R. H. Brill, “Medieval Stained Glasses.” Unpublished report prepared for a meeting at The Metropolitan Museum of Art, 1970.

ROBERT H. BRILL

"Medieval Stained Glasses"

Prepared for meeting at the
MMA, 1970. NEVER PUBLISHED.

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THE CORNING MUSEUM OF GLASS RESEARCH PROGRAM ON MEDIEVAL STAINED GLASSES

Our scientific investigations include the projects listed below. An asterisk marks those in which we have already collected data, some of which is discussed later in this report.

I. CHEMICAL ANALYSES

*a. Spectrographic analyses for minor and trace elements run independently by two different laboratories.

*b. Quantitative analyses of major and some minor elements by atomic absorption.

*c. Conventional x-ray fluorescence analyses for all elements, but especially for the non-metals, such as P, S, and Cl. (This method is especially well-suited for analyzing composite glasses, such as ruby "flashing" over a colorless base glass.)

*d. X-ray fluorescence analyses of stained portions of yellow and orange glasses. (The results identify the colorant species present in the stains, as well as traces of other ingredients used in the preparations by which the staining elements were introduced.)

*e. Non-dispersive x-ray fluorescence analyses which can be used for the non-destructive analysis of windows in situ.

f. Neutron-activation analyses, particularly for minor, trace and "trace-trace" elements.

*g. Spectrographic and x-ray fluorescence analyses of the paints in decorated portions of the glasses and of lead caming. (Such analyses may support classifications inferred from the glass analyses.)

*h. Electron microbeam probe analyses are being used to investigate the extent of inhomogeneity in stained glasses and possible incipient weathering.

II. ISOTOPE STUDIES

*a. Oxygen Isotopes

The determination of oxygen isotope ratios is an entirely new and very promising means for classifying early glasses according

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to the raw materials from which they were prepared. Results have been obtained for about a hundred early glasses spanning over 3000 years of glass history. To date we have results on only twelve stained glasses but we expect to study many others in the future. The stained glass results show that with oxygen isotope determinations it is possible to distinguish between some glasses which are very similar in chemical composition. We have also found, for example, that ruby glasses from different cathedrals sometimes resemble one another more closely than they do other colors of glasses from their own windows. This suggests that some ruby glasses may have been made in centers other than those where glasses of less difficult colors were made. (Note attached text and graphs.)

*b. Lead Isotopes

The determination of lead isotope ratios can be very useful for identifying the possible geographical origins of the ores from which lead samples were originally smelted. This method has proved very valuable in applications to archaeological objects. Determinations on minute bits of lead removed from the coming on stained glasses, or upon lead extracted chemically from the glasses themselves may prove to be equally valuable for classifying the glasses (or cames) according to geographical origins. A reprint of our earlier publication applying this technique to ancient glasses is included at the end of this report.

Another publication on this subject referring to applications to lead extracted from ancient glasses is now in press. (Robert H. Brill, "Lead and Oxygen Isotopes in Archaeological Objects", presented at the symposium, "The Impact of the Natural Sciences on Archaeology", London, December, 1969.)

III. MICROSCOPIC EXAMINATIONS

a. Low-power and high-power microscopic examinations are useful for identifying the types of imperfections occurring in early glasses, such as batch stones, devitrification stones, etc.

*b. Microscopic examinations are also useful for detecting weathering effects and afford a very powerful means for authentication, for it is ordinarily possible to distinguish between early glasses and modern replacements even in those cases where a visual examination may be inconclusive.

*c. Microscopic examinations reveal bubble patterns, tool marks, grozing edges, color laminations and similar features, which can can be used to establish what methods of manufacture were used.

d. We also plan to prepare sections of stained glass fragments for possible dating by the hydration rim technique or by similar methods.

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IV. INVESTIGATIONS OF WEATHERING PHENOMENA

*a. Chemical durability measurements are being carried out to determine the susceptibility of repolished and refired pieces of stained glasses to weathering.

*b. X-ray diffraction and x-ray fluorescence analysis are being used to identify the weathering products found on selected fragments of stained glasses and the materials deposited in weathering pits.

V. TRANSMISSION SPECTRA

*a. Transmission spectra have been measured which can be used to identify colorant species in various colors of stained glasses.

Robert H. Brill
The Corning Museum of Glass
Corning, New York
March 20, 1970

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PARTIAL LIST OF COLLABORATORS

C. A. Pelicka and R. H. Bell, Lucius Pitkin, Incorporated, New York City.

I. Perlman and R. Gicuque, Lawrence Radiation Laboratory, University of California, Berkeley, California.

R. N. Clayton and T. Mayeda, Fermi Institute, University of Chicago.

J. M. Wampler, Georgia Institute of Technology; and W. R. Shields, National Bureau of Standards.

D. Stephenson, M. Mackall, P. B. Adams, H. Walters, and R. French, all of Corning Glass Works.

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OUTLINE OF CATALOGUING OF MEDIEVAL STAINED GLASSES*

132-56 Istanbul, Zerek Çamii and Kariye Çamii. (see also 246, 247, 541, 1570-71, and 1574-80)

[illegible]-73 Chartres, CMG 60.3.71

58[illegible]-83 Rüst

1[illegible]-94 Canterbury

1[illegible]-97 Coventry (see also 2010-19)

1[illegible]-99 Winchester

1160 Norwich

1161-64 Batalha

1265-72 Nürnberg

1175-76 Ulm (see also 2080)

1177-78 and 1520 Speyer

1179 Oppenheim

1400-14 York

1[illegible]-05 Avignon

1520 (See 1177)

1570-80 (See 132)

2010-19 Coventry

2020-29 Canterbury

[2030-33] African beads

2034-39 York

2040-49 Winchester, Dorchester, Norwich

2050-59 Glastonbury (CMG 64.2.20)

2060-69 Erfurt

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OUTLINE OF CATALOGUING cont.

2070-79 Magdeburg

2080-89 Ulm

2090-99 Ulm, Milan and Hannover.

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* Note: Some numbers are unassigned but reserved for glasses from these sites.

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STAINED GLASSES FROM THE ZEREK CAMII AND KARIYE CAMII

(Fragments sent by Arthur H.S. Megaw on April 6, 1962.)

Samples of glass were removed from the fragments, and in some cases samples of the "paint" from designs. The numbers in parentheses are Mr. Megaw's numbers. (See his letter of 4/2/62).

Zerek Camii (ca. 1125)

132 - Pale green (no. 1)
133 - "Colorless" (no. 2)
134 - Pale amber (no. 3)
135 - Purple (no. 4)
136 - Pale purple (no. 5)
137 - Pale purple (no. 6)
138 - Deep blue (no. 7)
139 - Deep blue (no. 8)
140 - Deep blue (no. 9)
141 - Emerald green (no. 10)
142 - "Paint" from no. 141
143 - Deep blue (no. 11)
144 - Spongy black "paint" from no. 143.
145 - Dark blue (no. 12)
146 - Spongy black "paint" from no. 145.
147 - Dark blue (no. 13)
148 - "Paint" (poss. two colors) from no. 147.

Kariye Camii

149 - Deep blue (no. 15)
150 - Paint from no. 149.
151 - Dark glass (no. 16)
152 - Pale green (no. 17)
153 - Paint from no. 152.
154 - Amber (no. 18)
155 - Paint from no. 154.
156 - Emerald green (no. 19)

See also: 246-247 and 541-544. (Collected by RHB in 1962.)

See also: 1570-1580.

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526 - Chartres, 1225. Pale blue, slight pitting. CMG 60.3.71 F; Oxygen isotope sample 0-12.

527 - Chartres, 1225. Amber, some pitting, painted. CMG 60.3.71 L. Oxygen isotope sample 0-28.

528 - Chartres, 1225. Ruby flashing over green, large pits. CMG 60.3.71 L. Oxygen isotope sample 0-29.

FRAGMENTS FROM DR. EVA FRODL-KRAFT, OCT. 1, 1964
INSTITUT FÜR OSTERREICHISCHE KUNSTFORSCHUNG DES BUNDESDENKMALAMTES
WIEN 1, HOFBURG · SCHWEIZERHOF

584 - Austria, Stift Heilegenkreuz, ca. 1250. Greenish glass with black painted design.

585 - Austria, 14th or 15th century. Bright green glass showing some signs of hydrolysis on surface.

586 - Austria, Vienna Cathedral, 15th century. Green glass, half-circular fragment with black painted outline.

587 - Austria, Rüst, Bürgenland, 15th century. Dark blue glass. Oxygen isotope sample 0-111.

588 - Austria, Rüst, Bürgenland, 15th century. Amethyst glass. Oxygen isotope sample 0-112.

Also sent six fragments from house in Vienna (Sterngasse) occupied since Medieval times. Samples from Roman, Medieval and more recent times. Not analyzed because of indefinite dates.

[Note B_2O_3 and SrO contents.]

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SAMPLES OF MEDIEVAL STAINED GLASS

Fragments from Madeline Caviness and Brian Hobley. (Sampled and sent to Prof. I. Perlman for analysis with portable x-ray fluorescence analyzer.)

English Glasses

1151 - Canterbury, ca. 1200-1225. Green, moderate weathering, some paint. (Caviness no. 128).

1152 - Canterbury, ca. 1200-1225. Ruby flashing on colorless glass, heavily weathered and pitted, deformed by heat (?). (Caviness no. 130). Sample contains only ruby region. (Ruby streaks and some base glass.)

1153 - Canterbury, ca. 1200-1225. Amber, no weathering, some paint. (Caviness no. 132).

1154 - Canterbury, late 15th cent. Pale green, no weathering, some paint. (Caviness no. 134).

1158 - Winchester, ca. 1400. "Colorless", moderate weathering, some paint. (Caviness no. 137).

1159 - Winchester, ca. 1400. Pale green with silver stain, slight weathering, painted. (Caviness no. 138).

1160 - Norwich, first half 15th cent. "Colorless" with red paint, some pitting. (Caviness no. 140).

1155 - Coventry, 13th-14th cent. Green, some weathering. (Hobley no. 1).

1156 - Coventry, 13th-14th cent. Ruby flashing on green, slight weathering, some paint. (Hobley no. 1). [Quant. anal. ruby only (~15 percent green)].

1157 - Coventry, 13th-14th cent. Amber, moderate weathering, painted. (Hobley no. 3).

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PORTUGUESE GLASSES

Samples submitted by Mr. Carlos Vitorino de Silva Barros [illegible] 2, 1967.

1161 - Batalha, 15th or 16th cent. Pale green, dulled surface, some pitting.

1162 - Batalha, prob. 16th cent. Green with silver stain, some paint, dulled surface.

1163 - Batalha, prob. 15th cent. Ruby stain on colorless glass, slight dulling on one surface. [Quant. sample contains both glasses in original proportions.]

1164 - Batalha, prob. 16th cent. Ruby flashing over green glass, some paint, pitted on one side. [Quant. sample contains both glasses in original proportions.]

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GLASSES FROM GERMANY

From Gottfried Frenzel, 1/65.

1165 - Nürnberg, St. Sebald, 1379-86. Pale green, heavy fine pitting. Oxygen isotope sample O-153.

1166 - Nürnberg, St. Sebald, 1379-86. Pale blue, heavy fine pitting. Oxygen isotope sample O-152.

1167 - Nürnberg, St. Sebald, 1379-86. Ruby flashing over green, fine pitting. Oxygen isotope sample O-150. [Quant. anal. sample green and ruby.]

1168 - Nürnberg, St. Sebald, 1379-86. Amber, moderate weathering, painted. Oxygen isotope sample O-151.

1169 - Nürnberg, St. Sebald, 1480. Amber, dulled or weathered, some painting. Oxygen isotope sample O-161.

1170 - Nürnberg, St. Sebald, 17th cent. Colorless with silver staining and painting, little weathering.

1171 - Nürnberg, St. Lorenz, 1476. Colorless, moderate weathering, painted.

1172 - Nürnberg, St. Lorenz, 1476. Ruby flashing over pale green, heavily weathered. Oxygen isotope sample O-156. [Quant. sample green and ruby.]

1173 - Ulm, ca. 1400. Dark blue with painting, slight weathering.

1174 - Ulm, ca. 1400. Ruby flashing over green glass, heavily weathered, painted.

1175 - Ulm Münster, Chor Fenster, 1410. Ruby flashing over green, heavily weathered, painted. Oxygen isotope sample O-158.

1176 - Ulm Münster, Chor Fenster, 1410. Yellowish-amber, slight weathering, some paint (?). Oxygen isotope sample O-159.
(See also 2 [illegible])

1177 - Speyer Dom, 1170. Ruby flashing over green, moderate weathering, Oxygen isotope sample O-147. [Quant. sample contains both glasses in original proportions.]

1178 - Speyer Dom, 1170. Yellowish amber, slight weathering, painted. Oxygen isotope sample O-148.

[CONT OVER]

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GLASS FROM GERMANY cont.

1170 - Speyer Dom, 1170. Greenish glass. Oxygen isotope sample O-149.

1179 - Oppenheim, ca. 1300. Pale green glass, little weathering, painted.

See also 2010-2016

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YORK MINSTER

Stained glass fragments from York Minster. Samples given to RHB by Peter Newton, York, July 16, 1968. Samples to be used for chemical anal., O^{18}, XRD of W. products, artificial W. tests on a few pieces resurfaced by Dennis King's polishing technique. Glasses are from windows C-33 and C-34 in the nave clearstory. All date from the XIIth to the XIIIth cent.

Window C-33, XIIth Century

1400 - Two joining fragments of heavily weathered green transparent glass.

1401 - Same as 1400, but resurfaced on one side.

1402 - Two fragments of weathered dark blue transparent glass with paint.

1403 - Same as 1402, but resurfaced on one side. (All three pieces of 1402 and 1403 join.)

Window C-33, late XIIIth Century

1404 - Pale greenish ("colorless"?) glass with widely separated deep pits. (Another similar piece to follow.)

1405 -

1406 - Green transparent glass, very heavily weathered. Paint has protected glass on one side.

1407 - Ruby glass, very heavily weathered with white surface deposit.

1408 - Ruby glass, (flashing?) slight weathering.

