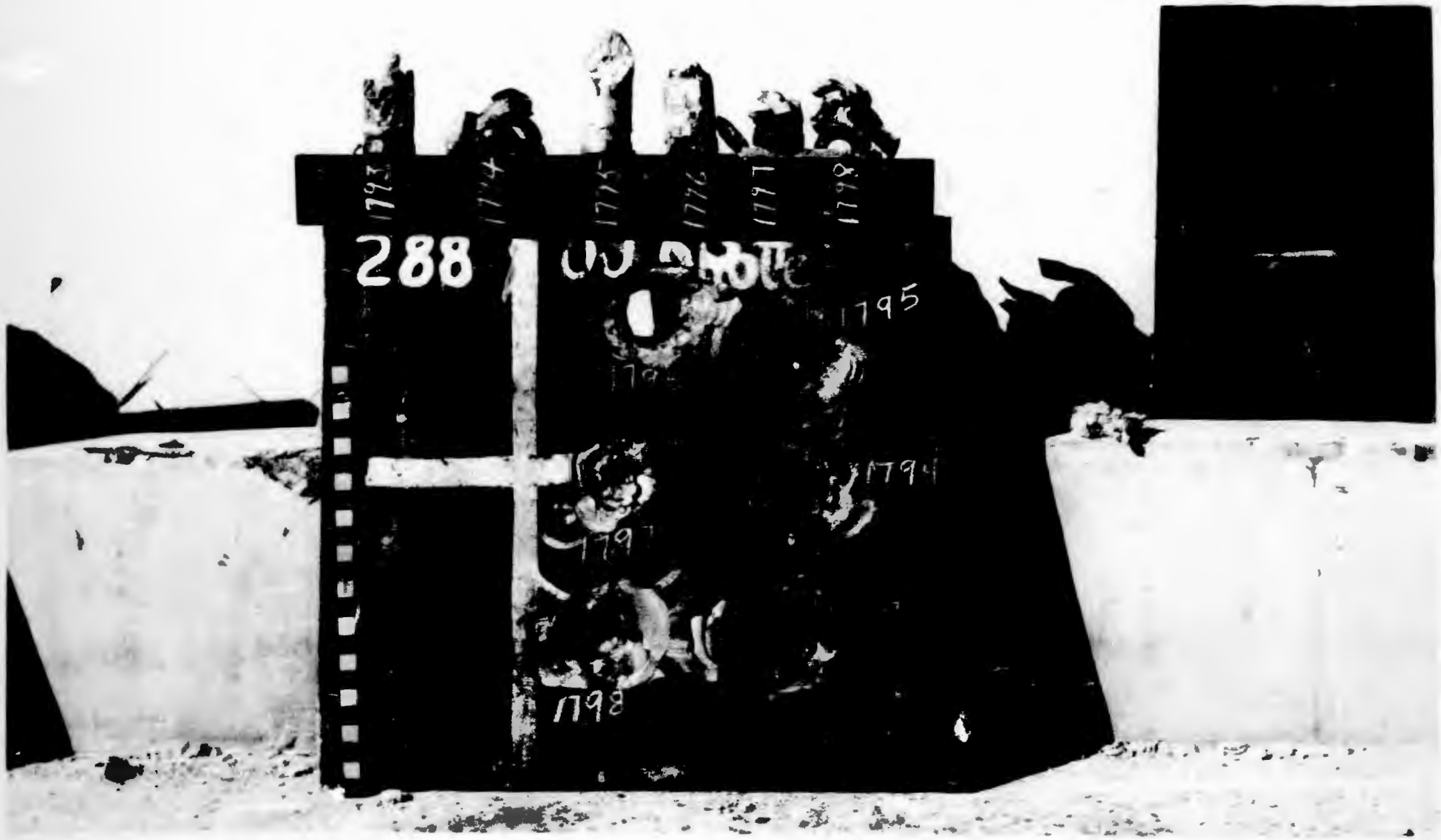

APPENDIX C

Hardness Distribution Curves Through Plate Cross Sections

NPG Photo No. 1302 (APL)

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HARDNESS DISTRIBUTION THROUGH
CROSS SECTION OF MIDVALE
3" CLASS "A" ARMOR PLATE

7226-2

22 December 1943

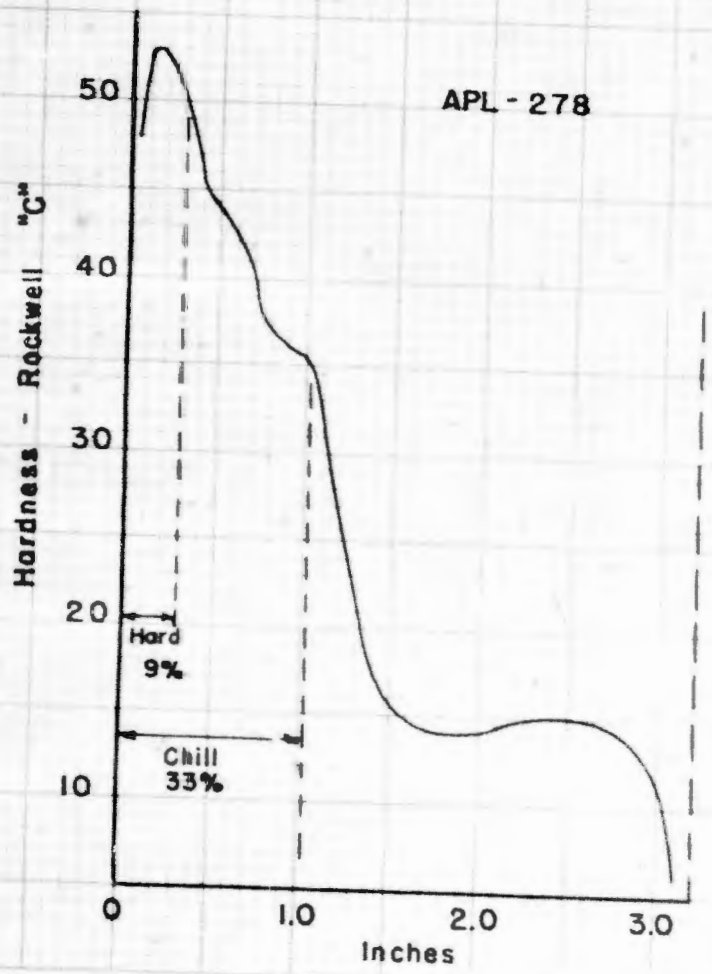

Fig. 9

NPG Photo No. 1303 (APL)

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HARDNESS DISTRIBUTION THROUGH CROSS SECTION OF CARNEGIE 3" CLASS "A" ARMOR PLATE

