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WATERTOWN ARSENAL LABORATORY

MEMORANDUM REPORT

NO. WAL 710/584

Metallurgical Examination of 3/4" Armor Plates

Manufactured by Great Lakes Steel Corp.

and the Standard Steel Spring Company

BY

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DATE 27 January 1944

WATERTOWN ARSENAL
WATERTOWN, MASS.

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Watertown Arsenal Laboratory

Memorandum Report #AL 710/584

Final Report on Problem B-4.14

27 January 1944

Metallurgical Examination of 3/4" Armor Plates Manufactured by Great Lakes Steel Corp. and the Standard Steel Spring Company

ABSTRACT

Twelve sections from 3/4 inch test plates fired at Aberdeen as a part of the effect of hardness program were examined metallurgically. Steel soundness was uniformly satisfactory on one series of six plates. However, three of the other six plates were of inferior steel soundness. Heat treatment was satisfactory on all plates. Crystallinity was evident on samples of plates at hardnesses above 330 Brinell.

1. As requested by Ordnance Research Center, Aberdeen (A.P.G. 470.5/1920 Wtn 470.5/7414(r)), a metallurgical examination has been completed on twelve (12) 3/4 inch armor plates submitted by the Standard Steel Spring Company as a part of the program correlating the ballistic properties of rolled homogeneous armor with hardness. Six (6) of the plates were made by the Great Lakes Steel Corp. and six (6) by Jones and Laughlin Steel Corp. The latter group of plates were assumed to have been heat treated by Standard Steel Spring Company.

2. The results of the tests conducted at this arsenal show that the plates made by Jones and Laughlin were of acceptable steel quality (rated B) and properly heat treated. The plate in this group possessing the highest hardness (369 BHN) exhibited some crystallinity associated with its high hardness.

Of the six plates made by Great Lakes Steel Corp., three (#58, #64, and #67) exhibited C quality steel and the remainder (#60, #62, and #66) D quality steel using standards in which D and E are considered rejectable. Plates having a hardness of 331 BHN or higher were observed to possess a trace or more of crystallinity depending upon the hardness. It is felt that this lack of ductility in the fracture test is not associated with an improper heat treatment but rather is a function of the hardness for this composition when efficiently heat treated under [redacted] conditions.

[redacted]

3. The plates under investigation were listed as follows:

Great Lakes Steel Corp.	Standard Steel Spring Co.
GLS 58	SCJ 1745
60	1747
62	1748
64	1750
66	1751
67	1753

The metallurgical examination consisted of the following tests:

a. Chemical analysis of plates GLS 67 and SCJ 1745.

b. Hardness Surveys.

c. Fracture tests for ductility and steel quality.

d. Macroexamination.

e. Microscopic examination including microstructure, grain size, and depth of decarburization.

4. Results and Discussion

a. Chemical Analysis

The analysis of one plate from each group was obtained and the results are shown in Table I.

Table I

Chemical Composition

Plate No.	C	Mn	Si	S	P	Ni	Cr	Mo	B	Ti	Al
GLS 67 (Great Lakes Steel Corp.)	.30	1.54	.33	.021	.020	tr	.62	.23	.0028	tr	.06
SCJ 1745 (Jones & Laughlin Steel Corp.)	.24	1.64	.24	.020	.016	tr	.02	.44	.0014	.045	.07

The two plates contain sufficient alloy to completely harden sections well over 3/4 of an inch thick. Both companies apparently used boron as an addition agent to improve the hardenability in the plates

under consideration.

b. Hardness Tests

Brinell and Rockwell C hardness surveys were conducted along a cross section of samples from each plate. The average values of Brinell reported are the average of three readings equidistantly spaced across the section. Rockwell C readings were made every 1/8 inch across the section. The results are summarized in Table II and the actual Rockwell C hardness readings are listed in Appendix A.

