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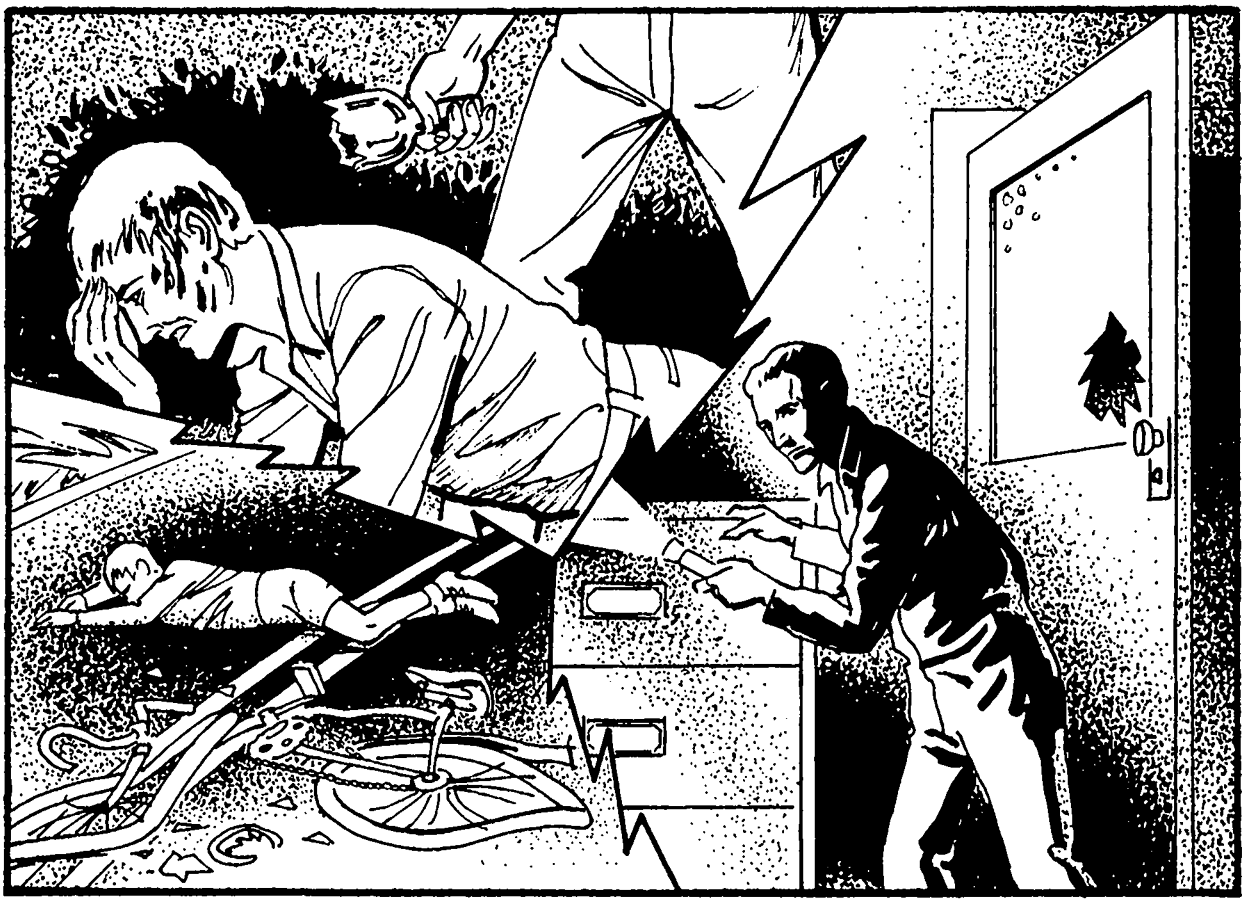
IDENTIFICATION OF SMALL GLASS FRAGMENTS FOR FORENSIC PURPOSES



By K.W.Terry, A.van Riessen and B.F. Lynch

20746-8-83

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PREFACE

This publication forms the final report of the Criminology Research Council project 9/80 entitled "The Identification of Small Glass Fragments for Forensic Purposes". The project was funded over a two year period from August 1980 to August 1982 with grants totalling $15,949.

The aim of the project was to implement a rapid and sensitive non-destructive method, based upon a scanning electron microscope, for the identification and comparison of small glass fragments. Full details of the various facets of the research programme have been recorded in two annual reports to the Criminology Research Council (Terry, van Riessen and Lynch 1981, 1982). These topics are listed in Appendix A of this report. This final report attempts to give an overall view of glass, glass analysis and the uses to which the analyses may be put. It is hoped that this will be of interest to law enforcement personnel and others in the criminal justice area as well as forensic scientists.

The three principal investigators have been Dr. K.W. Terry, Mr. A. van Riessen (both from the School of Physics and Geosciences, Western Australian Institute of Technology) and Mr. B.F. Lynch (Forensic Chemistry Division, Government Chemical Laboratories, Perth). Dr. K.W. Terry has acted as project leader but each of the principal investigators have been responsible for a clearly defined area of the programme as follows:

Mr. B.F. Lynch	Glass information, museum collection and cataloguing, chemical analysis, RI, comparitive glass analysis.
Dr. K.W. Terry	Electron induced analysis in the SEM, statistical analysis of the glass data.
Mr. A. van Riessen	X-ray induced elemental analysis in the SEM.

The salary component in the grant for a half-time graduate research assistant has been used to second David J. Vowles, Chief Technician, School of Physics and Geosciences, to the project for the two years.

We acknowledge the valuable contributions made to the project by the following people. Mr. D.J. Vowles for his dedicated assistance in all aspects of the project; Mr. N.G. Ware (A.N.U.) for his assistance in providing and help in installing his PIBS program; Dr. D.W. Reid and Ms. J. Posner (School of Mathematics and Computing) for their assistance in setting up the software system to enable the glass data to run on SPSS and CLUSTAN; Mr. A. Planken for his workmanship in constructing the two thin foil devices and other mechanical components; Ms. D. Hollingsworth for typing the manuscript.

We also acknowledge the cooperation of Pilkington ACI in providing samples, technical and commercial information. Finally we thank the Criminology Research Council for their financial support for the two years of funding.

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CHAPTER 1
INTRODUCTION

The term glass in its widest context refers to a physical state rather than to a composition. Glass is considered to be a non-crystalline solid which can be either inorganic or organic. The common usage of the term however implies an inorganic composition and an appropriate definition is that of the American Society for Testing and Materials (1978) which defines glass as "an inorganic product of fusion which has cooled to a rigid condition without freezing". To most people the term glass has an even narrower meaning which usually implies silicate glass. Silicate glasses are based on SiO_2 and may be modified by the addition of various agents to the melt to produce a number of basic types. The silicate glasses include soda-lime silica glass (by far the most common), borosilicate glass, aluminosilicate glass and lead silicate glasses. These groups can be further modified using such agents as MgO, PbO, Al_2O_3, BaO, K_2O, B_2O_3, Fe_2O_3, As_2O_3 and others. The non-silicate systems are very specialised glasses not in common use and would be easily identified but would be most unlikely to arise in a forensic context.

To any observer, glass is a very widely used commodity finding applications in buildings, containers, motor vehicles, electronics, lighting, tableware, cookware, scientific equipment and so on. A review of the sources and uses of glass in Australia is given in Chapter 2. The occurrence of glass fragments as physical evidence of crime is very probable from a wide variety of incidents, such as vandalism, breaking and entering offences, hit-run 'accidents' and assaults. In cases involving broken windows for example, it has been shown by Nelson and Revel (1967) that in addition to glass fragments being ejected in the direction of the breaking blow, glass fragments are also ejected in a backwards direction up to approximately 3 metres. Pounds and Smalldon (1978) have studied the deposition and distribution of such particles on the person of subjects standing nearby windows which were experimentally broken. Particles were recovered in greatest abundance from the surface of jackets and the hair. Few particles were recovered from subjects which exceeded 1 mm in size and most were in the size range 0 - 0.2 mm. Interestingly, the subjects involved in these experiments were totally unaware that any glass particles had landed on them. In another paper, Pounds (1977) showed that although tiny fragments may persist on clothing for a considerable time, particles $\geq$ 1 mm persist for only very short periods. In addition to glass particles being deposited by back fragmentation, there is also the probability of the criminal accumulating glass fragments in clothing or footware during subsequent entry to the premises. Clearly, the necessity in forensic glass analysis is to be able to analyse, preferably non-destructively, very small samples.

The major area of our work has been to commission techniques based on a scanning electron microscope equipped with an energy dispersive x-ray spectrometer. This enables accurate elemental analyses on small fragments to be obtained with little sample preparation or destruction. The initial technique was to use the conventional method of elemental analysis in a SEM/EDS system whereby the electron beam induces x-ray fluorescence of the sample. The second technique was a recently reported method (Gould and Healey, 1975) in which an x-ray beam is generated within the SEM and then used to fluoresce the sample. The two techniques are complementary and have great significance to glass analysis. This is due to the electron beam technique, with $\geq$ 1000 ppm detection limits, being most sensitive for low atomic number elements typical of the major and minor elements in glasses, while the x-ray beam technique, with its $\geq$ 30 ppm detection limits, being most sensitive for higher atomic number elements, typical of the trace elements in glasses. The details of these analytical techniques are documented in Chapter 3. A collection has been made of 177 samples of glasses used within Australia which includes both locally produced and imported glasses. Quantitative elemental analyses of the glasses have been obtained using the electron induced method together with qualitative elemental analyses using the x-ray induced method. These analyses are presented in Appendices B and C.

The ubiquity of glass gives rise to the possibility of mistaking glass particles found on clothing in connection with a crime for those which might be there purely by chance. This problem was highlighted by Pearson, May and Dabbs (1971) when they examined 100 suits, obtained from a dry cleaning agency, for the presence of glass fragments. They found in 63 of these suits a total of 551 glass particles exceeding 0.1 mm in size. It is most essential therefore to be able to discriminate between different glass particles. Traditionally, the discrimination techniques are based on refractive index and/or density and these measures are usually quite effective. There exists however, the possibility that from a combination of effects, glasses with quite different compositions can have the same refractive index or density. An important goal in the study has been to evaluate the usefulness of elemental analyses obtained in the scanning electron micro-scope for discerning whether glass particles are closely related types. Details of this are presented in Chapter 4.

In many investigations, glass analyses are requested for fragments found at a crime scene but for which no comparison sample is available. In these cases a glass identification or classification is required. A statistical analysis of the quantitative elemental analyses and the refractive indices of all the glasses has been undertaken using the Statistical Package for the Social Sciences (SPSS) package by Nie (1975), in particular using DISCRIMINANT, and then with the CLUSTAN 1C package by Wishart (1978). These procedures and the subsequent findings are presented in Chapter 5.

The final aspect of the work has been to assess the usefulness of the various techniques developed to forensic case studies that involve glass fragments. In Chapter 6 the details of 9 case studies involving a total of 27 glass fragments are presented.

CHAPTER 2
SOURCES AND USES OF GLASS IN AUSTRALIA

Throughout the Western world there are some 538 companies listed in the Glass Industry Directory (1981) which manufacture glass or glass products starting from melting the raw ingredients. Needless to say, there are many further glass making facilities in Eastern bloc countries. There are also a large number of companies who do not melt glass, but further process purchased glass. In Australia, we have relatively few primary glass making companies. They include the following :

i) Pilkington ACI which has a float glass plant at Dandenong, Victoria,and a plant for producing decorative figured rolled glass, wired cast glass, wired rolled glass and wired plate glass at Alexandria, New South Wales. Most of the products of these plants find use in the building industry, however some Australian float glass is further processed into windscreens and other products.

ii) Australian Consolidated Industries (ACI) which has glass making plants in each Australian state for the manufacture of glass containers in flint, amber and green colours.

iii) Glass Containers Ltd. with a plant at Penrith, NSW, for the manufacture of single use and returnable beer and beverage containers, food, milk and other containers.

iv) Crown Corning with a plant at Waterloo,NSW, for the manufacture of domestic glassware, decorative giftware, glass tumblers for food packaging, glassware for the hotel industry and scientific products.

In addition there are a number of small concerns at Newcastle, NSW, for making specialised glasses such as light globes, lightingware and TV tubes.

The companies mentioned above produce the majority of glass in common use in Australia but there is a significant number of imports. The Australian Bureau of Statistics tabulates in its overseas trade statistics the imports of glass and glass products in terms of the source country, quantity and monetary value. Table 2.1 shows categories of glass imports extracted from this source for 1979.

TABLE 2.1: AUSTRALIAN GLASS IMPORTS
(Source: Australian Bureau of Statistics, 1979)

GLASS COMMODITY	SOURCE COUNTRY*
Glass in the mass, waste glass (Cullett)	Nil
Glass tubes unworked	3,9,10,16,31,32
Glass balls, rods unworked	10,31,32
Blanks for corrective spectacle lenses	31,32
Optical glass elements, not optically worked	10,16,31,32
Clear sheet glass	3,5,10,13,16,17,19,21,22,25,26,31
Coloured sheet glass excluding grey	9,10
Grey sheet glass	3
Wired plate glass	16,31
Plate glass	10,15,16
Clear float glass	9,10,15,24,31,32
Bronze float glass	3,10,15,24,25,31,32
Grey float glass	3,10,15,24,31,32
Green float glass	4,32
Other float glass	10,15,24,31,32
Cast, rolled, drawn or blown glass, surface polished	9,10,16,19,31
Figured, rolled cathedral etc. uncoloured	3,10,16,22,25
Figured, rolled cathedral etc. coloured	3,10,16,31
Wired coloured	3,10,16,31
Wired uncoloured	3,10,16,22,25
Other cast, rolled glass	10,28,32
Safety glass for motor vehicles, laminated windscreens	10,16,24,31,32
Safety glass for motor vehicles, toughened glass	10,16,26,31,32
Other safety glass for motor vehicles, laminated	10,16
Other safety glass for motor vehicles, toughened	4,10,15,16,26,31,32
Safety glass, laminated	2,3,10,16,18,24,28,31,32
Safety glass, toughened	3,22,25,28,31,32
Mirrors	5,10,11,14,15,16,17,19,24,26,31,32
Multiple walled insulating glass	10,24,31
Single glazed tinted glass	16,31
Clock, watch glasses, etc.	10,16,27
Containers, less than 284 ml	3,6,7,9,10,12,15,16,17,18,25,27,31,32
Containers, 284-567 ml	9,16,19,31,32
Glass containers for beverages	9,15,19,31
Other glass containers	9,15,18,19,31,32

GLASS COMMODITY	SOURCE COUNTRY*
Heat resistant glassware for cooking	2,9,11,17,28,31,32
Drinking glasses, stemware, toughened	2,6,7,9,10,15,16,18,26,31,32
Drinking glasses, stemware, non-toughened	2,5,6,7,8,9,10,14,15,16,17,18,22,25,26, 28,31,32
Drinking glasses excluding stemware, toughened	1,4,6,7,9,10,15,16,19,25,26,28,31,32
Drinking glasses excluding stemware, non-toughened	1,4,5,6,7,8,9,10,14,15,16,17,19,22,25, 26,28,30,31,32
Drinking cups, saucers and plates, glass	1,2,4,6,8,9,10,15,16,17,18,20,26,28,30, 31,32
Table and kitchen articles of glass	2,3,4,54,6,7,8,9,10,11,14,15,16,17,19, 20,22,23,25,26,27,28,29,30,31,32,34
Other domestic articles of glass	2,4,6,7,8,9,10,11,14,15,16,17,18,19,22, 23,25,26,27,29,31,32
Glass ampoules	10,15
Microscope slides	3,5,10,11,17,27,32
Laboratory glassware	3,5,6,7,9,10,12,16,18,19,27,31,32
Hygienic pharmaceutical glassware	3,7,10,16,31,32
Imitation jewelry	2,6,10,15,16,27,32
Glass fragments etc. for mosaics and decoration	10,31,32
X-ray protection glass	10
Bricks, slabs, tiles etc. of pressed or moulded glass	10,15,31
Filament lamps, general lighting service	3,4,10,15,16,18,31,32
Lamp bulbs, automotive	4,9,10,16,18,28,31,32,34
Lamp bulbs, aircraft and marine	32
Lamp bulbs, projection	3,10,16,18,31,32
Other lamp bulbs	2,4,10,11,12,16,18,31,32
Sealed beam headlights	4,9,10,16,26,31,32

* 1. Argentina; 2. Austria; 3. Belgium-Luxembourg; 4. Canada; 5. China; 6. Czechoslovakia; 7. Denmark; 8. Finland; 9. France; 10. Germany; 11. Hong Kong; 12. India; 13. Indonesia; 14. Ireland; 15. Italy; 16. Japan; 17. Korea; 18. Netherlands; 19. New Zealand; 20. Norway; 21. Philippines; 22. Poland; 23. Portugal; 24. South Africa; 25. Spain; 26. Sweden; 27. Switzerland; 28. Taiwan; 29. Thailand; 30. Turkey; 31. United Kingdom; 32. United States of America; 33. Yugoslavia; 34. Hungary.

So far as forensic casework is concerned, the most important glass products are those derived from clear flat glass, which are used in windows, shopfronts, other building products, furniture and windscreens. The most common flat glasses are available in three types which vary in quality, quantity and price.

By far the most important flat glass now available is float glass. The float process is the latest technology for flat glassmaking and produces distortion free glass having perfectly flat, parallel surfaces with a bright fire polished finish. Float glass was invented by and first manufactured commercially by Pilkingtons in 1959 in the UK. Pilkington ACI first began manufacturing float glass in Australia in 1974. Float glass is also imported into Australia from countries as shown in Table 2.1. Table 2.2 shows the quantity of import compared to locally manufactured product based on 1979 figures.

Prior to 1974, Australian clear flat glass was manufactured by the drawn sheet process at plants at Alexandria, NSW and Dandenong, Victoria. With the introduction of float glass, sheet glass ceased being manufactured at Dandenong and in 1976 also ceased at Alexandria. As shown in Table 2.1, sheet glass is still imported from numerous countries. The quantities imported are shown in Table 2.2 and are compared with local and imported float glass.

TABLE 2.2: IMPORTED AND LOCALLY MADE FLAT CLEAR GLASS (1979)

Product (Thickness)	*Local Float	Imported Float	Imported Sheet
	- - - - - -	square metres	- - - - -
Less than 3 mm	1 487 200	307 336	223 909
3 mm - 4 mm	4 088 267	463 278	901 661
5 mm	1 825 840	52 094	76 897
6 mm - 7 mm	1 028 066	289 290	23 619
Greater than 7 mm	15 100	58 627	635

* Based on tonnages supplied by Pilkington ACI assuming density 2 500 kg/m^3

Figures 2.1 and 2.2 show trends for the import of float and sheet glass commodities into Australia during the period 1979-1982. These imports appear to fluctuate widely, however they are at such a level as to be a significant source of possible variability in forensic casework samples.

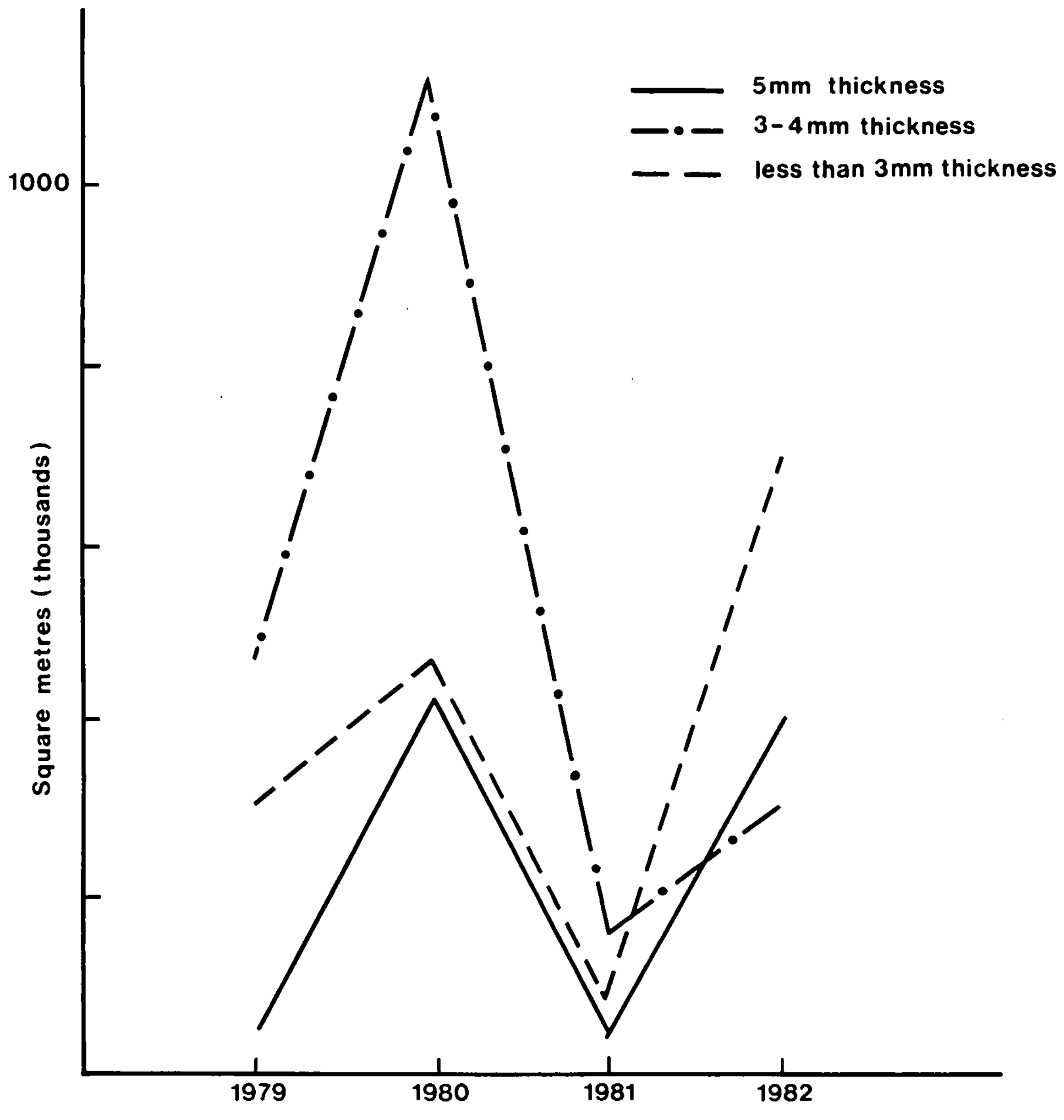


Figure 2.1 Import trends for imported clear float glass commodities (data extracted from Australian Bureau of Statistics overseas trade figures)

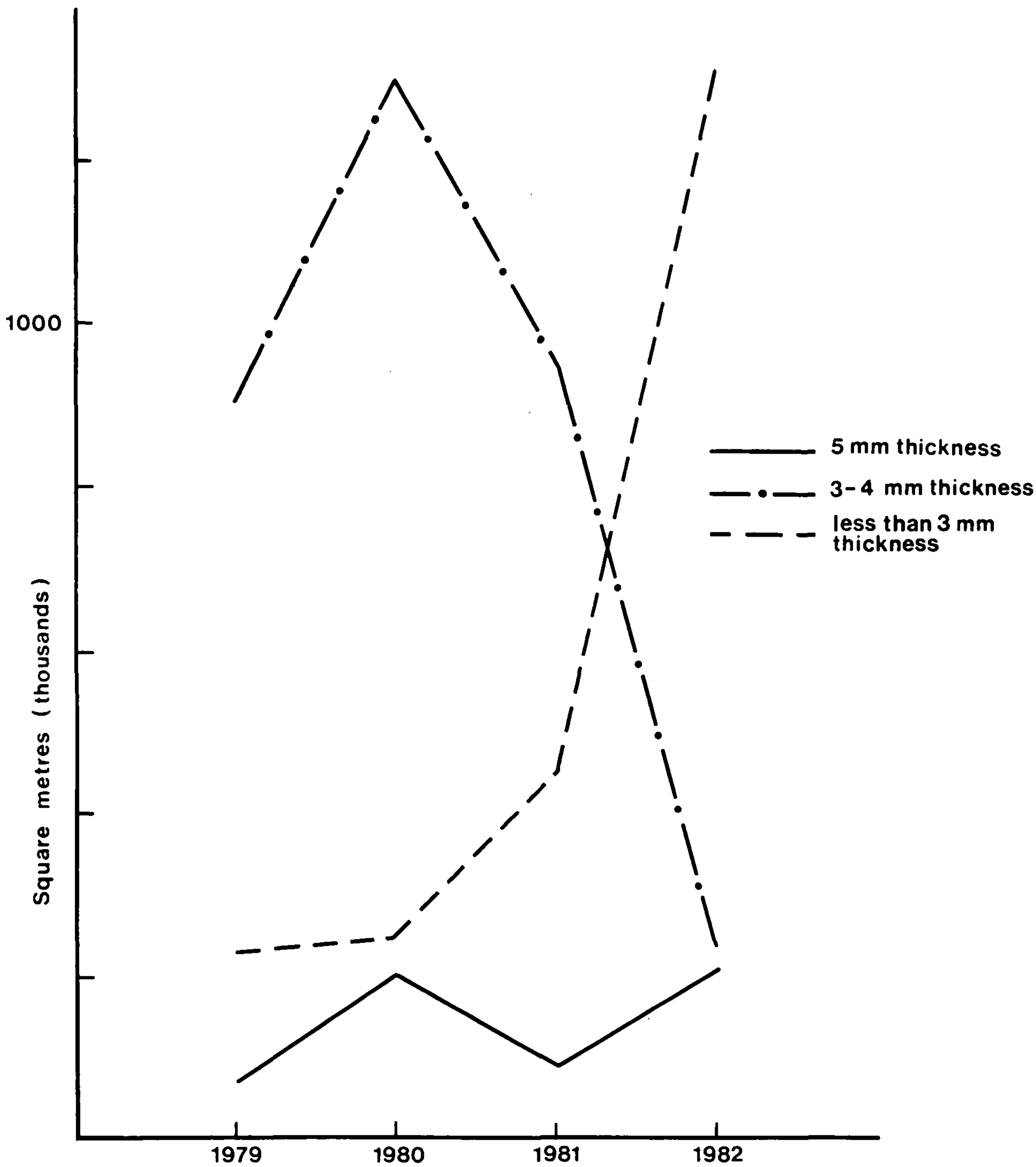


Figure 2.2 Import trends for imported clear sheet glass commodities (data extracted from Australian Bureau of Statistics overseas trade figures)

The remaining flat glass type in common use in Australia is rolled glass which is manufactured at Alexandria NSW by Pilkington ACI. In this process glass in a molten state is passed between two rollers, one of which usually has a pattern on it so that the resulting sheet is patterned on one side and plain on the other. Clear unpatterned glass is also produced with this process by using two plain rollers. Glass of this type is used where only low quality optical properties are required for such applications as horticulture. In fact glass of this type bears the trade description "Horts". Table 2.3 shows comparative import and locally manufactured production levels for 1979.

TABLE 2.3: IMPORTED AND LOCALLY MADE PATTERNED ROLLED GLASS (1979)

Product (Thickness)	*Local	Imported
	- - square metres - -	
Clear less than 5 mm	393 066	86 372
Clear 5 mm and above	326 653	25 106
Coloured less than 5 mm	84 799	121 270
Coloured 5 mm - 6 mm	66 213	48 111
Coloured greater than 6 mm	8 680	13 458

* Based on tonnages supplied by Pilkington ACI assuming a density of 2 500 kg/m^3.

The next most important glass product so far as forensic casework is concerned is windscreen and automotive glass products. Windscreens are manufacturedat Geelong, Victoria using Australian and imported flat glass. Table 2.4 shows comparative figures for imported and locally produced windscreens.

TABLE 2.4: WINDSCREENS FOR MOTOR VEHICLES LOCALLY PRODUCED AND IMPORTED (1979)

	Locally Produced	Imported
Toughened	200 385	14 734
Laminated	272 306	38 540

Headlamp glasses usually come from sealed beam headlights and in most cases they are made of borosilicate glass. All headlamps appear to be imported from countries as shown in Table 2.1.

The remaining major category of glass which is frequently considered in forensic casework is container and tableware glass. Glass is very widely distributed in the environment and broken or disused containers and/or tableware account for a large proportion of this. Particles of these glasses are most likely to be "naturally" present on articles of clothing etc. As mentioned earlier, the vast majority of container glass in use comes from Australian container glass plants located in all Australian states. As Table 2.1 shows however, there are imports from many countries. Table 2.5 shows quantities of these glass items imported.

TABLE 2.5: IMPORTED CONTAINER AND TABLEWARE ITEMS (1979)

Item	Number Imported (thousands)
Pharmaceutical, toiletry and cosmetic containers, < 284 ml	117 030
Other glass containers < 284 ml	74 454
Glass containers 284 ml - 567 ml	9 085
Glass containers for beverages	7 491
Other glass containers	13 334
Tableware and kitchenware glass items	54 020

CHAPTER 3
ANALYTICAL TECHNIQUES

3.1 Introduction

The approach in this project has been to analyse quantitatively for the major and minor elements that constitutes the glass network formers and glass modifiers together with a qualitative assessment of the trace elements. This has been achieved using a scanning electron microscope equipped with an energy dispersive x-ray spectrometer. Results from conventional electron induced XRF are supplemented with those obtained from an x-ray induced XRF method that has been developed in our JEOL JSM 35C (van Riessen and Terry, 1981, 1982).

Refractive index determinations of each glass sample was also carried out and used together with the elemental analyses to determine discrimination of pairs of glasses or to help in classifying a glass according to use.

3.2 Experimental

3.2.1 Refractive Index Determination

The refractive index of each glass sample was determined using a Mettler FP5 heating stage controlled by a Mettler FP52 temperature programmer in conjunction with an optical microscope. This equipment is shown in Figure 3.1a.