EE630

22 December 1943

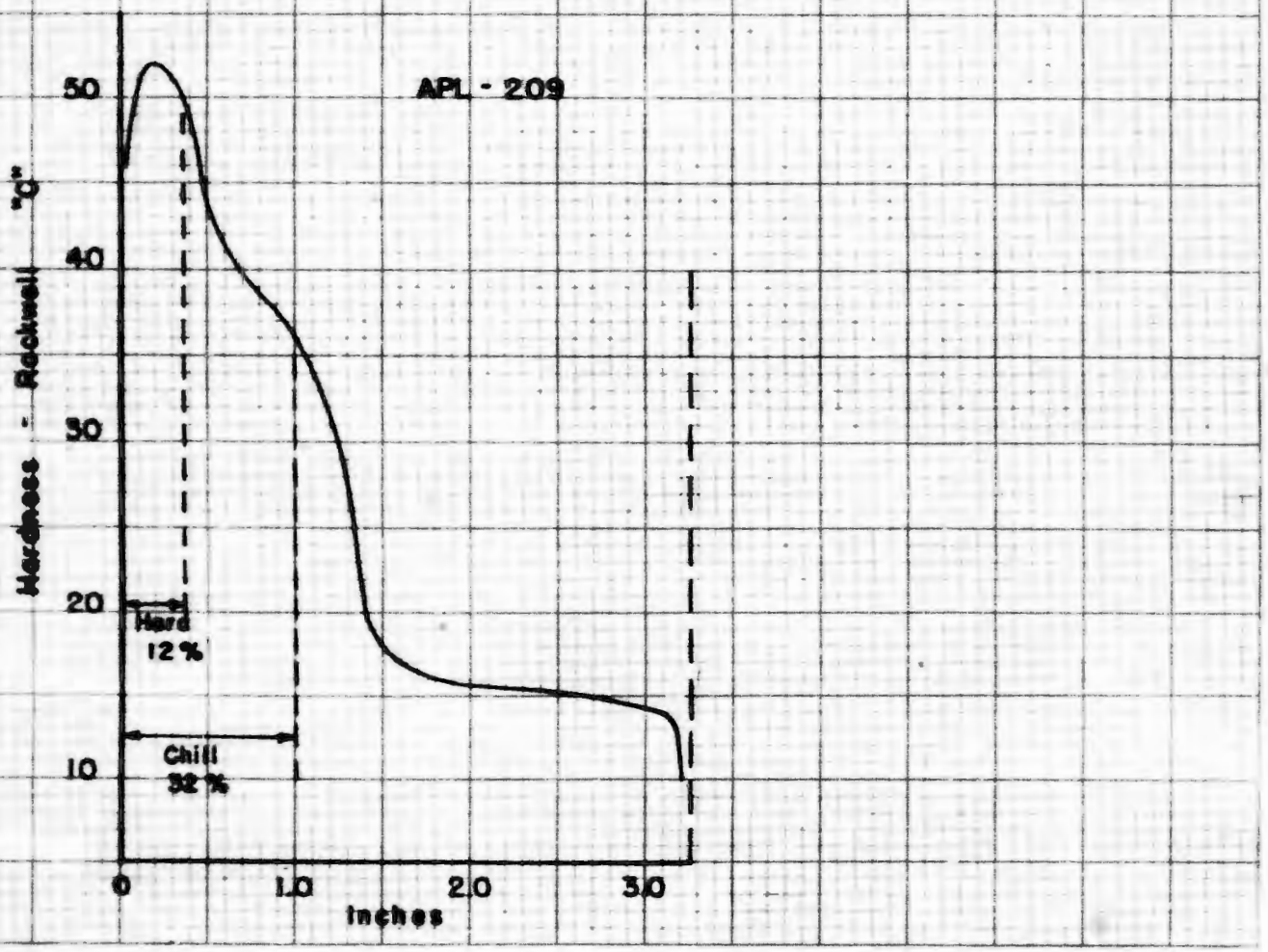

Fig. 10

NPG Photo No. 1304 (APL)

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HARDNESS DISTRIBUTION THROUGH CROSS SECTIONS OF CARNEGIE 3" CLASS "A" ARMOR PLATE

22 December 1943

JJ256

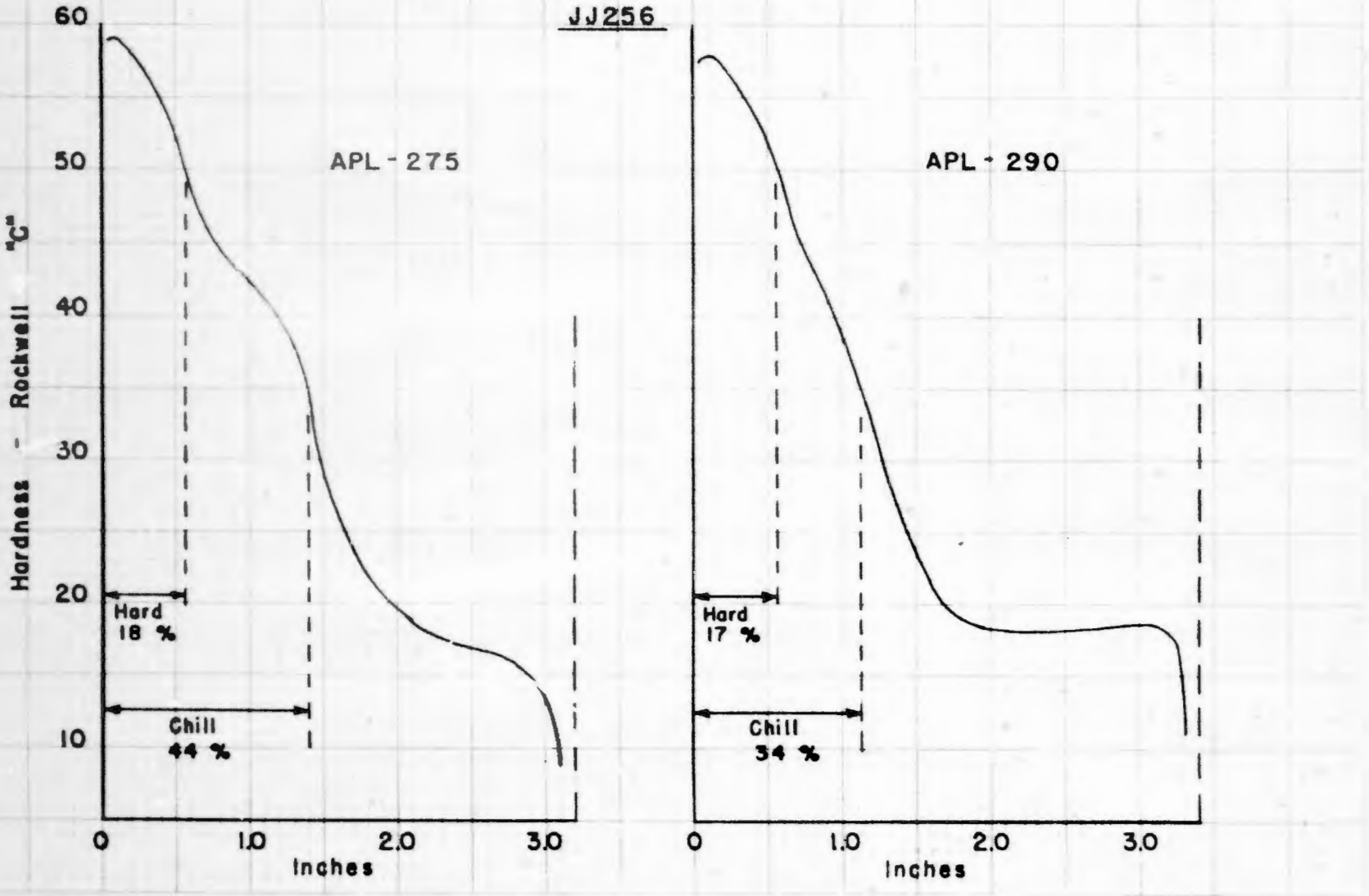


Fig. 11

NPG Photo No. 1305 (APL)