Table II

Hardness Tests

Plate No.	1/4" from Edge		Center		Average
	BHN	Rc	BHN	Rc	BHN
GLS 58	375	40.5	375	40	375
60	369	40	375	40.5	371
62	358	38.5	363	40	359
64	331	37	331	35.5	331
66	331	36.5	331	34	331
67	311	34	331	34.5	318
SCJ 1745	262	25.5	262	25.5	262
1747	369	40.5	388	40	375
1748	352	38.5	375	38.5	360
1750	326	35.5	331	35	328
1751	311	33.5	311	32	311
1753	285	30.5	293	30	288

c. Fracture Tests

Specimens were notched and broken for the fibre fracture test and the fracture test for steel quality having a fractured area of 1" x T and 2-1/2" x T respectively. The results are summarized in Table III.

Table III

Fracture Test Results

Sample	Steel Quality	Fibre Fracture	BHN
GLS 58	C	Mixed Fibrous and Crystalline	375
60	D	Small amount of crystalline	369
62	D	Trace crystalline	358
64	C	Trace crystalline	331
66	D	Trace crystalline	331
67	C	Fibrous	311
SCJ 1745	B	Fibrous	262
1747	B	Small amount of crystalline	369
1748	B	Trace crystalline	352
1750	B	Fibrous	326
1751	B	Fibrous	311
1753	B	Fibrous	285

The group of plates made by Jones and Laughlin Steel Corp. exhibited good quality steel on the basis of the fracture test; the Great Lakes plates were of inferior quality and plates GLS 60, 62, and 66 would be considered rejectable under the present fracture test standards.

The plates of high hardness exhibited some crystallinity in fractures from both producers. It is felt that the lack of ductility in the fracture test is not associated with improper heat treatment but rather with the high hardness of the plates. It has been observed that using a normal production heat treatment, there is an upper hardness limit above which the steel exhibits crystallinity. This limiting value apparently varies with the type composition and possibly the melting practice. A small amount of crystallinity in steel above 330 BHN should not be cause for rejection of armor of 3/4 - 1-1/8 inch thicknesses at the present time, for it is possible that with the compositions now in use having the high hardenability required for the heavier gage armor, it is impossible to consistently obtain fibre in hardnesses over 330 BHN. Factors which influence the maximum hardness at which the ductile fracture can be obtained on armor in these thickness ranges are being investigated at the present time.

d. Macroexamination

Macroetched sections of the plates were photographed and the results are shown in Figures 1 and 2. The plates are acceptable with respect to segregation, though plate 1753 does reveal prominent non-metallic segregations. The plates were cross-rolled as indicated by the similarity of etching characteristics in the transverse and longitudinal sections.

e. Microscopic Examination

A specimen from each plate was examined for grain size, extent of decarburization, non-metallic inclusion distribution and microstructure.

The plates exhibiting poor steel quality (plate 60, 62, 66) contained friable oxide stringers of the type shown in Figure 3A. For typical non-metallic inclusions observed in both GLS and SOJ plates, see Figures 3B and 3C.

The microstructure of all plates except plate 1745 was a uniform tempered martensite with no appreciable amount of ferrite. Typical structures are shown in Figure 4. The structure of plate 1745 shows a slight degree of banding associated with the low hardness of BHN 262.

The depth of decarburization, which varied somewhat, and the grain size of the plates were measured on the microspecimens at 100X. Results are listed in Table IV.