1409 - Ruby glass over colorless base glass. A few widely separated large deep pits. (Sample is of ruby glass only.)

Window C-34, late XIIIth Century

1410 - Yellowish glass with patterned diaper, deeply weathered. Paint has protected glass. (larger of two pieces) Could these be silver stained?

1411 - Similar to 1410, from same window.

1412 - Pale greenish ("colorless") glass, heavily pitted.

1413 - Yellowish glass, heavily weathered with painted circular designs. Red painted surfaces are uncorroded.

1414 - "Colorless" glass from 1409.

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Samples of stained glass excavated at Avignon. From: "Palais des Papes d'Avignon, Salle de Théologie. Niveau du XIVs." Sent by: Madame N. Lambert, 10, Pesmazoglou, Athens. See her letter of October 22, 1968 and RR 8482. Samples given to her by M. Gagnière, Conservateur du Palais des Papes. (Some opaque to x-rays)

Six of the 23 fragments were selected for analysis.

1420 Pale greenish ("colorless") glass with amber tinge (due to weathering); edge of crown showing thickening. (diam. ca. cm.)

1421 Green glass, irregularly-shaped fragment.

1422 Deep amber glass, irregularly-shaped fragment.

1423 Dark blue transparent glass, irregularly-shaped fragment.

1424 Pale greenish glass with thick ruby flashing. (Sample for base glass anal. excludes ruby flashing.)

1425 Pale greenish glass with very thin flashing. Ruby color not developed; ruddy orange color.

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(OVER)

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GLASSES FROM THE ZEREK CAMII AND KARIYE CAMII

Zerek Camii

Collected by RHB in 1962. (From the same find spot as all Zerek Camii glasses.)

541 - Purplish glass, probably from a window. (Unlettered) Oxygen isotope sample O-68.

1570 - Fragment of a dark blue transparent glass from the wall and rim of a vessel. Part of the folded over rim remains. (Sample A, RHB notes.)

1571 - Fragment of a solid lamp stem of bluish-green transparent glass; heavily weathered. (Unlettered.)

Zerek Camii, ca. 1125

Samples given to RHB by Mr. Megaw on Feb. 9, 1969 at Dumbarton Oaks.

1574 - Pale greenish glass.

1575 - Emerald green glass.

1576 - Emerald green glass.

1577 - Blue glass.

1578 - Dark blue glass.

1579 - Purple glass.

Kariye Camii

From Mr. Megaw, Feb. 9, 1969.

1580 - Purple glass.

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SAMPLES OF MEDIEVAL STAINED GLASS

Additional samples from Coventry Cathedral. Fragments had been coated earlier with polyvinyl acetate. (Samples were taken to Dr. Perlman, March 11, 1968.)

2010 - Ruby flashing on green, very thick piece, moderate weathering, (Hobley No. 3) [Quant. anal. sample of ruby glass only.]

2011 - Pale green glass, moderate weathering, some paint. (Hobley No. 2.)

2012 - Bright green, heavily weathered, some paint. (Hobley No. 2)

2013 - Amber, slight weathering, some paint. (Hobley No. 2)

2014 - Ruby flashing on green, heavily pitted. (Hobley No. 2) [Quant. anal. sample of green glass only.]

2015 - Ruby (orangish) flashing on green, slight weathering. (Hobley No. 2) [Quant. anal. sample of ~25 percent ruby and 75 percent green.]

2016 - Deep blue, heavy weathering. (Hobley No. 2)

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MEDIEVAL STAINED GLASSES

From Madeline Caviness, Sept. '67.

2020 - Canterbury, ca. 1200-1225. Colorless, with painting, heavily weathered. (Caviness no. 131).

2021 - Canterbury, ca. 1200-1225. Dark blue, little or no painting, moderately weathered. (Some modern putty on edges). (Caviness no. 129).

2022 - Canterbury, ca. 1200-1225. Colorless, with some traces of painting, heavily weathered, and old putty adhering. (Caviness no. 133).

2023 - Canterbury, ca. 1200-1225. Dark green with ruby flashing, with some painting (?), moderately weathered. (Caviness no. 127).

2024 - Same as 1152, but "colorless" base glass only.

[2030-2035 African beads from Perlman.]

BOOTH & EASE "MEDIEVAL GLASS"

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MEDIEVAL STAINED GLASSES

From Erhard Drachenberg, Berlin, 2/24/'66.

(According to his letter of 12/'69, all of the earlier samples dated from the first quarter of the 15th century.)

2060 - Erfurt, Augustine Kirche, ca. 1400-1425, "colorless", moderate weathering.

2061 - Same. Pale green (thinner than 2060.)

2062 - Same. Pale blue, moderate weathering.

2063 - Same. Yellow-amber, moderate weathering.

2064 - Same. Thin ruby flashing over colorless glass, light weathering in form of small pits. (Quant. sample contains both ruby and colorless glass in original proportions.)

2065 - Erfurt Cathedral, ca. 1375-1400. "Colorless" glass with heavy painting, moderate weathering. Written in pencil on the glass is, "SII4d." (This glass was received in Dec. 1969.)

MEDIEVAL STAINED GLASS

From Dr. Frenzel, Nürnberg, 1/65.

2080 - Ulm Münster, Chor Fenster, 1410. Pale blue, some painting, slight weathering. (0-160). (Compare to 1175, 1176).

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Numbers 64, Schuh, 1/29/65
From: Gottfried Frenzel, 1/65.

		Pale green (0-153) 1165	Pale blue (0-152) 1166	Ruby over green (Ruby & gr)(0-150) 1167	Amber (0-151) 1168		
SiO_2	A	~55	~60	~57	~67		
Na_2O	a	0.30	0.19	0.59	0.23		
CaO	a	19.1	18.2	18.6	16.1		
K_2O	a	19.0	17.4	14.2	13.1		
MgO	a	1.81	1.81	2.39	1.43		
Al_2O_3	a	1.19	0.81	2.31	0.91		
Fe_2O_3		1.5	0.8	0.7	0.2		
TiO_2		0.03	*	0.05	0.01		
Sb_2O_5		*	*	*	*		
MnO		0.7	0.4	0.8	0.4		
CuO		0.01	0.01	0.01	*		
CoO		0.02	0.2	*	*		
SnO_2		*	*	0.01	*		
As_2O		*	*	*	*		
PbO		0.20	0.15	0.20	0.20		
BaO		0.08	0.08	0.08	0.05		
SrO		0.08	0.08	0.15	0.12		
Li_2O		0.001	*	0.003	*		
Nb_2O		*	*	*	*		
B_2O_3		0.02	0.02	0.02	0.02		
V_2O_5		*	*	*	*		
Cr_2O_3		*	*	*	*		
NiO		*	*	*	*		
ZnO		*	*	*	*		
ZrO_2		*	*	*	*		
Bi_2O_3		*	*	*	*		
P_2O_5		~1	< 1	~3	< 1		
Σ		~45	~40.2	~43	~32.3		

A — SiO_2 estimated by difference.

Other Expt.: XRF, O^{18} | XRF, O^{18} | XRF, O^{18} | XRF, O^{18}

Report Number: LP 67585

Date: 3/18/70
Transcribed by: lr /

*less than std. glasses

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R. H. Brill, "Medieval Stained Glasses." Unpublished report prepared for a meeting at The Metropolitan Museum of Art, 1970.

Speyer Dom, ca. 1170
From: Gottfried Frenzel, 1/65

		Ruby over green (Ruby glass)(0-147) 1177	Yellowish amber (0-148) 1178	Greenish (0-149) 1520			
SiO_2	Δ	~ 59	~ 62	~ 61			
Na_2O	a	0.74	1.16	1.06			
CaO	a	20.3	20.3	18.1			
K_2O	a	14.1	7.20	10.7			
MgO	a	2.00	1.94	1.94			
Al_2O_3	a	1.46	3.05	2.92			
Fe_2O_3	a	0.3	1.0	0.8			
TiO_2		0.02	0.20	0.18			
Sb_2O_5		*	*	*			
MnO		0.5	0.5	0.7			
CuO		0.01	*	*			
CoO		*	*	*			
SnO_2		*	*	*			
Ag_2O		*	*	*			
PbO		0.01	0.03	0.08			
BaO		0.10	0.15	0.10			
SrO		0.15	0.18	0.05			
Li_2O		0.002	0.003	0.005			
Rb_2O		*	*	*			
B_2O_3		0.02	0.02	0.04			
V_2O_5		*	*	*			
Cr_2O_3		*	*	*			
NiO		*	*	*			
ZnO		*	*	*			
ZrO_2		*	*	*			
Bi_2O_3		*	*	*			
P_2O_5		~ 1	~ 2	~ 2			
Σ		~ 40.7	~ 37.7	~ 38.7			

~ SiO_2 estimated by difference.

Other Expt.: XRF, O^{18} | XRF, O^{18} | O^{18}

Report Number: LP 673854 Date: 3/18/70
Transcribed by: lr /

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* less than std. glasses

R. H. Brill, "Medieval Stained Glasses." Unpublished report prepared for a meeting at The Metropolitan Museum of Art, 1970.

Rust, Burgenland; 15th cent.
From: Eve Frodl-Kraft, 10/1/64.

	Dark blue (O-111) 587	Purple (O-112) 588				
SiO_2 Δ	~ 64	~ 61				
Na_2O a	0.38	0.19				
CaO a	15.4	20.3				
K_2O a	13.2	15.8				
MgO a	2.16	1.56				
Al_2O_3 a	1.31	0.46				
Fe_2O_3	0.7	0.05				
TiO_2	0.02	*				
Sb_2O_5	*	*				
MnO	0.4	0.3				
CuO	0.1	*				
CoO	0.2	*				
SnO_2	*	*				
Ag_2O	*	*				
PoO	*	0.10				
BaO	0.30	0.05				
SrO	0.20	0.05				
Li_2O	*	*				
Ro_2O	*	*				
B_2O_3	0.02	0.02				
V_2O_5	*	*				
Cr_2O_3	*	*				
NiO	0.10	*				
ZnO	*	*				
ZrO_2	*	*				
Bi_2O_3	*	*				
P_2O_5	~ 1	< 1				
Σ	~ 35.5	~ 38.9				

Δ – SiO_2 estimated by difference.

Other Expt.:	O^{18}	O^{18}				

Report Number: LP 673834

Date: 3/18/70
Transcribed by: lr /

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*less than std. glasses

Ulm, ca. 1400 and 1410 (Chor Fenster)
From: Gottfried Frenzel, 1/65.

	Dark blue 1173	Ruby over green 1174	Ruby over gr. (Chor Fnst.) (0-158) 1175	Yellowish-amber (Ch. Fnst)(0-159) 1176	Pale blue (Ch. Fnst.) (0-160) 2080	
SiO_2 Δ	~53	~55	~56	~58	~59	
Na_2O a	1.69	0.39	0.39	0.19	1.43	
CaO a	19.6	19.5	19.8	18.6	22.0	
K_2O a	18.6	18.8	16.5	17.3	7.93	
MgO a	3.24	3.10	3.26	3.20	3.90	
Al_2O_3 a	1.24	1.25	1.24	0.94	3.71	
Fe_2O_3	0.45	0.15	0.25	*?	0.35	
TiO_2						
Sb_2O_5	*	*	*	*	*	
MnO	1.2	1.2	1.2	1.0	1.2	
CuO	0.25	0.15	0.20	*	0.05	
CoO	0.12	*	*	*	0.12	
SnO_2	*	*	*	*	*	
Ag_2O	*	*	*	*	*	
PbO	0.12	0.25	0.50	0.08	*	
BaO	0.03	0.03	0.03	0.03	0.08	
SrO	0.18	0.15	0.15	0.15	0.15	
Li_2O	*	*	*	*	*	
Rb_2O	0.10	0.10	0.15	0.15	*	
B_2O_3	*	*	*	*	*	
V_2O_5	*	*	*	*	*	
Cr_2O_3	*	*	*	*	*	
NiO	0.03	*	*	*	0.05	
ZnO	*	*	*	*	*	
ZrO_2	*	*	*	*	*	
Bi_2O_3	*	*	*	*	*	
P_2O_5	<1	<1	<1	<1	<1	
Σ	~46.9	~45.1	~43.7	~41.6	~41.0	

Δ – SiO_2 estimated by difference.

Other Expt.: XRF | XRF | XRF | XRF

Report Number:

Date: 3/20/70
Transcribed by: lr /

Rakow Research Library, The Corning Museum of Glass - http://www.cmog.org

*Low than std. glasses

'R. H. Brill, "Medieval Stained Glasses." Unpublished report prepared for a meeting at The Metropolitan Museum of Art, 1970.

Erfurt, Augustine Kirche. ca. 1400-25. (One from ca. 1375-1400 Cathedral) From: Erhard Drachenberg. 2/24/66 and 12/69.

	"Colorless" 2060	Pale green 2061	Pale blue 2062	Yellow-amber 2063	Ruby over colorless (Ruby & col. 2064	"Colorless" Erf. Cath. 1375-1400 2065
SiO_2 Δ	~52	~60	~53	~53	~56	~54
Na_2O a	0.67	2.60	0.45	0.56	0.36	0.25
CaO a	21.9	22.7	21.5	20.5	21.0	19.0
K_2O a	17.9	5.30	17.2	19.2	15.5	20.7
MgO a	3.96	3.98	3.72	3.70	3.88	3.50
Al_2O_3 a	1.28	2.34	1.29	1.13	1.29	0.85
Fe_2O_3	0.38	1.5	0.45	0.40	0.40	0.10
TiO_2						
Sb_2O_5	*	*	*	*	*	*
MnO	1.1	1.2	1.0	0.45	0.40	0.50
CuO	*	*	*	*	*	*
CoO	*	0.03	0.02	*	*	*
SnO_2	*	*	*	*	*	*
Ag_2O	*	*	*	*	*	*
PbO	0.50	*	0.55	0.25	0.75	0.50
BaO	0.07	0.07	0.07	0.07	0.07	0.07
SrO	0.18	0.15	0.20	0.20	0.20	0.18
Li_2O	0.10	0.01	0.02	0.02	0.03	*
Rb_2O	0.20	*	0.10	0.20	0.20	0.05
B_2O_3	0.05	0.03	*	*	*	*
V_2O_5	*	*	*	*	*	*
Cr_2O_3	*	*	*	*	*	*
NiO	*	*	*	*	*	*
ZnO	*	*	*	*	*	*
ZrO_2	*	*	*	*	*	*
Bi_2O_3	*	*	*	*	*	*
P_2O_5	<1	<1	<1	<1	<1	<1
Σ	~48.3	~39.9	~46.6	~46.7	~44.1	~45.7

Δ − SiO_2 estimated by difference.