CONFIDENTIAL

HARDNESS DISTRIBUTION THROUGH CROSS SECTIONS OF CARNEGIE 3" CLASS "A" ARMOR PLATE

22 December 1943

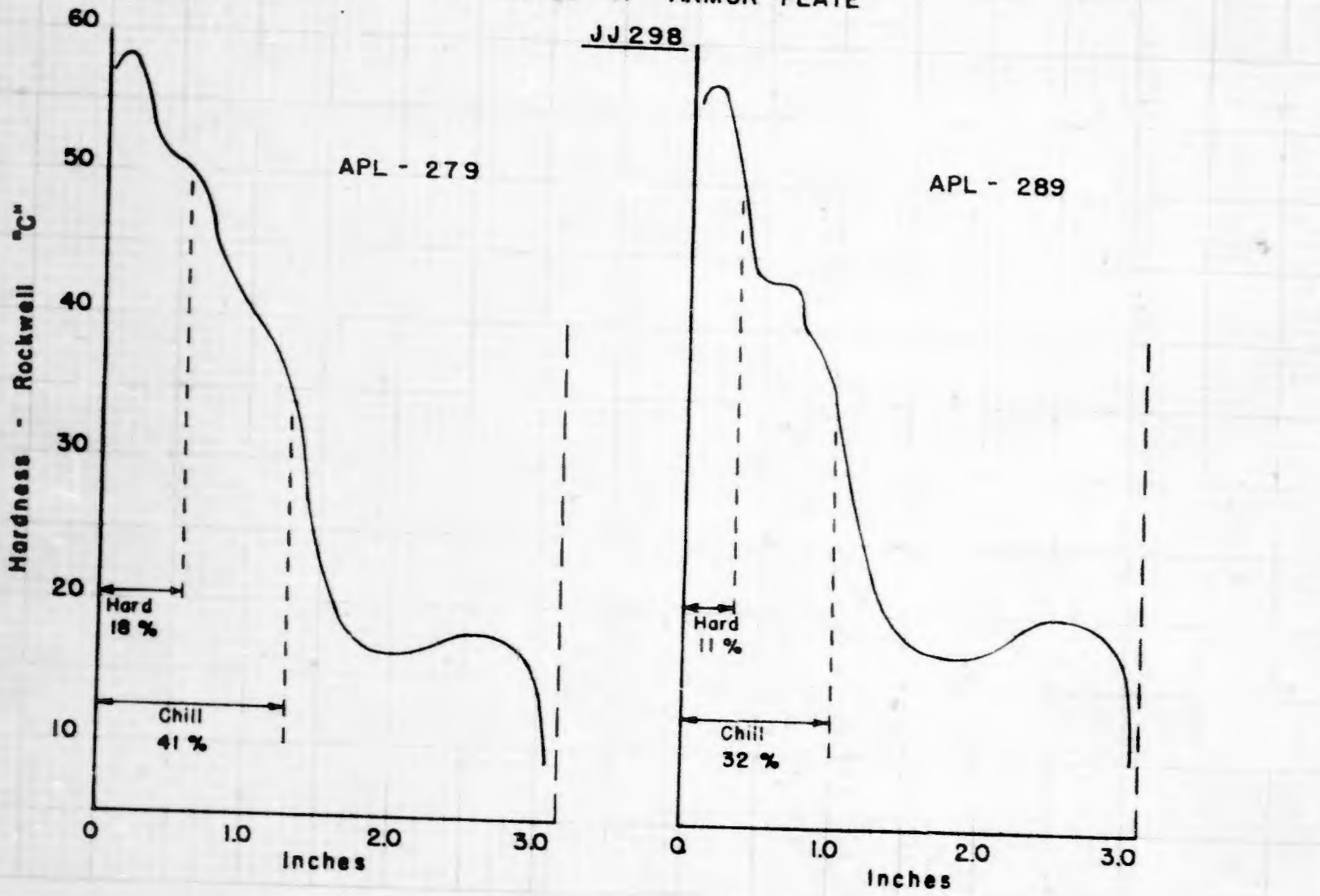


Fig. 12

NPG Photo No. 1306 (APL)

CONFIDENTIAL

HARDNESS DISTRIBUTION THROUGH CROSS SECTIONS OF CARNEGIE 3" CLASS "A" ARMOR PLATE

22 December 1943

JJ 654

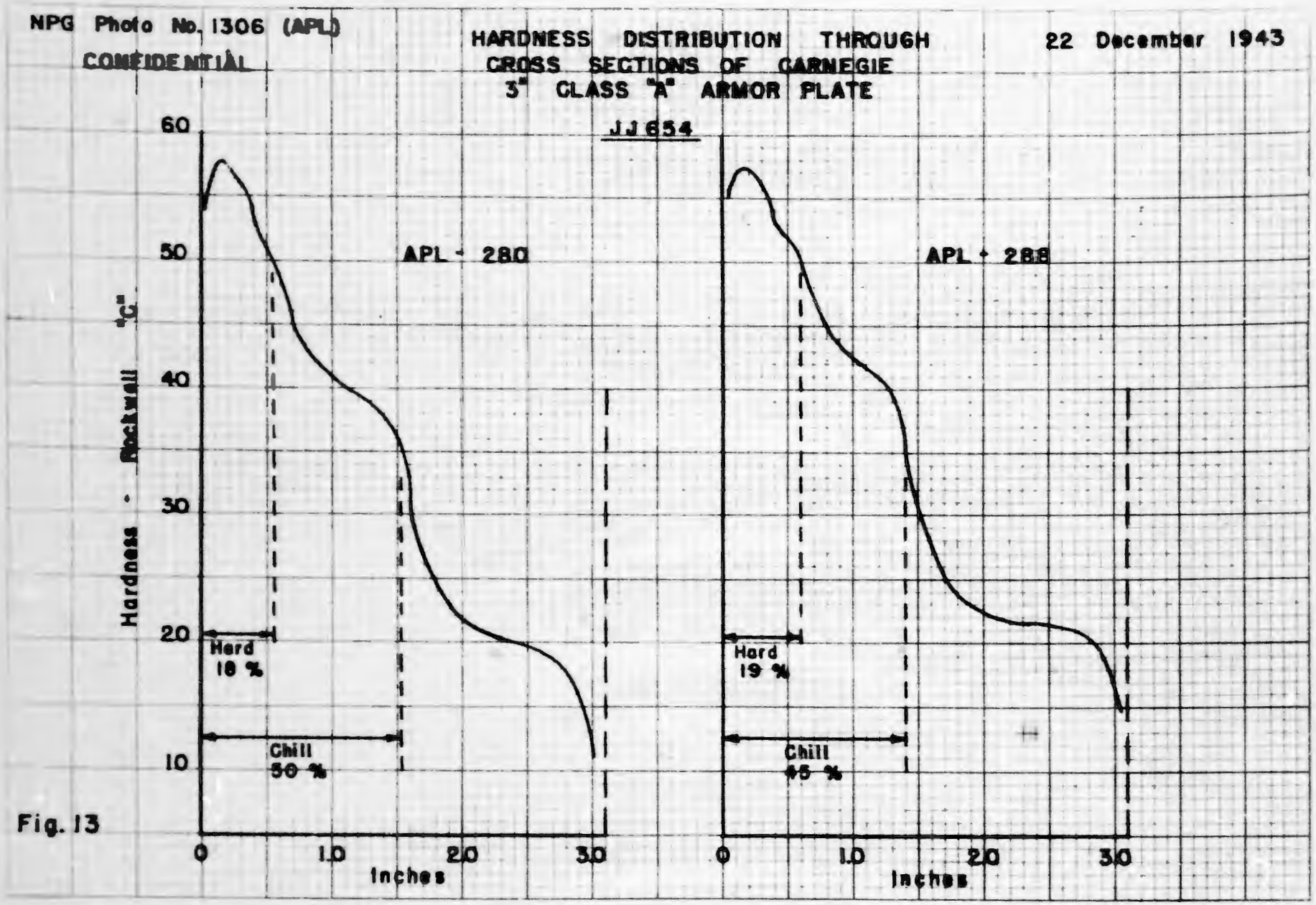


Fig. 13

APPENDIX D

Macro-etched Cross Sections of Plates.