Fragments of each glass were immersed in Dow Corning DC 710 silcone oil and the mean temperature obtained of the disappearance and reappearance of the Becke line in sodium light. Reference to the calibration chart for the oil, provided the value of the refractive index.

Equipment used to determine refractive index allows the temperature to be read to 0.5^0C, this in turn is reflected in an uncertainty in the refractive index of $\pm$ 0.0002, after using the appropriate calibration curve.

Samples of known refractive index used to check the technique provided either perfect matches or values within 1 in 10^4 of the accepted value.

3.2.2 Sample Preparation

Once the refractive index was determined, each piece of glass was mounted in a 12.5 mm diameter acrylic tubing. The sample was then ground and polished prior to being coated with a vacuum evaporated thin film of carbon. The glass fragments in this form are still available as a court exhibit if necessary. Figure 3.1b shows the full set of glass museum samples as prepared for elemental analysis in the SEM.

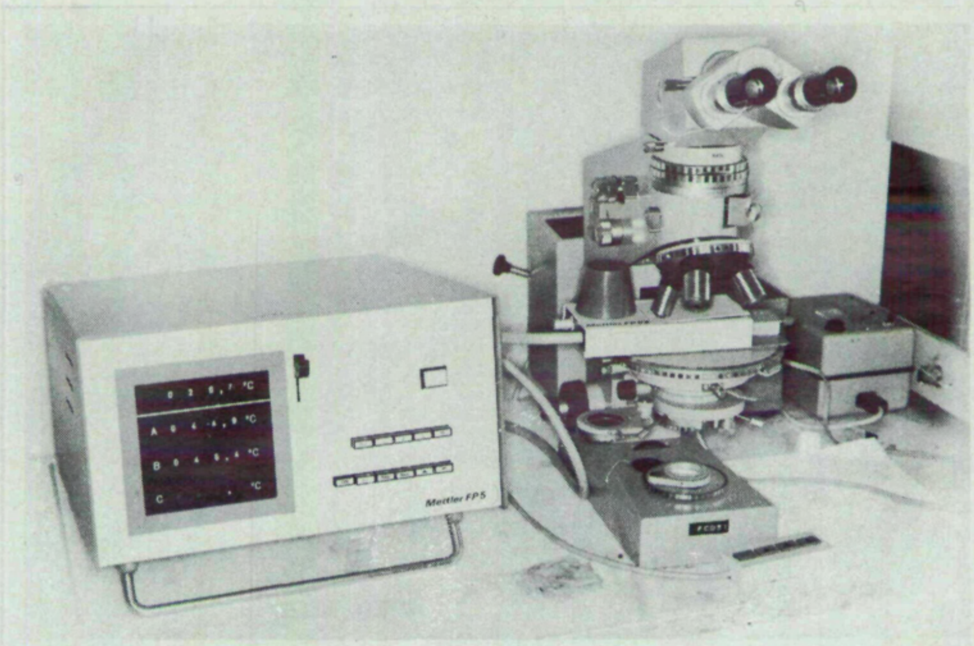


Figure 3.1 (a) Mettler FP 5 programmer, FP 52 Heating stage and microscope used for refractive index measurement

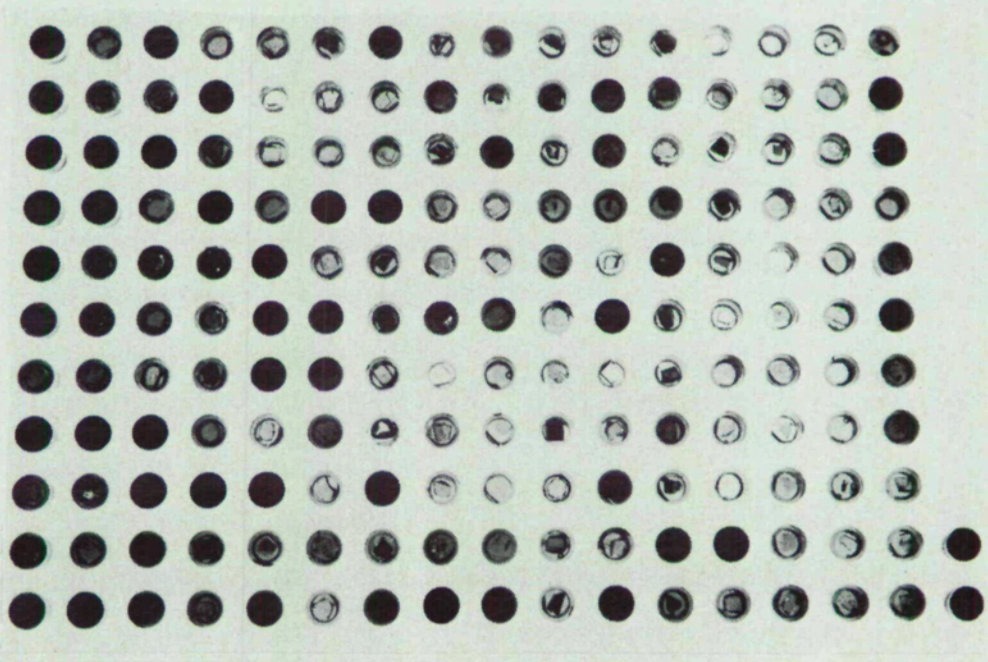


Figure 3.1 (b) Glass museum samples prepared for elemental analysis in the S.E.M.

3.2.3 Scanning Electron Microscopy and Energy Dispersive X-ray Spectrometry

(i) Electron Induced

The elemental analyses have been carried out using a JEOL JSM 35C scanning electron microscope equipped with an United Scientific lithium drifted silicon detector and asociated electronics (Figure 3.2a). The spectra are accummulated in a Tracor Northern TN 1705 multi-channel analyser (MCA). The adopted procedure for elemental analysis is to use 20 kV and 5×10^{-10} amps at normal incidence onto a 40 x 40 m raster on a polished sample and a detector take-off angle of 35° (see Fig 3.3a). A typical count rate of 5 kcps is obtained. The spectra are collected in the MCA for 50s live time and are then stored on a stereo cassette for subsequent batch processing on a PDP 11/10 computer. The elemental analysis is then computed using the peak integration with background subtraction (PIBS) technique of Ware (1981). The current program provides for an elemental analysis for Na, Mg, Al, Si, P, Cl, S or Pb, K, Ca, Ba or Ti, V, Cr, Fe, Mn and Zn expressed as oxides and has a sensitivity down to approximately 0.1%. The full set of data is presented in Appendix B.

Accuracy

The PIBS program of Ware that has been used to calculate the quantitative elemental analysis of each glass requires certain calibration factors to be determined using standard samples. Four glasses from the range of NBS Standard Reference Materials and certain mineral samples have been used to calibrate the program. The mean of the two analyses obtained from each of the four NBS glasses subsequent to the calibration procedure is given in Table 3.1.

TABLE 3.1: MEAN ANALYSES OF NBS STANDARD GLASSES COMPARED TO THEIR QUOTED COMPOSITIONS IN WT.%

GLASS		Na2O	MgO	Al2O3	SiO2	SO3	K2O	CaO	Fe2O3
NBS 621	STD	12.71	0.27	2.77	71.14	0.13	2.01	10.71	
	MEAN	12.8	0.3	2.8	71.3	0.2	2.0	10.7	
NBS K411	STD		14.67		54.3	0.0		15.47	14.42
	MEAN		14.8		55.2	0.1		15.4	14.5
NBS K412	STD		19.33	9.27	45.35			15.29	9.96
	MEAN		19.3	9.7	45.9			14.9	10.0
NBS 620	STD	14.4	3.6	1.8	72.1	0.0	0.4	7.1	
	MEAN	14.5	3.6	1.8	72.2	0.3	0.4	7.0	

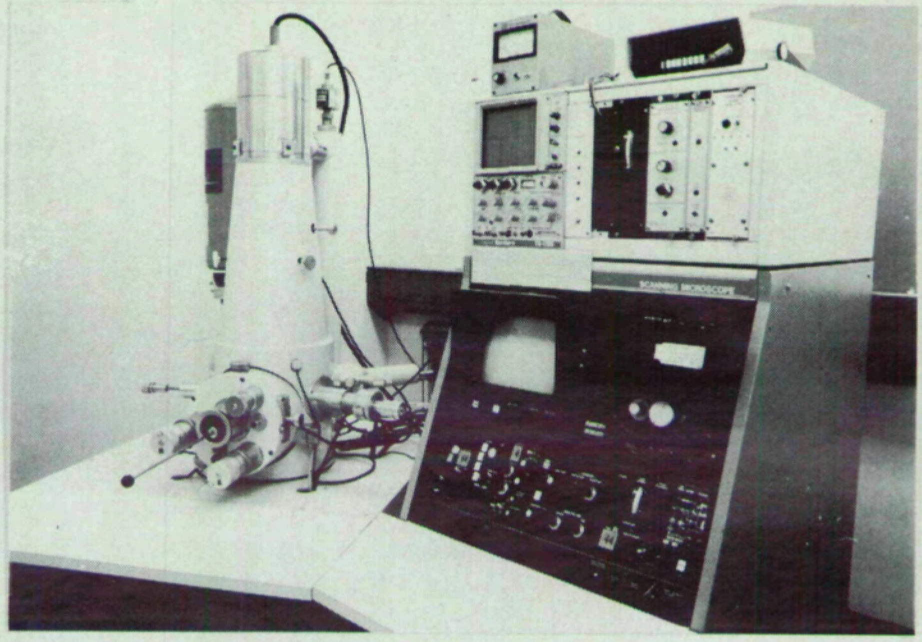


Figure 3.2 (a) JEOL JSM 35 C Scanning Electron Microscope and energy dispersive X-Ray analysis equipment.

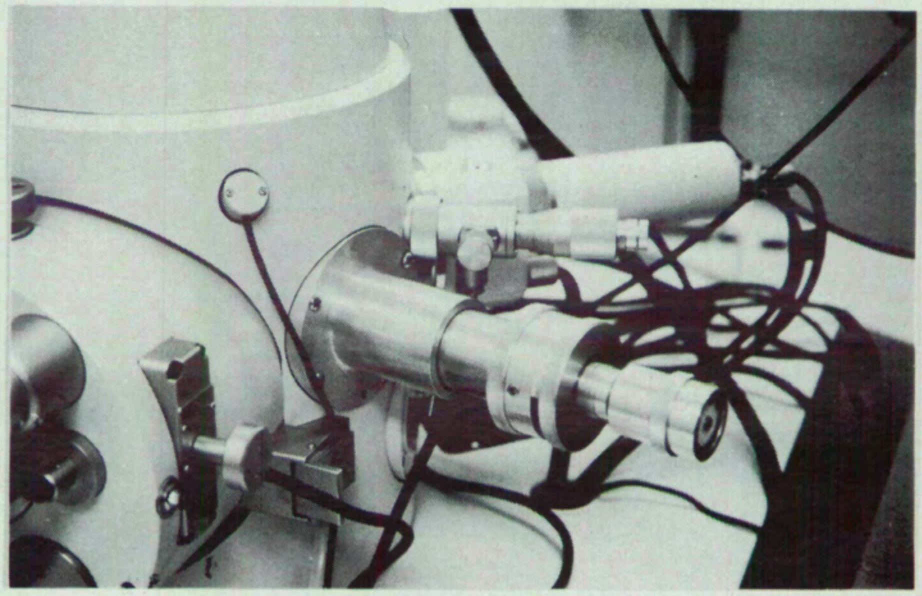


Figure 3.2 (b) Control for manipulating the thin foil device in place on the column of the S.E.M.

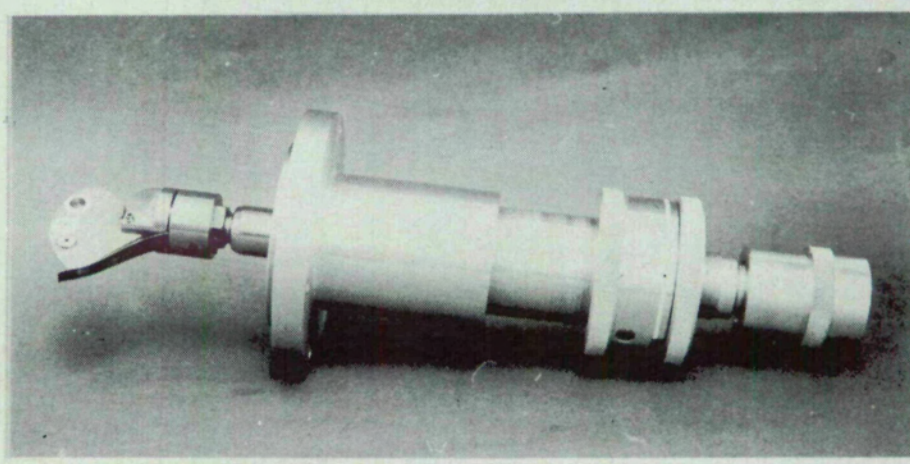


Figure 3.2 (c) Thin Foil Device.

Precision

The duplicate analyses of the 134 glass museum samples has taken place over a period of three months. During each analysis session NBS glass SRM 621 has been included as an internal control. The precision of the fifteen sets of data over this period is presented in Table 3.2. The resulting mean and standard deviation indicates a satisfactory level of performance of the technique.

TABLE 3.2: PRECISION OF RESULTS ON GLASS NBS 621 OVER THREE MONTHS IN WT.% (Electron induced technique)

	Na2O	MgO	Al2O3	SiO2	SO3	K2O	CaO
STANDARD NBS VALUE	12.7	0.27	2.77	71.14	0.13	2.01	10.71
EXPERIMENTAL MEAN (N=15)	12.6	0.2	2.8	71.3	0.1	2.0	10.8
STANDARD DEVIATION OF MEAN	0.3	0.1	0.1	0.3	0.1	0.0	0.2

(ii) **X-ray Induced**

The x-ray induced method that has been adopted is to focus the electron beam (obtained from using 39kV and 200nA) onto a silver foil of 10 μm thickness which acts as a transmission x-ray target (see Fig. 3.3b). The resultant primary x-ray beam, impinging on the sample, consists of the characteristic silver peaks and associated Compton peaks together with a continuum that has been self-filtered by the foil. Figure 3.2b shows the thin foil device in place on the column of the SEM, while the thin foil device itself is presented in Figure 3.2c. The incident primary x-ray beam causes secondary x-ray fluorescence in the sample so that characteristic x-rays of the elements in the sample are subsequently detected in the Si(Li) detector. With the sample tilted and rotated to directly face the x-ray detector the x-ray spot size on the sample is an ellipse with dimensions of approximately 1.5 x 2.5 mm. The technique inherently has a very low background so that sensitivities of better than 30 ppm are achieved for certain elements.

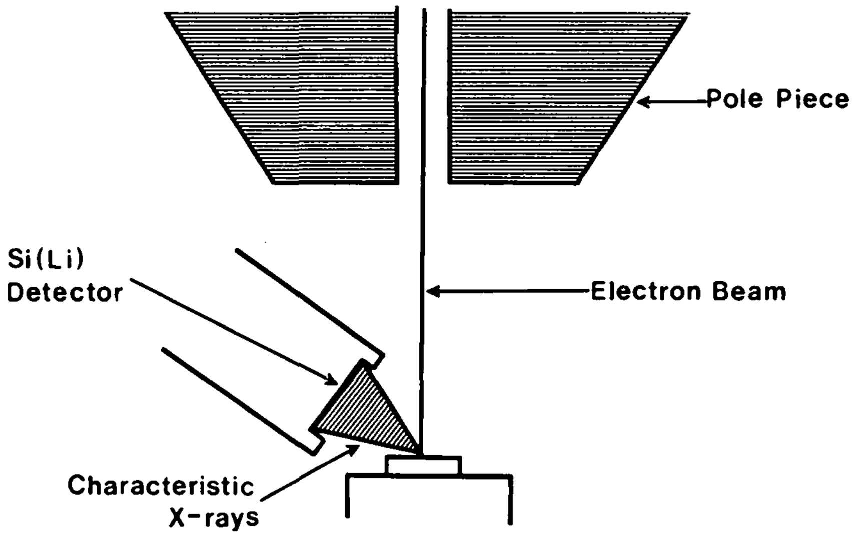


Figure 3.3(a) Schematic diagram of electron induced technique

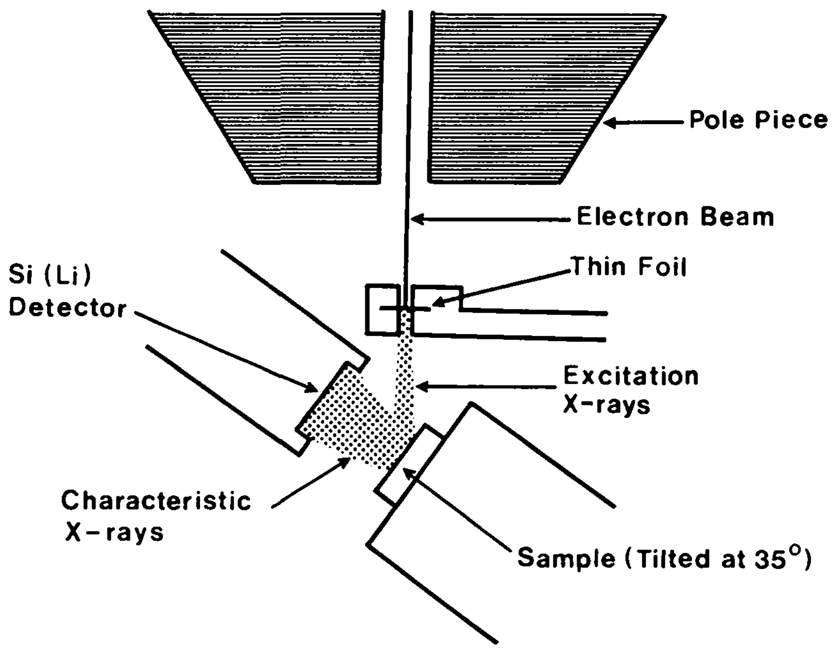


Figure 3.3(b) Schematic diagram of x-ray induced technique

Although better minimum detection levels are achieved considerably longer counting times (typically 1000s) are required to accumulate sufficient counts. Peak minus background counts extracted from spectra provide qualitative information regarding the amount of a particular element present in the sample. The full set of data is presented in Appendix C.

In glass analysis the x-ray induced method complements the electron induced method. As is shown in Fig. 3.4, the electron induced method is most sensitive for low atomic number elements, typical of the major and minor elements in glasses, while the x-ray induced technique is most sensitive for higher atomic number elements, typical of the trace elements in glasses.

Accuracy

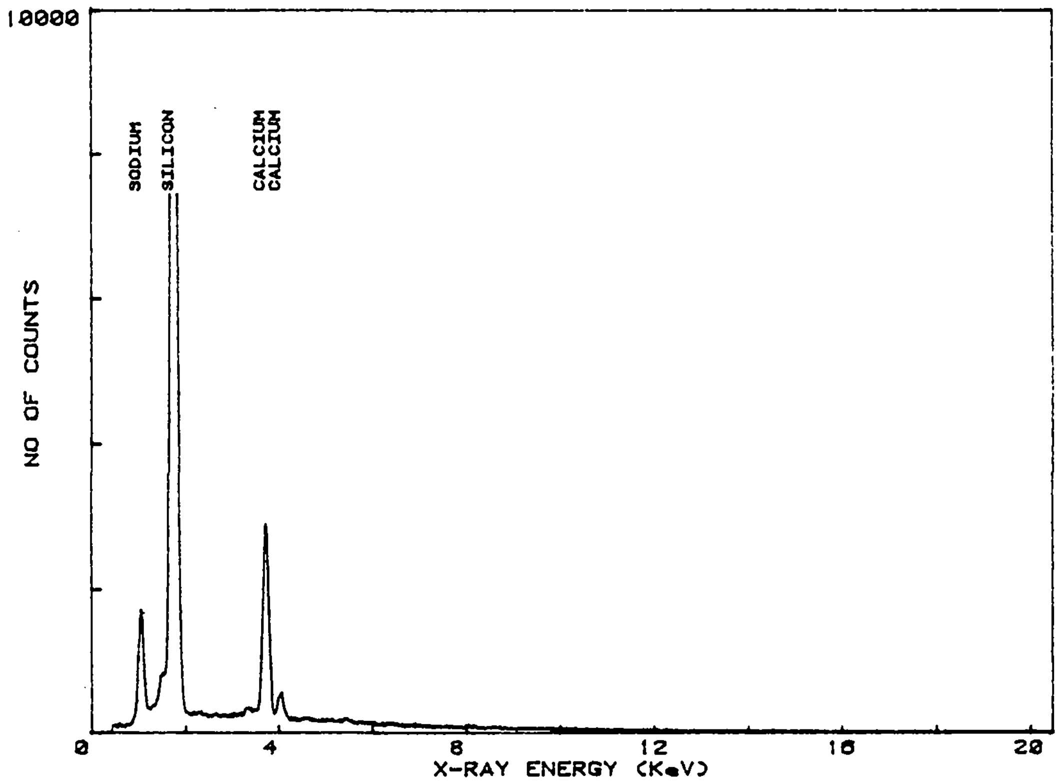
As the x-ray induced work was used in a qualitative fashion, a determination of accuracy for the technique is of little consequence. However, the glass museum samples have been analysed, by atomic absorption, for certain elements and this enables a comparison to be made between the two techniques. Similarly the electron induced and x-ray induced techniques could be compared for common elements. Limited comparisons for SrO between the x-ray induced technique (P-B counts for Sr) and atomic absorption (ppm of SrO) provide a linear relationship with a correlation coefficient of 0.986.

Precision

During the analyses of the 134 glass museum samples, glass NBS SRM 621 was included as an internal control. The precision of twelve sets of data over this period is presented in Table 3.3. The largest standard deviation occurred for iron which has the lowest counts and thus the worst counting statistics.

TABLE 3.3: PRECISION OF RESULTS ON GLASS NBS 621 OVER THREE MONTHS (X-ray induced technique)

	Si	K	Ca	Fe	As	Sr
MEAN (PEAK COUNTS)	404	121	555	50	126	139
STANDARD DEVIATION	29	7.5	31	6.5	13.8	8.6



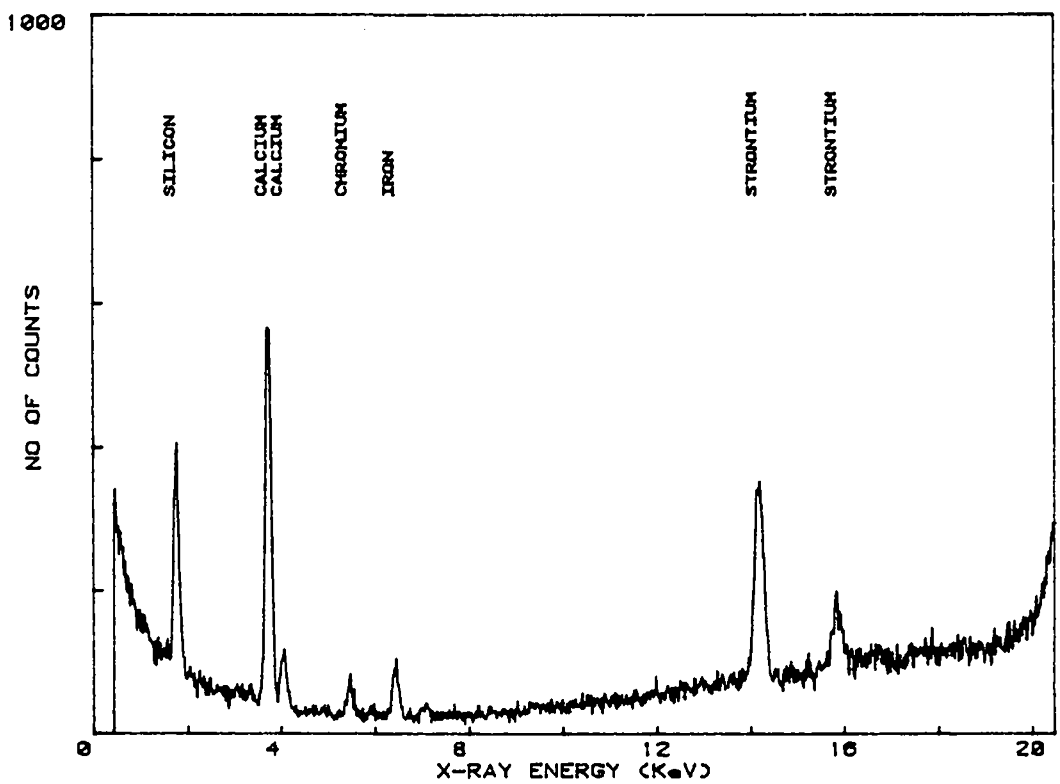


FIGURE 3.4 : TYPICAL X-RAY SPECTRA USING THE ELECTRON AND X-RAY INDUCED METHODS.

3.3 X-ray Induced Elemental Analysis Data

As mentioned previously a full set of data obtained using the thin foil technique is presented in Appendix C. As presented the data is qualitative, although for some elements supporting information from atomic absorption measurements enables semi-quantitative analyses to be made.

During the batch analysis it was apparent that for some elements the choice of accelerating voltage, foil type and foil thickness were not at their optimum values for minimum detection levels. For future case work, where only a few samples at a time would be analysed, the best conditions possible (for elements of interest) would be selected.

Peak minus background counts of 20 different trace elements were made from the glass museum samples. Other elements, constituting the glass network formers and modifiers were present but were not measured as better sensitivity was achieved for these elements using the electron induced approach. Certain elements measured (Fe, Cr and Zn) were detected by both the electron and x-ray induced techniques and acted as a check on the reproducibility of the techniques.

Of most interest were the trace elements, as these could not be observed with the electron induced technique. The detection of these additional elements aided in discriminating between two similar glasses when other approaches had failed (for an example see section 4.5).

The development and trial of the thin foil device has demonstrated the value of the technique in supporting electron induced data. An obvious advantage is the ability to obtain data from both techniques, consecutively, using the same equipment (SEM) on the same sample. The non destructive nature of the technique and its inherent sensitivity for a number of elements augments well for its further use and development in the field of forensic science.

CHAPTER 4
COMPARATIVE GLASS ANALYSIS

4.1 Introduction

A frequent casework requirement is the comparison of glass from a crime scene with glass particles found to be associated with a suspect. Such glass particles are often exceedingly small, examples of which are shown in Figure 4.9. The SEM/EDS technique offers a means by which certain compositional information may be obtained, virtually non-destructively, to supplement other information. In this chapter, quantitative SEM/EDS has been utilised in a two sample comparison in order to determine whether a pair falls within a close class relationship. In making these determinations variability associated with the SEM/EDS measurements is examined.

4.2 Data Analysis

As previously outlined in chapter 3, the quantitative analysis gives the oxide concentration for up to 15 elements. In most instances however only the oxides of sodium, magnesium, aluminimum, silicon, potassium and calcium occur at levels high enough for measurement.

In assessing multiple measurements, the technique proposed by Smalldon and Brown (1980) offers quite a convenient approach. In this treatment, a test parameter R is calculated by obtaining the ratio of an observed difference (D) in concentration to an expected difference (E) in concentration if the samples were from the same origin.

i.e. $$R = \frac{D}{E}$$

which extended to i dimensions becomes

$$R = \sqrt{\sum_{i=1}^{n} \left(\frac{Di}{Ei}\right)^2}$$

The expected differences were determined from 134 duplicate analyses. The observed difference between each duplicate was plotted against the mean of the duplicate. (Figures 4.1 - 6). NOTE: These plots were computer plotted and not all 134 points appear since

(i) in some cases the particular element was not detected, and
(ii) points occurring in a defined area are printed only once.

Certain parts of the scale are non linear to show the range of values.

These plots were tested by regression analysis to determine if any systematic relationship existed between the mean value and the difference between duplicates. No such relationship was detected and it was determined that the mean of the difference between duplicates was a suitable expected difference for each

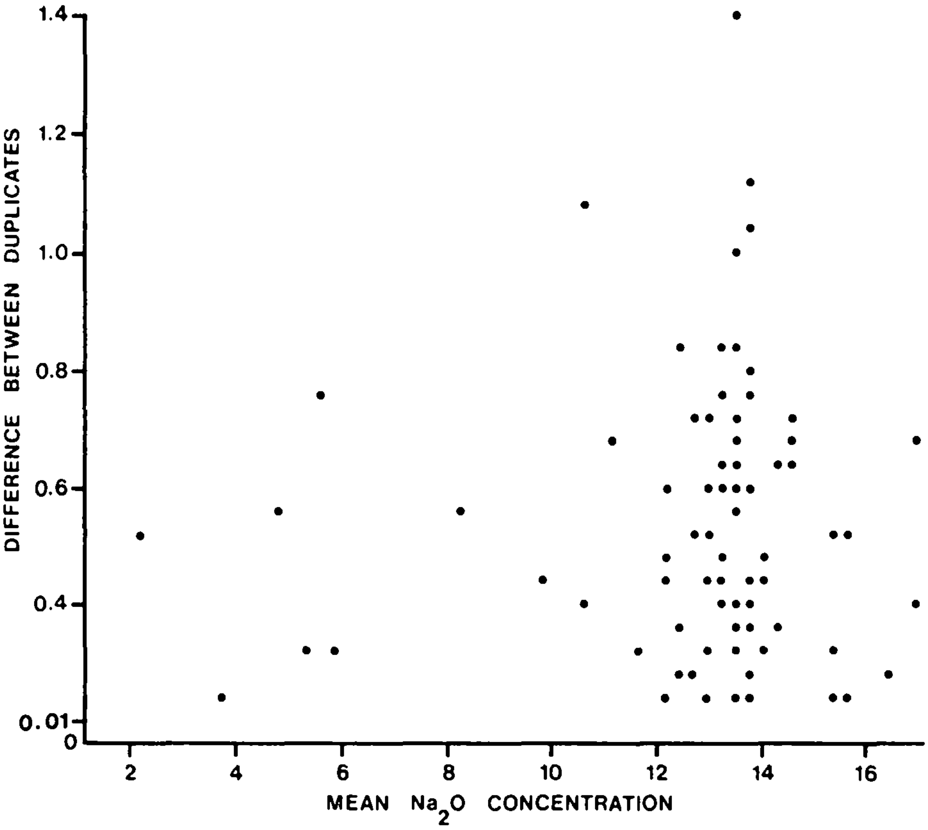


Fig.4.1 Mean Na_2O vs difference between duplicates.