Other Expt.:

Report Number:

Date: 3/20/70

Transcribed by: lr /

Rakow Research Library, The Corning Museum of Glass - http://www.cmog.org

*less than std. glasses

Chartres (ca. 1225)
CMG 60.3.71 (F,L,L)

	Pale blue (0-12) 526	Yellowish amber (0-28) 527	Ruby over colorless (Ruby only) (0-29) 528			
SiO_2 Δ	~56	~55	~51			
Na_2O a	0.58	0.80	0.75			
CaO a	13.0	12.8	15.5			
K_2O a	17.3	19.4	18.1			
MgO a	5.64	5.40	5.82			
Al_2O_3 a	1.77	1.58	1.46			
Fe_2O_3	0.5	0.6	0.5			
TiO_2	0.05	0.05	0.3			
Sb_2O_5	*	*	*			
MnO	0.4	0.4	0.5			
CuO	0.2	0.1	0.7			
CoO	0.03	*	*			
SnO_2	0.04	*	0.04			
Ag_2O	*	*	*			
PbO	0.08	0.01	0.02			
BeO	0.05	0.05	0.05			
SrO	0.12	0.08	0.10			
Li_2O	0.001	0.001	0.001			
Rb_2O	*	*	*			
B_2O_3	0.07	0.08	0.08			
V_2O_5	*	*	*			
Cr_2O_3	*	*	*			
NiO	*	*	*			
ZnO	*	0.01	0.01			
ZrO_2	0.01	0.01	0.01			
Bi_2O_3	*	*	*			
P_2O_5	~4	~4	~5			
Σ	~43.8	~45.4	~48.9			

Δ - SiO_2 estimated by difference.

Other Expt.:	XRF, O^{18}	XRF, O^{18}	XRF, O^{18}			

Report Number: IP 674034/674934 Date: 3/18/70

Rakow Research Library, The Corning Museum of Glass - http://www.cmog.org

Transcribed by: lr /

*less than std. glasses

Avignon, Palais des Papes, Salle de Théologie, 14th cent. level
From: N. Lambert.

		"Colorless" 1420	Green 1421	Deep amber 1422	Dark blue 1423	Ruby over green (green only) 1424	Ruby over green (green only) 1425
SiO_2	Δ	~47	~45	~47	~61	~51	~44
Na_2O	a	3.20	3.00	2.90	16.7	2.50	4.20
CaO	a	22.3	25.0	21.7	9.48	21.6	24.2
K_2O	a	16.2	16.2	17.0	5.01	14.3	15.8
MgO	a	4.96	5.16	5.22	2.06	5.34	5.78
Al_2O_3	a	3.51	2.51	3.02	2.06	2.91	3.00
Fe_2O_3		0.6	0.8	0.8	0.9	0.7	0.7
TiO_2		0.20	0.15	0.30	.0.01	0.30	0.35
Sb_2O_5		*	*	*	*	*	*
MnO		1.0	1.2	1.5	0.8	1.0	1.0
CuO		0.05	0.05	0.05	0.50	0.01	0.05
CoO		*	0.05	*	0.1	*	*
SnO_2		*	*	*	*	*	*
Ag_2O		*	*	*	*	*	*
PbO		*	0.04	0.25	0.05	0.04	0.08
BaO		0.3	0.3	0.3	0.04	0.3	0.3
SrO		0.10	0.10	0.10	0.07	0.09	0.09
Li_2O		*	*	*	*	*	*
Rb_2O		*	*	*	*	*	*
B_2O_3		0.1	0.1	0.01	0.01	0.01	0.01
V_2O_5		*	*	*	*	*	*
Cr_2O_3		*	*	*	*	*	*
NiO		*	*	*	*	*	*
ZnO		*	*	*	*	*	*
ZrO_2		0.01	0.02	0.02	0.01	0.02	0.02
Bi_2O_3		*	*	*	*	*	*
P_2O_5		<1	<1	<1	<1	<1	<1
Σ		~52.5	~54.7	~53.2	~37.8	~49.1	~55.6

Δ – SiO_2 estimated by difference

Other Expt.:

Report Number: LP 674216

Date: 3/18/70

Transcribed by: lr /

Rakow Research Library, The Corning Museum of Glass - http://www.cmog.org

*less than std. glasses

Coventry Cathedral; 13-14th cent.
From: Brian Hobley

	Green 1155	Ruby over green (mostly ruby) 1156	Amber 1157	Deep blue 2016		
SiO_2 Δ	52	55	55	54		
Na_2O &	2.01	1.84	2.25	1.27		
CaO &	16.2	13.8	14.4	14.5		
K_2O &	14.7	13.2	14.0	15.6		
MgO &	5.82	7.46	6.32	6.12		
Al_2O_3 a	2.46	1.34	1.56	2.06		
Fe_2O_3	0.8	0.7	0.4	0.7		
TiO_2	0.3	0.01	0.01	0.02		
Sb_2O_5	*	*	*	*		
MnO	0.4	0.6	0.3	0.6		
CuO	0.2	0.5	0.1	0.4		
CoO	*	*	*	0.15		
SnO_2	0.04	0.08	*	0.06		
Ag_2O	*	*	*	*		
PbO	0.05	0.3	*	0.15		
BaO	0.07	0.07	0.10	0.3		
SrO	0.10	0.12	0.12	0.12		
Li_2O	0.005	0.003	0.007	0.005		
Rb_2O	*	*	*	*		
B_2O_3	0.08	0.10	0.07	0.08		
V_2O_5	*	*	*	*		
Cr_2O_3	*	*	*	*		
NiO	*	*	*	*		
ZnO	0.01	0.01	0.01	0.01		
ZrO_2	*	*	*	*		
Bi_2O_3	*	*	*	*		
P_2O_5	~ 5	~ 5	~ 5	~ 4		
Σ	~ 48.2	~ 45.1	~ 44.6	~ 46.2		

Δ- SiO_2 estimated by difference.

Other Expt.: XRF | XRF | XRF | XRF

Report Number: LRP 67/1954 Date: 9/18/70
Transcribed by: lr /

Rakow Research Library, The Corning Museum of Glass - http://www.cmog.org

*R. H. Brill, "Medieval Stained Glasses." Unpublished report prepared for a meeting at The Metropolitan Museum of Art, 1970.

Canteroury, ca. 1200-1225. (One from late 15th cent.)
From: Madeline Caviness, 9/67.

	Green 1151	Amber 1153	Pale green Late 15th c. 1154	Colorless 2020	Dark blue 2021	
SiO_2 Δ	~63	~63	~64	~65	~69	
Na_2O a	2.48	2.80	2.76	0.72	0.90	
CaO a	15.1	13.7	15.2	18.9	16.2	
K_2O a	8.24	10.7	7.13	9.35	7.52	
MgO a	6.74	5.73	7.23	4.34	4.11	
Al_2O_3 a	1.68	1.44	2.15	1.05	1.29	
Fe_2O_3	1.15	0.40	0.50	0.10	0.55	
TiO_2	0.15	0.05	0.10	0.05	0.05	
Sb_2O_5	*	*	*	*	*	
MnO	1.3	1.2	1.1	0.30	0.30	
CuO	0.02	*	*	*	0.15	
CoO	*	*	*	*	0.17	
SnO_2	0.04	*	*	*	*	
Ag_2O	*	*	*	*	*	
PbO	0.03	*	*	*	0.09	
BaO	0.03	0.03	0.03	0.05	0.02	
SrO	0.07	0.10	0.08	0.01	0.01	
Li_2O	*	*	*	*	*	
Rb_2O	0.05	0.25	0.02	0.02	0.02	
B_2O_3	0.03	0.03	0.03	0.02	0.02	
V_2O_5	*	*	*	*	*	
Cr_2O_3	*	*	*	*	*	
NiO	*	*	*	*	*	
ZnO	*	*	*	*	*	
ZrO_2	*	*	*	*	*	
Bi_2O_3	*	*	*	*	*	
P_2O_5	< 1	< 1	< 1	< 1	< 1	
Σ	~37.1	~36.5	~36.3	~34.9	~31.4	

Δ- SiO_2 estimated by difference.

Other Expt.: XRF | XRF | XRF

Report Number:

Date: 3/19/70
Transcribed by: lr /

Rakow Research Library, The Corning Museum of Glass - http://www.cmog.org

*less than std. glasses

R. H. Brill, "Medieval Stained Glasses." Unpublished report prepared for a meeting at The Metropolitan Museum of Art, 1970.

Canterbury, ca. 1200-1225
From: Madeline Caviness, 9/67. ✓

	Ruby over colorless (Ruby only) 1152	Same as 1152 (colorless only) 2024				
SiO_2 Δ	~64	~68				
Na_2O a	1.40	1.49				
CaO a	17.5	18.0				
K_2O a	9.15	5.85				
MgO a	4.75	4.66				
Al_2O_3 a	0.97	1.02				
Fe_2O_3	0.25	0.20				
TiO_2	0.10	0.03				
Sb_2O_5	*	*				
MnO	1.3	0.30				
CuO	0.35	0.05				
CoO	*	*				
SnO_2	0.03	*				
Ag_2O	*	*				
PbO	0.01	*				
BaO	0.03	0.02				
SrO	0.01	0.01				
Li_2O	*	*				
Rb_2O	0.03	0.02				
B_2O_3	0.03	0.02				
V_2O_5	*	*				
Cr_2O_3	*	*				
NiO	*	*				
ZnO	*	*				
ZrO_2	*	*				
Bi_2O_3	*	*				
P_2O_5	<1	<1				
Σ	~35.9	~31.7				

Δ- SiO_2 estimated by difference

Other Expt.:						
	XRF					

Report Number:

Date: 3/19/70
Transcribed by: lr /

Rakow Research Library, The Corning Museum of Glass - http://www.cmog.org

*less than std. glasses

'R. H. Brill, Medieval Stained Glasses." Unpublished report prepared for a meeting at The Metropolitan Museum of Art, 1970.

York Minster: Window C-33 in nave clearstory, 12th century.
From: Peter Newton, 7/16/68.

	Green 1400	Dark blue 1402				
SiO_2 Δ	~~~60~~	~~~61~~				
Na_2O a	2.48	2.78				
CaO a	15.8	14.5				
K_2O a	5.26	7.43				
MgO a	7.66	8.27				
Al_2O_3 a	2.15	1.43				
Fe_2O_3	1.25	1.15				
TiO_2	0.17	0.05				
Sb_2O_5	*	*				
MnO	2.0	1.7				
CuO	2.5	0.5				
CoO	*	0.2				
SnO_2	0.27	0.10				
Ag_2O	*	*				
PbO	0.25	0.45				
BaO	0.05	0.05				
SrO	0.10	0.10				
Li_2O	*	*				
Rb_2O	0.05	0.10				
B_2O_3	0.07	0.07				
V_2O_5	*	*				
Cr_2O_3	*	*				
NiO	*	*				
ZnO	*	*				
ZrO_2	0.01	*				
Bi_2O_3	*	*				
P_2O_5	~~~~ 4.1	~~~~ 3.9				
Σ	~~~40.1 ~44.2	~~~38.9 ~42.8				
	Δ- SiO_2 estimated by difference. ~56					
Other Expt.:	durability tests	durability tests				

Report Number:

Date: 3/19/70
Transcribed by: lr /

*less than std. glasses

Rakow Research Library, The Corning Museum of Glass - http://www.cmog.org

York Minster; Windows C-33 and C-34 in nave clearstory. Late 13th cent. From: Peter Newton. 7/16/68.

		Pale greenish 1404	Green 1406	Ruby over "colorless" (Ruby only) 1409	"Colorless" glass from 1409 1414	Yellowish 1410	Pale greenish 1412
SiO_2	Δ	~~~61~~	~~~63~~	~~~61~~	~~~62~~	~~~62~~	~~~63~~
Na_2O	a	3.44	2.04	3.60	3.68	3.58	3.34
CaO	a	17.0	12.9	16.3	16.0	16.2	15.5
K_2O	a	8.09	8.50	8.43	8.26	9.35	9.20
MgO	a	7.09	7.13	7.27	7.11	6.71	6.78
Al_2O_3	a	1.11	1.51	0.98	1.11	0.88	0.78
Fe_2O_3		0.30	0.55	0.25	0.20	0.15	0.20
TiO_2		0.03	0.04	0.02	0.02	0.02	0.02
Sb_2O_5		*	*	*	*	*	*
MnO		1.5	1.5	1.2	1.3	1.2	1.3
CuO		0.10	2.3	1.0	.05	.01	.01
CoO		*	*	*	*	*	*
SnO_2		*	0.25	0.08	*	*	*
Ag_2O		*	*	*	*	*	*
PbO		*	0.30	0.01	*	*	*
BaO		0.02	0.03	0.02	0.03	0.02	0.03
SrO		0.05	0.08	0.05	0.05	0.07	0.05
Li_2O		*	*	*	*	*	*
Rb_2O		0.01	0.07	0.01	0.03	0.03	0.03
B_2O_3		0.09	0.03	0.05	0.04	0.03	0.03
V_2O_5		*	*	*	*	*	*
Cr_2O_3		*	*	*	*	*	*
NiO		*	*	*	*	*	*
ZnO		*	*	*	*	*	*
ZrO_2		*	*	*	*	*	*
Bi_2O_3		*	*	*	*	*	*
P_2O_5		← 1 3,5	← 1 4,1	← 1 3,9	← 1 3,1	← 1 4.7	← 1 4.3
Σ		~~~38.8~~	~~~37.2~~	~~~39.3~~	~~~37.9~~	~~~38.3~~	~~~37.3~~

Δ- SiO_2 estimated by difference.