NPG Photo No. 1320 (APL) -CONFIDENTIAL- 23 December 1943

MACROETCHED CROSS SECTION OF MIDVALE
3" CLASS "A" PLATE
7226-2

(Actual Size)

Etch A: 10% Ammonium Persulphate - Swab - 30 Secs.
Etch B: 38% HCl, 12% H_2SO_4, 50% H_2O - 2-3Hours - 160°F

APL - 278

Etch A -

Etch B -

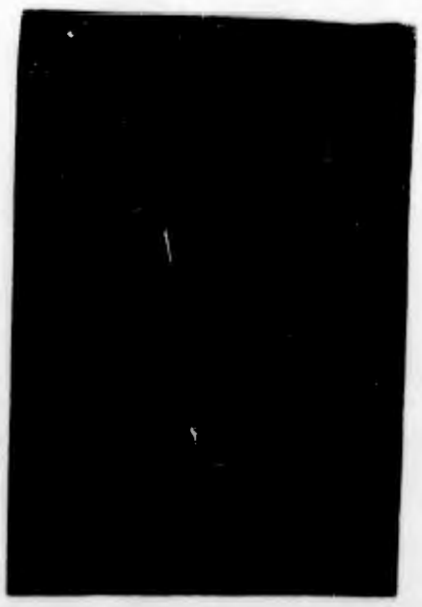


Fig. 14

NPG Photo No. 1321 (APL) -CONFIDENTIAL- 23 December 1943

MACROETCHED CROSS SECTION OF CARNEGIE
3" CLASS "A" PLATE
EE630

(Actual Size)

Etch A: 10% Ammonium Persulphate - Swab - 30 Secs.
Etch B: 38% HCl, 12% H_2SO_4, 50% H_2O - 2-3 Hours - 160°F

APL - 209

Etch A -

Etch B -

Fig. 15

NPG Photo No. 1322 (APL) -CONFIDENTIAL- 23 December 1943

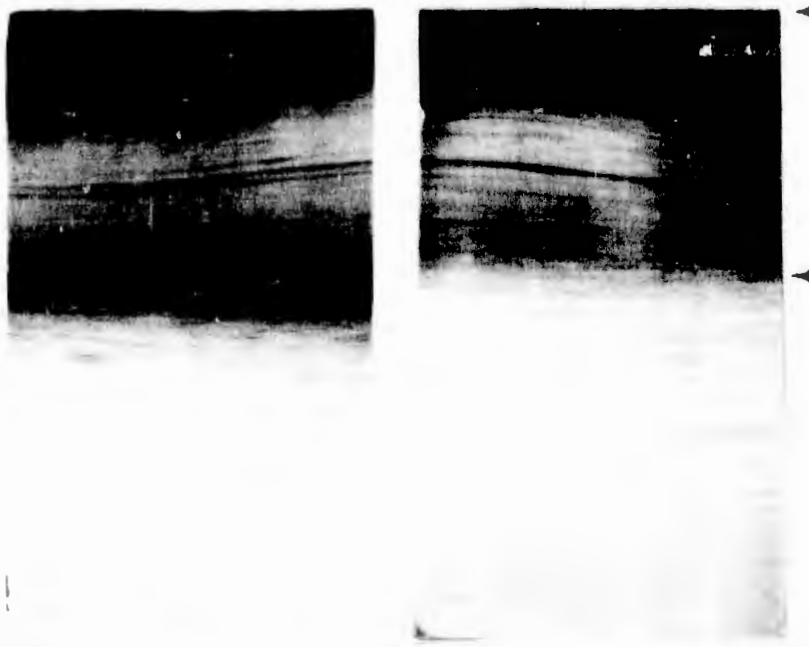
MACROETCHED CROSS SECTIONS OF CARNEGIE
3" CLASS "A" PLATE
JJ256

(Actual Size)

Etch A: 10% Ammonium Persulphate - Swab - 30 Secs.
Etch B: 38% HCl, 12% H_2SO_4, 50% H_2O - 2-3 Hours - 160°F

APL - 275 APL - 290

Etch A -



Etch B -

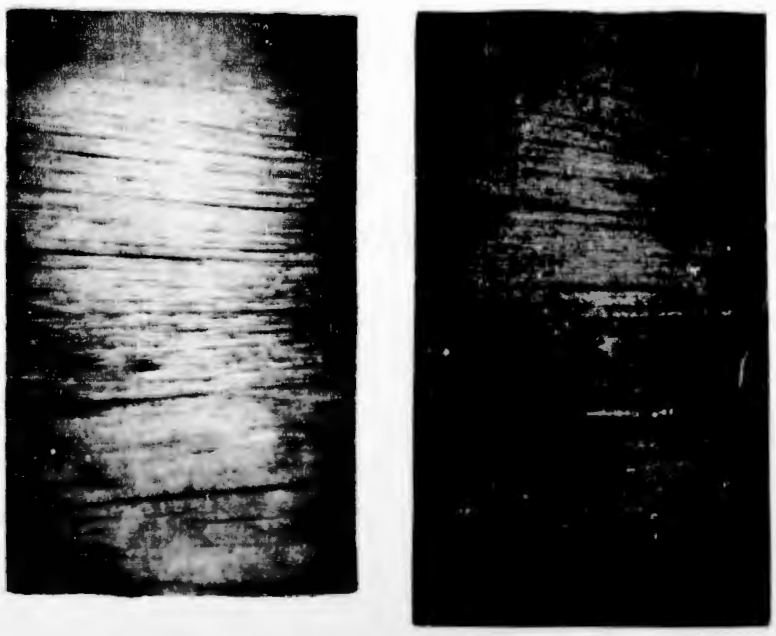


Fig. 16

NPG Photo No. 1323 (APL) -CONFIDENTIAL- 23 December 1943

MACROETCHED CROSS SECTIONS OF CARNEGIE
3" CLASS "A" PLATE
JJ298

(Actual Size)

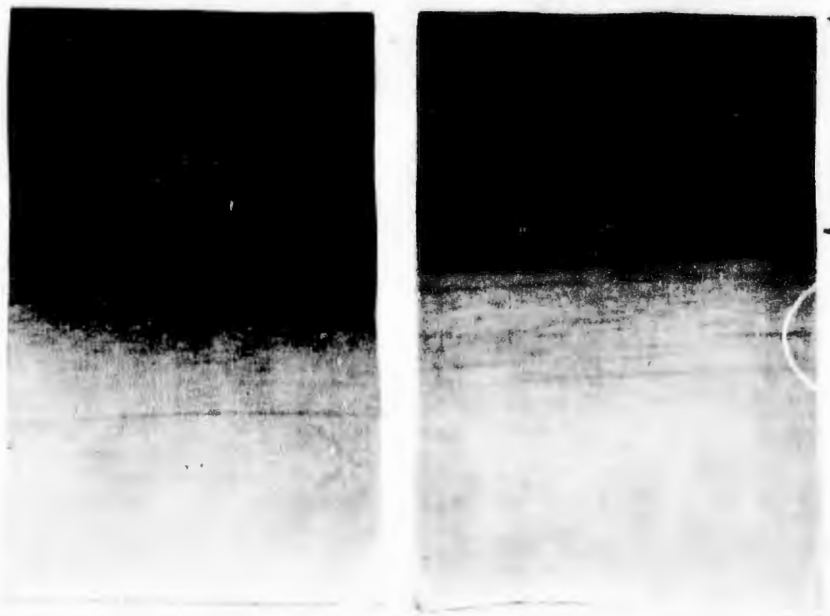
Etch A: 10% Ammonium Persulphate - Swab - 30 Secs.
Etch B: 38% HCl, 12% H_2SO_4, 50% H_2O - 2-3 Hours - 160°F