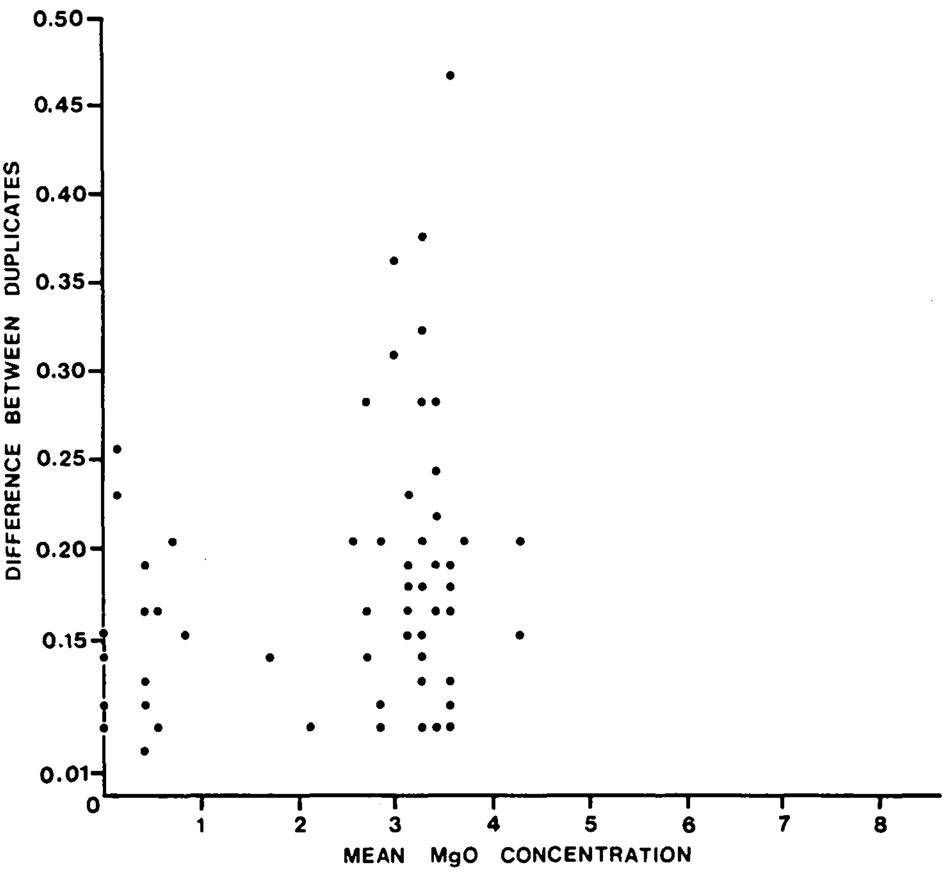


Fig.4.2 Mean MgO vs difference between duplicates.

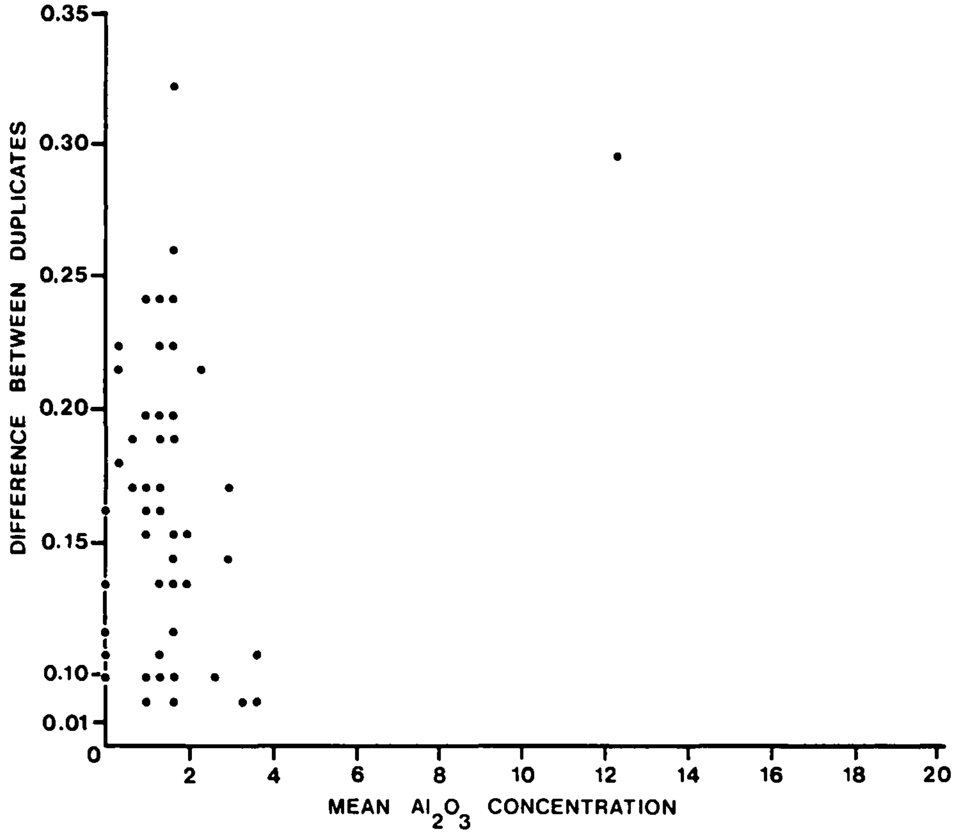


Fig.4.3 Mean Al_2O_3 vs difference between duplicates.

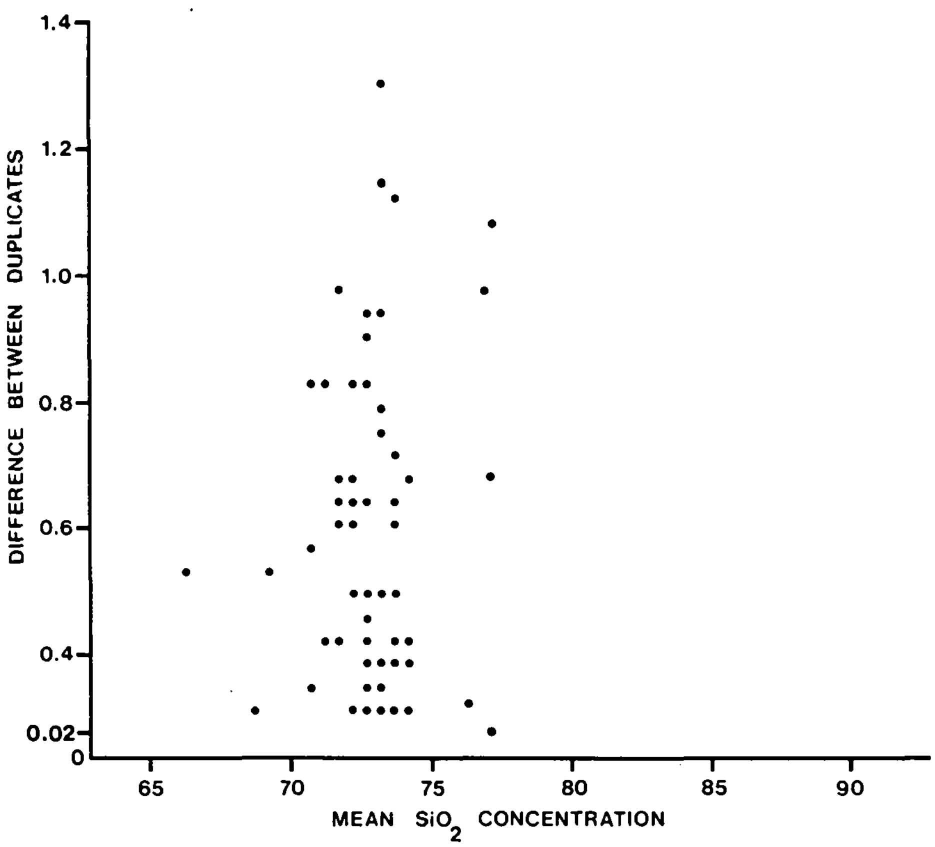


Fig. 4.4 Mean SiO_2 vs difference between duplicates.

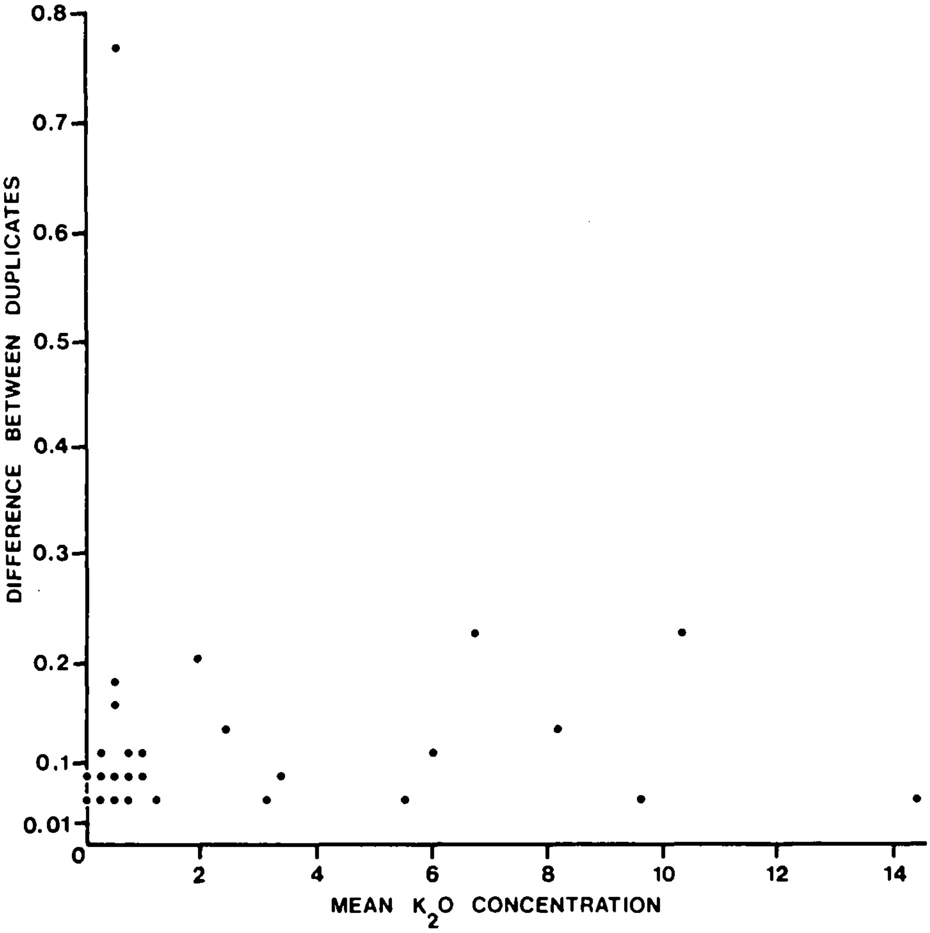


Fig.4.5 Mean K_2O vs difference between duplicates.

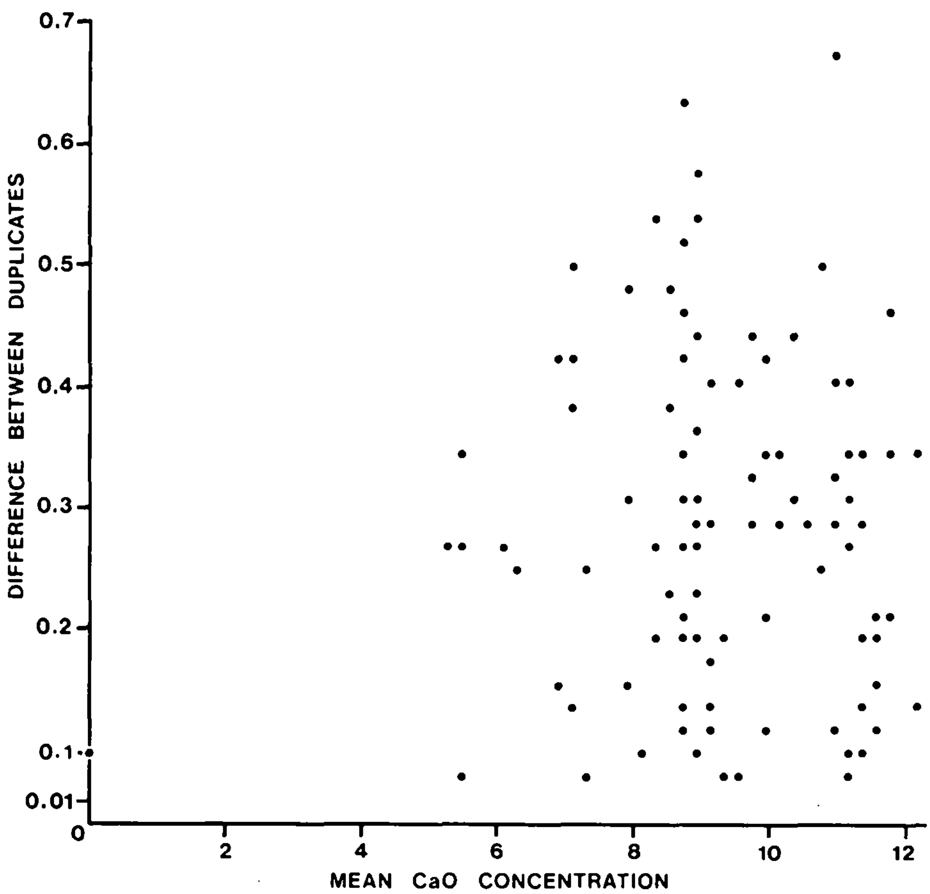


Fig.4.6 Mean CaO vs difference between duplicates.

component. The expected difference for the six major oxides are given in Table 4.1.

TABLE 4.1: EXPECTED DIFFERENCES BETWEEN DUPLICATES

Component	Expected difference (per cent)
Na_2O	0.423
MgO	0.210
Al_2O_3	0.204
SiO_2	0.406
K_2O	0.203
CaO	0.286

A computer program was written to

(i) Calculate a R value for all duplicates
(ii) Calculate a R value for all duplicate pairs excluding duplicates
(iii) Print a histrogram of (i) and (ii)

Frequency distribution of R values for the 134 duplicates are shown in Table 4.2.

TABLE 4.2: FREQUENCY DISTRIBUTION OF R VALUES FOR DUPLICATE SAMPLES

R	Frequency
1	8
2	54
3	54
4	15
5	3
>5	0
TOTAL	134

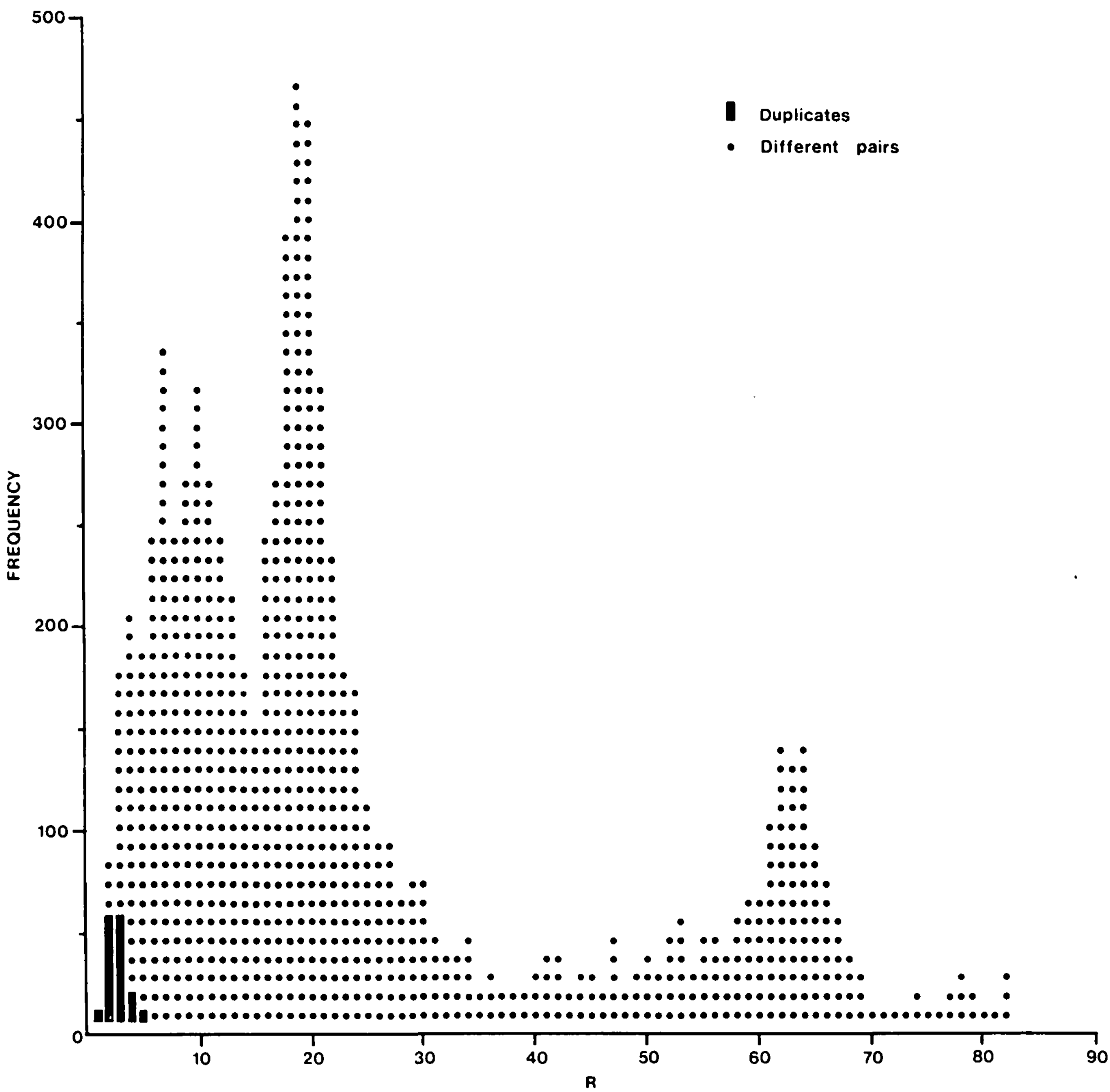


Fig.4.7 Histogram showing distribution of R values.

From this we could set a critical value of say R = 5 above which any pair of samples would not be expected to be in the same class relationship. Figure 4.7 shows the distributions of R for duplicates and all possible pairs. It can be seen that the vast majority of R values for dissimilar pairs exceeds value range (i.e. R = 0-5) of the R duplicates.

4.3 Identification of dissimilar pairs

Thirty pairs of glasses from the collection from different classes which were found to have similar refractive indices (±0.0001) were compared using this technique. The results are summarised in Table 4.3.

TABLE 4.3 R VALUES FOR DISSIMILAR PAIRS WITH SIMILAR RI

RI ± 0.0001	TYPES	R
1.5198	Float, container	19
1.5233	Float, spectacle	82
1.5237	Float, spectacle	52
1.5192	Float, tableware	17
1.5187	Float, tableware	18
1.5198	Float, patterned	5.5
1.5196	Float, patterned	3.9
1.5143	Sheet, lampbulb	7
1.5164	Sheet, container	19
1.5163	Sheet, tableware	17
1.5246	Patterned, container	12
1.5196	Patterned, container	18
1.5199	Patterned, container	19
1.5247	Patterned, container	26
1.5200	Patterned, container	15
1.5200	Patterned, container	17
1.5193	Patterned, container	16
1.5229	Patterned, spectacle	39
1.5247	Patterned, spectacle	51
1.5229	Patterned, spectacle	72
1.5188	Patterned, headlamp	22
1.5231	Wired, container	9
1.5228	Wired, spectacle	42
1.5235	Container, container	18
1.5203	Container, headlamp	28

Of these, all were identified except for one pair (R = 3.9). This pair was patterned Belgian glass and an American float glass. the next closest comparison for a dissimilar pair (R = 5.5) also featured patterned - float glasses. These are both window type glasses.

4.4 Discrimination of window glasses

As noted in Chapter 2, the bulk of window glass now being installed is float glass. The analysis of the six mentioned components obtained for 20 float glass samples is shown in Appendix B.2.

It can be seen that there is a remarkable uniformity in composition for the six major-minor elements. Information from Pilkington ACI is that the composition of their float glass is controlled within very rigid limits. Quite clearly the important question of discriminating such window glasses cannot be resolved from quantitative major-minor elemental comparison. An analysis of trace elements would be required to tackle this problem.

So far as trace element analysis in the SEM is concerned, the x-ray spectra obtained from the thin foil device may be of use in discriminating certain cases. As noted in the previous section, two window glasses not separable on the basis of refractive index or major-minor composition were resolvable with the thin foil spectra. These spectra are shown in Figure 4.8 below. A full listing of thin foil spectra for the glass collection is given in Appendix C.

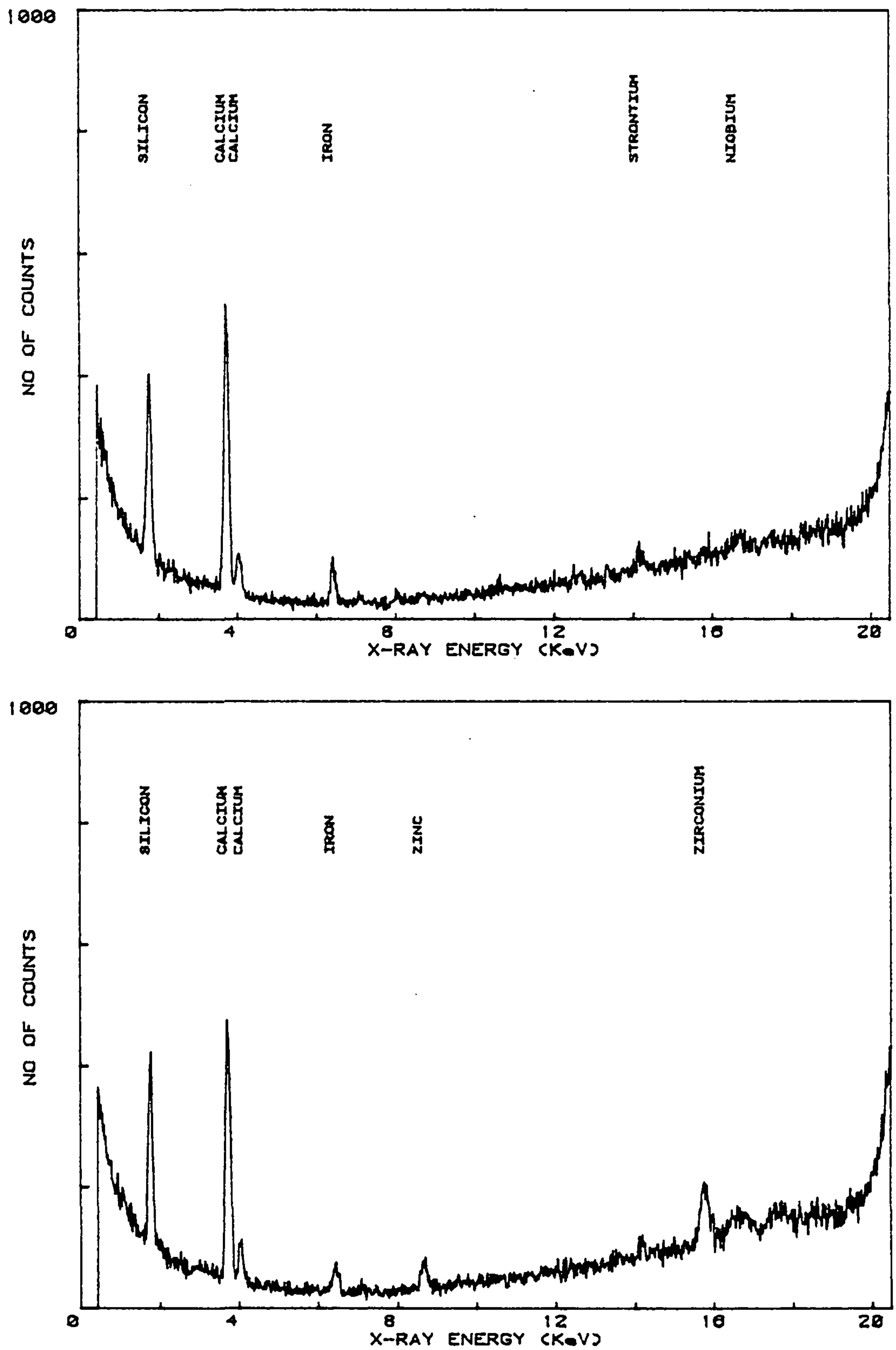


FIGURE 4.8 : X-RAY INDUCED X-RAY SPECTRA FROM AN AMERICAN FLOAT AND A BELGIUM PATTERNED GLASS

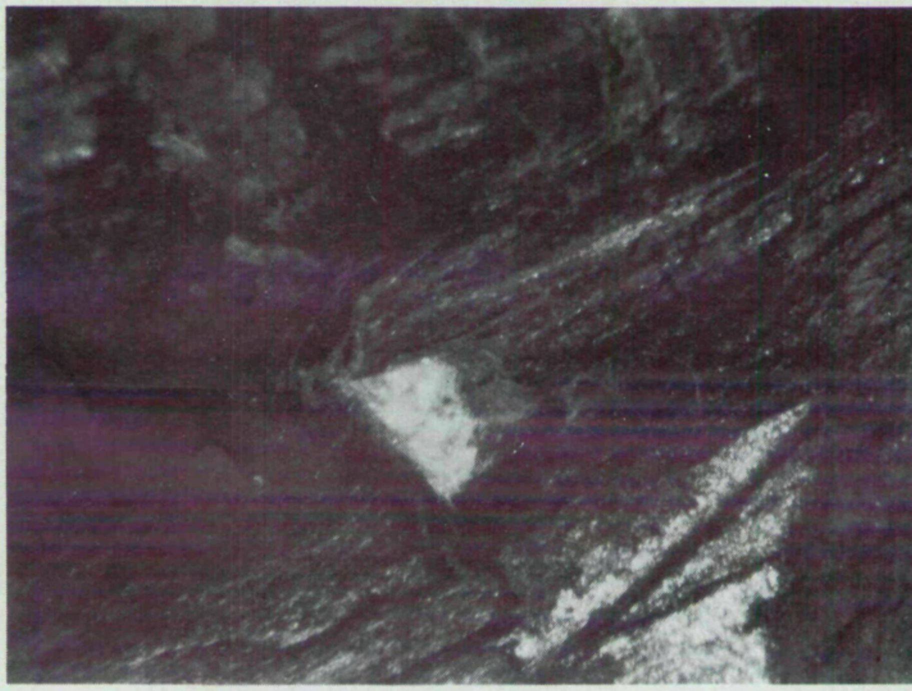


Figure 4.9 (a) Glass particles lodged in crevice in hammer handle (x 20)

Figure 4.9 (b) Glass particles from hammer handle

CHAPTER 5
STATISTICAL ANALYSIS OF THE GLASS DATA BANK

5.1 Introduction

One of the aims of this investigation has been explored in the previous chapter, namely, to predict whether two fragments of glass are of a close class relationship. In this chapter an account is given of attempts to classify correctly a single fragment of glass based upon the information measured on a data bank of the first 134 samples collected.

The 134 glass samples were initially catalogued into eleven categories, namely, float, sheet, patterned, wired, windscreen, container, light bulb, spectacle, tableware, labware and headlamp. For each glass sample data has been acquired comprising the refractive index and the elemental composition of up to fifteen elements expressed as oxides. The full set of data is presented in Appendix B.

In this chapter the data is intially assessed using basic statistical methods of means, standard deviations and histograms. It is then assessed using the Statistical Package for the Social Sciences (SPSS) package by Nie (1975), in particular using DISCRIMINANT, and then with the CLUSTAN 1C package by Wishart (1978).

5.2 Basic Statistical Methods

A summary of the data of the refractive index and the most commonly occurring oxides is presented in Table 5.1. The mean, and standard deviation fromthe mean, is provided for the appropriate subgroups such as country of origin, or type of glass, for each glass classification.

There are many significant features highlighted in Table 5.1. The float glasses from the three represented countries have a remarkable consistency about their data including the virtual absence of alumina and potash. The sheet glasses from Japan have consistent data and hence dominate the mean results for this classification. Each source of patterned glass has its own characteristic data. The Australian wired glass differs from the Japanese imports. The fourteen windscreens have come from eight different world wide car manufacturers so a common composition is not expected. Most containers used within Australia are manufactured locally in each State by the same national company. The two Victorian containers are repeated samples from a pharmaceutical pack and has an unusual composition. The thirteen overseas containers originate from nine countries and hence again there is a variability of data. The borosilicate headlamps have a fairly uniform set of data but the two soda-lime-silica headlamps are quite different.