Other Expt.:

Report Number:

Date: 3/19/70

Transcribed by: lr/

Rakow Research Library, The Corning Museum of Glass - http://www.cmog.org

*less than std. glasses

R. H. Brill, "Medieval Stained Glasses." Unpublished report prepared for a meeting at The Metropolitan Museum of Art, 1970.

Materials and Technology of Medieval Glass

From: Madeline Caviness, 9/67.

	"Colorless" 1160					
SiO_2 Δ	~62					
Na_2O a	2.77					
CaO a	22.7					
K_2O a	5.61					
MgO a	4.54					
Al_2O_3 a	1.49					
Fe_2O_3	.60					
TiO_2						
Sb_2O_5	*					
MnO	0.20					
CuO	*					
CoO	*					
SnO_2	*					
Ag_2O	0.002					
PbO	*					
BaO	0.10					
SrO	0.15					
Li_2O	0.01					
Rb_2O	*					
B_2O_3	0.03					
V_2O_5	*					
Cr_2O_3	*					
NiO	*					
ZnO	*					
ZrO_2	*					
Bi_2O_3	*					
P_2O_5	< 1					
Σ	~38.2					
Other Expt.:	XRF					

Δ – SiO_2 estimated by difference.

Report Number:

Date: 3/20/70
Transcribed by: lr/

Rakow Research Library, The Corning Museum of Glass - http://www.cmog.org

*less than std. glasses

R. H. Brill, "Medieval Stained Glasses." Unpublished report prepared for a meeting at The Metropolitan Museum of Art, 1970.

Batalha, 15th and 16th cent.
From: Carlos Barros, 1/2/67.

	Pale green 15th or 16th cent. 1161	Green (Ag st pr. 16th cent 1162	Ruby over "col." pr. 15 c. (R & c) 1163	Ruby over gr pr. 16 c. (Ruby & grn.) 1164		
SiO_2 Δ	~59	~62	~60	~61		
Na_2O a	1.13	2.54	3.83	2.34		
CaO a	22.2	22.2	23.5	21.7		
K_2O a	6.31	4.80	4.10	5.76		
MgO a	3.96	2.74	5.06	3.26		
Al_2O_3 a	3.97	2.56	1.71	3.11		
Fe_2O_3	0.75	0.40	0.70	0.40		
TiO_2						
Sb_2O_5	*	*	*	*		
MnO	2.0	1.7	0.3	2.0		
CuO	*	1.0	0.35	0.30		
CoO	*	*	*	*		
SnO_2	*	*	*	*		
Ag_2O	*	0.001	*	*		
PbO	*	*	0.10	*		
BaO	0.05	0.03	0.03	0.03		
SrO	0.08	0.05	0.20	0.03		
Li_2O	0.02	0.01	0.03	*		
Rb_2O	*	*	*	*		
B_2O_3	0.03	0.10	0.03	0.03		
V_2O_5	*	*	*	*		
Cr_2O_3	*	*	*	*		
NiO	*	*	*	*		
ZnO	*	*	*	*		
ZrO_2	*	*	*	*		
Bi_2O_3	*	*	*	*		
P_2O_5	< 1	< 1	< 1	< 1		
Σ	~ 40.5	~ 38.1	~39.9	~ 39.0		

Δ-- SiO_2 estimated by difference.

Other Expt.:	XRF	XRF	XRF	XRF		

Report Number:

Date: 3/20/70

Transcribed by: lr /

Rakow Research Library, The Corning Museum of Glass - http://www.cmog.org

*less than std. glasses

R. H. Brill, "Medieval Stained Glasses: Unpublished Data," unpublished report prepared for a meeting at The Metropolitan Museum of Art, 1970.

From: Derek Samii, Istanbul, 1965

From: Arthur H.S. Megaw 4/6/62.

	Amber (0-64) 134	Purple (0-63) 137	Emerald green 141	Deep blue (0-10) 143	Deep blue 145	
SiO_2	66	69	65	68		
Na_2O a	14.9	14.2	14.1	14.6	13.8 a	
CaO a	13.4	8.8	8.8	9.8		
K_2O a	1.16	2.02	1.56	1.56	1.9 a	
MgO a	1.20	1.40	1.27	1.20		
Al_2O_3 a	1.37	2.09	1.93	2.41		
Fe_2O_3	0.5	0.35	0.7	1.0		
TiO_2	0.03	0.03	0.05	0.10		
Sb_2O_5	*	*	*	*		
MnO	0.01	1.5	1.2	1.0		
CuO	*	*	4-5	0.05		
CoO	*	*	*	0.2		
SnO_2	*	*	0.08	0.02		
Ag_2O	*	*	0.005	*		
PbO	*	*	0.12	0.15		
BaO	*	0.05	*	*		
SrO	0.20	0.05	0.07	0.10		
Li_2O a	0.13	*	0.02 s	0.02 s	0.03 a	
Rb_2O	*	*	*	*		
B_2O_3 t	0.92	*	0.20 s	0.15 s	0.21 t	
V_2O_5	*	*	*	*		
Cr_2O_3	*	*	*	*		
NiO	*	*	*	*		
ZnO	*	*	*	*		
ZrO_2	*	*	*	*		
Bi_2O_3	*	*	*	*		
P_2O_5	< 1	< 1	< 1	< 1		
Σ	~33.9	~30.5	~34.6	~32.4		

Δ- SiO_2 estimated by difference.

t - by mannitol titration.

s - by spectrographic analysis.

Other Expt.:				O^{18}		

Report Number: LP 673834; CGW D8700-05

Date: 3/18/70

Transcribed by: lr /

*less than std. glasses

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NOTES ON ANALYSES

SiO_2	Estimated by difference unless otherwise noted. Usually an additional 1 percent is added to the sum of the other elements to account for the expected contents of phosphate, chloride, sulfate, and volatiles.
Na_2O	-----
CaO	-----
K_2O	* less than 0.01
MgO	* less than 0.01
Al_2O_3	* less than 0.1
Fe_2O_3	* less than 0.1
TiO_2	* less than 0.01
Sb_2O_5	* less than 0.01
MnO	* less than 0.01
CuO	* less than 0.01
CoO	* less than 0.01
SnO_2	* less than 0.01
Ag_2O	* less than 0.001
PbO	* less than 0.01
BaO	* less than 0.01
SrO	* less than 0.01
Li_2O	* less than 0.01
Rb_2O	* less than 0.01
B_2O_3	* less than 0.01
V_2O_5	* less than 0.01
Cr_2O_3	* less than 0.01
NiO	* less than 0.01
ZnO	* less than 0.01
ZrO	* less than 0.01
Bi_2O_3	* less than 0.001
P_2O_5	* less than approx. 1 per cent.

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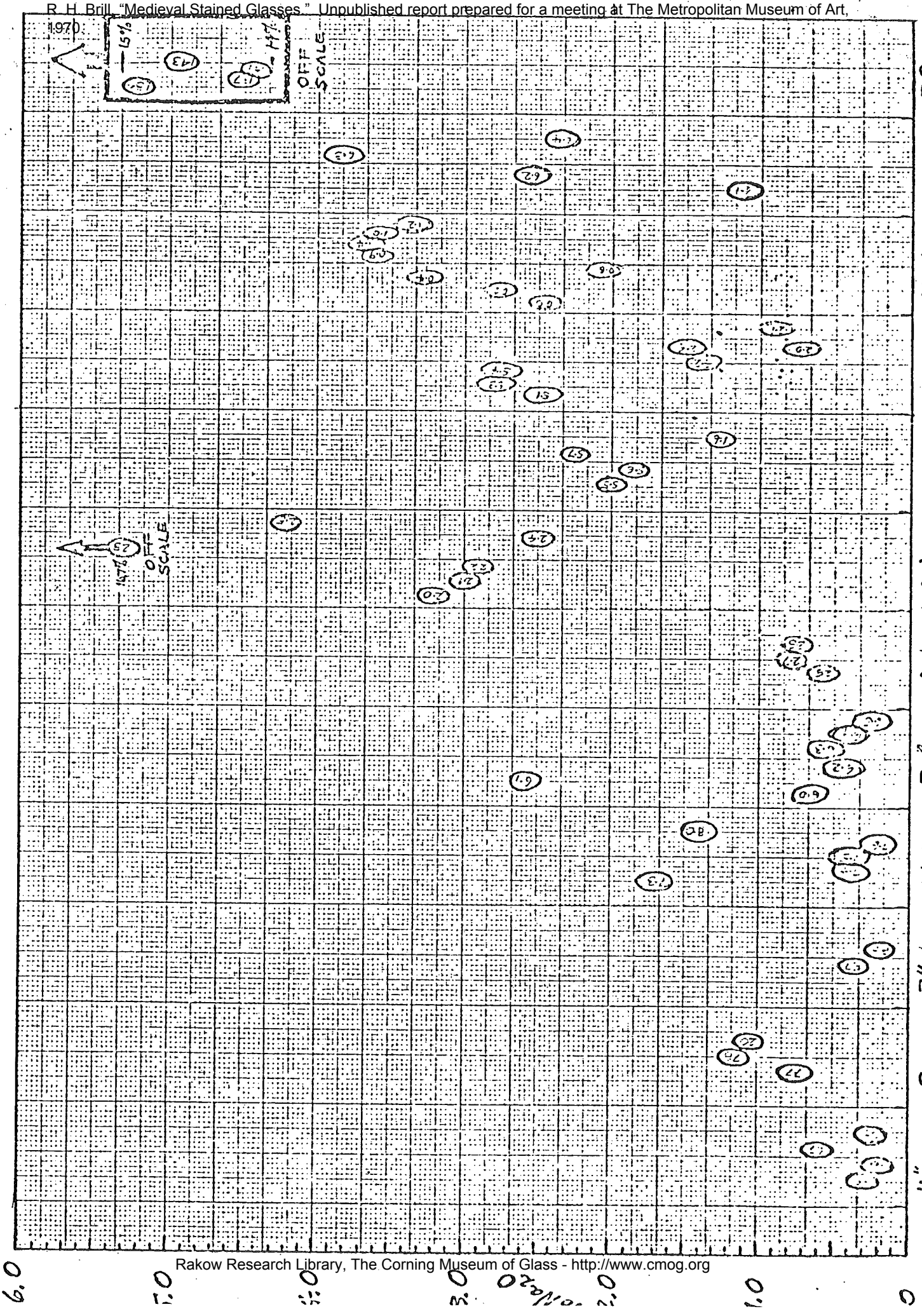

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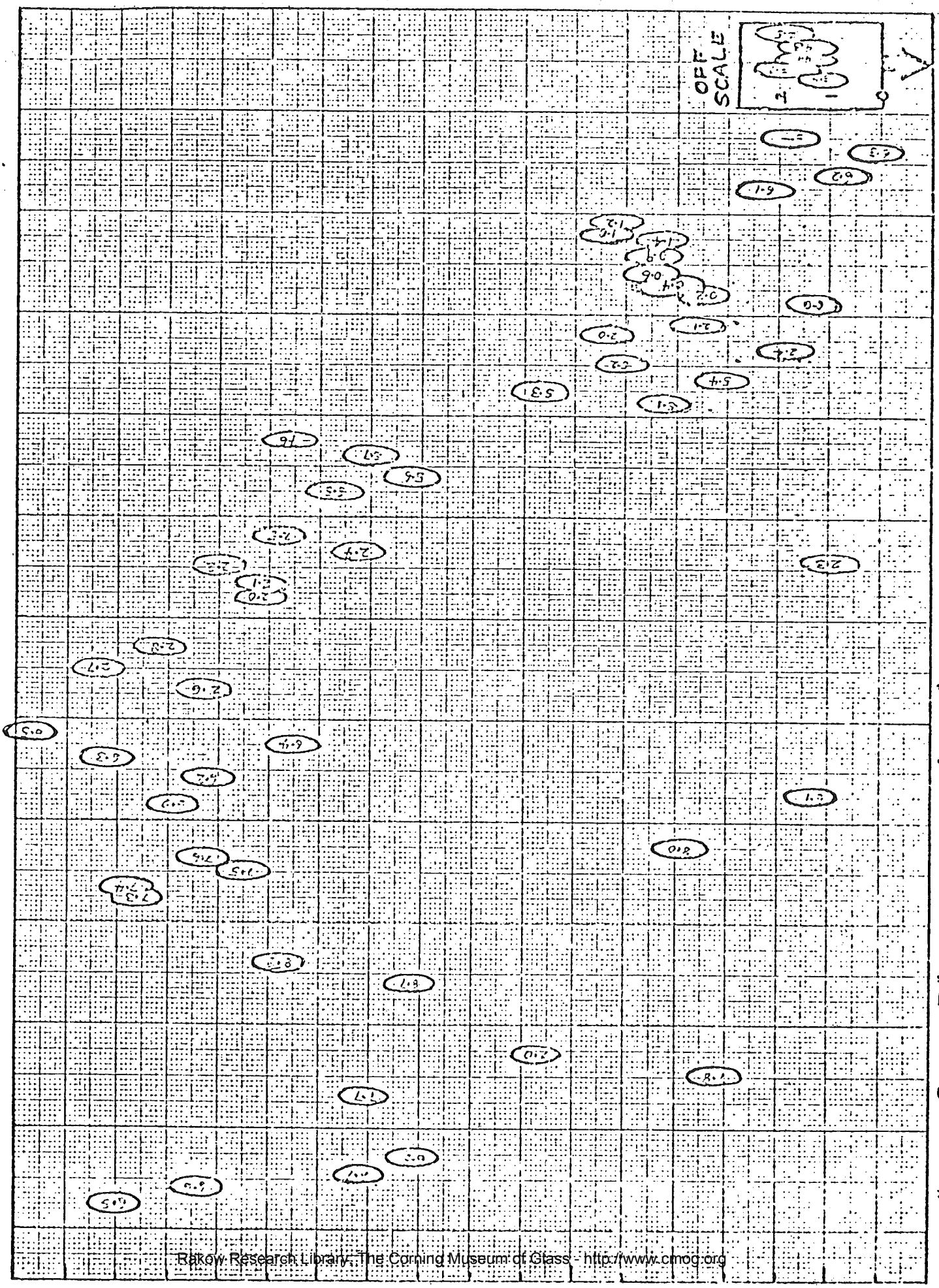