APL - 279 APL - 289

Face

Chill Depth

Etch A -



Face

Etch B -

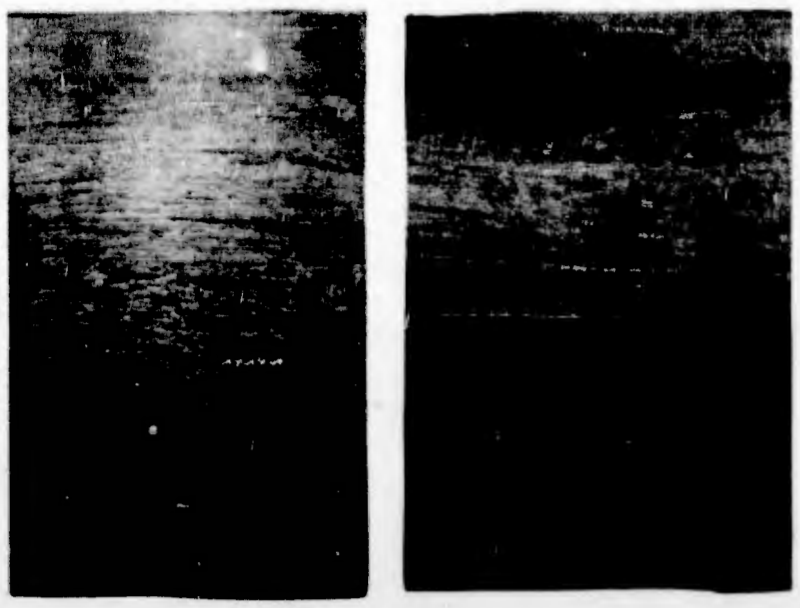


Fig. 17

NPG Photo No. 1324 (APL) -CONFIDENTIAL- 23 December 1943

MACROETCHED CROSS SECTIONS OF CARNEGIE
3" CLASS "A" PLATE
JJ654

(Actual Size)

Etch A: 10% Ammonium Persulphate - Swab - 30 Secs.
Etch B: 38% HCl, 12% H_2SO_4, 50% H_2O,- 2-3 Hours - 160°F

APL - 280 APL - 288

Face

Etch A -

Chill Depth

Face

Etch B -

Fig. 18

APPENDIX E

Representative Photomicrographs of Face and Back of Plates.

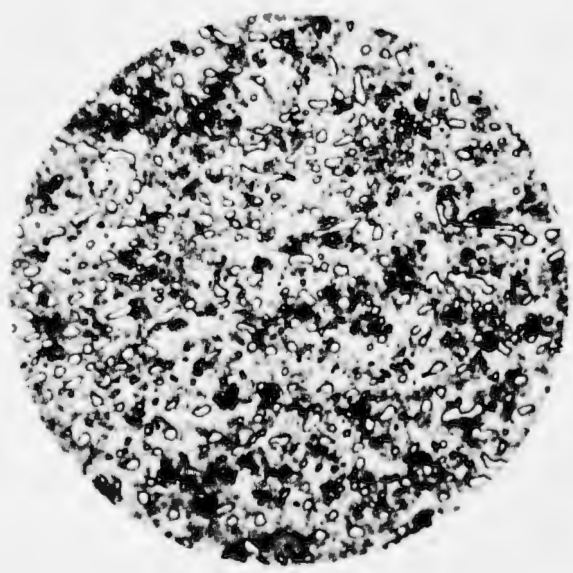
NPG Photo No. 1313 (APL) -CONFIDENTIAL- 22 December 1943

MICROSTRUCTURE OF FACE AND BACK
OF MIDVALE 3" CLASS "A" PLATE
7226-2

Magnification 1000X -- Picral-Nital Etch

M-336

Face



M-337

Back

Fig. 19

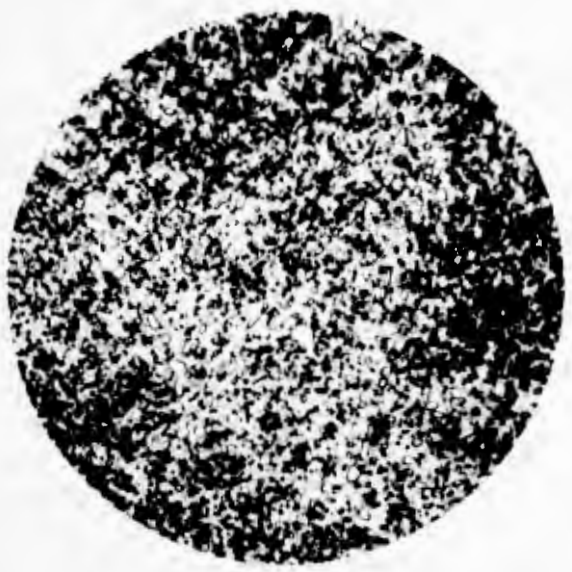
NPG Photo No. 1314 (APL) -CONFIDENTIAL- 22 December 1943

MICROSTRUCTURE OF FACE AND BACK
OF CARNEGIE 3" CLASS "A" PLATE
EE630

Magnification 1000X -- Picral-Nital Etch

M-160

Face



M-338

Back

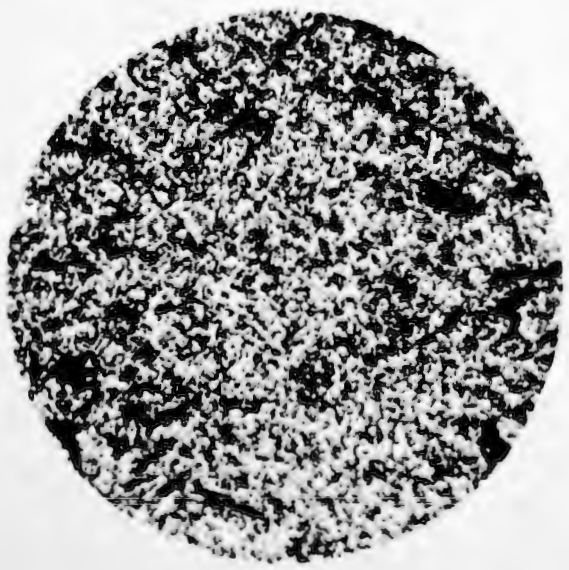


Fig. 20

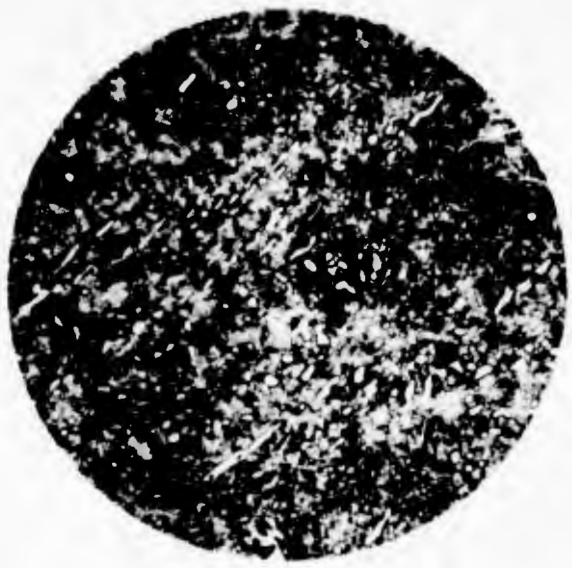
NPG Photo No. 1315 (APL) -CONFIDENTIAL- 22 December 1943