It can be seen that the borosilicate labware differs mainly in potash and lime to the borosilicate headlamp. A characteristic of the soda-lime-silica spectacle glasses is their potash content in excess of 5.0%, the only other glasses with such a potash

TABLE 5.1. SUMMARY OF DATA FROM GLASSES USED WITHIN AUSTRALIA

A:ORIGINAL CLASSIFICATIONS

GLASS CLASS	COUNTRY	NO.	REFRACTIVE INDEX	Na2O	MgO	Al2O3	SiO2	K2O	CaO
FLOAT	AUSTRALIA	9	1.5194(6)	13.9(1)	3.7(1)		73.2(3)		8.9(2)
	BELGIUM	1	1.5194	13.7	3.6		73.3		8.8
	USA	10	1.5208(20)	13.7(2)	3.6(2)	0.1(1)	73.1(8)		9.0(2)
	TOTAL	20	1.5201(16)	13.8(2)	3.6(1)	0.1(1)	73.1(6)		8.9(2)
SHEET	JAPAN	5	1.5145(2)	13.4(3)	3.6(1)	1.8(1)	73.1(3)	.9(0)	7.0(2)
	PHILIPPINES	1	1.5136	14.4	3.6	1.6	72.4	.3	7.0
	POLAND	1	1.5164	13.6	3.4	1.2	73.4		8.1
	TOTAL	7	1.5147(9)	13.6(4)	3.6(1)	1.7(2)	73.1	.7(3)	7.1(4)
PATTERNED	AUSTRALIA	7	1.5192(12)	13.6(2)	3.4(2)	1.2(3)	72.7(5)	.1(1)	8.5(3)
	BELGIUM	5	1.5238(23)	13.5(4)	3.9(9)	.4(3)	71.9(8)	.2(2)	9.8(5)
	JAPAN	1	1.5229	12.6	.7	1.6	72.3	.6	11.5
	W. GERMANY	1	1.5252	14.1	2.3	.8	71.5	.5	10.8
	TOTAL	14	1.5215(29)	13.6(4)	3.3(10)	.9(5)	72.3(7)	.2(2)	9.3(10)
WIRED	AUSTRALIA	1	1.5196	13.9	3.7	.6	72.8	.1	8.6
	JAPAN	7	1.5212(21)	13.1(7)	2.2(12)	1.6(1)	72.0(5)	.8(1)	10.0(14)
	TOTAL	8	1.5210(20)	13.2(7)	2.4(12)	1.5(3)	72.1(6)	.7(2)	9.8(14)
WINDSCREEN	TOTAL	14	1.5182(26)	13.1(4)	3.3(5)	1.0(5)	72.7(6)	.6(4)	8.9(10)
FLAT	TOTAL	63	1.5195(30)	13.5(5)	3.3(8)	.8(7)	72.7(7)	.3(4)	8.9(11)
CONTAINER	AUST. NSW	7	1.5201(10)	13.3(3)	.2(2)	1.6(1)	73.3(5)	.2(1)	11.1(1)
	AUST. SA	6	1.5214(8)	13.5(9)	.3(1)	1.8(6)	72.6(10)	.6(8)	11.0(4)
	AUST. TAS	3	1.5222(12)	13.8(2)	.1(1)	1.4(0)	72.8(4)		11.5(4)
	AUST. WA	6	1.5213(5)	14.0(2)	.6(1)	1.6(1)	72.4(2)	.1(1)	10.9(2)
	AUST. VIC	2	1.5154(0)	17.1(0)	3.4(0)	1.5(0)	70.4(3)		5.3(1)
	VARIOUS	13	1.5208(30)	13.7(12)	1.4(12)	2.2(11)	71.6(17)	.9(7)	9.7(14)
	TOTAL	37	1.5207(23)	13.8(12)	.8(11)	1.8(7)	72.2(14)	.5(6)	10.3(16)

Cont..

TABLE 5.1 Cont..

GLASS CLASS	COUNTRY	NO.	REFRACTIVE INDEX	Na2O	MgO	Al2O3	SiO2	K2O	CaO
HEADLAMP	SODA-LIME	2	1.5196(11)	14.5(11)	1.7(14)	1.6(3)	70.8(7)	2.2(7)	6.7(14)
	BOROSILICATE	5	1.4772(14)	4.5(3)	.2(2)	2.1(2)	73.8(35)	.2(2)	.1(1)
LIGHTBULB	LEAD	1	1.5626						
	OTHERS	3	1.5126(26)	16.1(4)	3.3(3)	1.8(3)	72.0(9)	.7(2)	5.9(7)
SPECTACLE	ALUMINA/LEAD	1	1.5232						
	OTHERS	7	1.5234(7)	9.9(14)	.2(3)	1.1(8)	70.5(14)	7.2(18)	8.1(12)
TABLEWARE	AUSTRALIA	4	1.5174(11)	15.5(2)		1.4(0)	73.3(4)		9.5(2)
	TOTAL	7	1.5175(33)	15.0(6)	.8(11)	1.4(1)	72.9(8)	.2(3)	9.0(12)
	LEAD	1	1.5488						
	HIGH ALUMINA	1	1.5325	1.3	8.9	19.7	62.8		6.8
LABWARE	SODA-LIME	1	1.5146	13.8	2.8	3.3	70.5	1.9	5.2
	BOROSILICATE	5	1.4776(91)	4.1(7)	.1(1)	2.9(14)	74.6(34)	.8(11)	.3(2)

B: FINAL FLAT GLASS CLASSIFICATIONS

GLASS CLASS	NO.	REFRACTIVE INDEX	Na2O	MgO	Al2O3	SiO2	K2O	CaO
FLOAT	20	1.5201(16)	13.8(2)	3.6(1)	0.1(1)	73.1(6)	-	8.9(2)
SHEET	7	1.5147(9)	13.6(4)	3.6(1)	1.7(2)	73.1(4)	0.7(3)	7.1(4)
ROLLED (OTHER)	6	1.5213(27)	13.5(4)	2.8(6)	1.5(3)	71.6(3)	0.7(1)	9.6(11)
NON FLOAT FLAT (AUS 3.6 MgO)	5	1.5188(13)	13.5(2)	3.6(1)	1.0(2)	73.0(3)	0.2(0)	8.4(3)
NON FLOAT FLAT (AUS 3.1 MgO)	3	1.5198(2)	13.9(1)	3.1(0)	1.5(1)	72.1(1)	0.1(1)	8.7(1)
ROLLED (JAPAN)	3	1.5228(1)	12.3(2)	0.6(1)	1.7(0)	72.5(2)	0.6(0)	11.7(2)
ROLLED (BELGIUM)	5	1.5235(23)	13.5(4)	3.9(9)	0.4(3)	71.9(8)	0.2(2)	9.8(5)

composition being lead glasses. It is difficult to make further comments upon the light bulbs, spectacles, tableware and labware due to the lack of sample numbers in each subgroup.

The data obtained is also presented in histogram form so as to visually display the similarities and differences of the various chosen glass classifications.

The differences in the various flat glasses is displayed in Figure 5.1 in which the refractive index is plotted for all the flat glasses, and for each of the five subgroups as well as for the entire glass museum. The float glasses have all very constant values apart from three American samples. The distribution of the data for sheet glasses reflect the country of origins, besides being all lower than the value of float glass. The wired glasses despite being mainly from one country indicate a bimodal distribution, which could suggest two sources from within Japan. The patterned glasses again reflect the fact that the origin of the samples is mainly from two countries. The windscreens have a wider distribution due to their multi-national origin. A check across classifications suggests that the single Japanese patterned glass is from the same source as one set of the Japanese wired glasses. The small number of samples make this cross interpretation suspect but the histograms themselves support the concept of maintaining the five classifications of flat glasses.

Recognising the lack of samples in each classification the histograms for the other parameters have been restricted to those classifications or groups with 20, or more, samples. This limits the plots to four categories, namely, float, container, all the flat glasses and the total collection.

The data for the soda content does not reveal in the initial plots, Figure 5.2 (a), (b), (c), (d), much differences between flat, float and containers. With the expanded plots in Figure 5.2 (e) and (f) the uniformity of the float glass compositions is again emphasised.

The magnesia data in Figure 5.3 demonstrates the usual magnesia content in flat glasses and its absence in containers, although of course exceptions exist. The magnesia content in floats do not appear to differ much from the bulk of other flat glasses.

The alumina data is plotted in Figure 5.4. These figures clearly reveal float glasses as being unique in having zero, or practically zero, content of alumina. However, other flat glasses have a wide range of alumina content while many containers are seen to have a fairly restricted range of alumina content.

The silica plots of Figure 5.5 do not help distinguish between flat, floats or container classifications.

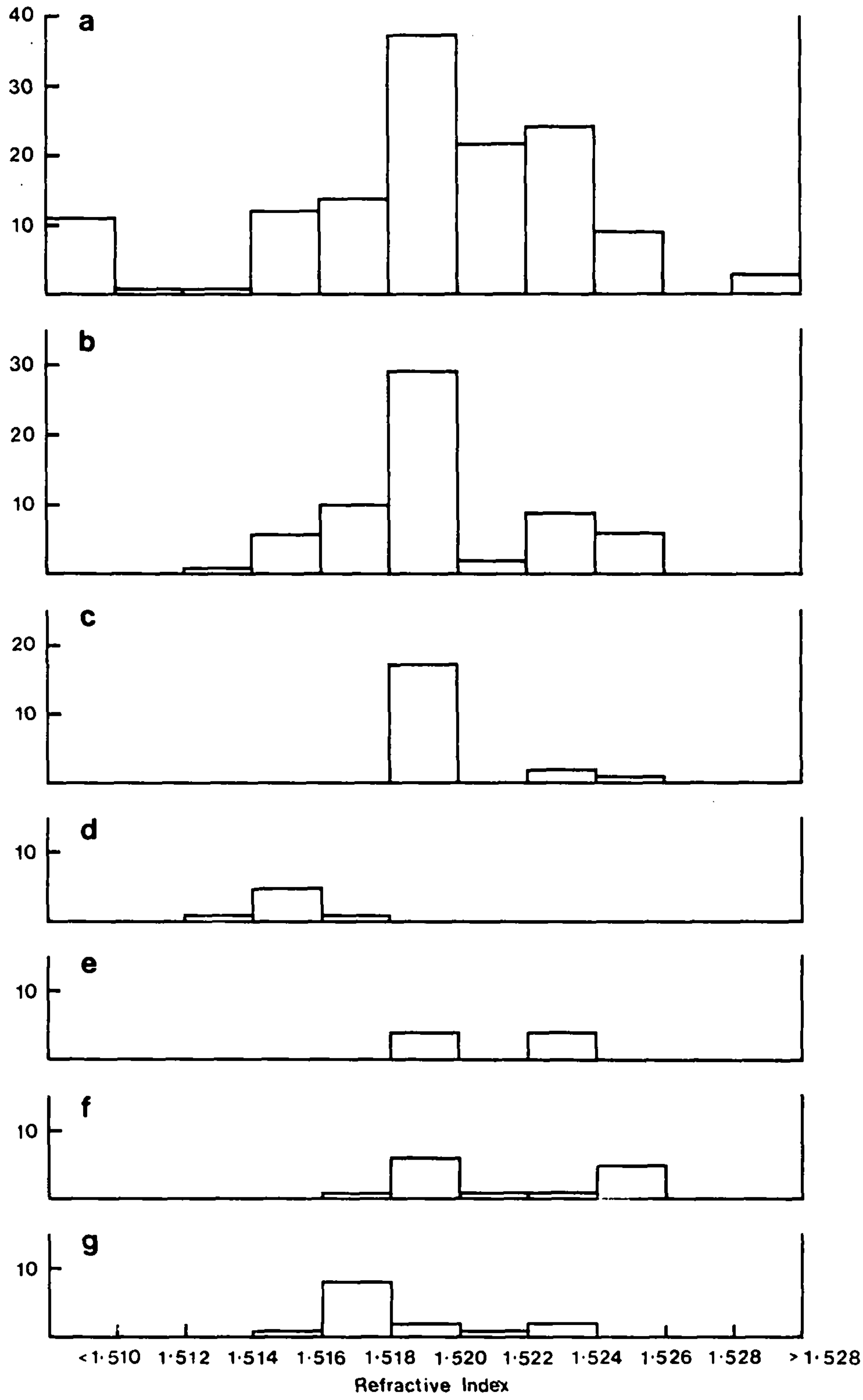


Figure 5.1 – Histograms of Refractive Indices for Glass

a – Total Glass Museum
b – Total Flat Glasses
c – Float
d – Sheet
e – Wired
f – Patterned
g – Windscreen

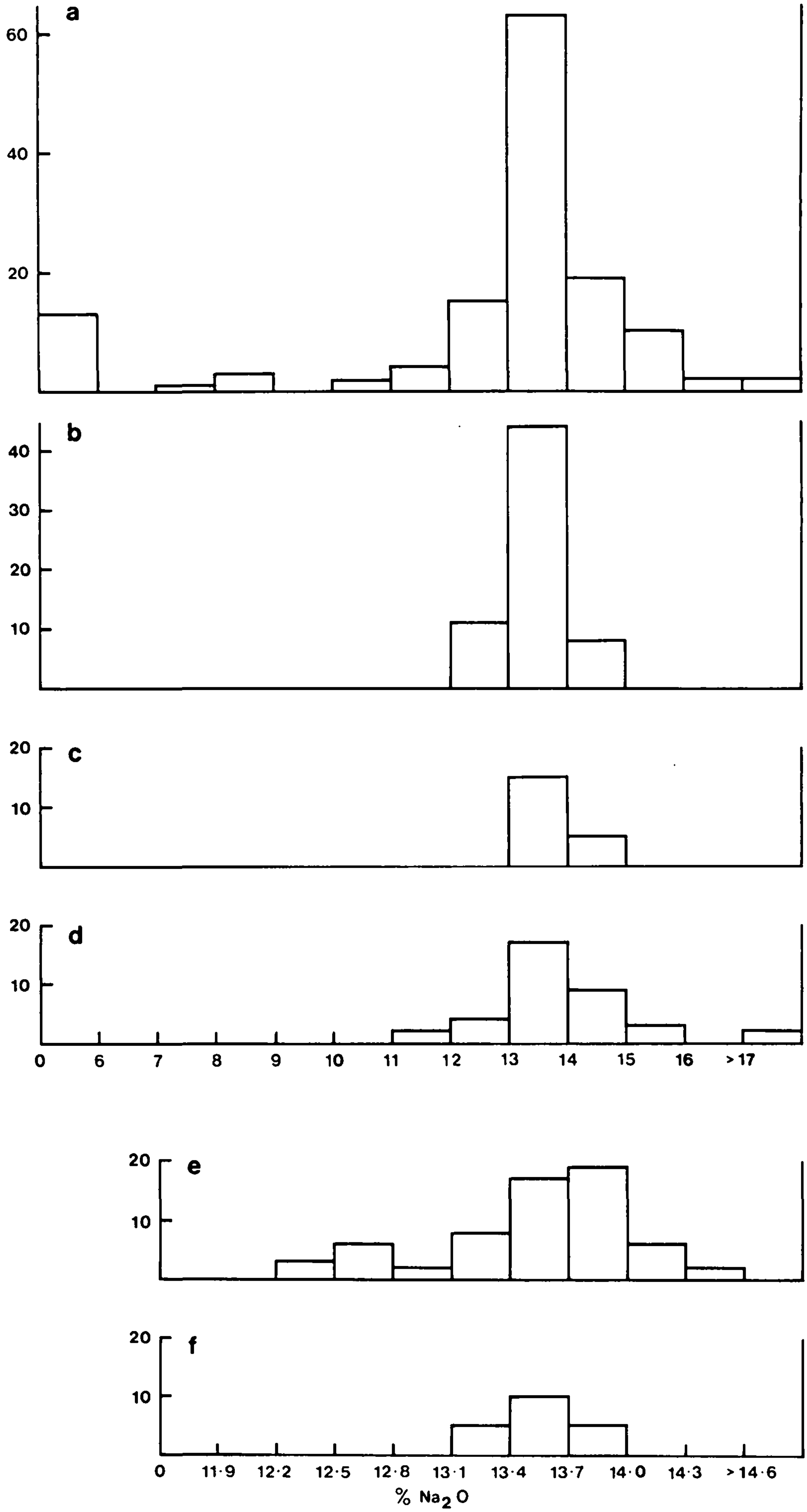


Figure 5.2 – Histograms of % Soda in Glass

a – Total Glass Museum
b – Total Flat Glass
c – Float
d – Container
e – Total Flat Glass
f – Float