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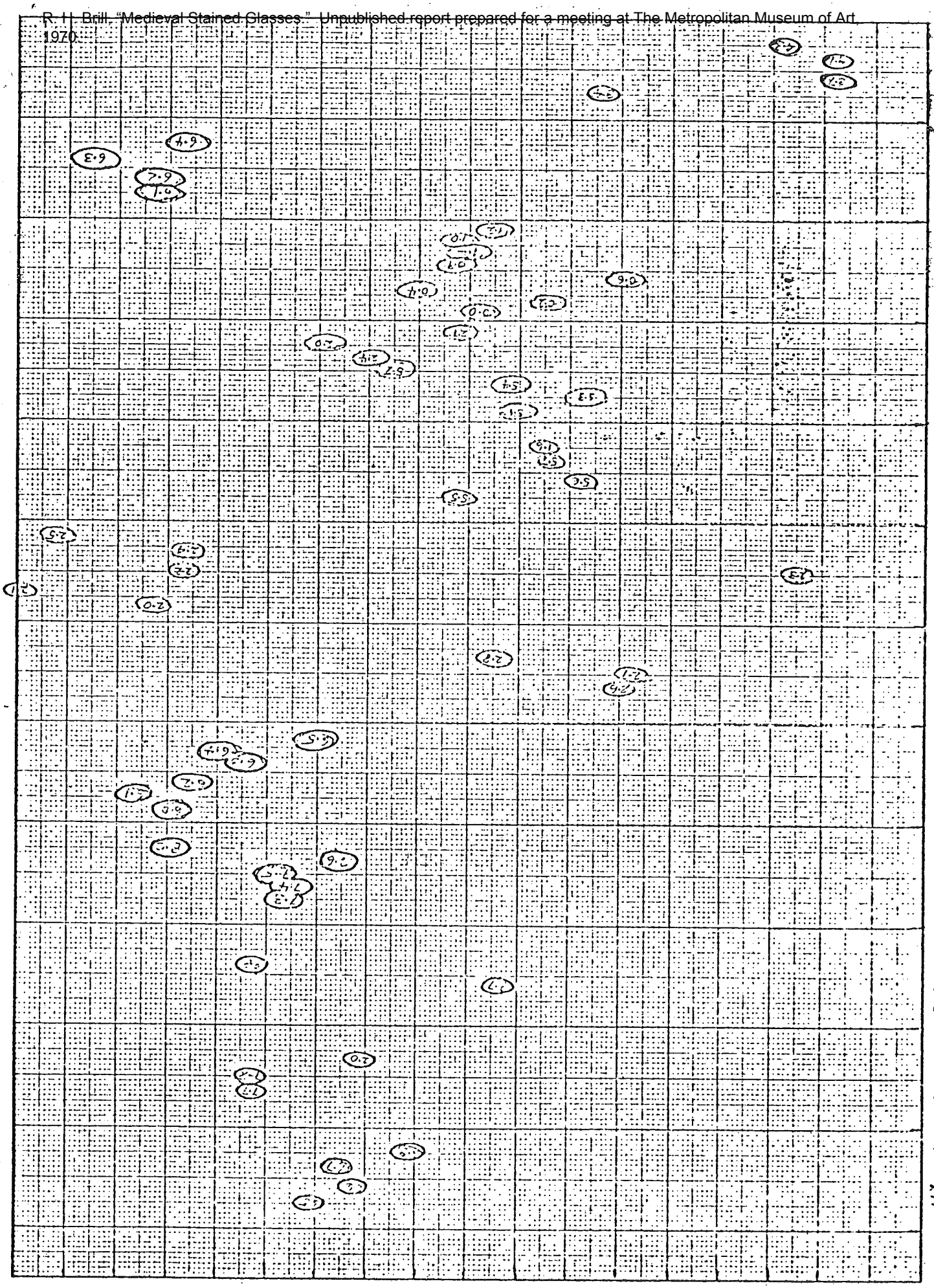

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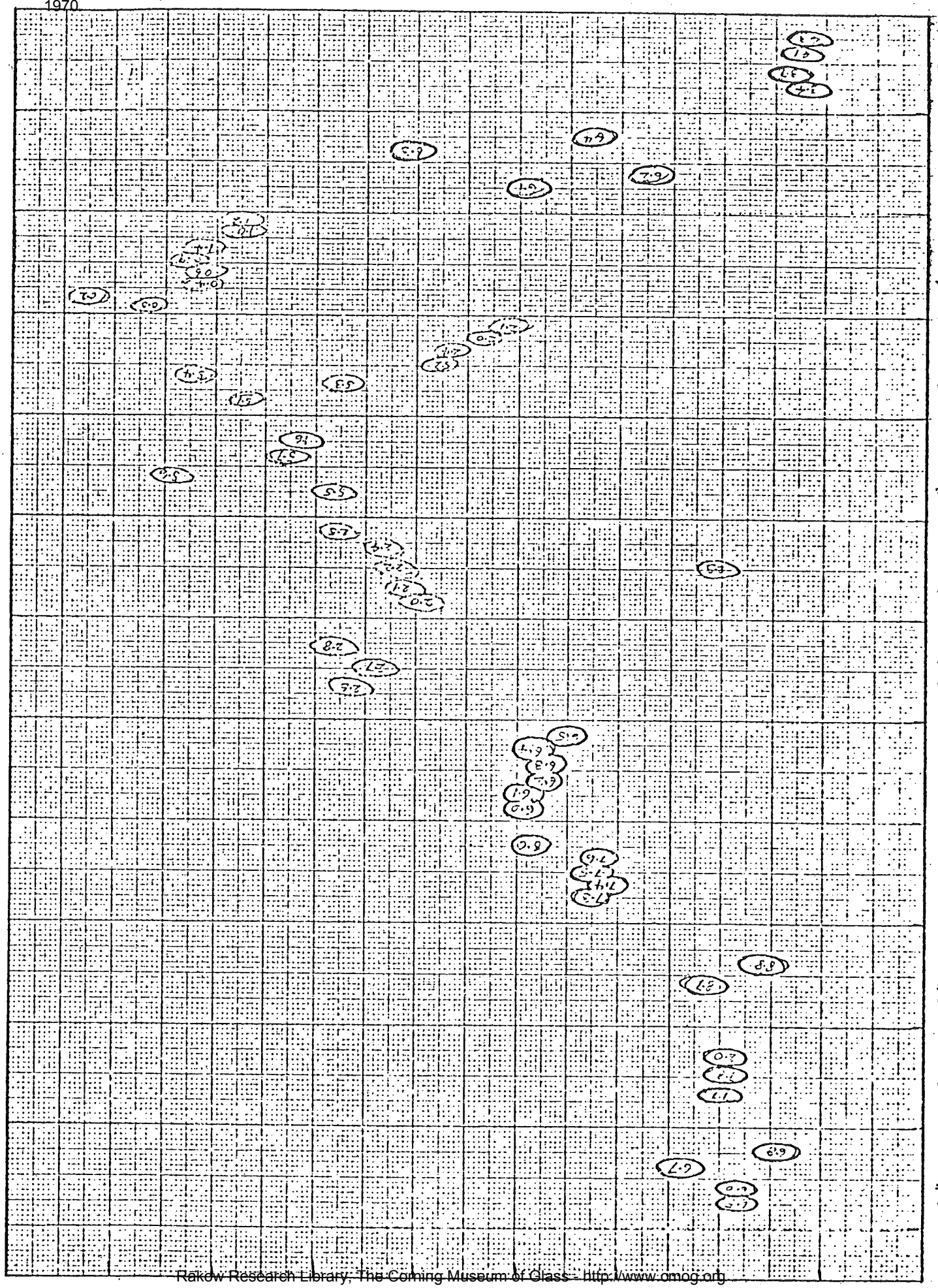

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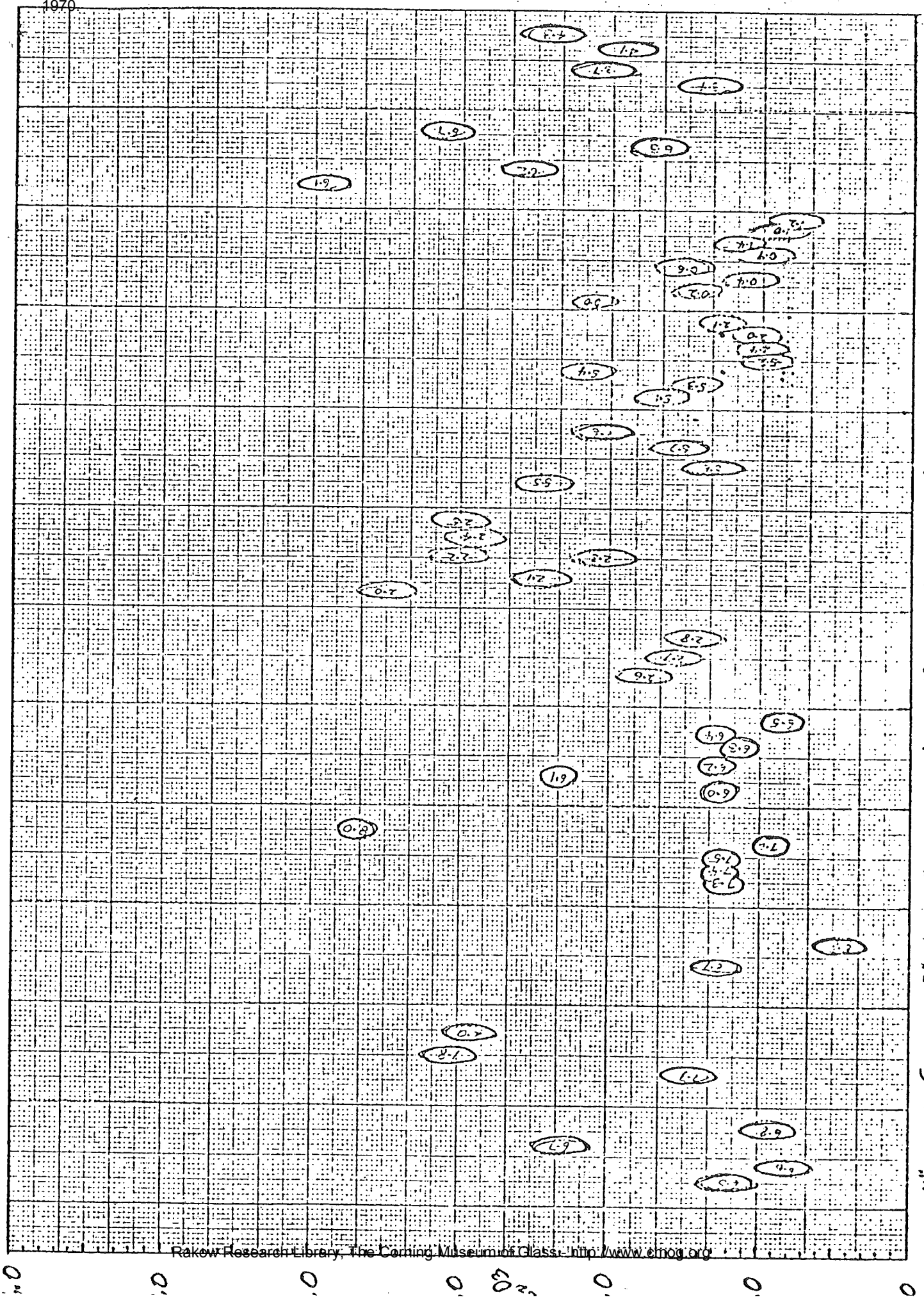

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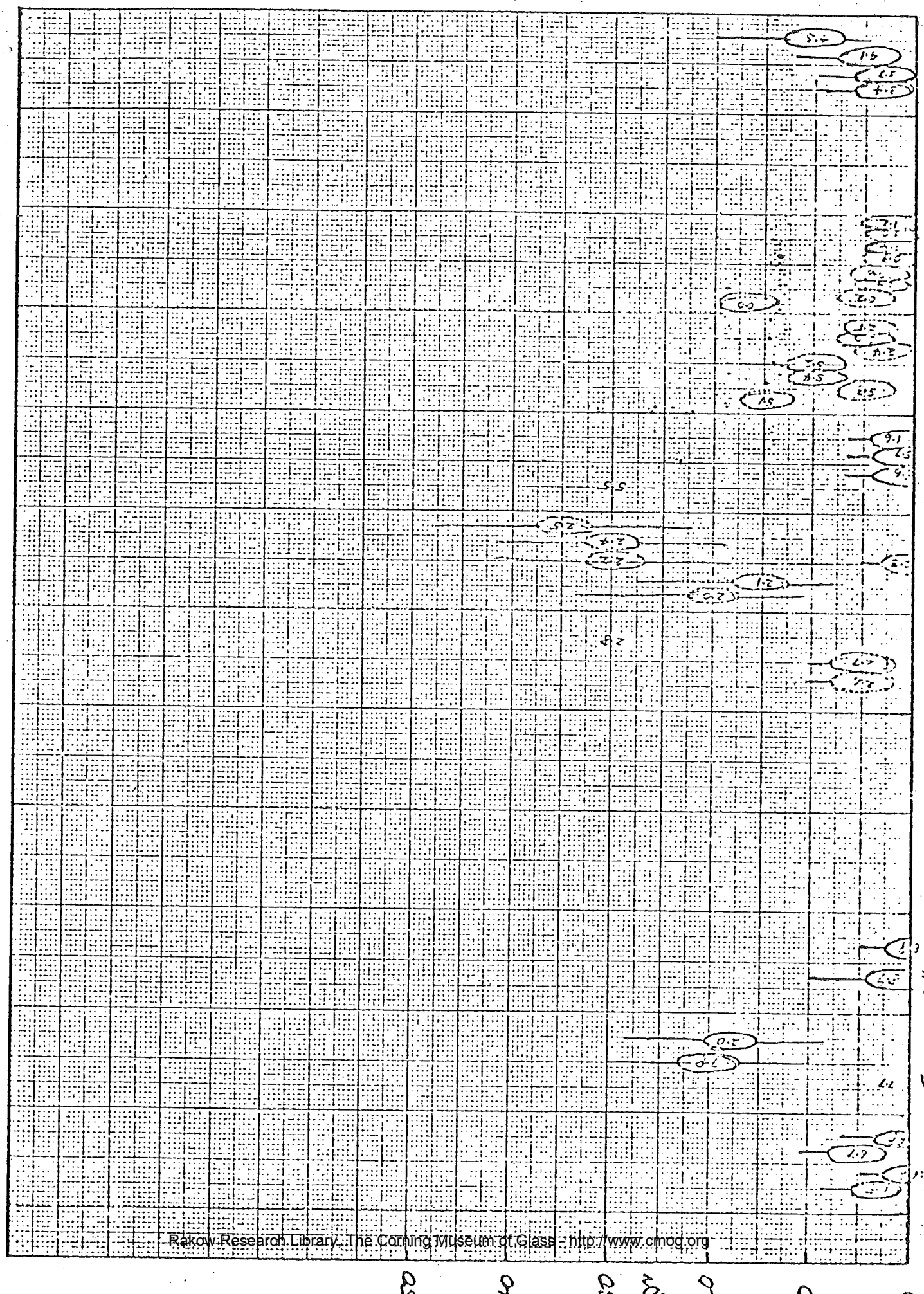