MICROSTRUCTURE OF FACE AND BACK
OF CARNEGIE 3" CLASS "A" PLATE
JJ256

Magnification 1000X -- Picral-Nital Etch

M-302

Face



M-303

Back

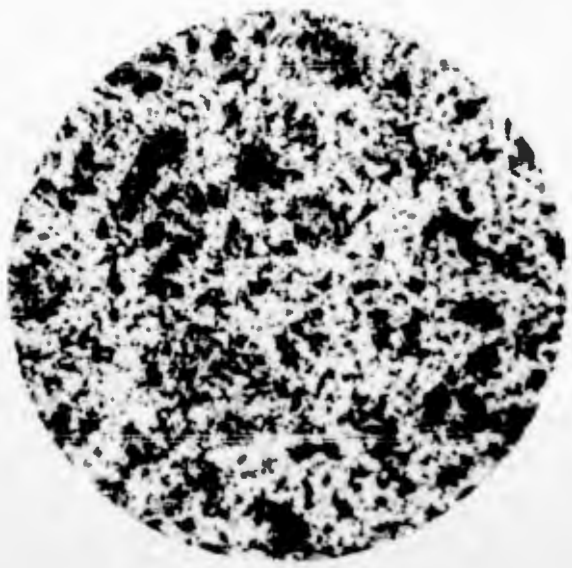


Fig. 21

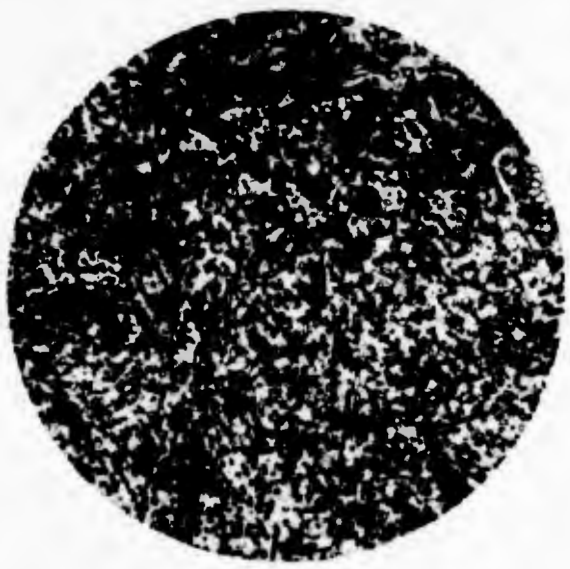
NPG Photo No. 1316 (APL) -CONFIDENTIAL- 22 December 1943.

MICROSTRUCTURE OF FACE AND BACK
OF CARNEGIE 3" CLASS "A" PLATE
JJ298

Magnification 1000X -- Picral-Nital Etch

M-305

Face



M-306

Back

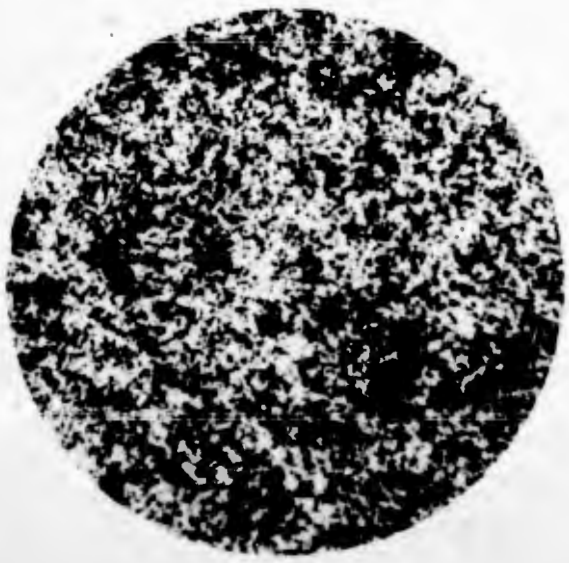


Fig. 22

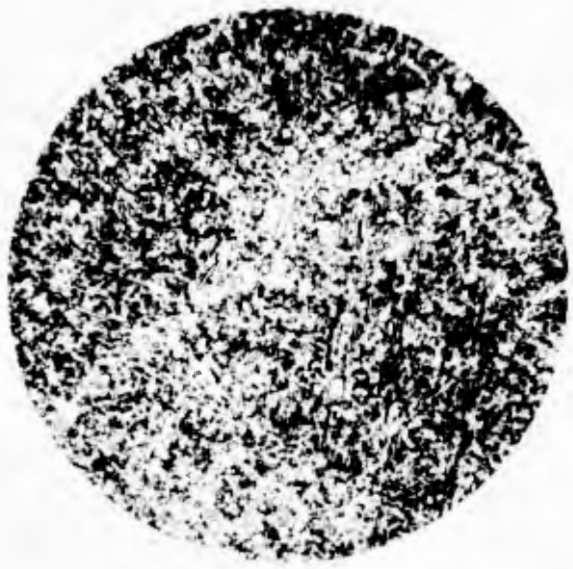
NPG Photo No. 1317 (APL) -CONFIDENTIAL- 22 December 1943

MICROSTRUCTURE OF FACE AND BACK
OF CARNEGIE 3" CLASS "A" PLATE
JJ654

Magnification 1000X -- Picral-Nital Etch

M-308

Face



M-307

Back

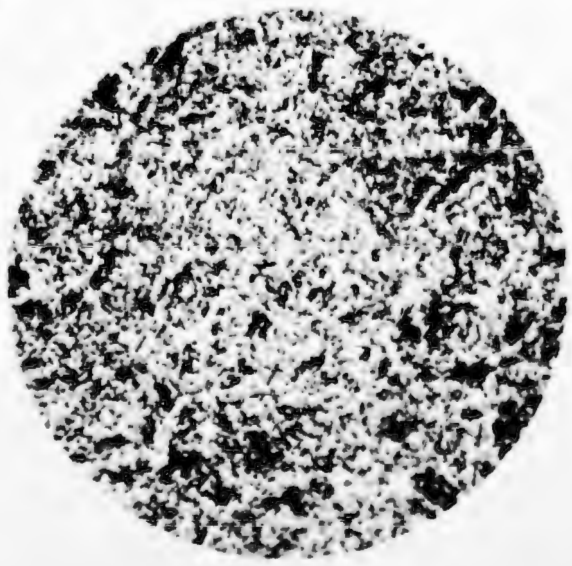


Fig. 23

APPENDIX F

CHEMICAL COMPOSITION

TENSILE PROPERTIES OF BACK

CHILL TEST RESULTS.

Chemical Analysis:

Plate		C	Mn	P	S	Si	Ni	Cr.
7226-2 Midvale	T-	0.32	0.27	.017	.022	.07	3.85	1.64
	B-	0.32	0.27	.016	.021	.07	3.86	1.64
APL		0.30	0.32	.012	.026	.07	3.68	1.64
ET630 Carnegie	T-	0.33	0.28	.019	.025	.07	3.91	1.98
	B-	0.32	0.26	.018	.026	.07	3.71	1.80
APL		0.34	0.26	.017	.024	.07	3.75	2.02
JJ256 Carnegie	T-	0.36	0.21	.015	.027	.07	3.68	1.66
	B-	0.33	0.20	.014	.026	.06	3.68	1.66
APL		0.33	0.23	.017	.022	.08	3.55	1.66
JJ298 Carnegie	T-	0.37	0.21	.014	.028	.07	3.22	1.45
	B-	0.37	0.20	.014	.028	.07	3.20	1.41
APL		0.35	0.20	.018	.022	.07	3.18	1.43
JJ654 Carnegie	T-	0.35	0.20	.013	.030	.09	3.68	1.74
	B-	0.34	0.22	.010	.026	.09	3.70	1.74
APL		0.33	0.21	.015	.017	.08	3.65	1.74

Tensile Properties of Back:

Plate		APL No.	Y.P.	T.S.	Elong.	R.A.
7226-2	Midvale	T- B-	90,000 90,500	109,500 110,000	27.0 26.8	69.9 68.5
	APL	278	90,750	108,625	26.3	67.4
EE630	Carnegie	T- B	83,140 80,880	107,600 107,300	27.0 27.0	69.3 63.5
	APL	B 209	90,200	104,500	26.4	72.0
JJ256	Carnegie	T- B-	81,880 80,280	104,800 102,100	26.5 27.0	71.4 71.4
	APL	T 290 B 275	80,400 80,000	100,150 100,100	25.7 28.6	73.9 72.5
JJ298	Carnegie	T- B-	81,140 85,080	106,800 109,500	26.5 29.0	65.9 66.5
	APL	T 289 B 279	84,900 92,700	105,300 107,300	26.1 26.4	67.5 69.0
JJ654	Carnegie	T- B	93,120 89,380	116,100 114,300	25.0 35.0	65.9 64.7
	APL	T 288 B 280	93,750 93,250	110,650 111,150	26.1 26.4	70.5 70.3