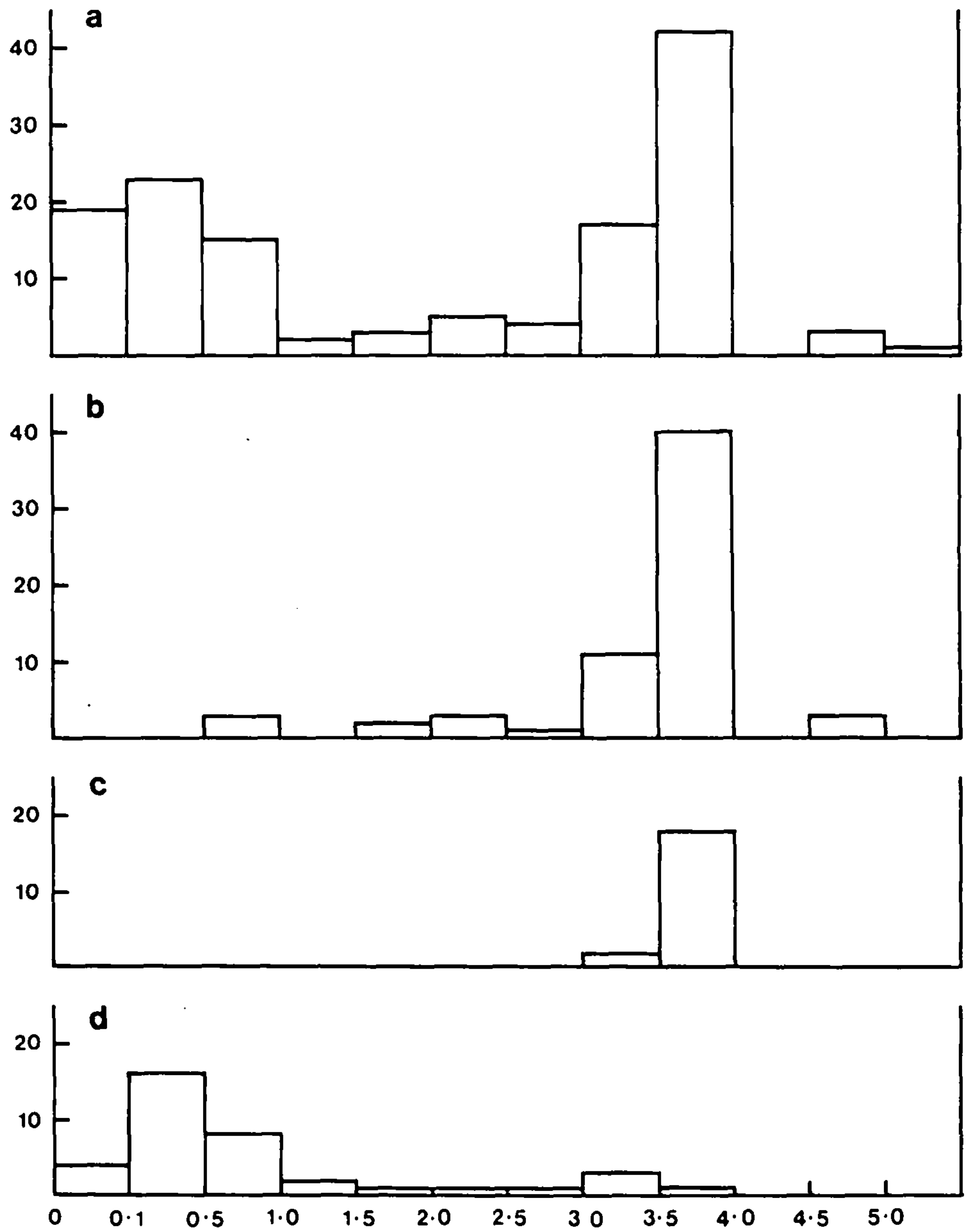


Figure 5.3 – Histograms of % Magnesia Content in Glass

a – Total Glass Museum
b – Total Flat Glass
c – Float
d – Container

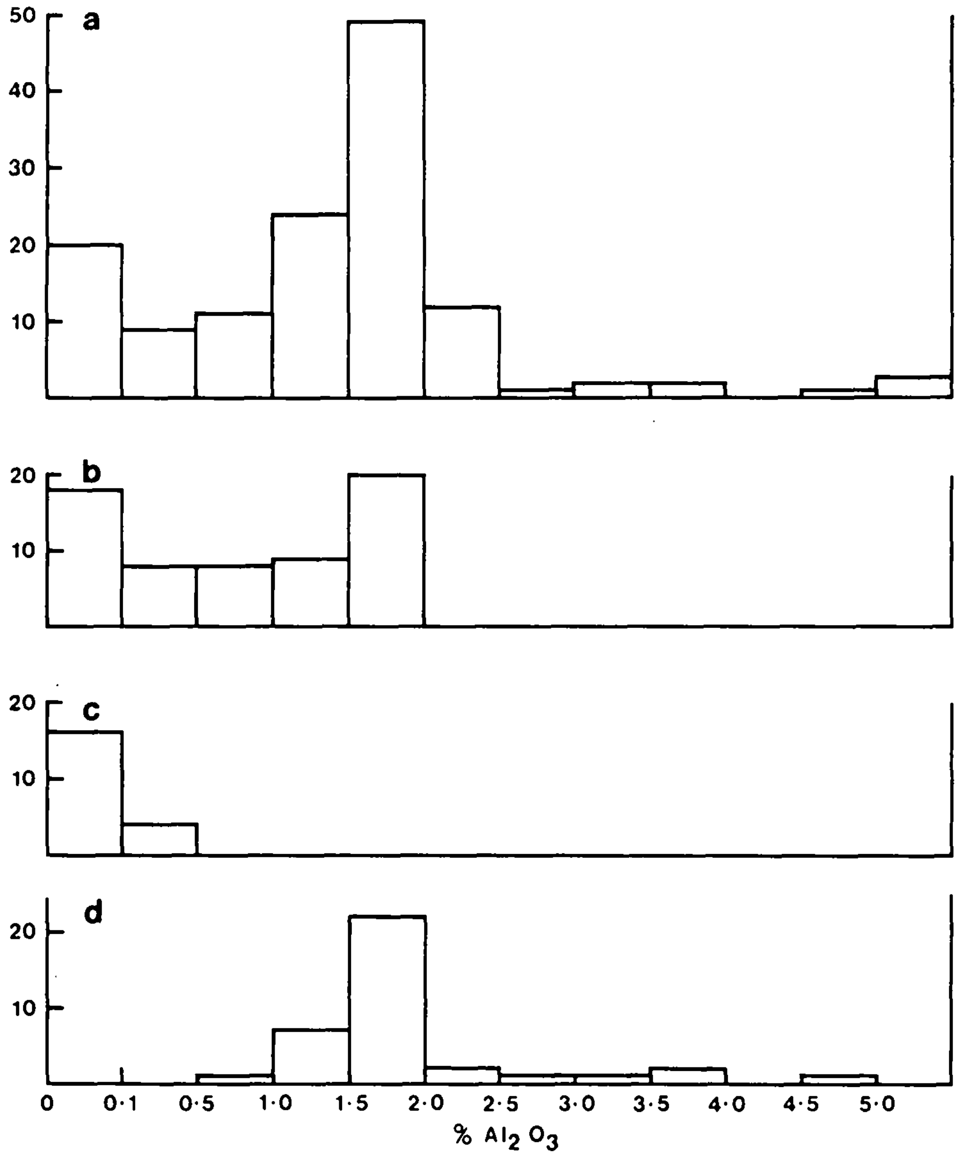


Figure 5.4 – Histograms of % Alumina in Glass

a – Total Glass Museum
b – Total Flat Glass
c – Float
d – Container

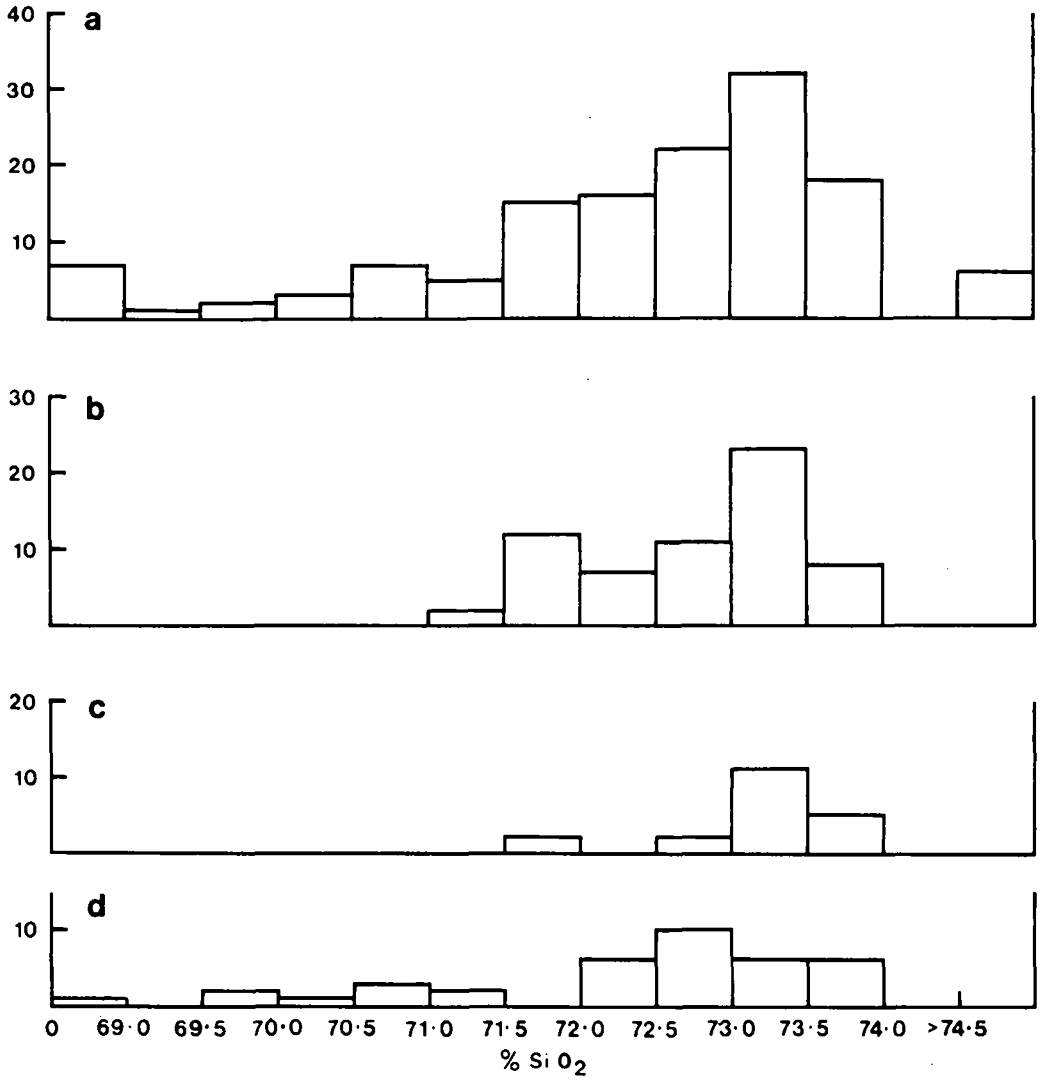


Figure 5.5 – Histograms of % Silica Content in Glass

a – Total Glass Museum
b – Total Flat Glass
c – Float
d – Container

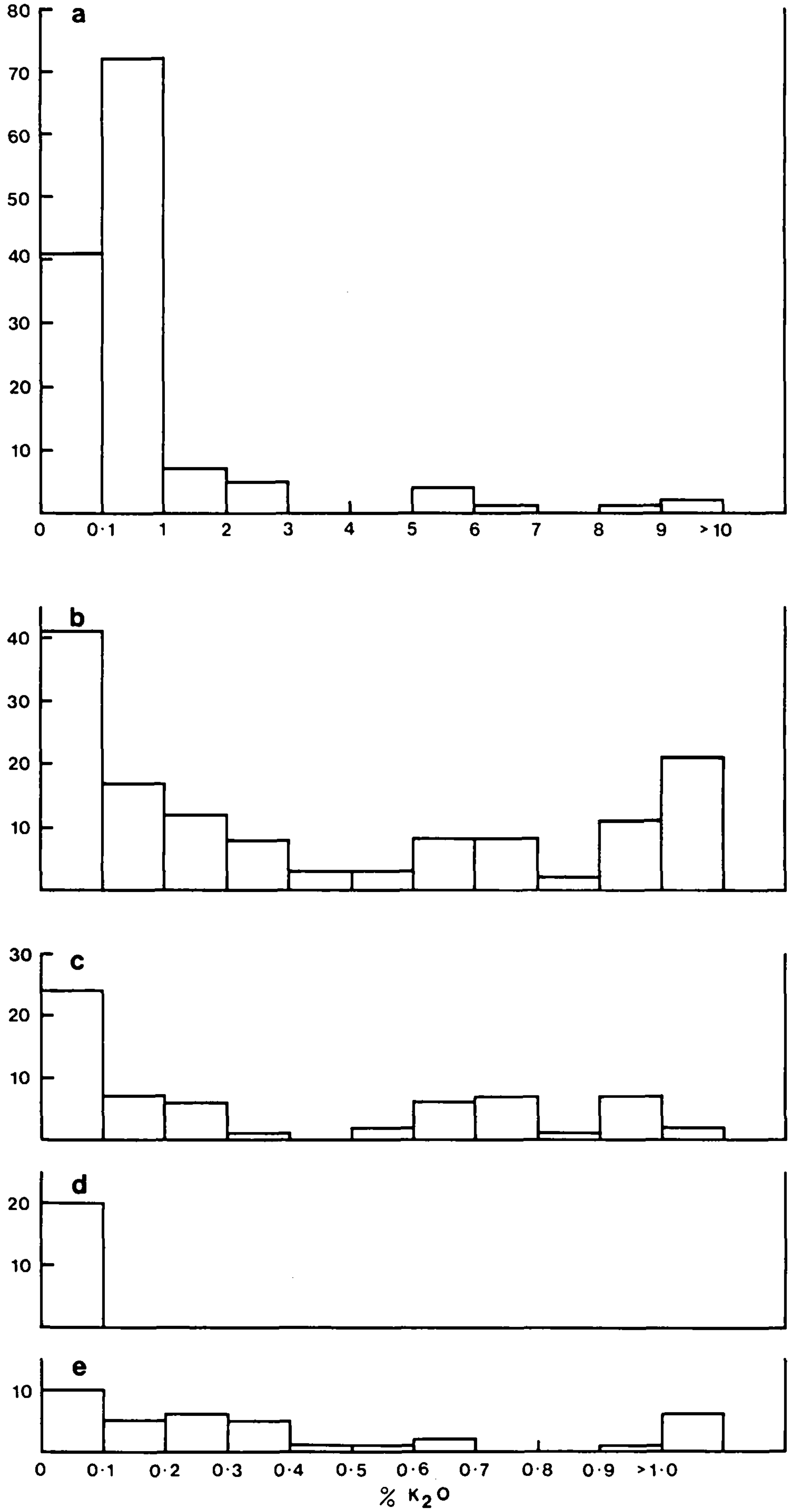


Figure 5.6 – Histograms of Potash Content in Glass

a, b – Total Glass Museum
c – Total Flat Glass
d – Float
e – Container

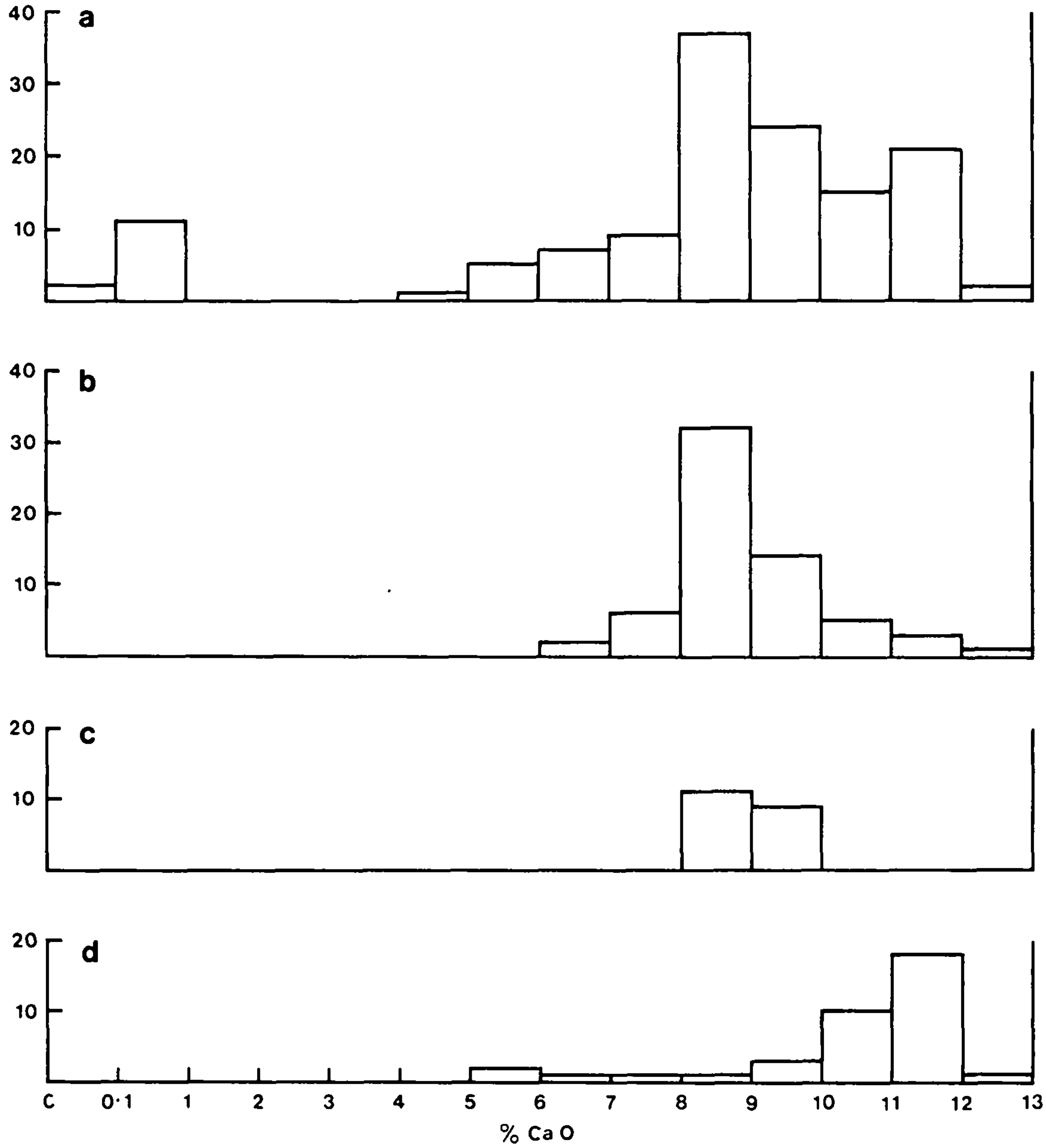


Figure 5.7 – Histogram of Lime Content in Glass

a – Total Glass Museum
b – Total Flat Glass
c – Float
d – Container

There is a wide range of potash content in the various glasses as shown in Figure 5.6 (a). However most of the glasses have a potash content of less than 1% so the accompanying plots of Figure 5.6 (b), (c), (d) and (e) are for this restricted range. The floats all have negligible, or zero, potash content but are not alone in that feature as some other flats and some containers also have this same lack of potash.

Finally Figure 5.7 displays the lime data and indicates that the lime content in soda-lime-silica glass is in the range 0 to 12.2%. A reasonably wide range of lime composition occurs in the flat and container classifications but its content in float glasses is again in a very restricted range.

5.3 Discriminant Analysis

The glass data bank of the initial 134 glasses has been examined using the SPSS subprogram DISCRIMINANT. Seven of the original samples have been excluded from this procedure so as to maintain the original eleven classifications with closely defined elemental compositions. The excluded glasses are the lead glasses (2), high alumina glass (1), soda-lime headlamps (2), and the soda-lime labware (1). The variables used have been limited to the refractive index and the oxide compositions of Na, Mg, Al, Si, K and Ca.

Beforeproceeding to discuss the results of the discriminant analysis it is appropriate to outline the information available during the execution of the subprogram DISCRIMINANT. For full details refer to Nie (1975).

5.3.1 Introduction to Discriminant Analysis

The aim of discriminant analysis is to statistically distinguish between two or more groups of cases by relying upon discriminating variables that measures characteristics on which the groups are expected to differ. It is necessary to weight and linearly combine the discriminating variables in some fashion so that the groups are forced to be as statistically distinct as possible.

Discriminant analysis attempts to do this by forming one or more linear combination of discriminating variables. These "discriminant functions" are of the form

$$D_i = d_{i1} Z_1 + d_{i2} Z_2 + \ldots\ldots d_{ip} Z_p$$

where D_i is the score on discriminant function i, d's are weighting coefficients and Z's are standardised values of the p discriminating variables. The maximum number of discriminant variables is one less than the number of groups, or equal to the number of variables, whichever is smaller.

The program includes tools for the interpretation of data.

Statistical tests are included for measuring the success with which the discriminating variables actually discriminate when combined into discriminant functions. It may be possible to obtain satisfactory discrimination with fewer functions. The program enables the original set of cases itself to be classified so as to see how many cases are correctly classified by the variables used, and to classify new cases with unknown membership.

The standardised canonical discriminant functions coefficients are tabulated during the running of DISCRIMINANT. The coefficients corresponds to the discriminant score for a case in which the original discriminating variables are in standard form. The discriminant score is computed by multiplying each discriminating variable by its corresponding coefficient and adding together these products. There will be a separate score for each case on each function. The coefficients have been derived in such a way that the discriminant scores produced are in standard form. This means that, over all cases in the analysis, the score from one function will have a mean of zero and a standard deviation of one. Thus, any single score represents the number of standard deviations that case is away from the mean for all cases on the given discriminant function. If there are several discriminant functions, each case will have a score on each function. By averaging the scores for the cases within a particular group, a group mean on the respective function is obtained. For a single group, the means on all the functions are referred to as the group centroid, which is the most typical location of a case from that group in the discriminant function space. A comparison of the group means on each function tells us how far apart the groups are along that dimension. The functions are arranged in order of decreasing importance, so that a given difference between group means on the higher number function is not as meaningful as the same difference on a lower number function.

The standardised discriminant function coefficients are of great analytic importance in and of themselves. Each coefficient represents the relative contribution of its asociated variable to that function. The sign merely denotes whether the variable is making a positive or negative contribution.

Having derived discriminant functions it is possible to use them in a classification procedure. By classification is meant the process of identifying the likely group membership of a case when the only information known is the case's values on the discriminating variables. Alternatively the adequacy of the derived discriminant functions may be determined by classifying the cases used to derive the functions in the first place and comparing predicted group membership with actual group membership.

The measure of success is the proportion of correct classifications.

5.3.2 Choice of Classification Groups using Discriminant Analysis

The subprogram DISCRIMINANT of the SPSS package has been run on 127 samples taken from the initial glass museum of 134 specimens. The seven excluded glasses are the lead glasses (3), a high alumina glass (1), the soda-lime headlamps (2) and the soda-lime labware glasses (1). These 127 samples had originally been grouped into eleven classifications. As a result of running the DISCRIMINANT procedure two other groupings of the samples have also been adopted. The details of these three sets of groupings are shown in Table 5.2.

TABLE 5.2
CLASSIFICATION GROUPINGS USED IN DISCRIMINANT

GROUPING NO. 1 (127 cases)	GROUPING NO. 2 (101 cases)	GROUPING NO. 3 (94 cases)
Float Sheet Patterned Wired Windscreen Headlamp (borosilicates) Lightbulb Spectacle Tableware Labware (borosilicates) Container	Flat Lightbulb Spectacles Container/ Tableware	Float Sheet Rolled (other) Non Float Flat (Aus, 3.6% MgO) Non Float Flat (Aus, 3.1% MgO) Rolled (Japan low MgO) Rolled (Belgium) Lightbulb Tableware Container
<u>Excluded:</u> Lead glass High alumina glass Headlamp (soda-lime) Labware (soda-lime)	<u>Excluded:</u> Lead glass High alumina glass Headlamp Labware Windscreen Container (Victorian)	<u>Excluded:</u> Lead glass High alumina glass Headlamp Labware Windscreen Container (Victorian) Spectacles

The discriminant functions and the standard scores of each classification's mean that resulted using Grouping No. 1 are shown in Table 5.3. Although only four of the functions are included in Table 5.3 all seven functions were used in the subsequent classification procedure. The important variables in Function 1 appear to be the refractive index and lime, while potash and alumina emerge as the extreme variables in Function 2. Soda and magnesia then begin to play an important role in Function 3.

TABLE 5.3:
DATA APPROPRIATE TO USING GROUPING NO. 1 WITH DISCRIMINANT

A. STANDARD SCORES OF CLASSIFICATIONS' MEANS

GROUP	RI	Na2O	MgO	Al2O3	SiO2	K2O	CaO
Float	0.3	0.4	1.0	-1.3	0.3	-0.5	0.1
Sheet	-0.2	0.3	1.0	0.4	0.3	-0.1	-0.5
Patterned	0.4	0.3	0.8	-0.4	-0.2	-0.4	0.3
Wired	0.4	0.1	0.3	0.2	-0.3	-0.1	0.4
Windscreen	0.1	0.1	0.8	-0.3	0.1	-0.1	0.1
Headlamp(B/S)	-3.3	-3.0	-1.1	0.9	0.8	-0.4	-2.9
Lightbulb	-0.3	1.2	0.8	0.6	-0.4	-0.1	-0.9
Spectacle	0.6	-1.0	-1.1	-0.2	-1.3	3.8	-0.1
Tableware	0.1	0.8	-0.8	0.1	0.2	-0.4	0.2
Labware(B/S)	-3.2	-3.1	-1.2	1.8	1.3	0.0	-1.1
Container	0.4	0.4	-0.8	0.6	-0.3	-0.2	0.6
Mean	1.5165	12.8	2.0	1.3	72.6	0.8	8.5
Std.Dev.	0.0120	2.8	1.6	0.9	1.6	1.7	2.9

B. STANDARD CANONICAL DISCRIMINANT FUNCTION COEFFICIENTS

	FUNCTION 1	FUNCTION 2	FUNCTION 3	FUNCTION 4
RI	-0.109	-0.569	-0.514	-0.954
Na2O	1.629	0.095	0.662	0.859
MgO	1.357	0.794	-0.680	0.539
Al2O3	0.090	1.170	0.536	0.207
SiO2	0.847	0.031	0.011	0.303
K2O	1.033	-1.194	0.272	0.745
CaO	2.021	0.995	0.478	0.592

C. CANONICAL DISCRIMINANT FUNCTIONS EVALUATED AT GROUP MEANS (GROUP CENTROIDS)

GROUP	FUNCTION 1	FUNCTION 2	FUNCTION 3	FUNCTION 4
Float	3.940	0.242	-2.394	-0.179
Sheet	1.958	1.571	-0.601	1.874
Patterned	3.582	1.184	-1.595	-0.578
Wired	2.887	0.987	-0.132	-0.481
Windscreen	2.291	0.984	-1.331	0.421
Headlamp	-31.826	0.937	-0.766	-0.409
Lightbulb	3.637	1.037	1.625	1.103
Spectacles	-0.668	-16.281	0.258	0.029
Tableware	2.487	0.468	2.569	0.872
Labware	-30.652	1.325	0.068	0.420
Container	2.218	1.139	1.972	0.599

The functions evaluated at the group means result in the borosilicates (headlamp and labware) being well separated from the other classifications in Function 1, and spectacles being separated by Function 2. The high negative values of Function 1 for the borosilicates is mainly due to their low values of soda, magnesia and lime. Surprisingly the low refractive index associated with borosilicates is not a significant variable since it would yield a positive component to the function. The high negative values of Function 2 for spectacles is due to all the variables, apart from the refractive index, contributing negative values although the potash component dominates. Function 3 is starting to distinguish tableware and containers on the one side and the flat glasses on the other side. This is due to the magnesia and alumina content. Finally the fourth function highlights the lightbulbs due to their high soda and magnesia levels.

The discriminant functions derived from Grouping No. 1 were used to classify the original 127 samples used to derive the functions. The success of correct predictions within both first choice only and first and second choices is shown in Table 5.4, along with details for the other two groupings. The success rate of predictions with Grouping No. 1 was not that good. Since the borosilicates are readily identified from the experimental derived data by their low values of refractive index, soda and lime they were excluded from subsequent groupings. The hope was that better success rates could be obtained on classifying more similar glasses. In addition the windscreens were excluded since they were obviously made from a range of flat glass categories and hence spoiling the singularity of the other nominated flat glass classifications. It was also decided to exclude the two Victorian containers from the data bank since they were from a pharmaceutical pack that had an unusual composition.

TABLE 5.4
ACCURACY OF PREDICTIONS USING DISCRIMINANT

GROUPING NO.	PERCENTAGE CORRECT	
	1ST CHOICE ONLY	1ST AND 2ND CHOICE
1	68.5	92.9
2	92.1	99.0
3	88.3	96.8

After several runs of DISCRIMINANT using various groups of classification it became apparent that the patterned and wired glasses should be grouped together as rolled glass and four subgroups be introduced. The first two subgroups are for some Japanese glasses with a low magnesia content

(~0.5%) and for Belgium glasses with a high magnesia content (~4.5%). The other two subgroups are for some Australian glasses with magnesia content of 3.1% and 3.6% respectively. Since our understanding of the Australian scene is that no sheet glass is currently manufactured, the term Non Float Flat (Australian) has been adopted for these two subgroups. It was found that no single grouping of classifications by itself yielded total prediction success. The proposed final scheme is a compromise involving two sets of classification groupings and then inspecting these results before making a final decision upon the classification. The two sets of groupings are shown in Table 5.2.

It is seen in Table 5.5 that only three discriminant functions result from using the four categories of Grouping No. 2. Upon considering these functions and the standard scores of each classifications' mean it is seen that Function 1 yields a high negative value for spectacles. This is because all variables result in a negative contribution to the discriminant function evaluated at the group mean. The magnesia content dominates Function 2 so that this function distinguishes the flat glasses from the containers/tableware. Finally light bulbs are highlighted in Function 3 by their high soda and low refractive index values which has more than compensated for the negative contribution due to the low lime content. Grouping No. 2 is a very coarse set of classifications but leads to the reasonable accuracy of predictions shown in Table 5.4. It is seen that there is a 99.0% probability of the correct grouping being among the first and second probability.

Inthe third grouping spectacles were excluded since their potash content singularly weight the standard scoresfor this variable. The discriminant functions and the standard scores of each classification's mean that resulted from using Grouping No. 3 are shown in Table 5.6. Again only four functions are shown although all seven were used in the subsequent classification procedure. The important variables in Function 1 are the magnesia and alumina content. The extreme variables in Function 2 are refractive index and alumina whilst refractive index and silica emerge as the extremes in Function 3. Finally refractive index and lime become the extreme variables in Function 4.

The functions evaluated at the group means results in the container like categories, namely containers, tableware and rolled (Japan, low MgO), being well separated from the flat glasses by Function 1. This is due mainly to the magnesia content. The lightbulb and sheet glasses are separated from the flat glasses by Function 2 due mainly to the refractive index and alumina while tableware is diverging away from containers.

TABLE 5.5

DATA APPROPRIATE TO USING GROUPING NO. 2 WITH DISCRIMINANT

A. STANDARD SCORES OF CLASSIFICATIONS' MEANS

GROUP	RI	Na_2O	MgO	Al_2O_3	SiO_2	K_2O	CaO
Flat	-0.1	0.1	0.8	-0.4	0.3	-0.3	-0.3
Lightbulb	-2.1	2.0	0.8	0.7	-0.3	-0.1	-2.3
Spectacle	0.9	-2.8	-1.1	-0.1	-1.6	3.4	-0.9
Container/ Tableware	0	0.2	-0.8	0.6	0.0	-0.2	0.6
Mean	1.5203	13.5	2.0	1.2	72.4	0.8	9.4
Std.Dev.	0.0036	1.3	1.6	0.9	1.2	1.9	1.5

B. STANDARD CANONICAL DISCRIMINANT FUNCTION COEFFICIENTS

	FUNCTION 1	FUNCTION 2	FUNCTION 3
RI	-0.426	0.411	-0.798
Na_2O	0.977	0.274	1.257
MgO	1.511	1.201	0.454
Al_2O_3	1.482	-0.072	0.059
SiO_2	0.944	0.700	0.167
K_2O	-0.383	0.534	0.918
CaO	1.890	0.229	0.806

C. CANONICAL DISCRIMINANT FUNCTIONS EVALUATED AT GROUP MEANS (GROUP CENTROIDS)

GROUP	FUNCTION 1	FUNCTION 2	FUNCTION 3
Flat	1.372	1.471	-0.178
Lightbulb	1.797	0.357	4.267
Spectacles	-15.682	0.312	0.064
Container + Tableware	0.884	-1.794	-0.107

TABLE 5.6

DATA APPROPRIATE TO USING GROUPING NO. 3 WITH DISCRIMINANT

A. STANDARD SCORES OF CLASSIFICATIONS' MEANS

GROUP	RI	Na2O	MgO	Al2O3	SiO2	K2O	CaO
Float	0.1	0	0.9	-1.2	0.5	-0.8	-0.4
Sheet	-1.7	-0.2	0.9	0.6	0.5	0.6	-1.6
Rolled (Other)	0.5	-0.3	0.4	0.3	-1.0	0.6	0.1
Non Float Flat (Aus 3.6% MgO)	-0.4	-0.3	0.9	-0.2	0.4	-0.4	-0.7
Non Float Flat (Aus 3.1% MgO)	0	0.1	0.6	0.3	-0.5	-0.6	-0.5
Rolled (Japan)	0.9	-1.7	-1.0	0.6	-0.1	0.4	1.5
Rolled (Belgium)	1.3	-0.3	1.1	-0.9	-0.7	-0.4	0.2
Lightbulb	-2.4	2.6	0.7	0.7	-0.6	0.6	-0.4
Tableware	-0.8	1.3	-0.9	0.2	0.3	-0.4	-0.3
Container	0.3	0	-0.9	0.7	-0.4	0.2	0.5
Mean	1.5199	13.8	2.2	1.2	72.6	0.4	9.5
Std.Dev.	0.0031	0.9	1.6	0.9	1.0	0.5	1.5

B. STANDARD CANONICAL DISCRIMINANT FUNCTION COEFFICIENTS

	FUNCTION 1	FUNCTION 2	FUNCTION 3	FUNCTION 4
RI	0.288	-0.632	0.325	-0.728
Na2O	1.340	0.800	0.899	2.205
MgO	1.926	0.446	2.184	2.121
Al2O3	-0.292	0.856	2.364	0.801
SiO2	1.286	0.740	2.566	1.368
K2O	0.865	-0.024	0.332	1.947
CaO	0.934	0.249	1.820	3.312

C. CANONICAL DISCRIMINANT FUNCTIONS EVALUATED AT GROUP MEANS (GROUP CENTROIDS)

GROUP	FUNCTION 1	FUNCTION 2	FUNCTION 3	FUNCTION 4
Float	4.039	-0.828	-0.813	-0.373
Sheet	1.206	2.678	1.857	-0.548
Rolled (Other)	0.784	-0.709	0.750	1.422
Non Float Flat (Aus 3.6% MgO)	2.440	0.496	1.361	-0.921
Non Float Flat (Aus 3.1% MgO)	0.651	0.658	1.372	-1.042
Rolled (Japan)	-4.098	-2.393	0.427	-0.288
Rolled (Belgium)	4.376	-2.252	0.686	1.179
Lightbulb	2.549	5.321	-0.693	1.924
Tableware	-1.676	1.796	-2.295	-0.339
Container	-3.245	-0.356	0.036	0.059

Tableware continues to diverge from containers in Function 3 due to their refractive index and lime values. These same variables contribute to the float and rolled (Belgium) glasses being separated by Function 3. Certain fine tuning of the data is being contributed by Function 4. It is seen that rolled (other) has remained fairly close to the means of the values of each function since its standard scores are all fairly low. Likewise the contributions due to the potash variable are also close to the mean values of each function.

The success of Grouping No. 3 is shown in Table 5.4. An increase in the prediction success can be achieved by applying the following rules.

- The correct classification is one of the two choices from Grouping No. 2.
- The correct classification is one of the two choices from Grouping No. 3.
- A flat glass needs to have two flat categories named in Grouping No. 3 except for rolled (Japan, low MgO) which are always associated with container. The first choice of the two named flat categories is taken as the correct classification.
- The non-flat category should be taken if it occurs associated with a flat category, except for rolled (Japan, low MgO) when associated with container.
- When two non-flat categories occur then use the first choice.
- All final decisions on classifications should be made after checking the original values of the variables, especially the magnesia content of flat glasses and high soda and low refractive index for tableware compared with container.

Using this approach the success rate of prediction of the correct classification of the 94 cases in Grouping No. 3 is 91.5%. However, if some uncertainty between tableware and containers, and between which flat glass, can be tolerated then the prediction rate is raised to 95.7%. The other four samples then not correctly classified are

(i) a Japanese wired glass containing 1.8% magnesia,
(ii) a West German tableware,
(iii) the Filipino sheet glass, and
(iv) a South African container.

Using this procedure on the fourteen windscreens that were originally excluded from the original 127 samples yields a 100% success in the prediction that the glasses are from a flat category. Since the spectacle and borosilicate glasses are also correctly predicted then the overall success rate of prediction of the classification of the original 127 samples is 96.9%.

5.3.3 Discriminant Analysis on New Samples

The initial glass museum of 134 samples has been extended by an additional sixteen samples of known origin so these were examined using DISCRIMINANT and the Groupings No. 2 and 3. The results are summarised in Table 5.7. Sample GM135 was excluded because it was another specimen of the container from Victoria which is from a pharmaceutical pack of unusual composition. Of the remaining fifteen, eleven were correctly predicted, two (GM137 and GM146) were partly predicted, one (GM145) predicted as an unusual glass and the fourth (GM150) predicted as a rolled (other) whilst it was labware. Sample GM145 was in fact a soda-lime labware, a classification not in the groupings used. The use of discriminant analysis on this limited sample of fifteen additional glasses give encouragement to its usefulness as a means of classification of glasses. Its use on case study glasses is discussed in a later chapter.

5.4 Cluster Analysis

5.4.1 Introduction

A second approach to the statistical analysis of the glass data has been to use the cluster analysis program CLUSTAN IC produced at University College, London, and described by Wishart (1978). In particular the data file has been obtained from that used in the discriminant analysis using procedure SPSS and the distance matrix generated using procedure CORREL. The procedure HIERARCHY has been used using the transformation method suggested by Ward (1963), and this then followed by the procedure TREE.

In this program the N objects, each of which is measured on each of p variables, are expressed in a distance matrix. The hierarchical technique then proceeds to fuse individuals, or groups of individuals, which are closest to each other. By a series of successive fusions the N individual entities can eventually be reduced to a single group. The results may be presented in a form of dendrogram,or tree, which is a two dimensional diagram illustrating the fusion which have been made at each successive level.

The method is expected to place similar glasses alongside each other on one of the branches of the tree. However, it should be remembered that only a two dimensional diagram is being used, and a fusion once made is irrevocable, so that alternate ordering in the tree structure can result from slight variation in data or additional samples.

TABLE 5.7: CLASSIFICATION OF NEW SAMPLES OF KNOWN ORIGIN USING DISCRIMINANT

GLASS MUSEUM NO.	COUNTRY OF ORIGIN	KNOWN CLASSIFICATION	GROUPING NO. 2		GROUPING NO. 3		COMMENTS	PREDICTED CLASSIFICATION
			FIRST CHOICE	SECOND CHOICE	FIRST CHOICE	SECOND CHOICE		
135	Aus (Vic)	Container					Unusual pharmaceutical pack	-
136	Aus	Container	Container	Flat	Container	Rolled (Japan)	No MgO	Container
137	UK	Lightbulb	Lightbulb	Container	Sheet	Tableware	2.4% MgO, low RI	Lightbulb or Tableware
138	USA	Container	Container	Flat	Container	Rolled (Japan)	No MgO	Container
139	Italy	Container	Container	Flat	Rolled (Japan)	Container	High Al2O3(5.1%), high RI, 1.9% MgO, not rolled (Japan)	Container (unusual type)
140	UK	Container	Container	Flat	Rolled (Japan)	Container	No MgO	Container
141	UK	Container	Container	Flat	Rolled (Japan)	Container	No MgO	Container
142	Spain	Container	Container	Flat	Rolled (Japan)	Container	No MgO	Container
143	Aus	Container	Container	Flat	Container	Rolled (Japan)	No MgO	Container
144	Aus	Float	Flat	Container	Float	Rolled (Belgium)		Float
145		Labware	Container	Flat	Tableware	Container	Low RI(1.5115), high K2O(1.8%). Does not fit any of predicted classes	Unusual glass type
146		Lightbulb	Lightbulb	Flat	Tableware	Non Float Flat (Aus 3.1% MgO)	High Na2O	Lightbulb or Tableware
147	Belgium	Rolled	Flat	Container	Rolled (Belgium)	Float	High MgO (4.1%)	Rolled (Belgium)
148	W.Germ.	Labware			Rolled (Japan)	Tableware	Low RI(1.4723)	Borosilicate glass
149	Aus	Rolled (Other)	Flat	Container	Rolled (Other)	Rolled (Belgium)	MgO(2.1%)	Rolled (Other)
150	USA	Labware	Flat	Container	Rolled	Sheet	Low RI(1.5158)	Rolled (Other)

5.4.2 CLUSTAN on Initial Data Bank

The same original data used as that used for DISCRIMINANT has been used for CLUSTAN. This means that seven glasses have been excluded from the original 134 glass samples and the variables limited to seven,namely, refractive index and the oxide compositions of Na, Mg, Al, Si, K and Ca. An inspection of the dendrogram obtained using these 127 glasses is upon first glance rather confusing. However, upon closer examination it is possible to distinguish five main groups that can be broadly identified as non-float flat glasses, float glasses, containers, spectacles and borosilicate glasses. The apparent mismatches within these five groups reveal significant subgroups so that there is an extension to the number of classifications that can be identified.

A simplified version of the dendrogram is shown in Figure 5.8. The group with the major number of subgroups is seen to be the non-float flat glasses. The five Japanese sheet glasses, the two containers from Victoria together with a lightbulb, and the two flat glasses with magnesia content of 2.3%, each form distinct subgroups. There are two subgroups of Australian flat glasses with a magnesia content of 3.1% and 3.6% respectively. A further subgroup of four members results from two lightbulb, the Filipino sheet and a West German tableware. There then only remains three containers (South African, British, and French) and an Italian tableware that are mismatches among the total number of forty three glasses within this group of non-float flat glasses.

The group of float glasses contain a total of 27 samples. At one end of the group there occurs a subgroup of rolled glass from Belgium having a magnesia content of 4.5%. Neighbouring this subgroup are two USA float glasses that upon inspection of their original data have higher refractive indices than the other float glasses. In fact their refractive indices match closely with those of this Belgium subgroup. The only non-float glass located within this group is a rolled glass from Belgium that has a magnesia content of 3.9%.

The next group is that of containers consisting of 35 members. At one end next to the float glasses are three flat glasses that can be identified as rolled glass from Japan with a magnesia content of 0.5%. The only other subgroup is located centrally within the group and contains four of the tableware samples. Significantly all four are Australian products while the other tableware is dispersed throughout the dendrogram. The only further non-container in the group is an Italian tableware glass.