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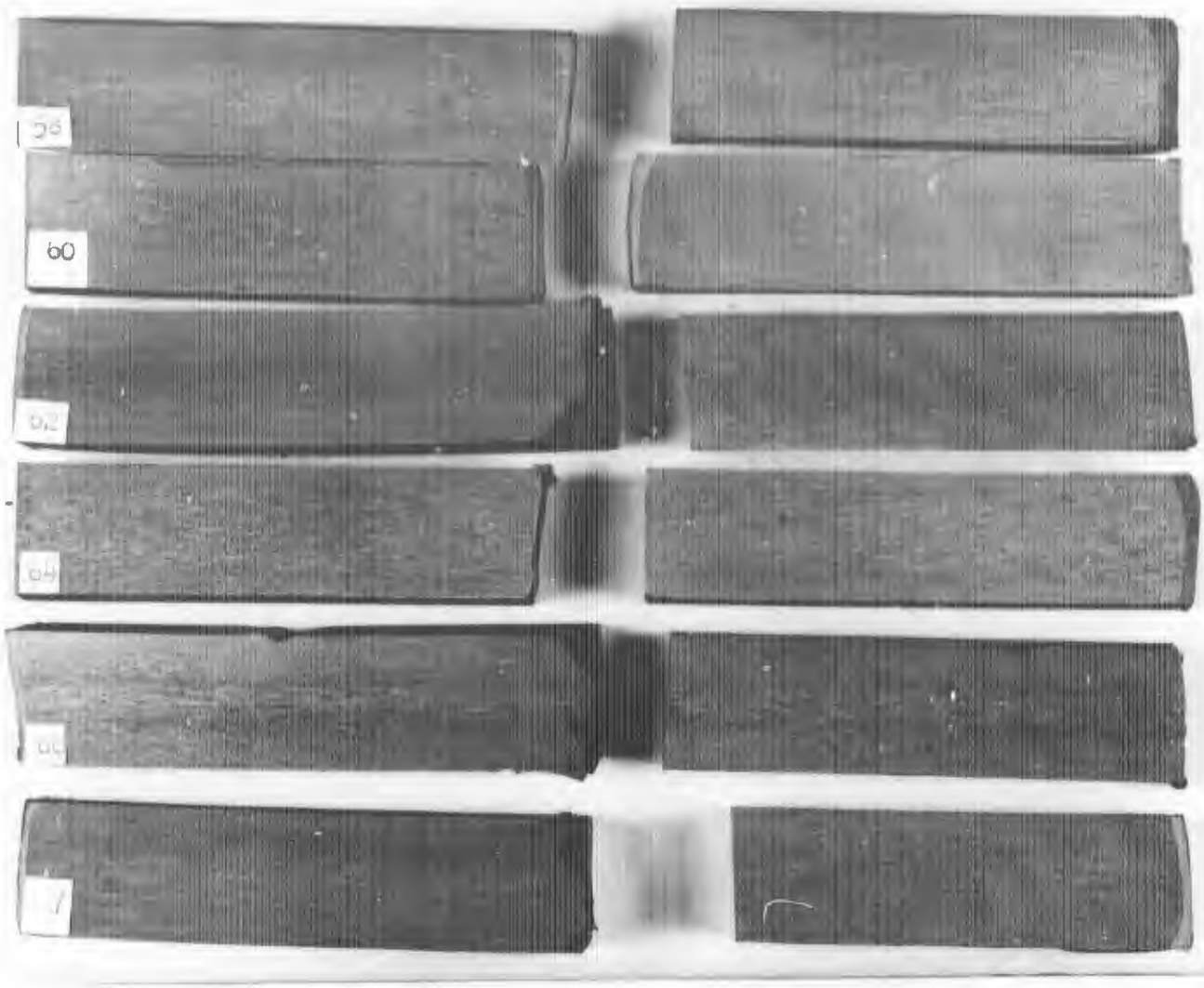
Table IV

Depth of Decarburization, and Grain Size

Plate No.	Decarburization Inches	ASTM G.S.
GLS 58	.010	6 - 8
60	.015	6 - 8
62	.014	6 - 8
64	.003	6 - 8
66	.010	6 - 8
67	.005	5 - 8
SCW 1745	.013	6 - 8
1747	.015	7 - 8
1748	.015	7 - 8
1750	.014	7 - 8
1751	.015	7 - 8
1753	.005	5 - 8