Chill Test Results: (APL Chill - Depth at "RC" 35)
(APL Undrillable - Depth at "RC" 50)

Plate		APL No.	Gauge (in.)	Chill (in.)	Chill (%)	Undrill (in.)	Undrill (%)
7226-2	Midvale	T-	3-1/8	1-1/2	48	-	-
		B-	3-1/16	1-3/8	39	-	-
	APL	278	3.2	1.05	33	.30	9
EE630	Carnegie	T-	3-1/4	1-3/16	34.8	3/4	23.1
		B-	3-1/4	1-1/16	32.7	5/8	19.2
	APL	B-209	3.25	1.05	32	.38	11.7
JJ256	Carnegie	T-	3-3/8	1-1/4	37.0	1/2	14.8
		B-	3-5/16	1-9/16	47.1	5/8	18.9
	APL	T 290	3.4	1.15	34	.57	16.8
		B 275	3.2	1.40	44	.56	17.5
JJ298	Carnegie	T-	3-3/16	1-1/16	33.3	7/16	13.7
		B-	3-3/16	1-1/2	47.0	5/8	19.5
	APL	T-289	3.1	1.0	32	.33	10.7
		B-279	3.15	1.30	41	.55	17.5
JJ654	Carnegie	T-	3-3/16	1-7/16	45.1	1/2	15.6
		B-	3-1/8	1-5/8	52.0	1/2	16.0
	APL	T -288	3.1	1.4	45	.60	19.4
		B -280	3.1	1.55	50	.55	17.8

Carbon Gradients: (as reported by manufacturer)

Plate	1/8"	1/2"	3/4"	Back
7226-2 Midvale	T- 1.04 B- 1.03	.58 .58	.32 .32	.32 .32

Plate	1/16"	1/4"	1/2"	1"	Back
EE630 Carnegie	T- .91 B- 1.03	.80 1.08	.40 .48	.33 .37	.33 .32
JJ256 Carnegie	T- .92 B- 1.36	.99 1.20	.60 .67	.34 .36	.36 .33
JJ298 Carnegie	T- .94 B- .98	1.23 .96	.64 .60	.38 .38	.37 .37
JJ654 Carnegie	T- .96 B- .92	1.04 1.05	.72 .59	.36 .35	.35 .34

APPENDIX G

Sketches of Manufacturers' Plate Sectioned for Small Test Plates.

3" Class "A" Projectile Test Plate

Midvale No. 7226-2

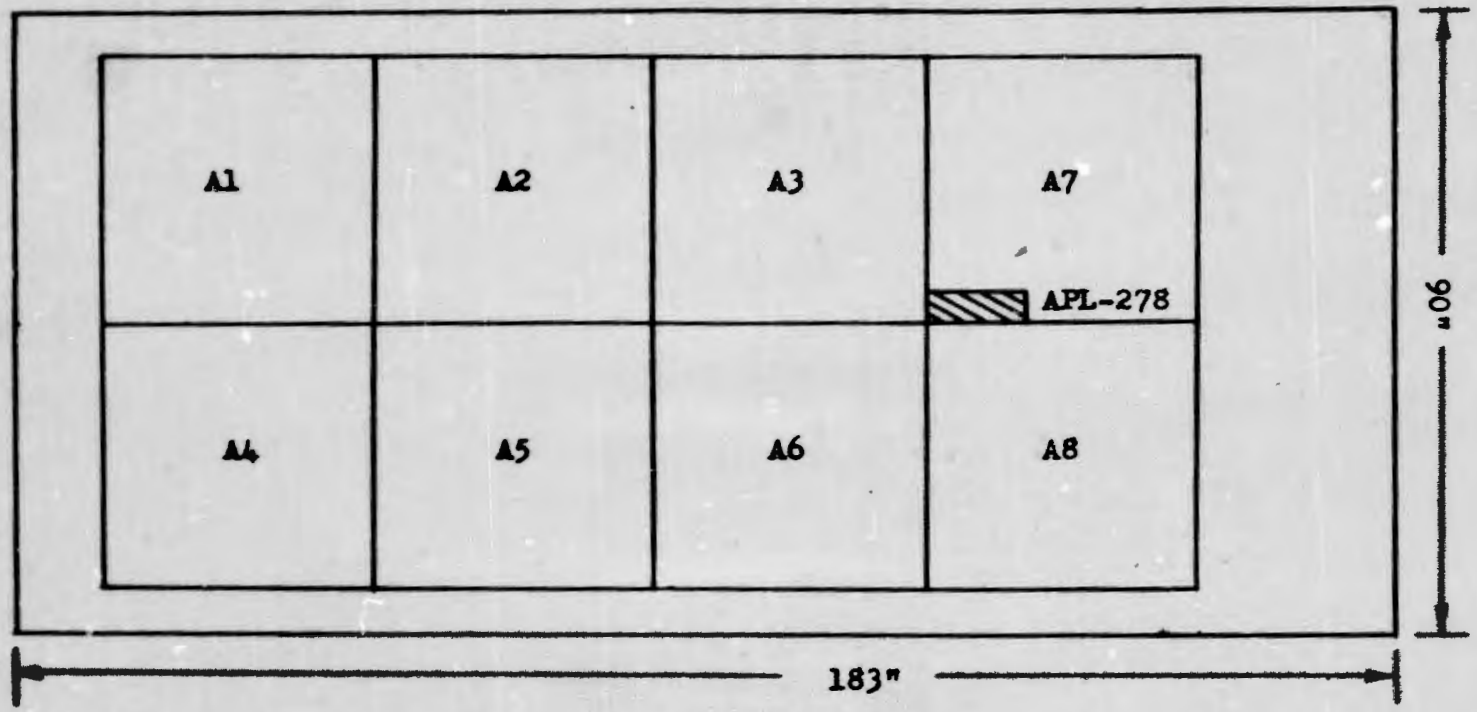


Fig. 24

NPG Photo No. 1307 (APL) -CONFIDENTIAL- 22 December 1943

3" Class "A" Projectile Test Plate

Carnegie No. KE630

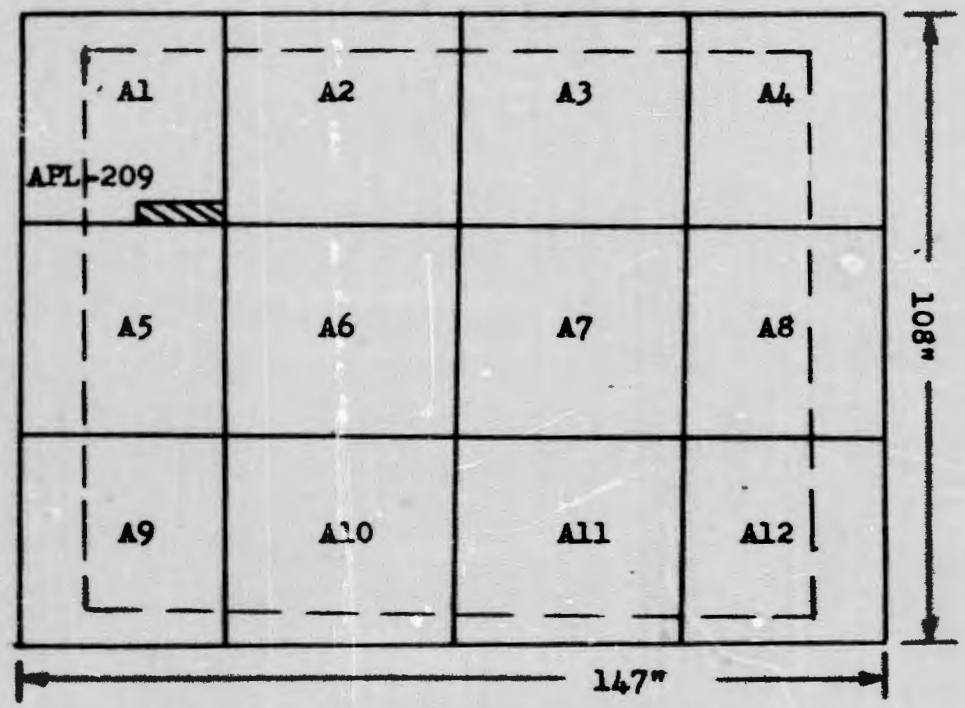


Fig. 25

AD

309 984

2 OF 2

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3" Class "A" Projectile Test Plate