The fourth group contains initially the seven spectacles all next to each other. At one end are positioned five

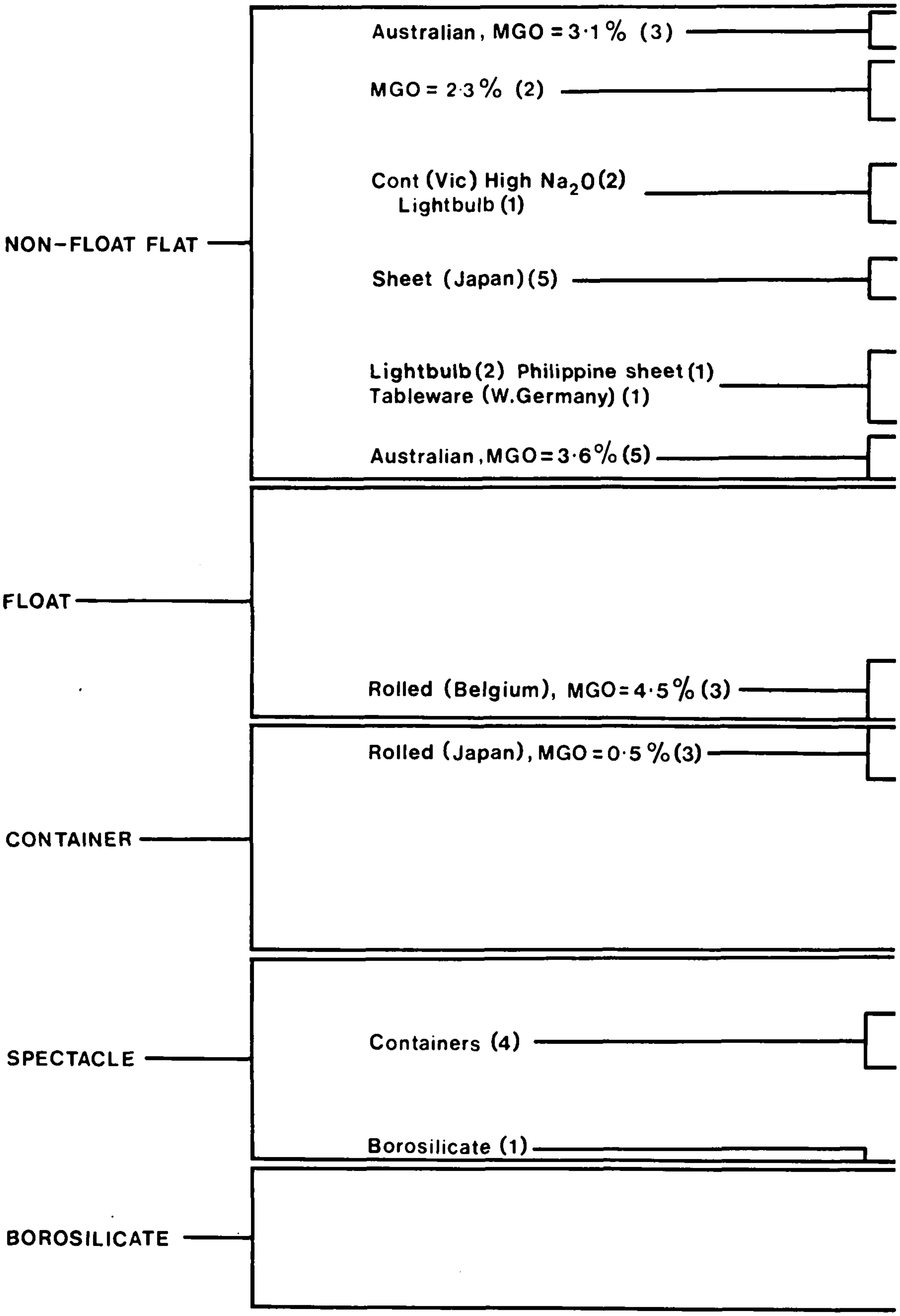


Figure 5.8 Simplified dendrogram of original samples using clustan

imported containers from various countries and then an Argentine tableware followed by a borosilicate headlamp.

The fifth and final group contains the remaining eight borosilicates with no other intruder.

The dendrogram produced in this work has been reasonably successful in sorting the original data into groups. Duplicate samples from the same source of glass have been placed alongside each other. Likewise the five Japanese sheet glasses have been located together. It has supported the existence of the rolled glasses from Belgium with a magnesia content of 4.5% and the rolled glasses from Japan with a magnesia content of 0.5%. It has highlighted the non float flat categories of Australian flat glasses with a magnesia content of 3.1% and 3.6% respectively. These four groupings have arisen out of the discriminant analysis. It has also revealed the existence of rolled glasses with a magnesia content of 2.3%, and a group of Australian tableware. Also it has shown the existence of the subgroup of USA float glasses that have a higher refractive index than other float glasses.

An extra test of the procedure is by inspecting the placement of the windscreen samples that occur in the original data. All fourteen samples are located within the two flat glass categories. Furthermore, they occur distributed as follows: Float (3), Sheet (3), Non float flat (Australian, 3.6% MgO) (5), Rolled (Others) (2), Rolled (Others, 2.3% MgO) (1).

5.4.3 CLUSTAN on New Samples

The sixteen samples of known origin that have been added to the initial glass museum have each in turn been added to the original 127 samples and run on CLUSTAN. Running eachsample separately results in the minimum amount of change in the original ordering within the dendrogram. The location of the addition within the dendrogram has been noted and interpreted on the basis of the original data. The results are summarised in Table 5.8.

Of the sixteen samples thirteen have been correctly predicted. Of the others, sample GM145 is predicted as a Sheet (Japan) but it differs quite significantly from this group. This sample has a lowrefractiveindex andhigh potash content so does not fit any of the established classes. In fact the sample is a soda-lime labware, a classification not in the groupings used. Sample GM147 although a rolled glass from Belgium only contains 4.1% magnesia so does not fit the special group of rolled (Belgium, 4.5% MgO). Consequently it fits better into the float glass category. Finally GM150 is a soda-lime labware so again, like GM145, this is a classification not in the groupings used.

TABLE 5.8 CLASSIFICATION OF NEW SAMPLES OF KNOWN ORIGIN USING CLUSTAN

GLASS MUSEUM NO.	COUNTRY OF ORIGIN	KNOWN CLASSIFICATION	NEAREST NEIGHBOURS	COMMENTS	PREDICTED CLASSIFICATION
135	Aus (Vic)	Container	Container (Vic) Lightbulb (USA)	Matches container (Vic)	Container (Vic)
136	Aus	Container	Container (S.Aus) -		Container
137	UK	Lightbulb	Sheet (Philippines) Lightbulb (Philips)	Lower soda, higher potash than sheet	Lightbulb
138	USA	Container	Container (NSW) Container (S.Aus)		Container
139	Italy	Container	Container (Italy) -		Container
140	UK	Container	Container (Portugal) -		Container
141	UK	Container	Container (S.Aus) -		Container
142	Spain	Container	Container (Spain) Container (S.Aus)		Container
143	Aus	Container	Container (Tas) Container (Tas)		Container
144	Aus	Float	Float (Aus) -	No alumina or potash	Float
145		Labware	Sheet (Japan) -	Variables differ from those for Sheet (Japan)	?
146		Lightbulb	Container (Vic) Lightbulb (USA)	RI and soda do not match Container (Vic)	Lightbulb
147	Belgium	Rolled	Float (Aus) -	High RI for float, low soda, and magnesia for rolled (Belgium)	Float/Rolled (Belgium)
148	W.Germ.	Labware	Labware (Czech) Headlamp (Japan)	Borosilicate	Borosilicate
149	Aus	Rolled	Rolled (Belgium, 2.3% MgO)		Rolled (Other)
150	USA	Labware	Sheet (Japan)	Variables differ from those for Sheet (Japan). Similar to GM145.	?

CHAPTER 6
CASE STUDIES INVOLVING GLASS FRAGMENTS

6.1 Introduction

The collection of the 177 samples for the glass museum has included 27 items from forensic and non-forensic case studies. The results of processing them through the various techniques developed in this work are reported upon below.

6.2 Case 1 Glass Nos. GC151-159

This involved a murder in which the victim's throat was cut. Investigating police wished to determine the possible movements of the victim prior to his death. Sweepings from a suspect's car revealed a number of glass particles. The classifications given by DISCRIMINANT and CLUSTAN are shown in Table 6.1. The predicted classification of lightbulbs glass for six of the fragments was interesting since the victim's job was to repair faulty pin ball machines and he was known to carry spare bulbs for the purpose. Reference to the original data for refractive indices and elemental analyses clearly reveals that the fragments are from more than one broken lightbulb. The decision to select for GC153 the classification of Rolled (Other) was based upon the fact that it is a flat glass which contains 0.6% K20. The other two fragments were predicted as container glass.

6.3 Case 2 Glass Nos. 160-161

This case involved a wilful damage incident in which a wired glass screen was alleged to have been smashed with a mattock. Particles in the handle of the mattock near the head were presented for comparison with the screen. The elemental analyses showed dissimilarity in that the glass from the mattock contained no potash compared to 0.7% K20 in the screen glass. The two glasses were predicted by DISCRIMINANT to be different flat glasses. Their actual predictions are in doubt due to the potash content of GC160 and the magnesia content of GC161. Both glasses caused a rearrangement of many of the flat glasses in the dendrogram using CLUSTAN, but they each finished up in a different subgroup. The conclusion was that they are both unusual glasses of different composition, especially potash.

6.4 Case 3 Glass Nos. GC162-163

This case concerned breaking, entering and stealing from a motor vehicle. Glass particles from a suspect were submitted for comparison with glass from the victim's car. No differences in refractive index or chemical composition were detected and both glasses were clearly classified as float glass. See Table 6.1. The trace elements revealed by the x-ray induced technique are also very similar so suggesting that the two samples are from common sources. It has to be remembered, however, that many car windows are made from float glass.

6.5 Case 4 Glass No. GC164

The interest in this case was to attempt to locate the classification and hence origin of a glass fragment found in a loaf of bread. From Table 6.1 it is seen that both statistical

TABLE 6.1 PREDICTED CLASSIFICATION OF CASE SAMPLES

CASE NO.	GLASS NO.	SOURCE OF GLASS	DISCRIMINANT PREDICTION	CLUSTAN PREDICTION	FINAL PREDICTION
1	151	Car Interior	Lightbulb	Lightbulb	Lightbulb
	152	" "	Container	Container	Container
	153	" "	Rolled (Other)	Non float flat (Aus, 3.6% MgO)	Rolled (Other)
	154	" "	Lightbulb	Lightbulb	Lightbulb
	155	" "	Lightbulb	Lightbulb	Lightbulb
	156	" "	Tableware	Container	Container
	157	" "	Lightbulb	Lightbulb	Lightbulb
	158	" "	Lightbulb	Lightbulb	Lightbulb
	159	" "	Lightbulb	Lightbulb	Lightbulb
2	160	Wired Screen	Non float flat (Aus, 3.6% MgO)	Unusual-sheet	Unusual flat
	161	Suspect Mattock	Non float flat (Aus, 3.1% MgO)	Unusual-lightbulb	Unusual flat
3	162	Suspect	Float	Float	Float
	163	Victim's car window	Float	Float	Float
4	164	Bread	Lightbulb	Lightbulb	Lightbulb
5	165	Hair of suspect	Rolled (Other)	Rolled (Other)	Rolled (Other)
	166	Clothing of suspect	Rolled (Other)	Rolled (Other)	Rolled (Other)
	167	Bank 1 window	Float	Non float flat (Aus, 3.6% MgO)	Non float flat (Aus, 3.6% MgO)
	168	Bank 2 window	Non float flat (Aus, 3.6% MgO)	Rolled (Other)	Rolled (Other)
6	169	Sandwich	Container	Container	Container
7	170	Shop 1 window	Tableware	Rolled (Other)	Same as GC172
	171	Shop 2 window	Float	Float	Float
	172	Shoe of suspect	Tableware	Rolled (Other)	Same as GC170
8	173	Sugar	Pure silica	Rolled (Other)	Pure silica
9	174	Windscreen	Float	Rolled (Other)	Same as GC175
	175	Hammer	Float	Rolled (Other)	Same as GC174
10	176	Hammer	Non float flat (Aus, 3.1% MgO)	Rolled (Other)	Same as GC177
	177	Window	Non float flat (Aus, 3.1% MgO)	Rolled (Other)	Same as GC176

procedures predicted the fragment to be of lightbulb glass.

6.6 Case 5 Glass Nos. GC165-168
The requirement in this case was to compare glass fragments on a breaking and entering suspect with windows from broken-in premises. A comparison of the data showed distinct differences in refractive index and composition between the samples from the suspect and those from the crime scenes. The classifications predicted for these samples are shown in Table 6.1. The DISCRIMINANT analysis clearly indicate that the fragments were all flat glasses. Those on the suspect were similar to each other but different to those from the broken windows. In addition the two window fragments are different to each other. Interestingly CLUSTAN had difficulty in separating GC165,166 and 168 despite their refractive index differences. Sample GC168 also has a lower magnesia content from that associated with the classification predicted for it on both statistical procedures. The chemical composition of sample GC167 indicates the presence of alumina and potash so is not that expected for a float glass. Consequently the non float flat (Aus, 3.6% MgO) classification has been chosen as the final prediction. The two fragments from the suspect (GC165,166) have had the final prediction of rolled (other) assigned to them due to their potash content of 0.5%.

6.7 Case 6 Glass No. GC169
A sliver of glass that had been found in a sandwich needed to be classified in this inquiry. The results from both statistical procedures, as shown in Table 6.1, was for a container glass.

6.8 Case 7 Glass Nos. 170-172
Particles from the boot of a breaking and entering suspect were submitted for comparison with windows from two broken premises. No differences in refractive index or chemical composition were detected between the suspect and shop 1 glass samples. Glass from shop 2 was distinctly dissimilar in these respects. The DISCRIMINANT analysis yielded a first choice of rolled (other) and second choice of tableware for samples GC170 and 172. Using the rules developed during this project this leads to a prediction of tableware despite the fact that GC170 is known to be a flat glass. The third glass, GC171, is predicted as a flat glass of the float classification. The use of CLUSTAN puts GC170 and GC172 in the identical place at one end of the non float flat (Australian, 3.6% MgO) category, while GC171 is confirmed as float glass. It appears that the glass from shop 1 window and the shoe of suspect are from a similar source of a flat glass not within our original glass museum.

6.9 Case 8 Glass No. GC173
Fractured glass particles found in sugar were submitted for identification. They were shown to be pure silica glass particles.

6.10 Case 9 Glass Nos. GC174-175
This case involved an assault with a hammer on a detective in a remote location. The offender then damaged the police vehicles`s

windscreen and fled. The hammer was subsequently recovered from the suspect. Glass particles lodged in the hammer handle were compared with the damaged windscreen glass and no differences in RI or chemical analysis could be detected. The statistical analysis for both glasses gives the category of float from DISCRIMINANT while CLUSTAN places them at the end of the non-float flat grouping neighbouring the float glasses. The final prediction was that the glass fragments were from a similar source of flat glass not within our original glass museum. This and other evidence led to conviction.

6.11 Case 10 Glass Nos. GC176-177
The premises of a car rental company were burgled at night after thieves had gained entry via a broken window. The window was covered with adhesive tape prior to being broken. Suspects were interviewed the following day and police took possession of, amongst other things, a wooden handled claw hammer. Some fine particles of glass impacted into a crevice in the hammer handle were revealed by examination under an optical microscope. An inspection of the RI and chemical composition clearly reveal that the two samples are from similar sources. It is interesting to see the predicted classifications. DISCRIMINANT yields the prediction of non-float flat (Australian, 3.1% MgO) while CLUSTAN places then at the end of the non-float flat grouping next to the float glass. The conclusion was that they were glass fragments from a similar source of flat glass not within our original museum. The suspects subsequently pleaded guilty in this case.

CHAPTER 7
CONCLUSIONS

The activities of the project have been aimed at implementing a rapid and sensitive non-destructive method for identifying and comparing small glass fragments that may be significant in a forensic context. The tendencies of previous workers in glass analysis have been to supplement the refractive index information with the analyses of the trace element components of the glass. The approach in this work has been primarily to analyse for the major and minor constituents of the glass matrix. The trace elements have only been used to provide extra discriminating information when necessary. This approach has been based upon using a SEM/EDS system, a facility that is becoming more widely available and commonly used by forensic scientists. In previous chapters the results from this method have been reported and they illustrate the potential of this approach.

In assessing the success, or otherwise, of this work it is worth considering the various activities which were initially put forward in the proposed outline of the research.

With the stated aim to obtain data from glass fragments that may be significant in a forensic context it was necessary to know the likely range of glass products that might be encountered. Consequently a review was undertaken on the uses of glass within Australia and their sources. This has been documented in Chapter 2 where it can be seen that although the majority of flat and container glass used within Australia is locally made there is a significant amount imported. Furthermore the imports come from a large number of countries so potentially causing considerable difficulties to the Australian forensic scientist.

A collection of 177 glass samples has been made from a variety of sources and initially classified under the headings of float, sheet, patterned, wired, windscreen, lightbulb, headlamps, spectacles, tableware, labware and containers. The museum is clearly not representative of the overall Australian scene but reflects those glasses more readily obtained in Western Australia. Continuing effort and resources are required to constantly update and expand the museum. It had been hoped to collect manufacturer's specifications on these glasses but this is one area in which the companies insisted upon confidentiality of information. Consequently all elemental data expressed in this document is that determined by the research team.

A major activity of the project has been in improving the detection limits of the SEM/EDS system. Quantitative elemental analysis are now possible using the conventional electron beam technique with a detection limit of 0.1%. In addition, the x-ray induced technique has been developed and implemented so resulting in semi-quantitative analysis with a detection limit down to 30 ppm for certain elements. Consequently the major and minor elements can be quantitatively analysed while the trace elements analyses are semi-quantitative. The accuracy of the electron induced analysis have been tested using a range of standard NBS glasses. A satisfactory precision has been obtained.

Data has been obtained from both techniques for all the 177 glasses in the museum. This data together with refractive indices has been used in the three statistical analyses of the data.

For comparative analyses, quantitative electron induced major-minor elemental data has been shown effective in highlighting glasses from different classifications. This greatly enhances the predictions achieved by refractive index measurement alone. The "trace" surveys obtained with the x-ray induced technique further facilitates classification. Further work remains to fully assess this information. The DISCRIMINANT procedure of SPSS and the CLUSTAN package have both been found to be very useful in predicting the classification of a single glass fragment. The data bank used as a reference contains only 134 samples so that prediction successes are impressive. Even when the unknown fragment is of a classification not within the original selections there is a good chance that this will be highlighted by the two statistical packages. This is shown by each procedure predicting a different classification since they both operate on different selection criteria.

The use of DISCRIMINANT and CLUSTAN has lead to a revision of the classifications used. The changes are all associated with the glasses originally classified as patterned or wired. The collective term of rolled glass has been used for these glasses. However, since sheet glasses are no longer produced in Australia the term non-float flat has been adopted for such glasses of known Australian origin. The final list of classifications is now float, sheet, rolled (other), non-float flat (Australian, 3.6% MgO), non-float flat (Australian, 3.1% MgO), rolled (Japan), rolled (Belgium), lightbulb, spectacles, tableware, container, and borosilicates.

These three statistical procedures have given great confidence in the approach adopted to use the major and minor elements only as a means to identify closely related samples, and classify, glasses. This is significant to other workers since it eliminates the needs for trace element analyses that may be time consuming. In the SEM/EDS system all the elements are detected simultaneously in an analysing time of 50s.

The various procedures developed in this work have been applied to several fragments of glasses from case studies. In some instances the data obtained from the glass fragments reveal directly whether they are similar or not. The use of the statistical package to predict the classification of a glass has been successful on many samples. Doubts in the predicted classifications have arisen on a few samples and it appears that the fragments are from glasses not within the original collection. Such problems are expected to occur until the glass data bank itself is much larger but at least the statistical procedures do tend to highlight when this occurs.

Activities have been carried out on all the various facets of the original research proposal. This document contains the status of this work at the end of the funding period. There exists the potential, and the need, to extend the glass data bank and to refine some of the procedures that have been implemented.

REFERENCES

American Society for Testing and Materials (1978).

The Glass Industry (Directory Issue) 1981 Vol. 61 No. 10.

Gould, R.W. and Healey, J.T. 1975. Secondary Fluorescent Excitation in the Scanning Electron Microscope: Improved Sensitivity of Energy Dispersive Analysis. Review of Scientific Instruments, 46(10), 1427.

Nelson, D.F. and Revel, B.C. 1967. Backward Fragmentation from Breaking Glass. Journal of Forensic Science Society, 7, 58-61.

Nie, N.H., Hull, C.H., Jenkins, J.G., Steinbrenner, K. and Bent, D.H. 1975. SPSS: Statistical Package for the Social Sciences, Second Edition. McGraw-Hill Book Company.

Pearson, E.F., May, R.W. and Dabbs, M.D.G. 1971. Glass and Paint Fragments Found in Men's Outer Clothing - Report of a Survey. Journal of Forensic Sciences, 16, 283-300.

Pounds, C.A. 1977. The Efficiency of Searching for Glass on Clothing and the Persistence of Glass on Clothing and Shoes. Home Office Central Research Establishment Report No. 208.

Pounds, C.A. and Smalldon, K.W. 1978. The Distribution of Glass Fragments in Front of a Broken Window and the Transfer of Fragments to Individuals Standing Nearby. Journal of Forensic Science Society, 18, 197-203.

Smalldon, K.W. and Brown, L. 1980. The Evidential Value of Multiple Continuous Measurements - a Simplified Approach to Data Analysis. Medicine Science and the Law 20(3) 154-162.

Terry, K.W., van Riessen, A. and Lynch, B.F. 1981. Criminology Research Council Project 9/80 - The First Year. School of Physics and Geosciences (WAIT) Internal Report SPG 276/1981/AP 20.

Terry, K.W., van Riessen, A. and Lynch, B.F. 1982. Criminology Researh Council Project 9/80 - The Second Year. School of Physics and Geosciences (WAIT) Internal Report SPG 312/1982/AP 50.

van Riessen, A. and Terry, K.W. 1981. Improved Sensitivity of X-ray Elemental Analysis in the Scanning Electron Microscope: an Aid in Glass Analysis. Proceedings of the Australian Seventh International Symposium on the Forensic Sciences, March, 1981.

van Riessen, A. and Terry, K.W. 1982. X-ray Induced X-ray Fluorescence in a JSM-35C Scanning Microscope. JEOL News 20E, 19-23.

Ward, J.H. 1963. Hierarchical Grouping to Optimize an Objective Function. Journal of the American Statistical Association, 58, 236-244.

Ware, N.G. 1981. Computer Programs and Calibration with the PIBS Technique for Quantitative Electron Probe Analysis using a Lithium-Drifted Silicon Detector. Computers and Geosciences, 7, 167-184.

Wishart, D. 1978. Clustan Users Manual, Third Edition. Inter-University/Research Councils Series Report No. 47, January, 1978.

APPENDIX A

INTERIM REPORTS TO THE CRIMINOLOGY RESEARCH COUNCIL

TOPIC A: Optimum voltage for maximising peak to background ratio.

TOPIC B: Variation of total background with accelerating voltage.

TOPIC C: Variation in x-ray spectra with input count rate.

TOCIC D: Variation of detector count rates with sample-detector distance.

TOPIC E: Reduction of extraneous x-rays in a Jeol JSM 35C scanning electron microscope. (Available as School of Physics and Geosciences Internal Report SPG 267/1981/ AP 11.)

TOPIC F: X-ray spectra handling and library facility. (Available as School of Physics and Geosciences Internal Report SPG 257/1981/AP 2.)

TOPIC G: Homogeneity of sample and reproducibility of results.

TOPIC H: Effects of tilting polished samples.

TOPIC I: Refractive index determinations for soda-lime-silica glass.

TOPIC J: X-ray spot size determination.

TOPIC K: Performance of the amplifier.

TOPIC L: Dead-time correction of the EDS system.

TOPIC M: Atomic absorption analysis of glasses.

TOPIC N: Quantitative electron induced x-ray fluorescence analysis of glasses in the SEM. (Available as School of Physics and Geosciences Internal Report SPG 272/ 1981/AP 16.)

TOPIC O: Accumulated data on glass museum samples.

TOPIC P: Homogeneity of glass across thickness.

TOPIC Q: Comparative glass analysis using multiple continuous measurements - data analysis.

TOPIC R: An initial study of a discriminative analysis to predict glass categories.

TOPIC S: Inter-laboratory comparison of quantitative elemental analysis of glass.

TOPIC T: X-ray induced x-ray data on glass museum samples.

TABLE 3.1
ACCUMULATED DATA OF GLASS MUSEUM SAMPLES 1-177
ELECTRON INDUCED ELEMENTAL ANALYSIS

GLASS	ORIGIN	TYPE	COLOUR Note 1	THICK-NESS (mm) Note 2	FLUORES Note 3	REFRAC-TIVE INDEX	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	(PbO) SO_3	Cl	K_2O	CaO	(BaO) TiO_2	V_2O_5	Cr_2O_3	MnO	FeO	ZnO
1	JAPAN (ASAHI)	WIRED		6.67	NIL	1.5195	13.6	3.3	1.6	71.8		0.3		0.7	8.6						
2	JAPAN (ASAHI)	WIRED		~6.5	NIL	1.5227	12.2	0.5	1.7	72.6		0.2		0.7	12.0	0.2					
3	JAPAN (ASAHI)	WIRED		~6.2	NIL	1.5188	13.2	3.3	1.6	72.1		0.3		0.7	8.6						
4	JAPAN (ASAHI)	PATT-ERNED		~5.35	NIL	1.5229	12.6	0.7	1.6	72.3		0.4		0.6	11.5	0.2					
5	JAPAN (NSG)	WIRED		6.26	NIL	1.5227	13.9	2.3	1.5	71.1		0.3		0.7	10.2						
6	JAPAN (NSG)	WIRED	BRONZE	6.61	NIL	1.5232	12.8	1.8	1.6	71.8		0.2		0.9	10.9						
7	JAPAN (ASAHI)	SHEET	-	3.88	NIL	1.5143	13.5	3.6	1.9	72.7		0.2		0.9	7.0						
8	JAPAN (ASAHI)	WIRED	-	~6.30	NIL	1.5228	12.2	0.5	1.7	72.7		0.3		0.7	11.6	0.2					
9	USA (PPG)	FLOAT	BRONZE	5.54	ONE SURFACE	1.5198	13.4	3.6		73.3		0.4			8.9					0.3	
10	USA (PPG)	FLOAT	GREY	5.86	ONE SURFACE	1.5238	14.1	3.9	0.3	71.5		0.4			9.4					0.2	
11	USA (PPG)	FLOAT	BRONZE	5.75	ONE SURFACE	1.5198	13.6	3.6		73.3		0.2			9.0					0.3	
12	USA (PPG)	FLOAT	DARK GREY	5.68	ONE SURFACE	1.5241	13.7	3.6		73.3		0.4			9.0						
13	AUSTR-ALIA	FLOAT		2.29	ONE SURFACE	1.5198	14.0	3.7		73.1		0.2			8.9						
14	AUSTR-ALIA	FLOAT		3.99	ONE SURFACE	1.5198	13.8	3.6		73.1		0.2			9.0						
15	AUSTR-ALIA	FLOAT		5.07	ONE SURFACE	1.5199	14.0	3.7	0.1	72.7		0.3			9.0						

TABLE B.1
ACCUMULATED DATA OF GLASS MUSEUM SAMPLES 1-177
ELECTRON INDUCED ELEMENTAL ANALYSIS

GLASS	ORIGIN	TYPE	COLOUR Note 1	THICK-NESS (mm) Note 2	FLUORES Note 3	REFRAC-TIVE INDEX	Na2O	MgO	Al2O3	SiO2	P2O5	(PbO) SO3	Cl	K2O	CaO	(BaO) TiO2	V2O5	Cr2O3	MnO	FeO	ZnO
16	AUSTR-ALIA	FLOAT		5.93	ONE SURFACE	1.5198	14.0	3.6		73.2					9.1						
17	AUSTR-ALIA	PATT-ERNED		~3.2	NIL	1.5193	13.5	3.5	0.9	73.0				0.1	8.6						
18	AUSTR-ALIA	PATT-ERNED	YELLOW BROWN	~4	NIL	1.5199	13.9	3.1	1.7	72.1			0.5		8.5						
19	USA	FLOAT	BRONZE	5.74	ONE SURFACE	1.5199	13.5	3.6		73.2		0.3			8.9					0.3	
20	USA	FLOAT	DARK GREY	5.725	ONE SURFACE	1.5186	13.7	3.5		73.9		0.2			8.7						
21	USA	FLOAT	BRONZE (MIRROR FINISH)	5.70	ONE SURFACE	1.5198	13.8	3.4		73.5		0.2			8.8					0.2	
22	JAPAN	SHEET		~2.85	NIL	1.5144	13.7	3.6	1.6	73.1		0.2		0.9	7.0						
23	BELGIUM	FLOAT	GREY	3.17	ONE SURFACE	1.5194	13.7	3.6		73.3		0.3			8.8					0.2	
24	WEST GERMANY	PATT-ERNED	YELLOW	~4	SLIGHT BULK	1.5252	14.1	2.3	0.8	71.5				0.5	10.8						
25	AUSTR-LIA	WIRED		~6.36	NIL	1.5196	13.9	3.7	0.6	72.8		0.2		0.1	8.6						
26	JAPAN (ASAHI)	WIRED		~6.6	NIL	1.5186	13.7	3.4	1.6	71.7		0.2		0.9	8.2					0.1	
27	AUSTR-LIA	FLOAT		4.97	NIL	1.5197	14.0	3.7		73.0		0.3			8.9						
28	AUSTR-LIA	FLOAT		5.71	NIL	1.5198	13.8	3.5		73.5		0.2			8.8						
29	AUSTR-LIA	PATT-		3.3	NIL	1.5188	13.2	3.6	1.0	73.4		0.2		0.2	8.4						
30	JAPAN	SHEET		~3.4	SLIGHT BULK	1.5144	13.5	3.8	1.8	72.9				0.9	6.8	0.1				0.1	