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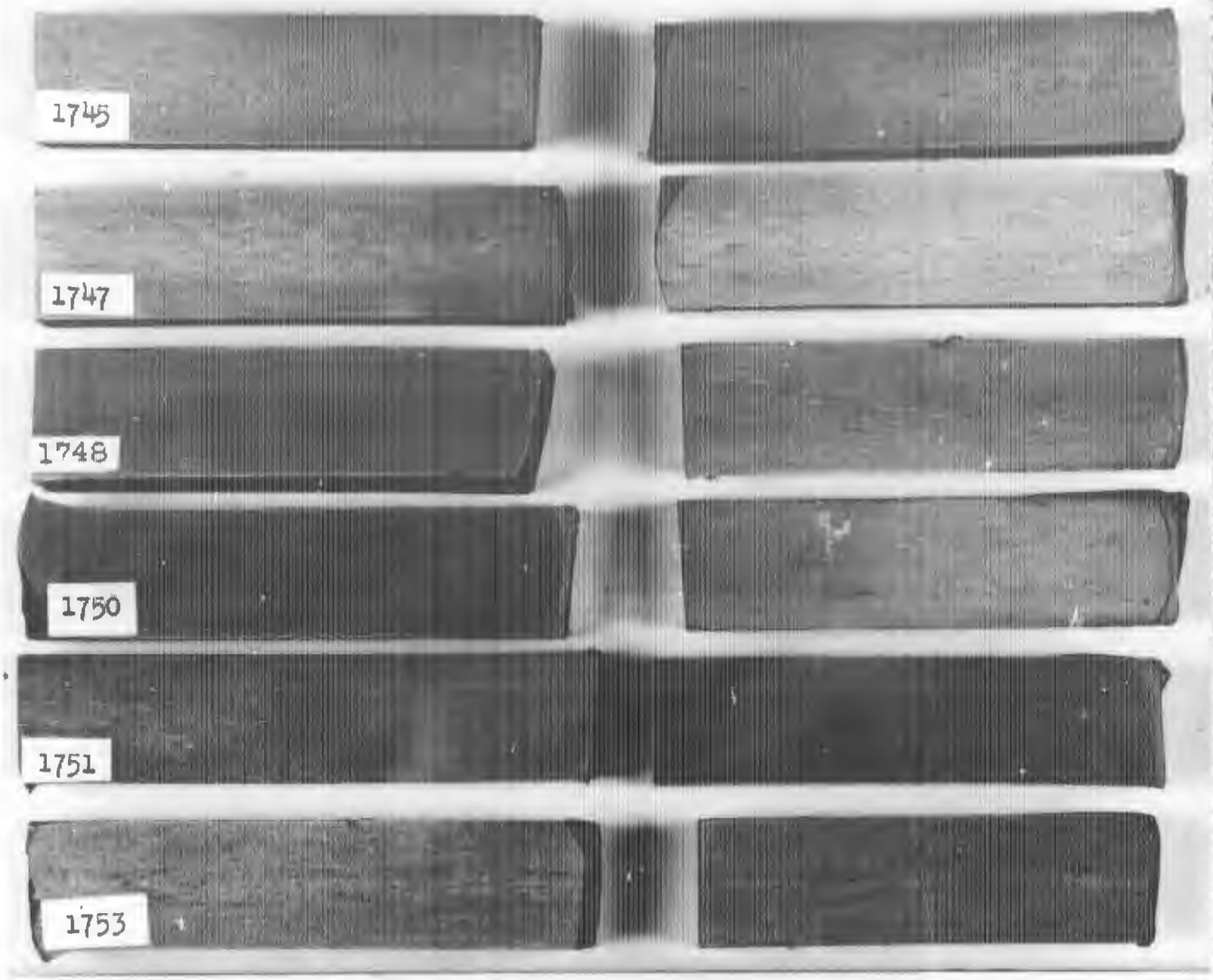
WATERTOWN ARSENAL.

MACROETCHED SECTIONS OF 3/4" ARMOR PLATE MADE BY GREAT LAKES STEEL CORPORATION.
21 DECEMBER 1943

MAG. X 1
WTN.710-2222

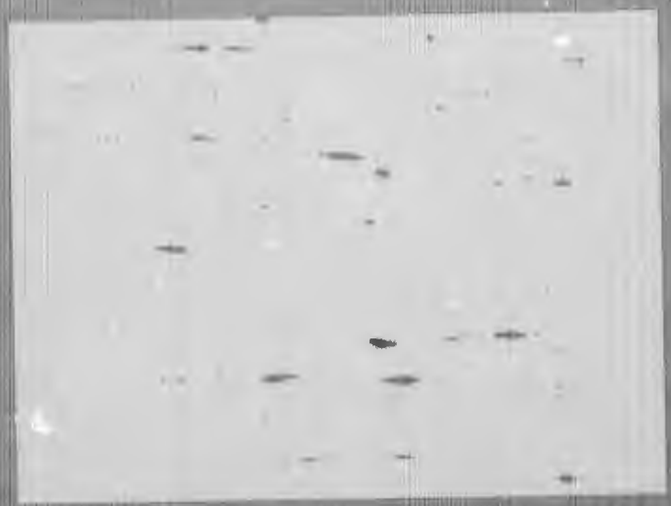
FIGURE 1



MACROETCHED SECTIONS OF 3/4" ARMOR PLATE MADE BY STANDARD STEEL COMPANY. 21 DECEMBER 1943 WTN.710-2223

FIGURE 2

X100 A Unetched
Plate 6a. Prindle oxide type non-metallic segregations observed in plates 6J and 6b.