Carnegie No. JJ256

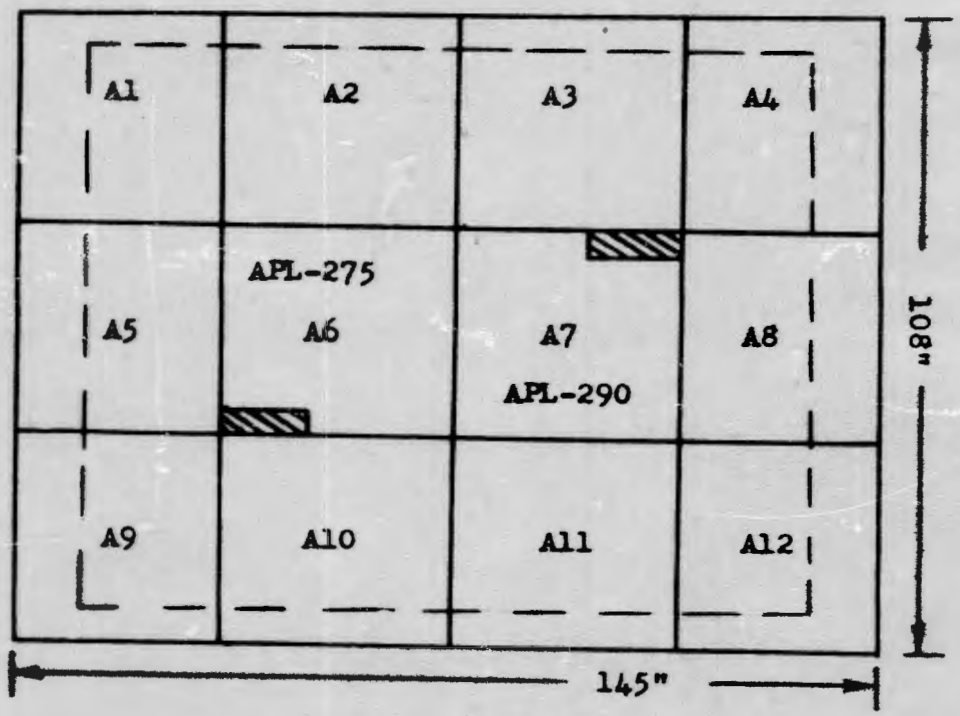

Fig. 26

3" Class "A" Projectile Test Plate

Carnegie No. JJ298

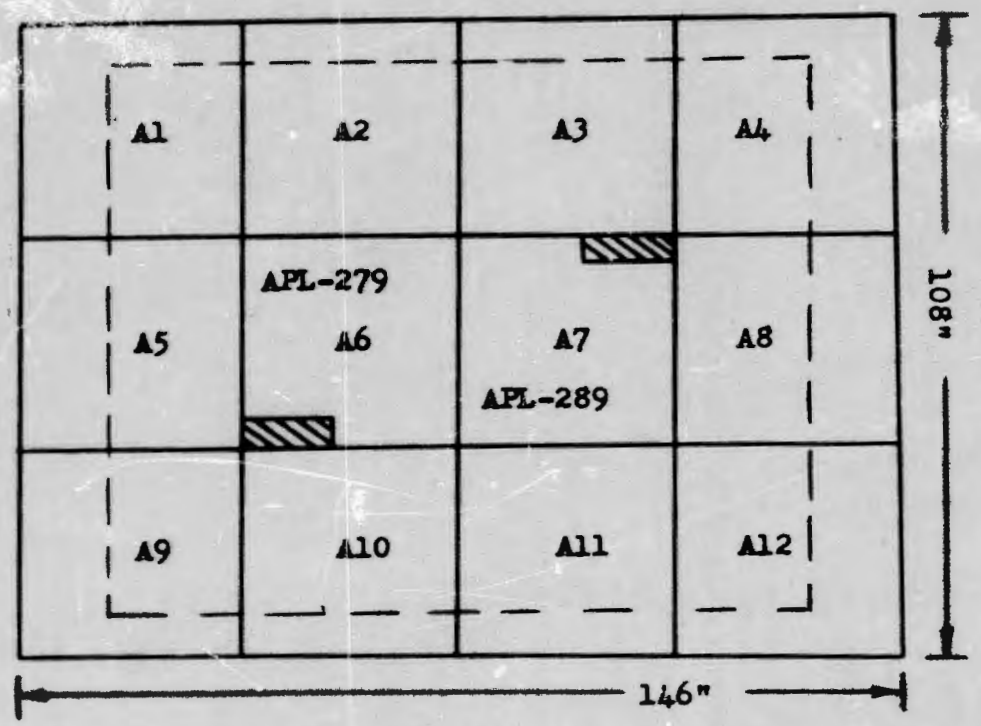

Fig. 27

3" Class "A" Projectile Test Plate

Carnegie No. JJ654

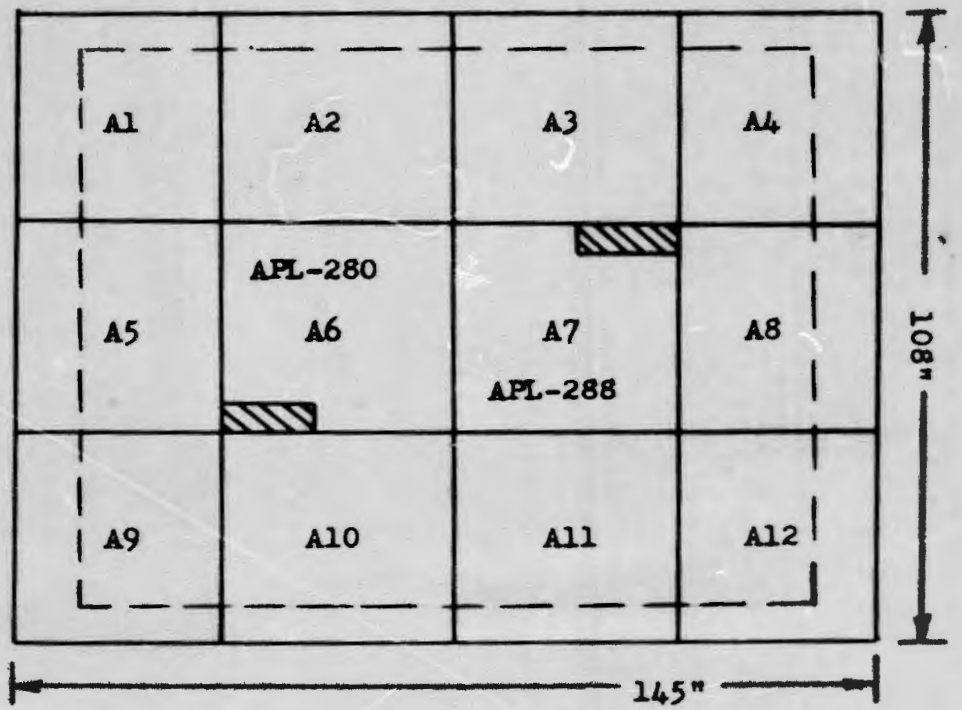

Fig. 28

UNCLASSIFIED

UNCLASSIFIED