TABLE B.1
ACCUMULATED DATA OF GLASS MUSEUM SAMPLES 1-177
ELECTRON INDUCED ELEMENTAL ANALYSIS

GLASS	ORIGIN	TYPE	COLOUR Note 1	THICK-NESS (mm) Note 2	FLUORES Note 3	REFRAC-TIVE INDEX	Na2O	MgO	Al2O3	SiO2	P2O5	(PbO) SO3	Cl	K2O	CaO	(BaO) TiO2	V2O5	Cr2O3	MnO	FeO	ZnO
31	AUSTR-LIA	FLOAT		5.71	NIL	1.5189	13.9	3.6		73.8					8.7						
32	BELGIUM	PATT-ERNED	YELLOW	~4	NIL	1.5248	13.2	4.6	0.2	71.8				0.1	9.9						
33	AUSTR-LIA	PATT-ERNED	YELLOW	~5	NIL	1.5196	13.8	3.1	1.3	72.3			0.5	0.2	8.8						
34	JAPAN	SHEET		2.95	SLIGHT BULK	1.5148	13.4	3.8	1.7	73.3		0.1		0.8	6.8						
35	BELGIUM	PATT-ERNED	BROWN GREY	~5	NIL	1.5247	13.3	4.5		71.7		0.3		0.1	9.9					0.2	
36	BELGIUM	PATT-ERNED	LIGHT BROWN GREY	~4.5	NIL	1.5250	13.3	4.5	0.6	71.2		0.3		0.1	9.8					0.2	
37	AUSTR-ALIA	PATT-ERNED		~4	NIL	1.5166	13.5	3.7	1.2	73.3				0.2	7.8						
38	AUSTR-ALIA	PATT-ERNED	YELLOW	~5	NIL	1.5200	13.9	3.1	1.6	72.0			0.5	0.2	8.7						
39	AUSTR-ALIA	PATT-	GREY	4.7	NIL	1.5199	13.6	3.6	1.0	72.6		0.2		0.2	8.5					0.3	
40	USA	FLOAT	GREY	3.10	ONE SURFACE	1.5233	13.9	3.8	0.3	71.0		0.3			9.5					0.3	
41	AUSTR-ALIA	FLOAT		2.905	ONE SURFACE	1.5193	13.8	3.8		72.8		0.3			8.9					0.1	
42	BELGIUM	PATT-ERNED	YELLOW	~4	NIL	1.5247	14.3	2.3	0.8	71.5				0.5	10.6						
43	AUSTR-ALIA	FLOAT		4.865	ONE SURFACE	1.5183	13.6	3.7	0.2	73.3		0.3			8.5						
44	HOYA	SPEC-TACLE		-	NIL	1.5230	8.0		1.9	68.3		0.2		9.9	8.5	0.2					3.0
45	USA (AO)	SPEC-TACLE		-	NIL	1.5232	2.5		12.2	71.1	2.1	(3.5)	0.2			(7.4)	0.8				

TABLE B.1
ACCUMULATED DATA OF GLASS MUSEUM SAMPLES 1-177
ELECTRON INDUCED ELEMENTAL ANALYSIS

GLASS	ORIGIN	TYPE	COLOUR Note 1	THICK-NESS (mm) Note 2	FLUORES Note 3	REFRAC-TIVE INDEX	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	(PbO) SO_3	Cl	K_2O	CaO	(BaO) TiO_2	V_2O_5	Cr_2O_3	MnO	FeO	ZnO
46	UK (MW)	SPEC-TACLE	GREEN	-	NIL	1.5228	11.4		0.3	72.4		0.2		5.9	5.5	0.1				4.2	
47	UK (UKO)	SPEC-TACLE		-	NIL	1.5236	10.8	0.9	0.8	70.0		0.4		5.3	9.7	(2.0)	0.1				
48	USA (AO)	SPEC-TACLE			NIL	1.5237	8.2	0.2	1.9	69.0				9.3	8.7	0.3					2.5
49	UK	SPEC-	LIGHT PINK BROWN		NIL	1.5229	10.9		2.1	70.9				6.6	7.8		0.9	0.4	0.4		
50	CANADA (AO)	SPEC-TACLE	GREY GREEN		NIL	1.5246	8.7			71.8		0.1		8.1	8.7					2.5	
51	THAIL-AND (HOYA)	SPEC-	-	-	NIL	1.5229	11.1		0.5	70.8				5.2	7.6	(2.6)	0.2				1.9
52	CZECHO-SLOVAKIA	TABLE-WARE	-	-	NIL	1.5488	1.0			65.9		(16.5)	0.5	14.0	0.2						1.7
53	AUSTR-ALIA	TABLE-WARE			NIL	1.5178	15.6		1.4	73.1		0.1			9.6						
54	CANADA (LUCAS)	HEAD-LAMP			NIL	1.4783	4.9		2.0	77.1				0.1	0.1						
55	CANADA (LUCAS)	HEAD-LAMP			NIL	1.5188	13.4	0.3	1.3	71.5				2.9	8.1	(2.3)	0.2				
56	AUSTR-ALIA (LEY LAND)	WIND-SCREEN TOUGH-ENED		5.98	NIL	1.5232	13.5	2.8	0.7	71.7		0.3		0.2	10.7						
57	AUSTR-ALIA (LEY-LAND)	WIND-SCREEN TOUGH-ENED		6.01	NIL	1.5177	13.7	3.6	0.2	73.1		0.4			8.9					0.1	

TABLE B.1
ACCUMULATED DATA OF GLASS MUSEUM SAMPLES 1-177
ELECTRON INDUCED ELEMENTAL ANALYSIS

GLASS	ORIGIN	TYPE	COLOUR Note 1	THICK-NESS (mm) Note 2	FLUORES Note 3	REFRAC-TIVE INDEX	Na2O	MgO	Al2O3	SiO2	P2O5	(PbO) SO3	Cl	K2O	CaO	(BaO) TiO2	V2O5	Cr2O3	MnO	FeO	ZnO
58	TOYOTA	WIND-SCREEN LAMIN-ATED		5.74	NIL	1.5210	13.1	3.5	1.4	71.5		0.3		0.9	8.9					0.1	
59	AUSTR-ALIA (GMH)	WIND-SCREEN TOUGH-ENED		4.91	NIL	1.5169	13.6	3.8	0.4	73.1		0.4			8.5						
60	AUSTR-ALIA (GMH)	WIND-SCREEN TOUGH-ENED		5.97	NIL	1.5167	12.7	3.5	0.9	73.4		0.2		0.6	8.7						
61	BMW	WINDOW TOUGH-ENED	LIGHT BLUE	4.91	NIL	1.5147	13.4	3.5	1.8	72.4		0.2		1.1	7.1					0.3	
62	AUSTR-ALIA (FORD)	WIND-SCREEN TOUGH-ENED	-	5.83	NIL	1.5161	13.1	3.5	1.0	73.3		0.2		0.6	8.3						
63	AUSTR-ALIA (CHRYS-LER)	WIND-SCREEN TOUGH-ENED		4.71	NIL	1.5175	13.8	3.5		73.5		0.3		0.1	8.6						
64	AUSTR-ALIA (WA)	CONT-AINER			NIL	1.5208	14.4	0.5	1.7	72.2		0.3	0.1		10.7						
65	AUSTR-ALIA (WA)	CONT-AINER			NIL	1.5217	14.0	0.6	1.7	72.1		0.3		0.1	11.0						
66	AUSTR-ALIA (WA)	CONT-AINER	BROWN		NIL	1.5209	14.0	0.7	1.5	72.3		0.2	0.1	0.2	10.8					0.1	
67	AUSTR-ALIA (WA)	CONT-AINER	BROWN		NIL	1.5214	13.8	0.6	1.5	72.7				0.1	10.7					0.2	

TABLE B.1
ACCUMULATED DATA OF GLASS MUSEUM SAMPLES 1-177
ELECTRON INDUCED ELEMENTAL ANALYSIS

GLASS	ORIGIN	TYPE	COLOUR Note 1	THICK-NESS (mm) Note 2	FLUORES Note 3	REFRAC-TIVE INDEX	Na2O	MgO	Al2O3	SiO2	P2O5	(PbO) SO3	Cl	K2O	CaO	(BaO) TiO2	V2O5	Cr2O3	MnO	FeO	ZnO
68	PHILI-PPINES	CONT-AINER	BROWN		NIL	1.5201	14.8	0.2	1.8	72.2		0.2	0.1	0.3	10.1					0.2	
69	THAI-LAND	CONT-AINER	BROWN		NIL	1.5205	14.6	0.4	1.5	73.1					10.2					0.2	
70	UK	CONT-AINER			NIL	1.5193	13.2	0.3	1.3	73.5		0.2		0.3	11.0						
71	CHINA PEOPLES REPUB.	CONT-AINER			NIL	1.5164	12.5	3.5	3.7	69.9		0.2		2.2	6.9	(0.6)				0.2	
72	JAPAN	CONT-AINER	BROWN		NIL	1.5197	15.6	1.0	3.7	69.5		0.2		2.0	7.2				0.2	0.1	0.5
73	AUSTR-ALIA (SA)	CONT-AINER	GREEN		NIL	1.5219	15.0	0.3	1.5	72.0			0.1	0.3	10.5			0.2			
74	AUSTR-ALIA (VIC)	CONT-AINER			NIL	1.5154	17.1	3.4	1.5	70.1		0.5			5.2	(1.8)	0.1	0.1			
75	UK	CONT-AINER			NIL	1.5198	14.1		1.3	72.9		0.4		0.4	10.7						
76	CHINA	LAB-WARE			NIL	1.4751	3.9	0.2	2.2	77.0			0.1	0.3	0.5					0.1	0.3
77	ARGENT-INA	LAB-WARE			NIL	1.4938	5.4	0.2	5.8	68.5			0.2	2.9	0.6	(2.4)	0.3				
78	CZECHO-SLOVAKIA	LAB-WARE			NIL	1.4735	3.2	0.1	2.2	73.4		0.1	0.1	0.9	0.1	0.1					
79	WEST GERMANY	LAB-WARE			NIL	1.5146	13.8	2.8	3.3	70.5		0.3		1.9	5.2	(1.9)	0.2				
80	UK	LAB-WARE			NIL	1.4724	4.0		2.1	76.9				0.1	0.1						
81	AUSTR-ALIA	LAB-WARE			NIL	1.4732	4.2	0.2	2.4	77.2			0.1	0.1	0.1						

TABLE B.1
ACCUMULATED DATA OF GLASS MUSEUM SAMPLES 1-177
ELECTRON INDUCED ELEMENTAL ANALYSIS

GLASS	ORIGIN	TYPE	COLOUR Note 1	THICK-NESS (mm) Note 2	FLUORES Note 3	REFRAC-TIVE INDEX	Na2O	MgO	Al2O3	SiO2	P2O5	(PbO) SO3	Cl	K2O	CaO	(BaO) TiO2	V2O5	Cr2O3	MnO	FeO	ZnO
82	AUSTR-ALIA (VIC)	CONT-AINER			NIL	1.5154	17.2	3.4	1.5	70.7		0.5			5.4	(1.0)	0.2				
83	ITALY	CONT-AINER	YELLOW		NIL	1.5206	15.0	0.7	1.2	72.5				0.5	9.5	0.5					
84	AUSTR-ALIA (CORN-ING)	TABLE-WARE			NIL	1.5187	15.7		1.4	72.7		0.2			9.8						
85	USA (CROWN CORNING)	TABLE-WARE COOK-WARE			NIL	1.5325	1.3	8.9	19.7	62.8	0.5				6.8						
86	WEST GERMANY	TABLE-WARE			NIL	1.5114	14.1	2.9	1.1	73.6		0.3		0.9	6.1	(0.8)					
87	ITALY	TABLE-WARE			NIL	1.5192	15.2	0.6	1.3	72.0			0.1	0.3	9.3	(1.0)					
88	AUSTR-ALIA (CORN-ING)	TABLE-WARE			NIL	1.5163	15.2		1.4	73.6		0.2			9.3						
89	ITALY	TABLE-WARE			NIL	1.5222	14.0	2.3	1.6	71.4				0.4	9.7	(0.4)					
90	AUSTR-ALIA (CORNING)	TABLE-WARE			NIL	1.5168	15.3		1.3	73.6		0.3			9.4						
91	PHILIPS	LAMP BULB			NIL	1.5096	16.6	3.1	1.8	73.1				0.4	4.9						
92	UNKNOWN	LAMP BULB			NIL	1.5626	7.7		1.6	62.5	0.3	(20.8)	0.6	5.4	0.3				0.3		
93	UNKNOWN	LAMP BULB			NIL	1.5141	15.6	3.0	1.4	72.2		0.3		0.8	6.6						

TABLE B.1
ACCUMULATED DATA OF GLASS MUSEUM SAMPLES 1-177
ELECTRON INDUCED ELEMENTAL ANALYSIS

GLASS	ORIGIN	TYPE	COLOUR Note 1	THICK-NESS (mm) Note 2	FLUORES Note 3	REFRAC-TIVE INDEX	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	(PbO) SO_3	Cl	K_2O	CaO	(BaO) TiO_2	V_2O_5	Cr_2O_3	MnO	FeO	ZnO
94	USA (G.E.)	LAMP BULB			NIL	1.5140	16.0	3.7	2.1	70.9		0.3	0.1	0.9	6.1					0.1	
95	AUSTR-ALIA (NSW)	CONT-AINER	COLOUR LESS TO VERY PALE GREEN		NIL	1.5211	13.2	0.4	1.6	72.8		0.3		0.2	11.4						
96	AUSTR-ALIA (NSW)	CONT-AINER			NIL	1.5180	13.4	0.2	1.6	73.3		0.2			11.2						
97	AUSTR-ALIA (NSW)	CONT-AINER	BROWN		NIL	1.5203	13.0		1.6	73.7				0.2	11.0					0.2	
98	AUSTR-ALIA (NSW)	CONT-AINER	BROWN		NIL	1.5198	13.1	0.2	1.6	73.9				0.2	11.0						
99	AUSTR-ALIA (NSW)	CONT-AINER	YELLOW GREEN (PALE)		NIL	1.5200	13.2	0.1	1.6	73.7				0.1	11.1						
100	AUSTR-ALIA (NSW)	CONT-AINER	GREEN		NIL	1.5208	13.2	0.6	1.4	72.5		0.2		0.3	11.3			0.3		0.2	
101	AUSTR-ALIA (NSW)	CONT-AINER	YELLOW		NIL	1.5207	13.8	0.2	1.7	73.1				0.1	11.0						
102	AUSTR-ALIA (TAS)	CONT-AINER			NIL	1.5220	13.5		1.5	72.7		0.2			12.0						
103	AUSTR-ALIA (TAS)	CONT-AINER	BROWN		NIL	1.5212	13.8		1.4	73.4					11.1					0.2	
104	AUSTR-ALIA (TAS)	CONT-AINER	GREEN		NIL	1.5235	14.1	0.2	1.4	72.3		0.2			11.3			0.2		0.2	

TABLE B.1
ACCUMULATED DATA OF GLASS MUSEUM SAMPLES 1-177
ELECTRON INDUCED ELEMENTAL ANALYSIS

GLASS	ORIGIN	TYPE	COLOUR Note 1	THICK-NESS (mm) Note 2	FLUORES Note 3	REFRAC-TIVE INDEX	Na2O	MgO	Al2O3	SiO2	P2O5	(PbO) SO3	Cl	K2O	CaO	(BaO) TiO2	V2O5	Cr2O3	MnO	FeO	ZnO
105	PHILI-PPINES	SHEET		2.87		1.5136	14.4	3.6	1.6	72.4	0.3	0.4		0.3	7.0					0.1	
106	BELGIUM	PATT-ERNED	YELLOW BROWN			1.5196	13.4	3.9	0.3	73.5				0.1	8.9						
107	POLAND	SHEET		4.0	NIL	1.5164	13.6	3.4	1.2	73.4		0.2			8.1						
108	USA (PPG)	FLOAT		5.87	ONE SURFACE	1.5196	13.7	3.5		73.2		0.3			9.2						
109	USA (PPG)	FLOAT	GREY	5.58	ONE SURFACE	1.5196	13.5	3.4		73.7		0.2			9.0					0.3	
110	JAPAN	SHEET		4.01		1.5148	12.9	3.5	1.8	73.5		0.1		0.9	7.3						
111	CANADA (LUCAS)	HEAD-LAMP			NIL	1.4783	4.7	0.1	1.9	76.2			0.1								
112	AUSTR-ALIA (LEYLAND)	WIND-SCREEN TOUGHENED		5.91		1.5186	12.7	3.3	0.9	73.1		0.2		0.6	9.2						
113	JAPAN (MAZDA)	WIND-SCREEN		-	-	1.5179	12.7	3.7	1.7	72.9				0.7	8.3						
114	JAPAN KOTO	HEAD-LAMP			NIL	1.4778	4.3	0.5	2.1	67.3				0.1	0.2						
115	DATSUN	WIND-SCREEN LAMI NATED			NIL	1.5166	12.4	3.5	1.7	72.7		0.3		1.3	8.1						
116	JAPAN TOSHIBA	HEAD-LAMP			NIL	1.4765	3.9	0.5	2.3	73.5				0.7	0.1						
117	AUSTR-ALIA (GMH)	WIND-SCREEN TOUGH-ENED		4.99		1.5166	12.7	3.5	1.1	73.1		0.2		0.6	8.5						

TABLE B.1
ACCUMULATED DATA OF GLASS MUSEUM SAMPLES 1-177
ELECTRON INDUCED ELEMENTAL ANALYSIS

GLASS	ORIGIN	TYPE	COLOUR Note 1	THICK-NESS (mm) Note 2	FLUORES Note 3	REFRAC-TIVE INDEX	Na2O	MgO	Al2O3	SiO2	P2O5	(PbO) SO3	Cl	K2O	CaO	(BaO) TiO2	V2O5	Cr2O3	MnO	FeO	ZnO
118	AUSTR-ALIA LEYLAND	WIND-SCREEN TOUGH-ENED		4.92		1.5186	13.2	3.4	1.1	72.6		0.2		0.6	9.0						
119	BOSCH	HEAD-LAMP			BULK	1.5203	15.6	3.1	1.9	70.1				1.4	5.4	(2.4)	0.1				
120	DATSUN	WIND-SCREEN LAMI-NATED				1.5233	12.6	1.8	1.5	71.8		0.3		0.7	11.3						
121	JAPAN (KOTO)	HEAD-LAMP				1.4751	4.6		2.0	74.9				0.1	0.1						
122	AUSTR-ALIA (WA)	CONT-AINER	GREEN			1.5221	13.6	0.5	1.5	72.6		0.2		0.1	11.2			0.3			
123	PORTU-GAL	CONT-AINER	GREEN			1.5225	11.4	1.5	1.6	72.9		0.2		0.9	11.1			0.2		0.3	
124	ITALY	CONT-AINER	GREEN			1.5236	14.7	2.2	4.6	67.6		0.2	0.1	1.6	8.6	0.1		0.1		0.4	
125	SOUTH AFRICA	CONT-AINER	YELLOW TO OLIVE			1.5154	11.9	3.4	0.9	73.6				0.4	9.6						
126	SPAIN	CONT-AINER	GREEN			1.5246	13.2	0.2	2.5	70.5		0.2		1.5	11.4			0.2		0.2	
127	FRANCE	CONT-AINER	GREEN			1.5255	13.3	1.4	2.1	71.3				0.6	10.8			0.2		0.4	
128	AUSTR-ALIA (SA)	CONT-AINER	LIGHT GREEN			1.5212	12.5	0.2	3.1	70.7		0.3		2.3	10.9						
129	AUSTR-ALIA (SA)	CONT-AINER	GREEN			1.5224	13.2	0.4	73.0					0.2	11.2			0.2		0.1	

TABLE B.1
ACCUMULATED DATA OF GLASS MUSEUM SAMPLES 1-177
ELECTRON INDUCED ELEMENTAL ANALYSIS

GLASS	ORIGIN	TYPE	COLOUR Note 1	THICKNESS (mm) Note 2	FLUORES Note 3	REFRACTIVE INDEX	Na2O	MgO	Al2O3	SiO2	P2O5	(PbO) SO3	Cl	K2O	CaO	(BaO) TiO2	V2O5	Cr2O3	MnO	FeO	ZnO
130	AUSTRALIA (SA)	CONTAINER				1.5201	12.9	0.3	1.6	73.4		0.2			11.3						
131	AUSTRALIA (SA)	CONTAINER	BROWN			1.5215	12.7	0.2	1.5	73.6				0.2	11.5					0.2	
132	UK	CONTAINER	GREEN			1.5230	13.3	2.9	2.0	71.0		0.2		1.0	9.2			0.3		0.3	
133	AUSTRALIA (WA)	CONTAINER	PALE GREEN			1.5211	13.8	0.5	1.6	72.5		0.3			11.0			0.1			
134	AUSTRALIA (SA)	CONTAINER	BROWN			1.5213	14.5	0.3	1.5	72.6			0.1	0.3	10.5					0.1	
135	AUSTRALIA (VIC)	CONTAINER			NIL	1.5154	17.0	3.3	1.5	71.0		0.4	0.0		5.5	(1.0)	0.2				
136	AGM	CONTAINER				1.5196	12.7		1.4	74.0		0.2		0.1	11.6						
137	UK	LAMP BULB	SEMI-OPAQUE			1.5138	14.2	2.4	1.9	72.8		0.2		1.1	7.2						
138	USA	CONTAINER				1.5177	13.0		1.7	73.7		0.2		0.4	10.9						
139	ITALY	CONTAINER				1.5296	12.9	1.9	5.1	66.3				1.7	11.5	0.1				0.4	
140	UK	CONTAINER				1.5221	11.3		1.5	73.8				1.1	12.1					0.2	
141	UK	CONTAINER				1.5189	11.2		1.7	74.2				0.9	11.6					0.3	
142	SPAIN	CONTAINER				1.5244	12.1		2.2	71.2		0.2		1.5	12.2			0.2		0.3	

TABLE B.1
ACCUMULATED DATA OF GLASS MUSEUM SAMPLES 1-177
ELECTRON INDUCED ELEMENTAL ANALYSIS

GLASS	ORIGIN	TYPE	COLOUR Note 1	THICK-NESS (mm) Note 2	FLUORES Note 3	REFRAC-TIVE INDEX	Na2O	MgO	Al2O3	SiO2	P2O5	(PbO) SO3	Cl	K2O	CaO	(BaO) TiO2	V2O5	Cr2O3	MnO	FeO	ZnO
143	AUSTR-ALIA (AGM)	CONT-AINER				1.5205	13.7		1.4	72.6		0.4			11.7						
144	AUSTR-ALIA	FLOAT				1.5197	12.7	3.3		73.9		0.2			9.9						
145		LAB WARE				1.5115	13.4	2.3	2.5	72.5		0.3		1.8	6.0	0.9	0.2				
146						1.5162	16.2	3.3	1.5	71.4		0.3	0.1	0.1	5.7	0.9	0.2	0.1		0.1	
147	BELGIUM	PATT-ERNED				1.5248	12.0	4.1		73.0					10.9						
148	WEST GERMANY	LAB WARE				1.4723	2.8		2.0	73.6				0.7	0.1						
149	AUSTR-ALIA	PATT-ERNED				1.5235	12.9	2.1	0.8	71.9				0.6	11.4			0.1		0.1	
150	USA	LAB WARE				1.5158	13.4	3.5	1.1	72.6		0.3		1.1	7.8						
151	CASE					1.5083	16.9	3.3	1.2	72.9		0.3		0.3	4.7						0.4
152	CASE		BROWN			1.5216	14.4	0.6	1.5	72.3				0.1	10.7					0.1	
153	CASE					1.5165	13.7	3.6	1.0	72.4		0.2		0.6	8.3					0.1	
154	CASE					1.5083	16.8	3.2	1.3	73.0		0.4		0.3	4.8						
155	CASE					1.5136	14.1	3.3	1.6	72.4		0.2		0.8	7.2						
156	CASE					1.5201	14.9	1.2	1.6	71.9		0.3			9.7						0.3
157	CASE					1.5136	14.1	3.5	1.6	72.1		0.2		0.9	7.2						
158	CASE					1.5086	17.4	3.2	1.1	72.9		0.2		0.2	4.8						
159	CASE					1.5090	16.8	2.8	2.5	70.6		0.4		0.7	6.0						
160	CASE					1.516	13.5	3.8	1.3	72.3		0.2		0.7	7.8					0.1	

TABLE B.1
ACCUMULATED DATA OF GLASS MUSEUM SAMPLES 1-177
ELECTRON INDUCED ELEMENTAL ANALYSIS

GLASS	ORIGIN	TYPE	COLOUR Note 1	THICK-NESS (mm) Note 2	FLUORES Note 3	REFRAC-TIVE INDEX	Na2O	MgO	Al2O3	SiO2	P2O5	(PbO) SO3	Cl	K2O	CaO	(BaO) TiO2	V2O5	Cr2O3	MnO	FeO	ZnO
161	CASE					1.5168	14.3	3.7	1.2	72.1		0.2	0.0		8.0						
162	CASE					1.5189	14.4	3.8		72.6		0.1			8.9						
163	CASE					1.5189	14.2	3.7		73.0					9.0						
164	CASE					1.5083	16.4	1.8	1.0	74.4				0.9	5.2						
165	CASE					1.5164	13.4	3.5	1.0	72.9		0.2		0.5	8.4						
166	CASE					1.5164	13.2	3.8	1.0	72.8		0.3		0.6	8.3						
167	CASE					1.5197	14.0	3.6	0.8	72.2		0.3		0.2	8.9						
168	CASE					1.5180	13.3	2.9	0.8	73.4		0.2		0.4	8.9						
169	CASE					1.5179	12.4		1.4	73.8		0.3	0.1	0.4	11.5						
170	CASE					1.5178	13.3	2.0	0.5	73.3		0.3	0.2	0.5	9.8						
171	CASE					1.5197	12.8	3.1		73.6		0.3	0.2		9.9						
172	CASE					1.5178	13.5	2.1	0.6	73.4		0.2	0.1	0.4	9.6						
173	CASE					>1.6				99.8			0.1								
174	CASE					1.5185	12.8	3.0		73.8		0.3	0.2		9.9						
175	CASE					1.5185	12.7	3.1		73.7		0.3	0.2		10.0						
176	CASE					1.5166	12.6	3.1	0.9	74.0					9.1						
177	CASE					1.5166	12.5	3.2	0.9	73.8					9.1						

NOTE 1. No entry indicates uncoloured glass.

NOTE 2. Only flat window glass are accurate thickness measurements. Remainder are nearest approximations. No entry indicates sample unsuitable for thickness measurement.

NOTE 3. Fluorescence with 253.7 nm light (U.V.).