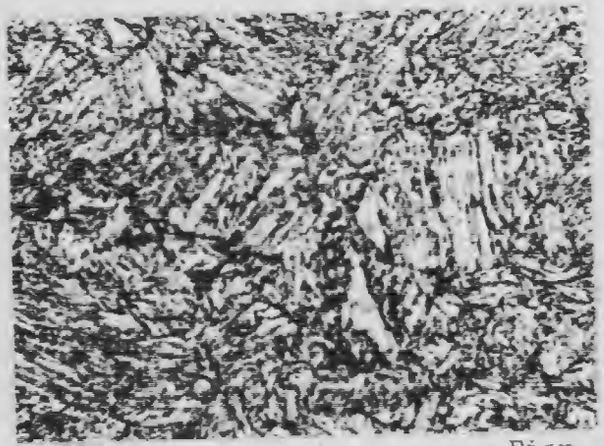
X100 B Unetched
Plate 6c. Type of non-metallics observed in six 6J3 plates.

X100 C Unetched
Plate 6d. Type of non-metallics observed in six 6J plates.

FIGURE 3.

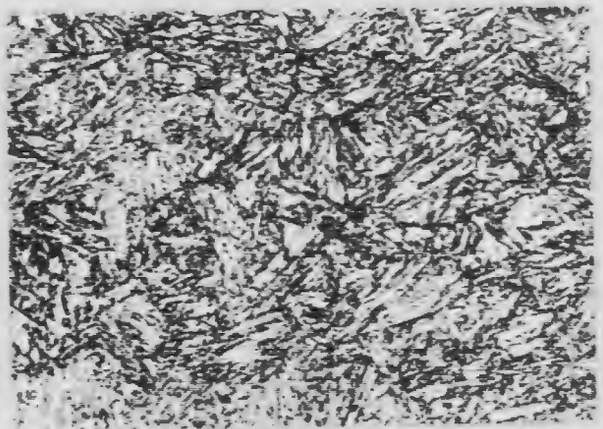
MICROSTRUCTURE OF PLATES

GREAT LAKES STEEL CORPORATION



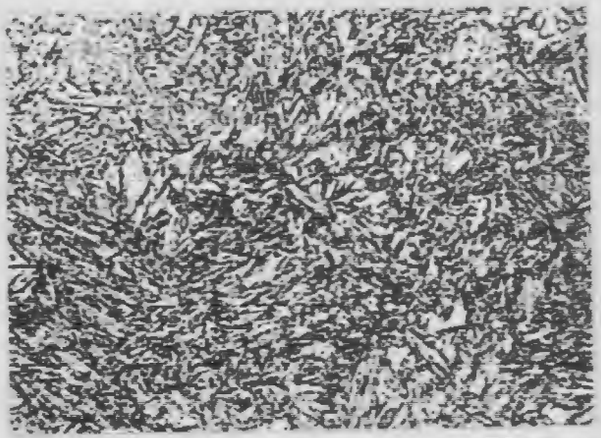
X1000 A Picral

Plate 67. Acicular tempered martensite. BHN 318.



X1000 B Picral

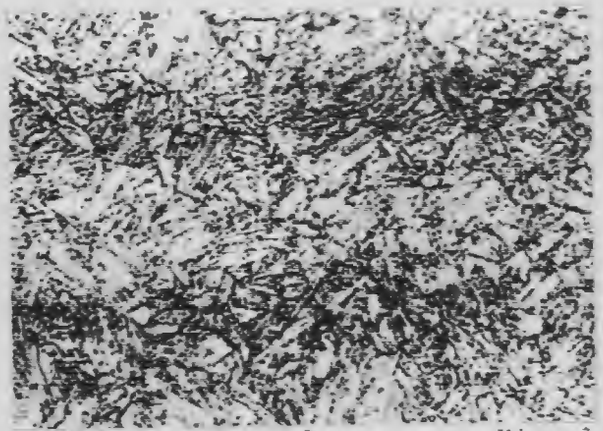
Plate 66. Acicular tempered martensite. BHN 331.