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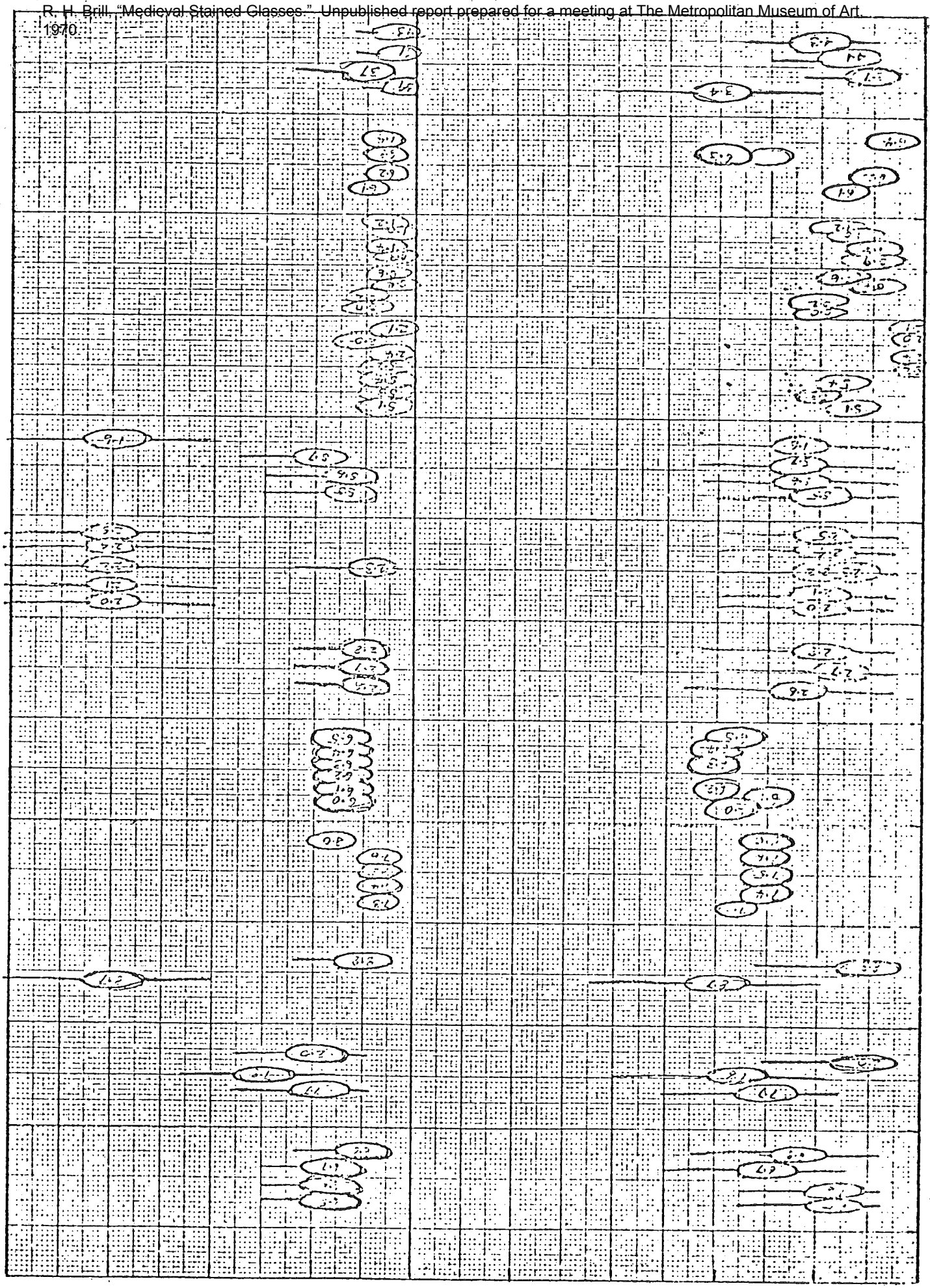

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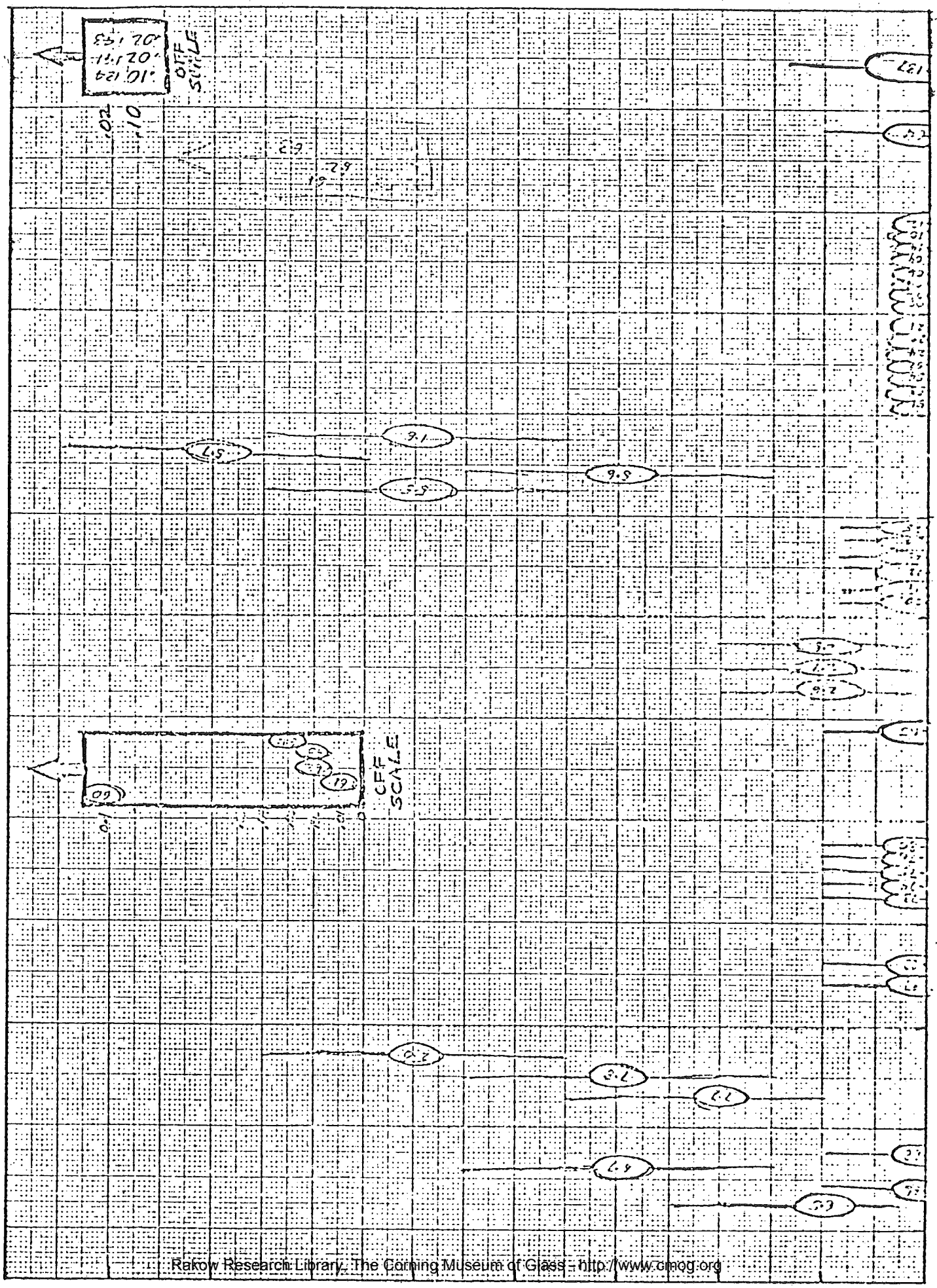

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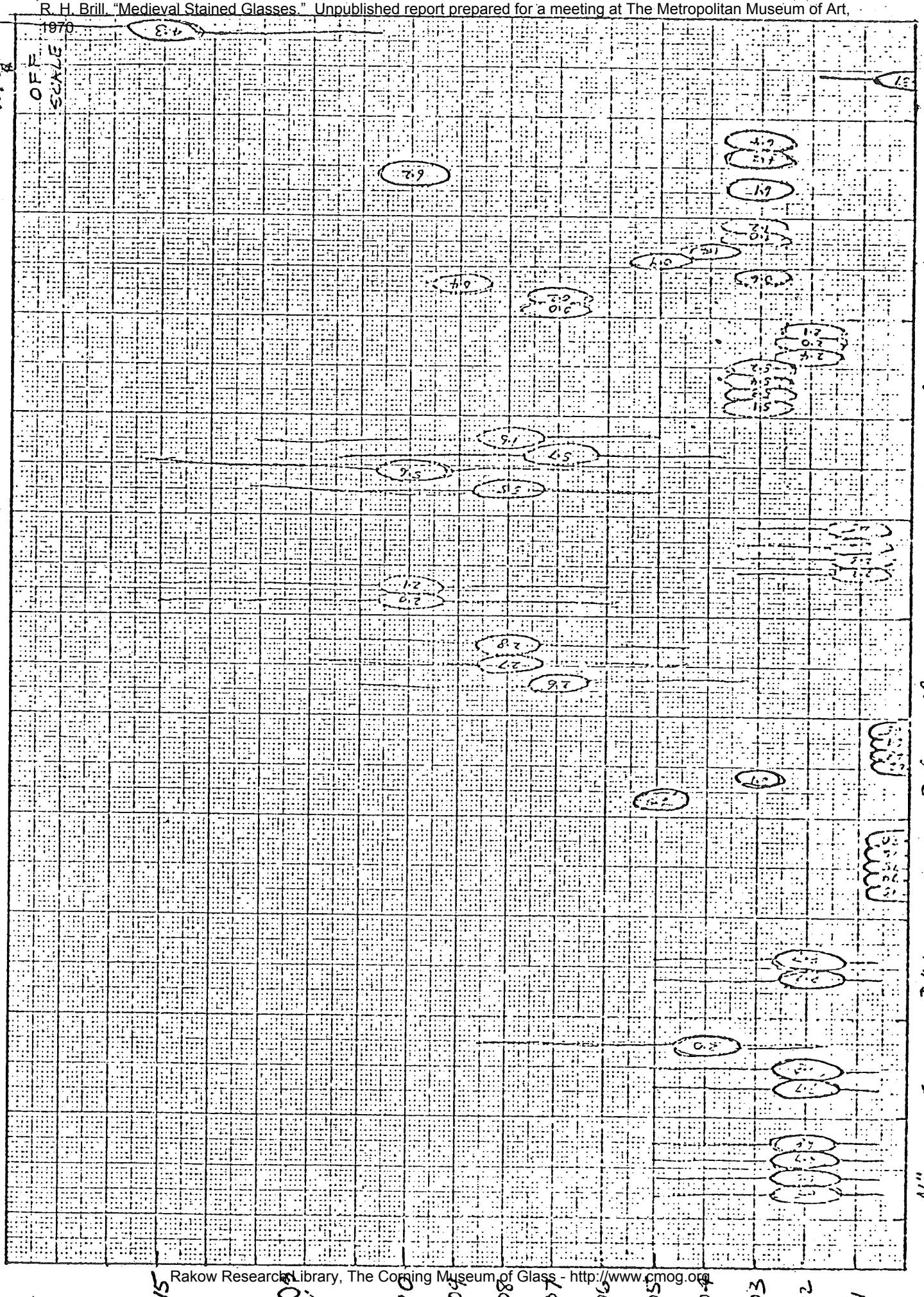

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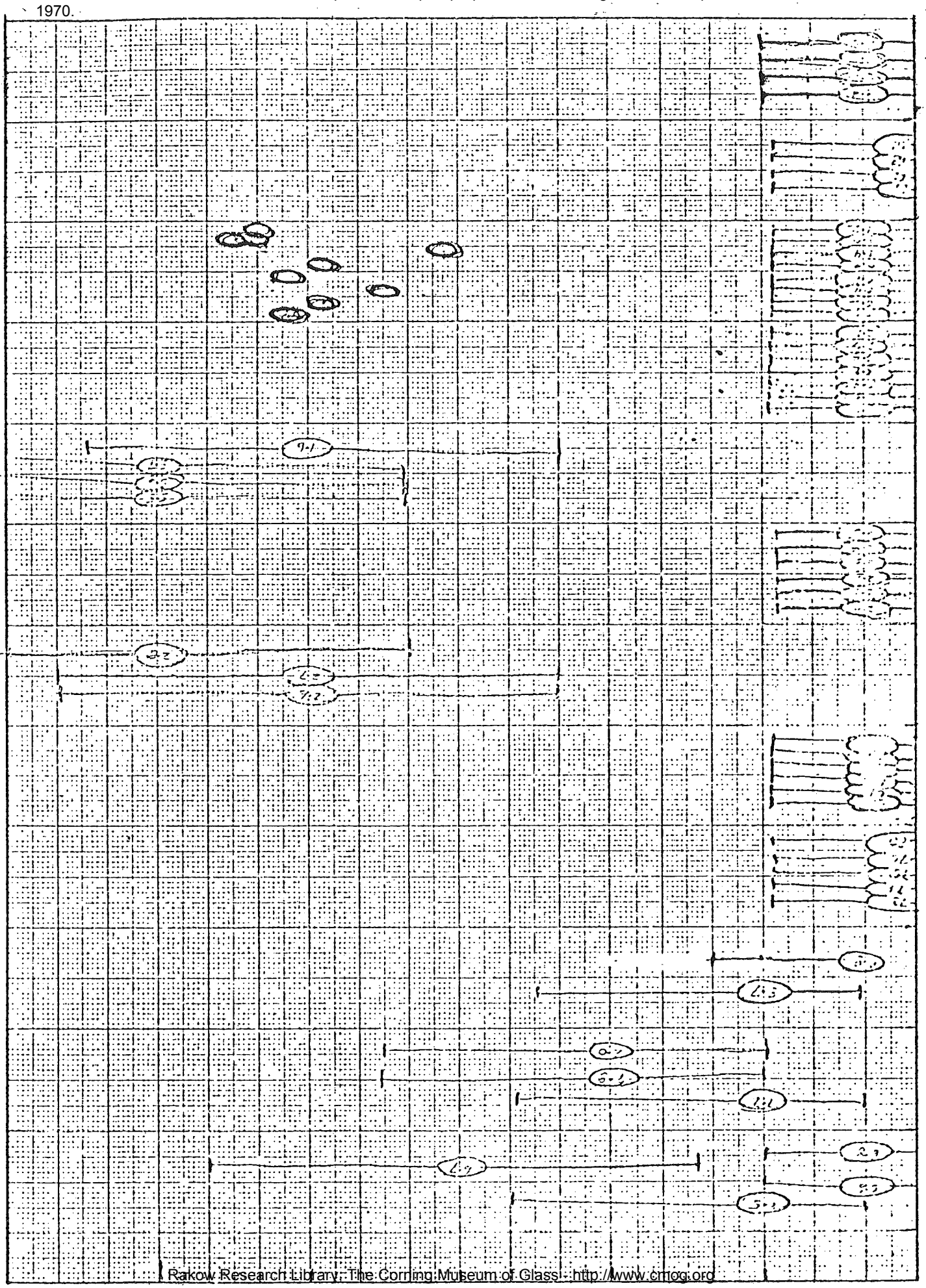

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THE PORTABLE X-RAY FLUORESCENCE ANALYZER

A new instrument, the portable x-ray fluorescence spectrometer, may prove to have several useful applications in the study of early glasses, as well as other archaeological materials. Its main feature, portability, allows the instrument to be taken directly to excavation sites and on field surveys, or into museums or other places where it can be used to analyze in situ objects which cannot be sampled or removed from the premises. The portability of the instrument is made possible by the use of small radioactive sources to excite secondary x-rays from the samples being analyzed. When this is coupled with a semiconductor x-ray detector it is possible to assemble a small probing device which can be placed against an object to be analyzed and attached by cable to the other parts of the apparatus. Two types of portable x-ray instruments have been constructed and described by Dr. Harry R. Bowman and his colleagues at the Lawrence Radiation Laboratory, and by Dr. E.T. Hall at Oxford.30

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The importance of this instrument lies not so much in the kind of analysis that it can do, because it does have some of the same limitations as all x-ray fluorescence analyzers, but rather in the way in which it does the analysis. It should become very valuable for analyzing large collections of sherds, for example, in museum storerooms in countries or institutions which do not permit the export or removal of samples for analysis. Two particularly tempting applications occur to the glass analyst.

Those familiar with the opus sectile panels excavated by Prof. Robert Scranton and his colleagues at Kenchreai,[31] will recall that many of the glass inlays forming these designs, are very heavily weathered from centuries of submersion in the sea. Thus for the most part the glass inlays have lost their original colors, and the only direct way to tell what the colors were is to remove the weathering products from the inlays to examine the color of the undecomposed glass in the interiors, if any remains. It has been shown earlier that chemical analyses of the weathering products are sufficient to allow one to identify indirectly the original colors of most of the glasses.[32] But even so, it is obviously impossible to remove samples from the most important panels, such as the

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very striking one depicting Homer. The colors would then be known, but the panel would be badly damaged. Therefore, qualitative analyses for certain specific elements in the weathered inlays by means of the portable x-ray fluorescence spectrometer could serve to identify the original colors of the glasses, and allow one to prepare accurate color reconstructions of the panels.

This instrument may also lead to an entirely new approach to the analysis of stained-glass windows. Until now it has always been necessary to work with excavated fragments, or samples removed from the windows, or found lying loose in old workshops.[33] But now it seems quite feasible to support one of these instruments on a scaffolding, and by positioning the probe in contact with selected glasses for a matter of some minutes, to obtain completely nondestructive chemical analyses of representative glasses in situ. Simultaneous analyses of the painted decorations could be used to supplement the glass analyses. Analyses might also provide a means for distinguishing replacement glasses, in cases where visual examination is inconclusive.[34]

In order to explore these possibilities Dr. Perlman and Dr. Bowman

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of the Lawrence Radiation Laboratories have analyzed a series of stained-glass fragments and of weathered opus sectile inlays from Kenchreai.[35] The results of these trial experiments suggest that both of the projects proposed above are quite feasible. Table 6 presents some results on the stained glasses obtained by Mr. Robert Giauque using their portable x-ray emission analyzer.

The samples, 33 in number, represent stained glasses of various colors from several geographical locations and of different dates. The sampling leaves something to be desired, but we were limited in this preliminary study to the samples most readily available. Even in these limited data though, some encouraging signs can be seen. For the most part glasses from the same cathedral of the same date look alike in the elements where they would be expected to. (Samples 58 and 59.) There are indications that glasses from different cathedrals do indeed differ significantly from one another in some elements. (Samples 41, 60, 69, 71, and 79.) Some glasses from the same cathedral but of different dates also differ significantly. (Samples 69 and 70 vs. 65, 66, 67, and 68.) There is even one case where the ruby glasses from two nearby cathedrals

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of similar dates resemble one another more closely than the glasses of other colors within their own cathedrals, as if the ruby glasses might have been made in the same workshop from special cullet or ingredients. (See for example the Rb_2O contents of samples 72, 74, and 75. These same three samples, along with 67, contain significantly more PbO and have the lowest MnO contents of the glasses analyzed, reenforcing still further their similarities.)[36]

As with all methods of analysis one must be careful to determine just what it is that has been analyzed. For example, some of the ruby stained glasses analyzed in this study consist of ruby flashings on a "colorless" glass, while others consist of thin layers of ruby glass laminated within a "colorless" glass matrix. Since the x-ray fluorescence technique yields essentially a surface analysis the results on two differently structured glasses may not be strictly comparable.

Of course many more analyses are required before the particular inferences mentioned above could be proven, or compositional patterns discerned, but the point of these experiments was to make a quick survey of stained-glass fragments to see what the possibilities are for further

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research. Even the scant evidence presented here seems strong enough to justify some full-fledged analyses of a few stained-glass cathedral windows *in situ*. We hope it will be possible to initiate experiments of this sort in the near future.

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TABLE 6

ANALYSES OF SOME EARLY STAINED GLASSES*

	Provenience	Date	Color	MnO	Fe_2O_3	CuO
51	Canterbury	1200-25	grn.	2.1	1.1	.05
52	"	"	ruby	.9	.6	.4
53	"	"	amb.	1.4	.5	---
54	"	late XV	p. grn.	1.2	.7	---
55	Coventry	XIII-XIV	grn.	.9	.8	.1
56	"	"	ruby	1.3	.5	.3
57	"	"	amb.	1.2	.5	---
58	Winchester	ca. 1400	c.	1.2	.8	---
59	"	"	grn., ss.	1.2	.6	---
60	Norwich	1400-50	c.	1.5	.5	---
61	Batalha	XV or XVI	p. grn.	1.0	.7	---
62	"	XVI	grn., ss.	.5	.4	---
63	"	XV	ruby	.9	.5	.2
64	"	XVI	ruby	.9	1.0	.1
65	Nürnberg, St.S.	1379-86	p. grn.	1.5	1.5	.1
66	"	"	p. bl.	1.7	.9	.15
67	"	"	ruby	2.0	.5	.15
68	"	"	amb.	.8	.2	.05
69	"	1480	amb.	.8	2.3	---
70	"	XVII	c., ss.	.8	.4	---
71	Nürnberg, St. L.	1600-1700	c.	2.4	.4	---
72	"	ca. 1476	ruby	.6	.4	.7
73	Ulm	ca. 1400	dk. bl.	.8	.6	.15
74	"	"	ruby	.4	.3	1.6
75	Ulm, Chor-Fenster	1410	ruby	.7	.5	.7
76	" , "	"	yl. amb.	1.0	.3	---
77	Speyer Dom	ca. 1170	ruby	1.3	.4	.3
78	"	"	yl. amb.	1.1	.7	---
79	Oppenheim	ca. 1300	p. grn.	.8	.8	---
526	Chartres	ca. 1225	p. bl.	.9	.6	.1
527	"	"	amb.	.8	.5	.05
528	"	"	ruby	1.0	.5	.8
541	Zerek Çamii	XII (?)	mulb.	4.3	2.3	0.1

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	ZnO	Rb_2O	SrO	ZrO_2	Ag_2O	SnO_2	BaO	PbO
51	.1	.02	.05	.02	---	.02	.10	.2
52	.7	.02	.03	.02	---	.02	.07	.2
53	.05	.04	.07	---	---	---	.20	.1
54	.05	.02	.05	.01	---	---	.10	.1
55	.05	.03	.04	.02	---	.01	.14	.1
56	---	.03	.06	---	---	.05	.14	.3
57	---	.03	.06	.01	---	---	.24	.1
58	.05	.03	.06	.02	---	.02	.13	.2
59	.05	.03	.06	.02	.02	.03	.14	.2
60	<.05	.02	.07	.03	---	---	.33	.2
61	<.05	.02	.05	.01	---	---	.21	.1
62	.1	.02	.05	.02	---	---	.11	.1
63	---	.02	.09	.02	---	---	.18	.2
64	<.05	.01	.05	.01	---	---	.20	.2
65	.1	.05	.07	.01	---	.01	.21	.5
66	.2	.04	.06	.01	---	---	.24	.2
67	.1	.04	.05	---	---	.02	.19	.5
68	.05	.04	.06	---	---	---	.15	.2
69	.1	.03	.15	.03	---	---	.4	.4
70	---	.02	.07	.02	.12	.02	.19	.1
71	<.05	.02	.13	.03	---	---	.30	.03
72	---	*	.07	*	---	.01	.19	1.
73	.05	.03	.06	.01	---	---	.21	.3
74	---	*	.07	*	---	.03	.18	2.
75	.1	*	.07	*	---	.03	.18	3.
76	.05	.05	.06	.01	---	---	.21	.2
77	---	.03	.05	.01	---	---	.18	.1
78	.05	.02	.05	.02	---	---	.28	.1
79	.05	.02	.10	.02	---	---	.34	.2
526	.05	.02	.04	.01	---	.02	.12	.1
527	<.05	.02	.04	.02	---	---	.10	.1
528	.1	.02	.04	.01	---	.02	.13	.1
541	0.15	0.01	0.07	0.01	---	0.01	0.04	0.2

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Notes to accompany Table 6.

All analyses by Mr. Robert Giauque, working under the direction of Dr. H. Bowman and Dr. I. Perlman of The Lawrence Radiation Laboratory, using a portable x-ray fluorescence spectrometer. Trial analyses done in the laboratory, not in situ. Cooperative research project of the Lawrence Radiation Laboratory and The Corning Museum of Glass.

Abbreviations: Roman numerals-centuries; St. S.- St. Sebalds; St. L.- St. Lorenz. c -"colorless"; grn. - green; bl. - blue; amb.- amber; yl. - yellow; mulb. - mulberry; p. - pale; dk. - dark; ss. - silver stained.

*No analysis due to interference of PbO.

The samples of glass were provided by the following donors to whom we express our gratitude: [The Dean and Chapter, Canterbury Cathedral; Mrs. Madeline Caviness and Mr. Dennis King; Mr. B. Hobley, Herbert Art Gallery and Museum; Mr. C.V. da Silva Barros, Museu Nacional de Arte Antiga, Lisbon; Dr. Gottfried Frenzel, Nürnberg; and Dr. A.H.S. Megaw.]

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28 Brill, R.H. (1967). "Chemical Studies of Islamic Lustre Glass", presented at The International Conference on Applications of Science to Medieval Archaeology, University of California, Los Angeles, Oct. 1967; to appear in a forthcoming issue of Contributions of the University of California Archaeological Research Facility.

29 X-ray emission analyses by Donald Stephenson and Dorothy Kimble, both of Corning Glass Works; spectrographic analyses by Charles Jedlicka of Lucius Pitkin, Inc., New York City.

30 Bowman, H.R.; Hyde, E.K.; Thompson, S.G.; Jared, R.C. (1966). "Application of High-Resolution Semiconductor Detectors in X-ray Emission Spectrography", Science, 151 (3710), 562-68; Hall, E.T. (1965). "Recent Research at the Research Laboratory for Archaeology and the History of Art, Oxford." Application of Science in Examination of Works of Art, p. 110, Museum of Fine Arts, Boston.

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31 Scranton, R.L. (1967). "Glass Pictures from the Sea," Archaeology, 20 (3), 163-73; Scranton, R.L. & Ramage, E.S. (1967). "Investigations at Corinthian Kenchreai," Hesperia, 36 (2), 124-86.

32 Brill, R.H., unpublished analyses.

33 A set of comprehensive analyses appears in Geilmann, W., op. cit., II and III; see footnote 10.

34 In actual practice if the glasses are covered with an accretion of dirt, it would be necessary to clean a small spot, perhaps 1 cm. in diameter, in order that the instrument would analyze the glass rather than the accumulated dirt. It would also be necessary to avoid weathered areas as much as possible. Because of the much lower dosage of radiation delivered to the sample, there is no danger of discoloration as there is with the conventional instruments.