X1000 C Picral

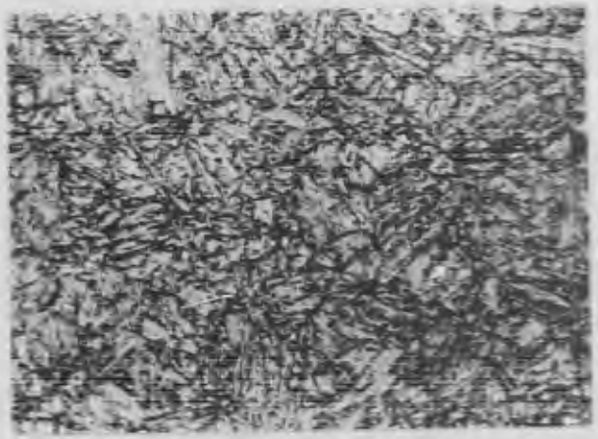
Plate 68. Tempered martensite. BHN 371

STANDARD STEEL SPRING COMPANY



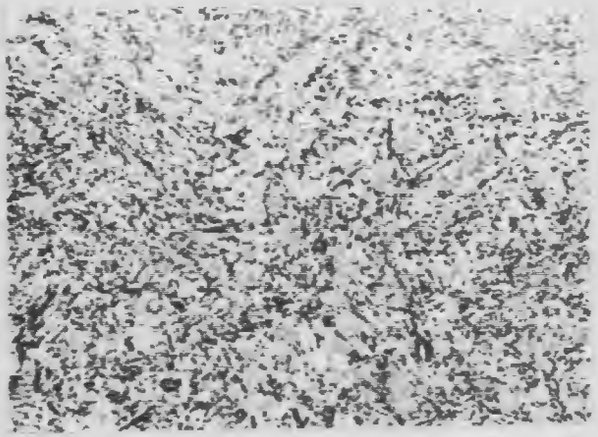
X1000 D Picral

Plate 45. Tempered martensite, evidence of banding at low hardness of BHN 262.



X1000 E Picral

Plate 50. Acicular tempered martensite. BHN 348



X1000 F Picral

Plate 47. Tempered martensite. BHN 375.

FIGURE 4.

APPENDIX A

Hardness Surveys

APPENDIX A

Table 1

Rockwell C Hardness Tests

Plate No.	Readings every 1/8 inch across section
GLS 58	40.5 40.5 40.5 39.5 39.5 40.5 40.5 41.5 41.5 40.5
60	40.0 40.0 40.0 40.5 40.5 40.5 40.0 40.5 40.5 41.0 39.5
62	37.5 37.5 38.5 39.5 40.0 40.5 39.5 39.5 38.5 38.0 38.5
64	36.0 36.5 36.5 36.5 35.5 35.5 35.5 36.5 37.5 37.5 37.0
66	35.5 36.5 36.5 36.5 34.5 33.5 35.5 35.5 36.5 35.5 36.5
67	33.5 33.5 34.5 34.5 34.5 34.5 34.5 34.5 34.5 34.5 33.5
SGJ 1745	26.5 26.5 25.5 25.0 25.5 25.5 25.5 25.5 26.0 26.5
1747	40.5 40.5 40.5 40.5 40.0 40.5 38.5 40.5 41.5 42.5 41.5
1748	37.5 38.5 38.5 38.5 39.0 38.5 38.5 38.5 38.5 37.5
1750	34.5 35.5 34.5 35.5 34.5 35.5 34.5 35.5 35.5 35.5
1752	33.5 33.5 34.5 32.0 32.0 32.5 32.0 32.5 33.5 33.5 33.5
1753	30.0 31.0 30.5 32.0 30.5 30.0 30.5 31.5 30.5 30.5