35 This is a cooperative research project of The Corning Museum of Glass and the Lawrence Radiation Laboratory.

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All of the ruby glasses were found to be copper rubies, with apparent CuO contents ranging from about 0.1 up to 1.6 percent. There do not seem to be any particular correlations with concentrations of other elements, except that most of the rubies contain SnO_2, but several glasses of other colors also were found to contain SnO_2. ZnO was found, surprisingly, in 26 of the 33 glasses, with the ruby sample from Canterbury containing about 0.7 percent ZnO. Only the silver-stained glasses showed the presence of silver. Manganese, as might be expected, was found in all of the glasses. See Geilmann, op. cit., II. in footnote 10.

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OXYGEN ISOTOPE STUDIES

Another type of isotope research, which may find even broader application, is oxygen isotope analysis. Whereas lead occurs in most early glasses only as a trace component, oxygen is universally present, accounting for about 45 percent of the weight of most glasses.

The isotope of interest to us here is O^{18}, which is not very abundant in nature, accounting for only one atom out of about every 500. Since oxygen is relatively susceptible to fractionation, the O^{18} content of oxygen from different natural sources is quite variable. For example, the oxygen in inland fresh water can differ significantly from that in ocean water, and both differ from atmospheric oxygen. There is also considerable variation in O^{18} contents among different types of minerals. O^{18} contents are usually stated in terms of δ, the deviation from an accepted reference point on the scale of O^{18} contents of natural materials (Figure 14).[55] Realizing that the various raw materials used for making glasses throughout history have come from sources which probably had differing O^{18} contents, it appeared worthwhile to investigate some early

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glasses to see if these differences might not be reflected in the O^{18} contents of the glasses themselves.

In a cooperative project with The Corning Museum of Glass, Prof. Robert N. Clayton and Mrs. Toshiko Mayeda, of the Fermi Institute, have determined the O^{18} contents of more than a hundred glasses, using a technique they perfected for the analysis of silicate rocks.[56] Although the work is still in progress and many questions remain to be answered, it already seems likely that these determinations may offer an entirely new means for characterizing early glasses, or more specifically, for grouping glasses empirically, just as has been attempted by means of chemical analysis.

The first experiments with glasses melted under controlled laboratory conditions suggest that time and temperature of melting do not drastically effect δ of the resultant glasses, but that δ depends primarily upon the O^{18} contents of the original ingredients. Some typical values for the glasses are shown in Figure 15.

Another publication on this topic is now in press. "Lead and Oxygen Isotopes in Ancient Objects," by Robert H. Brill. A lecture presented at, "The Impact of the Natural Sciences on Archaeology," London, Dec. 12, 1969. (Co-sponsored by the Royal Institution and the British Academy.)

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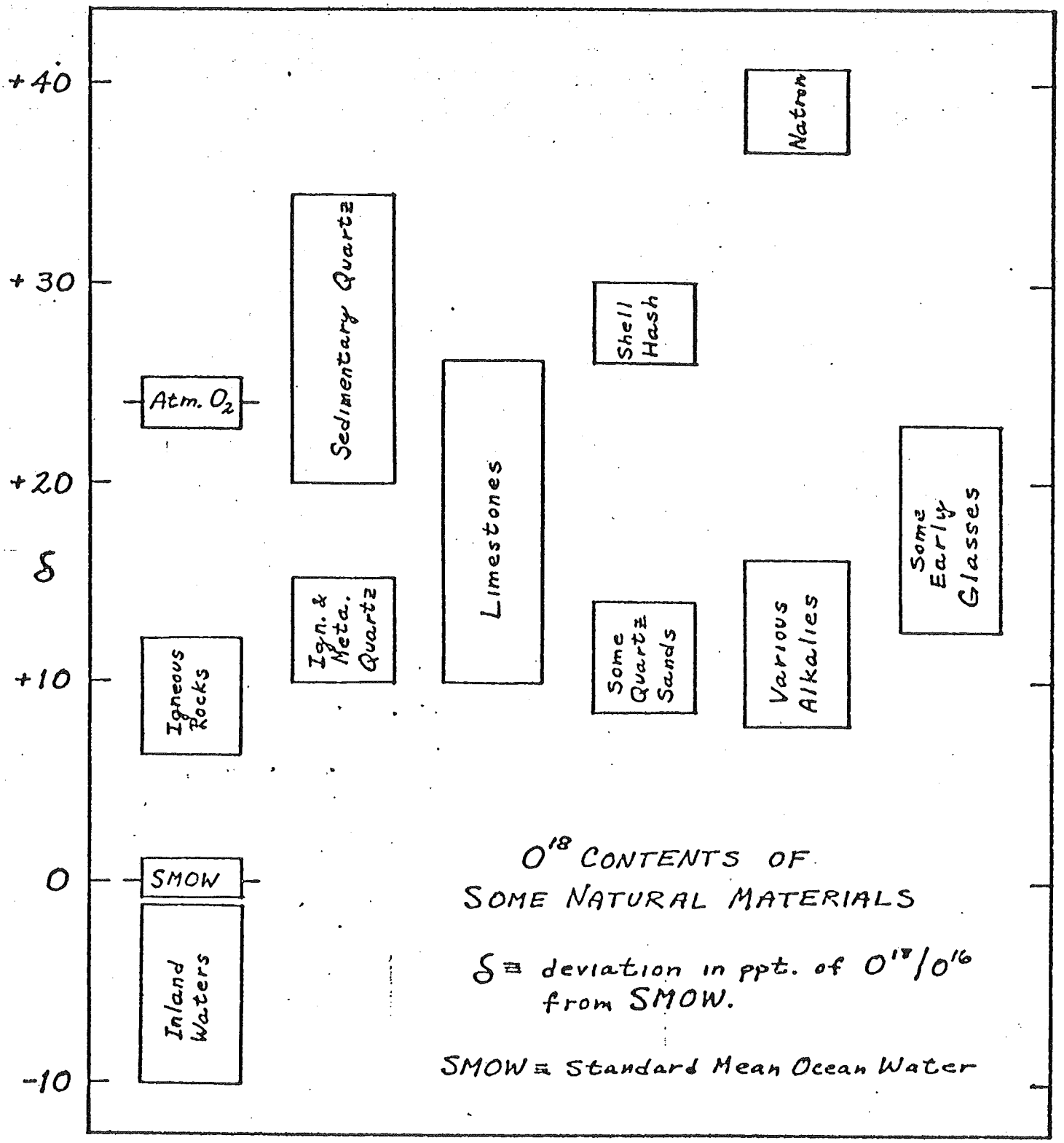

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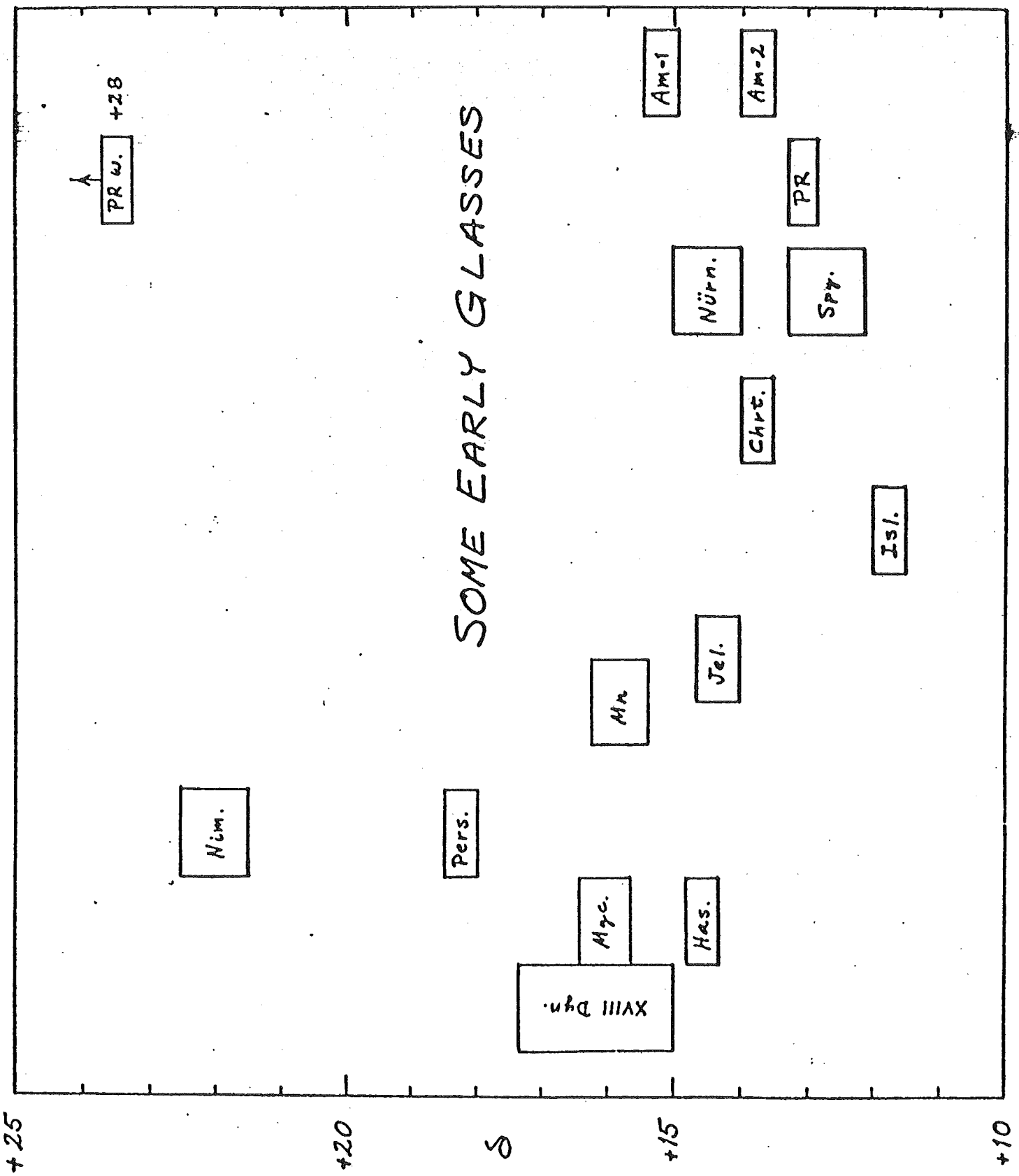

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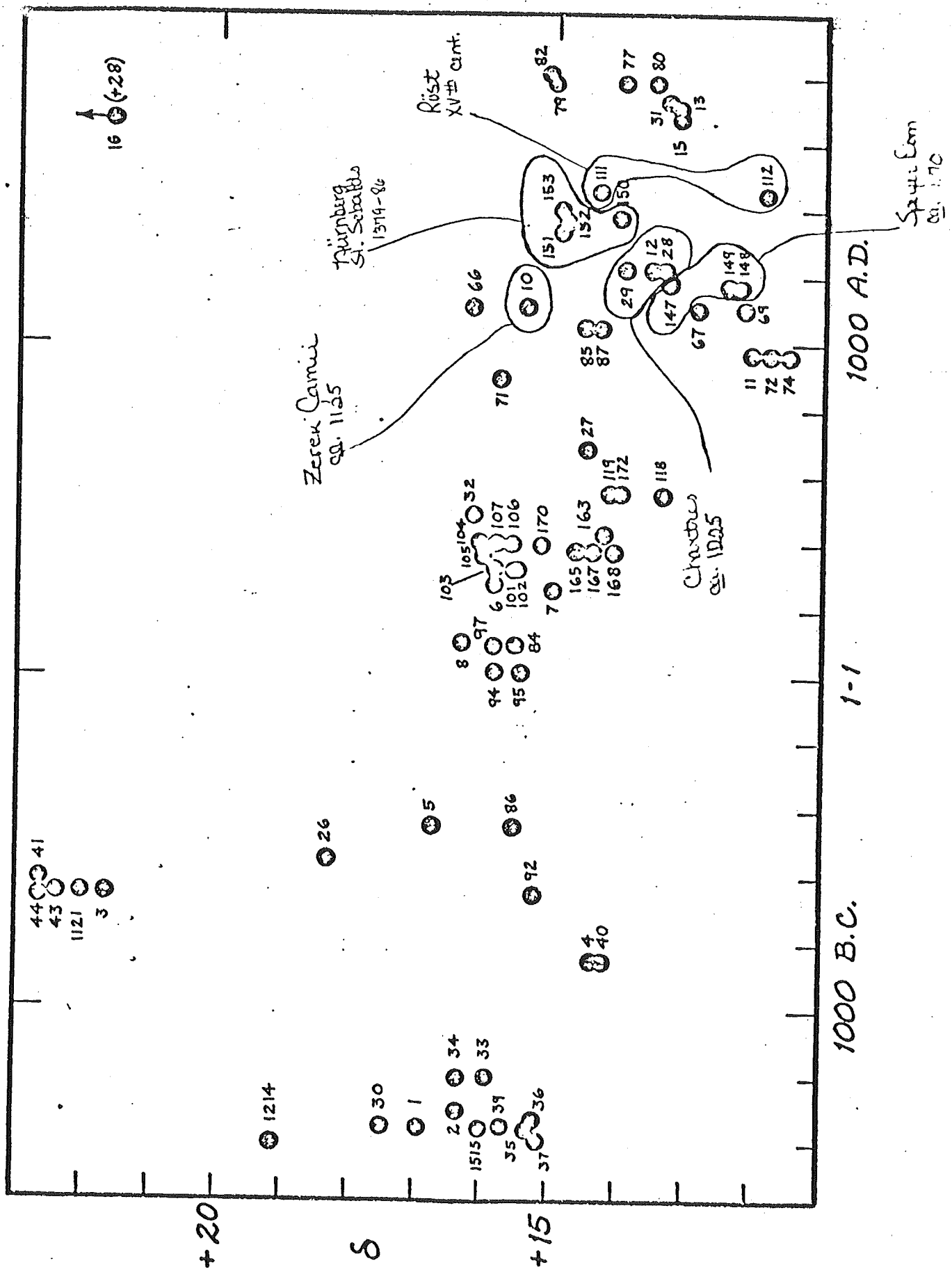

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