TABLE B.2 FLOAT GLASSES

GLASS NO.	ORIGIN	REFRACTIVE INDEX	Na2O	MgO	Al2O3	SiO2	P2O5	SO3	Cl	K2O	CaO	TiO2	V2O5	Cr2O3	MnO	FeO	ZnO
9	USA	1.5198	13.4	3.6		73.3		0.4			8.9					0.3	
10	USA	1.5238	14.1	3.9	0.3	71.5		0.4			9.4					0.2	0.2
11	USA	1.5198	13.6	3.6		73.3		0.2			9.0					0.3	
12	USA	1.5241	13.7	3.6		73.3		0.4			9.0						
13	AUSTRALIA	1.5198	14.0	3.7		73.1		0.2			8.9						
14	AUSTRALIA	1.5198	13.8	3.6		73.1		0.2			9.0						
15	AUSTRALIA	1.5199	14.0	3.7	0.1	72.7		0.3			9.0						
16	AUSTRALIA	1.5198	14.0	3.6		73.2					9.1						
19	USA	1.5199	13.5	3.6		73.2		0.3			8.9					0.3	0.1
20	USA	1.5186	13.7	3.5		73.9		0.2			8.7						
21	USA	1.5198	13.8	3.4		73.5		0.2			8.8					0.2	
23	BELGIUM	1.5194	13.7	3.6		73.3		0.3			8.8					0.2	
27	AUSTRALIA	1.5197	14.0	3.7		73.0		0.3			8.9						
28	AUSTRALIA	1.5189	13.8	3.5		73.5		0.2			8.8						
31	AUSTRALIA	1.5189	13.9	3.6		73.8					8.7						
40	USA	1.5233	13.9	3.8	0.3	71.8		0.3			9.5					0.3	
41	AUSTRALIA	1.5193	13.8	3.8		72.8		0.3			8.9					0.1	0.2
43	AUSTRALIA	1.5183	13.6	3.7	0.2	73.3		0.3			8.5						
108	USA	1.5196	13.7	3.5		73.2		0.3			9.2						
109	USA	1.5196	13.5	3.4		73.7		0.2			9.0					0.3	
144	AUSTRALIA	1.5197	12.7	3.3		73.9		0.2			9.9						

TABLE B.3 SHEET GLASSES

GLASS NO.	ORIGIN	REFRACTIVE INDEX	Na2O	MgO	Al2O3	SiO2	P2O5	SO3	Cl	K2O	CaO	TiO2	V2O5	Cr2O3	MnO	FeO	ZnO
7	JAPAN	1.5143	13.5	3.6	1.9	72.7		0.2		0.9	7.0						
22	JAPAN	1.5144	13.7	3.6	1.6	73.1		0.2		0.9	7.0						
30	JAPAN	1.5144	13.5	3.8	1.8	72.9				0.9	6.8	0.1				0.1	
34	JAPAN	1.5148	13.4	3.8	1.7	73.3		0.1		0.8	6.8						
105	PHILI-PPINES	1.5136	14.4	3.6	1.6	72.4	0.3	0.4		0.3	7.0					0.1	
107	POLAND	1.5164	13.6	3.4	1.2	73.4		0.2			8.1						
110	JAPAN	1.5148	12.9	3.5	1.8	73.5		0.1		0.9	7.3						

TABLE B.4 ROLLED (OTHERS)

GLASS NO.	ORIGIN	REFRACTIVE INDEX	Na2O	MgO	Al2O3	SiO2	P2O5	SO3	Cl	K2O	CaO	TiO2	V2O5	Cr2O3	MnO	FeO	ZnO
1	JAPAN	1.5195	13.6	3.3	1.6	71.8		0.3		0.7	8.6						
3	JAPAN	1.5188	13.2	3.3	1.6	72.1		0.3		0.7	8.6						
5	JAPAN	1.5227	13.9	2.3	1.5	71.1		0.3		0.7	10.2						
6	JAPAN	1.5232	12.8	1.8	1.6	71.8		0.2		0.9	10.9						
24	W. GERMANY	1.5252	14.1	2.3	0.8	71.5				0.5	10.8						
26	JAPAN	1.5186	13.7	3.4	1.6	71.7		0.2		0.9	8.2					0.1	

TABLE B.5 NON FLOAT FLAT (AUSTRALIAN, 3.6% MgO)

GLASS NO.	ORIGIN	REFRACTIVE INDEX	Na2O	MgO	Al2O3	SiO2	P2O5	SO3	Cl	K2O	CaO	TiO2	V2O5	Cr2O3	MnO	FeO	ZnO
17	AUSTRALIA	1.5193	13.5	3.5	0.9	73.0				0.1	8.6						
25	AUSTRALIA	1.5196	13.9	3.7	0.6	72.8		0.2		0.1	8.6						
29	AUSTRALIA	1.5188	13.2	3.6	1.0	73.4		0.2		0.2	8.4						
37	AUSTRALIA	1.5166	13.5	3.7	1.2	73.3				0.2	7.8						0.1
39	AUSTRALIA	1.5199	13.6	3.6	1.0	72.6		0.2		0.2	8.5					0.3	

TABLE B.6 NON FLOAT FLAT (AUSTRALIAN, 3.1% MgO)

GLASS NO.	ORIGIN	REFRACTIVE INDEX	Na2O	MgO	Al2O3	SiO2	P2O5	SO3	Cl	K2O	CaO	TiO2	V2O5	Cr2O3	MnO	FeO	ZnO
18	AUSTRALIA	1.5199	13.9	3.1	1.7	72.1			0.5		8.5						
33	AUSTRALIA	1.5196	13.8	3.1	1.3	72.3			0.5	0.2	8.8						
38	AUSTRALIA	1.5200	13.9	3.1	1.6	72.0			0.5	0.2	8.7						

TABLE B.7 ROLLED (JAPAN, 0.5% MgO)

GLASS NO.	ORIGIN	REFRACTIVE INDEX	Na2O	MgO	Al2O3	SiO2	P2O5	SO3	Cl	K2O	CaO	TiO2	V2O5	Cr2O3	MnO	FeO	ZnO
2	JAPAN	1.5227	12.2	0.5	1.7	72.6		0.2		0.7	12.0	0.2					
4	JAPAN	1.5229	12.6	0.7	1.6	72.3		0.4		0.6	11.5	0.2					
8	JAPAN	1.5228	12.2	0.5	1.7	72.7		0.3		0.7	11.6	0.2					

TABLE B.8 ROLLED (BELGIUM, 4.5% MgO)

GLASS NO.	ORIGIN	REFRACTIVE INDEX	Na2O	MgO	Al2O3	SiO2	P2O5	SO3	Cl	K2O	CaO	TiO2	V2O5	Cr2O3	MnO	FeO	ZnO
32	BELGIUM	1.5248	13.2	4.6	0.2	71.8				0.1	9.9						
35	BELGIUM	1.5247	13.3	4.5		71.7		0.3		0.1	9.9					0.2	
36	BELGIUM	1.5250	13.3	4.5	0.6	71.2		0.3		0.1	9.8					0.2	
42	BELGIUM	1.5247	14.3	2.3	0.8	71.5				0.5	10.6						
106	BELGIUM	1.5196	13.4	3.9	0.3	73.5				0.1	8.9						

TABLE B.9 WINDSCREEN GLASSES

GLASS NO.	ORIGIN	REFRACTIVE INDEX	Na2O	MgO	Al2O3	SiO2	P2O5	SO3	Cl	K2O	CaO	TiO2	V2O5	Cr2O3	MnO	FeO	ZnO
56	LEYLAND	1.5232	13.5	2.8	0.7	71.7		0.3		0.2	10.7						
57	LEYLAND	1.5177	13.7	3.6	0.2	73.1		0.4			8.9					0.1	
58	TOYOTA	1.5210	13.1	3.5	1.4	71.5		0.3		0.9	8.9					0.1	
59	GMH	1.5169	13.6	3.8	0.4	73.1		0.4			8.5						
60	GMH	1.5167	12.7	3.5	0.9	73.4		0.2		0.6	8.7						
61	BMW	1.5147	13.4	3.5	1.8	72.4		0.2		1.1	7.1					0.3	
62	FORD	1.5161	13.1	3.5	1.0	73.3		0.2		0.6	8.3						
63	CHRYSLER	1.5175	13.8	3.5		73.5		0.3		0.1	8.6						
112	LEYLAND	1.5186	12.7	3.3	0.9	73.1		0.2		0.6	9.2						
113	MAZDA	1.5179	12.7	3.7	1.7	72.9				0.7	8.3						
115	DATSUN	1.5166	12.4	3.5	1.7	72.7		0.3		1.3	8.1						
117	GMH	1.5166	12.7	3.5	1.1	73.1		0.2		0.6	8.5						
118	LEYLAND	1.5186	13.2	3.4	1.1	72.6		0.2		0.6	9.0						
120	DATSUN	1.5233	12.6	1.8	1.5	71.8		0.3		0.7	11.3						

TABLE B.10 HEADLAMP GLASSES

GLASS NO.	ORIGIN	REFRACTIVE INDEX	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	V_2O_5	Cr_2O_3	MnO	FeO	ZnO
54	GE	1.4783	4.9		2.0	77.1				0.1	0.1						
55	LUCAS	1.5188	13.4	0.3	1.3	71.5				2.9	8.1	(2.3)	0.2				
111	LUCAS	1.4783	4.7	0.1	1.9	76.2			0.1								
114	KOTO	1.4778	4.3	0.5	2.1	67.3				0.1	0.2						0.1
116	TOSHIBA	1.4765	3.9	0.5	2.3	73.5				0.7	0.1						
119	BOSCH	1.5203	15.6	3.1	1.9	70.1				1.4	5.4	(2.4)	0.1				
121	KOTO	1.4751	4.6		2.0	74.9				0.1	0.1						

TABLE B.11 LIGHT BULB GLASSES

GLASS NO.	ORIGIN	REFRACTIVE INDEX	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	V_2O_5	Cr_2O_3	MnO	FeO	ZnO
91	UNKNOWN	1.5096	16.6	3.1	1.8	73.1				0.4	4.9						
92	UNKNOWN	1.5626	7.7		1.6	62.5	0.3	(20.8)	0.6	5.4	0.3				0.3		0.3
93	UNKNOWN	1.5141	15.6	3.0	1.4	72.2		0.3		0.8	6.6						
94	USA	1.5140	16.0	3.7	2.1	70.9		0.3	0.1	0.9	6.1					0.1	
137	UK	1.5138	14.2	2.4	1.9	72.8		0.2		1.1	7.2						

TABLE B.12 SPECTACLE GLASSES

GLASS NO.	ORIGIN	REFRACTIVE INDEX	Na2O	MgO	Al2O3	SiO2	P2O5	SO3	Cl	K2O	CaO	TiO2	V2O5	Cr2O3	MnO	FeO	ZnO
44	UNKNOWN	1.5230	8.0		1.9	68.3		0.2		9.9	8.5	0.2					3.0
45	USA	1.5232	2.5		12.2	71.1	2.1	(3.5)	0.2			(7.4)	0.8				
46	UK	1.5228	11.4		0.3	72.4		0.2		5.9	5.5	0.1				4.2	
47	UK	1.5236	10.8	0.9	0.8	70.0		0.4		5.3	9.7	(2.0)	0.1				
48	USA	1.5237	8.2	0.2	1.9	69.0				9.3	8.7	0.3					2.5
49	UK	1.5229	10.9		2.1	70.9				6.6	7.8		0.9	0.4	0.4		
50	CANADA	1.5246	8.7			71.8		0.1		8.1	8.7					2.5	
51	THAILAND	1.5229	11.1		0.5	70.8				5.2	7.6	(2.6)	0.2				1.9

TABLE B.13 TABLEWARE GLASSES

GLASS NO.	ORIGIN	REFRACTIVE INDEX	Na2O	MgO	Al2O3	SiO2	P2O5	SO3	Cl	K2O	CaO	TiO2	V2O5	Cr2O3	MnO	FeO	ZnO
52	CZECHO-SLOVAKIA	1.5488	1.0			65.9		(16.5)	0.5	14.0	0.2						1.7
53	AUSTRALIA	1.5178	15.6		1.4	73.1		0.1			9.6						
83	ITALY	1.5206	15.0	0.7	1.2	72.5				0.5	9.5	0.5					
84	AUSTRALIA	1.5187	15.7		1.4	72.7		0.2			9.8						
85	USA	1.5325	1.3	8.9	19.7	62.8	0.5				6.8						
86	WEST GERMANY	1.5114	14.1	2.9	1.1	73.6		0.3		0.9	6.1	(0.8)					
87	ITALY	1.5192	15.2	0.6	1.3	72.0			0.1	0.3	9.3	(1.0)					
88	AUSTRALIA	1.5163	15.2		1.4	73.6		0.2			9.3						
89	ITALY	1.5222	14.0	2.3	1.6	71.4				0.4	9.7	(0.4)					
90	AUSTRALIA	1.5168	15.3		1.3	73.6		0.3			9.4						

TABLE B.14 LABWARE GLASSES

GLASS NO.	ORIGIN	REFRACTIVE INDEX	Na2O	MgO	Al2O3	SiO2	P2O5	SO3	Cl	K2O	CaO	TiO2	V2O5	Cr2O3	MnO	FeO	ZnO
76	CHINA	1.4751	3.9	0.2	2.2	77.0			0.1	0.3	0.5					0.1	0.3
77	ARGENTINA	1.4938	5.4	0.2	5.8	68.5			0.2	2.9	0.6	(2.4)	0.3				
78	CZECHO-SLOVAKIA	1.4735	3.2	0.1	2.2	73.4		0.1	0.1	0.9	0.1	0.1					
79	WEST GERMANY	1.5146	13.8	2.8	3.3	70.5		0.3		1.9	5.2	(1.9)	0.2				
80	UK	1.4724	4.0		2.1	76.9				0.1	0.1						
81	AUSTRALIA	1.4732	4.2	0.2	2.4	77.2			0.1	0.1	0.1						
145		1.5115	13.4	2.3	2.5	72.5		0.3		1.8	6.0	0.9	0.2				
148	WEST GERMANY	1.4723	2.8		2.0	73.6				0.7	0.1						
150	USA	1.5158	13.4	3.5	1.1	72.6		0.3		1.1	7.8						

TABLE B.15 CONTAINER GLASSES

GLASS NO.	ORIGIN	REFRACTIVE INDEX	Na2O	MgO	Al2O3	SiO2	P2O5	SO3	Cl	K2O	CaO	TiO2	V2O5	Cr2O3	MnO	FeO	ZnO
64	AUSTRALIA	1.5208	14.4	0.5	1.7	72.2		0.3	0.1		10.7						
65	AUSTRALIA	1.5217	14.0	0.6	1.7	72.1		0.3		0.1	11.0						
66	AUSTRALIA	1.5209	14.0	0.7	1.5	72.3		0.2	0.1	0.2	10.8					0.1	
67	AUSTRALIA	1.5214	13.8	0.6	1.5	72.7				0.1	10.7					0.2	
68	PHILI-PPINES	1.5201	14.8	0.2	1.8	72.2		0.2	0.1	0.3	10.1					0.2	
69	THAILAND	1.5205	14.6	0.4	1.5	73.1					10.2					0.2	
70	UK	1.5193	13.2	0.3	1.3	73.5		0.2		0.3	11.0						
71	CHINA	1.5164	12.5	3.5	3.7	69.9		0.2		2.2	6.9	(0.6)				0.2	0.2
72	JAPAN	1.5197	15.6	1.0	3.7	69.5		0.2		2.0	7.2				0.2	0.1	0.5
73	AUSTRALIA	1.5219	15.0	0.3	1.5	72.0			0.1	0.3	10.5			0.2			
74	AUSTRALIA	1.5154	17.1	3.4	1.5	70.1		0.5			5.2	(1.8)	0.1	0.1			0.1
75	UK	1.5198	14.1		1.3	72.9		0.4		0.4	10.7						
82	AUSTRALIA	1.5154	17.2	3.4	1.5	70.7		0.5			5.4	(1.0)	0.2				0.2
95	AUSTRALIA	1.5211	13.2	0.4	1.6	72.8		0.3		0.2	11.4						
96	AUSTRALIA	1.5180	13.4	0.2	1.6	73.3		0.2			11.2						
97	AUSTRALIA	1.5203	13.0		1.6	73.7				0.2	11.0					0.2	
98	AUSTRALIA	1.5198	13.1	0.2	1.6	73.9				0.2	11.0						
99	AUSTRALIA	1.5200	13.2	0.1	1.6	73.7				0.1	11.1						
100	AUSTRALIA	1.5208	13.2	0.6	1.4	72.5		0.2		0.3	11.3			0.3		0.2	
101	AUSTRALIA	1.5207	13.8	0.2	1.7	73.1				0.1	11.0						
102	AUSTRALIA	1.5220	13.5		1.5	72.7		0.2			12.0						

TABLE B.15 (CONT'D) CONTAINER GLASSES

GLASS NO.	ORIGIN	REFRACTIVE INDEX	Na2O	MgO	Al2O3	SiO2	P2O5	SO3	Cl	K2O	CaO	TiO2	V2O5	Cr2O3	MnO	FeO	ZnO
103	AUSTRALIA	1.5212	13.8		1.4	73.4					11.1					0.2	
104	AUSTRALIA	1.5235	14.1	0.2	1.4	72.3		0.2			11.3			0.2		0.2	
122	AUSTRALIA	1.5221	13.6	0.5	1.5	72.6		0.2		0.1	11.2			0.3			
123	PORTUGAL	1.5225	11.4	1.5	1.6	72.9		0.2		0.9	11.1			0.2		0.3	
124	ITALY	1.5236	14.7	2.2	4.6	67.6		0.2	0.1	1.6	8.6	0.1	0.1		0.4		
125	S. AFRICA	1.5154	11.9	3.4	0.9	73.6				0.6	9.6						
126	SPAIN	1.5246	13.2	0.2	2.5	70.5		0.2		1.5	11.4			0.2		0.2	
127	AUSTRALIA	1.5255	13.3	1.4	2.1	71.3				0.6	10.8			0.2		0.4	
128	AUSTRALIA	1.5212	12.5	0.2	3.1	70.7		0.3		2.3	10.9						
120	AUSTRALIA	1.5224	13.2	0.4	1.4	73.0				0.2	11.2			0.2			0.1
130	AUSTRALIA	1.5201	12.9	0.3	1.6	73.4		0.2			11.3					0.1	
131	AUSTRALIA	1.5215	12.7	0.2	1.5	73.6				0.2	11.5					0.2	
132	UK	1.5230	13.3	2.9	2.0	71.0		0.2		1.0	9.2			0.3		0.3	
133	AUSTRALIA	1.5211	13.8	0.5	1.6	72.5		0.3			11.0			0.1			
134	AUSTRALIA	1.5213	14.5	0.3	1.5	72.6			0.1	0.3	10.5					0.1	
135	AUSTRALIA	1.5154	17.0	3.3	1.5	71.0		0.4			5.5	(1.0)	0.2				
138	USA	1.5177	13.0		1.7	73.7		0.2		0.4	10.9						
139	ITALY	1.5296	12.9	1.9	5.1	66.3				1.7	11.5	0.1				0.4	
140	UK	1.5221	11.3		1.5	73.8				1.1	12.1					0.2	
141	UK	1.5189	11.2		1.7	74.2				0.9	11.6					0.3	
142	SPAIN	1.5244	12.1		2.2	71.2		0.2		1.5	12.2			0.2		0.3	
143	AUSTRALIA	1.5205	13.7		1.4	72.6		0.4			11.7						

GLASSES2.KWT

APPENDIX C

X-RAY INDUCED ELEMENTAL ANALYSIS DATA

TABLE C.1
ACCUMULATED DATA OF GLASS MUSEUM SAMPLES 1-172
THE RESULTS ARE ELEMENTAL PEAK MINUS BACKGROUND COUNTS OBTAINED FROM X-RAY INDUCED X-RAY SPECTRA

GLASS NO.	ORIGIN	TYPE	COLOUR Note 1	THICKNESS (mm) Note 2	FLUORES Note 3	REFRACTIVE INDEX	Fe(K_α)	Sr(K_α)	Sr(K_β) and/or ZR(K_α) Note 4	Zn(K_α)	As(K_α)	Rb(K_α)	Nb(K_α)	Ba(L_α)	OTHER PEAKS
1	JAPAN (ASAHI)	WIRED		6.67	NIL	1.5195	86	57	68						
2	JAPAN (ASAHI)	WIRED		~6.5	NIL	1.5227	90	116	110						
3	JAPAN (ASAHI)	WIRED		~6.2	NIL	1.5188	83	40	98						
4	JAPAN (ASAHI)	PATTERNED		~5.35	NIL	1.5229	84	44	80						
5	JAPAN (NSG)	WIRED		6.26	NIL	1.5227	71	-	47						
6	JAPAN (NSG)	WIRED	BRONZE	6.61	NIL	1.5232	105	39	38			20			
7	JAPAN (ASAHI)	SHEET	-	3.88	NIL	1.5143	82	38	74						
8	JAPAN (ASAHI)	WIRED	-	~6.30	NIL	1.5228	81	132	133						
9	USA (PPG)	FLOAT	BRONZE	5.54	ONE SURFACE	1.5198	252	35	47				32		
10	USA (PPG)	FLOAT	GREY	5.86	ONE SURFACE	1.5238	207	20	32						
11	USA (PPG)	FLOAT	BRONZE	5.75	ONE SURFACE	1.5198	230	24	50						
12	USA (PPG)	FLOAT	DARK GREY	5.68	ONE SURFACE	1.5241	48	27	58						Ni(K_α)128
13	AUSTR-ALIA	FLOAT		2.29	ONE SURFACE	1.5198	93	41	26						

TABLE C.1
ACCUMULATED DATA OF GLASS MUSEUM SAMPLES 1-172
THE RESULTS ARE ELEMENTAL PEAK MINUS BACKGROUND COUNTS OBTAINED FROM X-RAY INDUCED X-RAY SPECTRA

GLASS NO.	ORIGIN	TYPE	COLOUR Note 1	THICKNESS (mm) Note 2	FLUORES Note 3	REFRACTIVE INDEX	Fe(K_α)	Sr(K_α)	Sr(K_β) and/or ZR(K_α) Note 4	Zn(K_α)	As(K_α)	Rb(K_α)	Nb(K_α)	Ba(L_α)	OTHER PEAKS
14	AUSTR-ALIA	FLOAT		3.99	ONE SURFACE	1.5198	74	41	28						
15	AUSTR-ALIA	FLOAT		5.07	ONE SURFACE	1.5199	84	35	-						
16	AUSTR-ALIA	FLOAT		5.93	ONE SURFACE	1.5198	81	35	-						
17	AUSTR-ALIA	PATTERNED		~3.2	NIL	1.5193	98	34	80						
18	AUSTR-ALIA	PATTERNED	YELLOW BROWN	~4	NIL	1.5199	81	33	81						
19	USA	FLOAT	BRONZE	5.74	ONE SURFACE	1.5199	243	33	37						
20	USA	FLOAT	DARK GREY	5.725	ONE SURFACE	1.5186	48	44	52						Ni(K_α)119
21	USA	FLOAT	BRONZE (MIRROR FINISH)	5.70	ONE SURFACE	1.5198	200	-	-						
22	JAPAN	SHEET		~2.85	NIL	1.5144	96	34	52						
23	BELGIUM	FLOAT	GREY	3.17	ONE SURFACE	1.5194	174	31	35						Ni(K_α)18
24	WEST GERMANY	PATTERNED	YELLOW	~4	SLIGHT BULK	1.5252	68	-	41						
25	AUSTR-LIA	WIRED		~6.36	NIL	1.5196	125	46	61						
26	JAPAN (ASAHI)	WIRED		~6.6	NIL	1.5186	74	38	54						

TABLE C.1

ACCUMULATED DATA OF GLASS MUSEUM SAMPLES 1-172

THE RESULTS ARE ELEMENTAL PEAK MINUS BACKGROUND COUNTS OBTAINED FROM X-RAY INDUCED X-RAY SPECTRA

GLASS NO.	ORIGIN	TYPE	COLOUR Note 1	THICKNESS (mm) Note 2	FLUORES Note 3	REFRACTIVE INDEX	Fe(K_α)	Sr(K_α)	Sr(K_β) and/or ZR(K_α) Note 4	Zn(K_α)	As(K_α)	Rb(K_α)	Nb(K_α)	Ba(L_α)	OTHER PEAKS
27	AUSTR-LIA	FLOAT		4.97	NIL	1.5197	98	34	-						
28	AUSTR-LIA	FLOAT		5.71	NIL	1.5198	63	-	138						
29	AUSTR-LIA	PATTERNED		3.3	NIL	1.5188	89	31	86						
30	JAPAN	SHEET		~3.4	SLIGHT BULK	1.5144	73	45	78						
31	AUSTR-LIA	FLOAT		5.71	NIL	1.5189	57	34	143						
32	BELGIUM	PATTERNED	YELLOW	~4	NIL	1.5248	72	27	54						
33	AUSTR-LIA	PATTERNED	YELLOW	~5	NIL	1.5196	77	28	88						
34	JAPAN	SHEET		2.95	SLIGHT BULK	1.5148	81	27	59			26			
35	BELGIUM	PATTERNED	BROWN GREY	~5	NIL	1.5247	175	43	63						Se(K_α)18
36	BELGIUM	PATTERNED	LIGHT BROWN GREY	~4.5	NIL	1.5250	157	-	38		26				Se(K_α)30
37	AUSTR-ALIA	PATTERNED		~4	NIL	1.5166	90	39	50						
38	AUSTR-ALIA	PATTERNED	YELLOW	~5	NIL	1.5200	87	38	66						
39	AUSTR-ALIA	PATTERNED	GREY	4.7	NIL	1.5199	179	34	63						

TABLE C.1
ACCUMULATED DATA OF GLASS MUSEUM SAMPLES 1-172
THE RESULTS ARE ELEMENTAL PEAK MINUS BACKGROUND COUNTS OBTAINED FROM X-RAY INDUCED X-RAY SPECTRA

GLASS NO.	ORIGIN	TYPE	COLOUR Note 1	THICKNESS (mm) Note 2	FLUORES Note 3	REFRACTIVE INDEX	$Fe(K_\alpha)$	$Sr(K_\alpha)$	$Sr(K_\beta)$ and/or $ZR(K_\alpha)$ Note 4	$Zn(K_\alpha)$	$As(K_\alpha)$	$Rb(K_\alpha)$	$Nb(K_\alpha)$	$Ba(L_\alpha)$	OTHER PEAKS
40	USA	FLOAT	GREY	3.10	ONE SURFACE	1.5233	206	33	-						
41	AUSTR-ALIA	FLOAT		2.905	ONE SURFACE	1.5193	79	43	-						
42	BELGIUM	PATTERNED	YELLOW	~4	NIL	1.5247	57	31	46						
43	AUSTR-ALIA	FLOAT		4.865	ONE SURFACE	1.5183	83	35	-						
44	HOYA	SPECTACLE		-	NIL	1.5230	15	-	-	4849	172				
45	USA (AO)	SPECTACLE		-	NIL	1.5232	23	74	3035					335	$Ce(L_\alpha)$57, $Cu(K_\alpha)$49, $Pb(L_\alpha)$3679.
46	UK (MW)	SPECTACLE	GREEN	-	NIL	1.5228	2249	131	49		273				
47	UK (UKO)	SPECTACLE		-	NIL	1.5236	15	151	78	105	34			107	$Cu(K_\alpha)$118
48	USA (AO)	SPECTACLE			NIL	1.5237	-	32	62	4109	643			21	
49	UK	SPECTACLE	LIGHT PINK BROWN		NIL	1.5229	48	-	-						$Ce(L_\alpha)$248, $Sm(M_\alpha)$74, $Mn(K_\alpha)$143, $Y(K_\alpha)$101, $Mo(K_\alpha)$32.
50	CANADA (AO)	SPECTACLE	GREY GREEN		NIL	1.5246	1308	45	47	64					$Mo(K_\alpha)$99
51	THAIL-AND (HOYA)	SPECTACLE	-	-	NIL	1.5229	-	60	67	3296					$Ti(K_\alpha)$126, $Nd(L_\alpha)$38.

TABLE C.1
ACCUMULATED DATA OF GLASS MUSEUM SAMPLES 1-172
THE RESULTS ARE ELEMENTAL PEAK MINUS BACKGROUND COUNTS OBTAINED FROM X-RAY INDUCED X-RAY SPECTRA

GLASS NO.	ORIGIN	TYPE	COLOUR Note 1	THICKNESS (mm) Note 2	FLUORES Note 3	REFRACTIVE INDEX	Fe(K_α)	Sr(K_α)	Sr(K_β) and/or ZR(K_α) Note 4	Zn(K_α)	As(K_α)	Rb(K_α)	Nb(K_α)	Ba(L_α)	OTHER PEAKS
52	CZECHO-SLOVAKIA	TABLE-WARE	-	-	NIL	1.5488	18	-	62	1204					Pb(L_α)9116
53	AUSTR-ALIA	TABLE-WARE			NIL	1.5178	19	33	59		242				
54	CANADA (LUCAS)	HEAD-LAMP			NIL	1.4783	33	-	596						
55	CANADA (LUCAS)	HEAD-LAMP			NIL	1.5188	23	111	267		59			147	
56	AUSTR-ALIA (LEY LAND)	WIND-SCREEN TOUGH-ENED		5.98	NIL	1.5232	69	30	41		232				
57	AUSTR-ALIA (LEY-LAND)	WIND-SCREEN TOUGH-ENED		6.01	NIL	1.5177	80	-	-						
58	TOYOTA	WIND-SCREEN LAMIN-ATED		5.74	NIL	1.5210	67	39	-						
59	AUSTR-ALIA (GMH)	WIND-SCREEN TOUGH-ENED		4.91	NIL	1.5169	68	35	-						
60	AUSTR-ALIA (GMH)	WIND-SCREEN TOUGH-ENED		5.97	NIL	1.5167	58	33	73						
61	BMW	WINDOW TOUGH-ENED	LIGHT BLUE	4.91	NIL	1.5147	191	32	40						

TABLE C.1
ACCUMULATED DATA OF GLASS MUSEUM SAMPLES 1-172
THE RESULTS ARE ELEMENTAL PEAK MINUS BACKGROUND COUNTS OBTAINED FROM X-RAY INDUCED X-RAY SPECTRA

GLASS NO.	ORIGIN	TYPE	COLOUR Note 1	THICKNESS (mm) Note 2	FLUORES Note 3	REFRACTIVE INDEX	Fe(K_α)	Sr(K_α)	Sr(K_β) and/or ZR(K_α) Note 4	Zn(K_α)	As(K_α)	Rb(K_α)	Nb(K_α)	Ba(L_α)	OTHER PEAKS
62	AUSTR-ALIA (FORD)	WIND-SCREEN TOUGH-ENED	-	5.83	NIL	1.5161	65	42	45						
63	AUSTR-ALIA (CHRYS-LER)	WIND-SCREEN TOUGH-ENED		4.71	NIL	1.5175	65	34	74						
64	AUSTR-ALIA (WA)	CONT-AINER			NIL	1.5208	23	313	102						
65	AUSTR-ALIA (WA)	CONT-AINER			NIL	1.5217	29	341	95						
66	AUSTR-ALIA (WA)	CONT-AINER	BROWN		NIL	1.5209	88	296	114						
67	AUSTR-ALIA (WA)	CONT-AINER	BROWN		NIL	1.5214	100	295	88						
68	PHILI-PPINES	CONT-AINER	BROWN		NIL	1.5201	124	87	81						Pb(L_α)64
69	THAI-LAND	CONT-AINER	BROWN		NIL	1.5205	161	46	68						
70	UK	CONT-AINER			NIL	1.5193	31	77	56						
71	CHINA PEOPLES REPUB.	CONT-AINER			NIL	1.5164	NO SPECTRUM AVAILABLE								

TABLE C.1
ACCUMULATED DATA OF GLASS MUSEUM SAMPLES 1-172
THE RESULTS ARE ELEMENTAL PEAK MINUS BACKGROUND COUNTS OBTAINED FROM X-RAY INDUCED X-RAY SPECTRA

GLASS NO.	ORIGIN	TYPE	COLOUR Note 1	THICKNESS (mm) Note 2	FLUORES Note 3	REFRACTIVE INDEX	Fe(K_α)	Sr(K_α)	Sr(K_β) and/or ZR(K_α) Note 4	Zn(K_α)	As(K_α)	Rb(K_α)	Nb(K_α)	Ba(L_α)	OTHER PEAKS
72	JAPAN	CONT-AINER	BROWN		NIL	1.5197	136*	54	119	764					Mn(K_α)124, Pb(L_α)268, Y(K_α)34.
73	AUSTR-ALIA (SA)	CONT-AINER	GREEN		NIL	1.5219	83	288	108						
74	AUSTR-ALIA (VIC)	CONT-AINER			NIL	1.5154	40	141	110						Pb(L_α)123
75	UK	CONT-AINER			NIL	1.5198	30	78	141						
76	CHINA	LAB-WARE			NIL	1.4751	80	-	-	418	380				
77	ARGENT-INA	LAB-WARE			NIL	1.4938	45	567	189		45	73		111	
78	CZECHO-SLOVAKIA	LAB-WARE			NIL	1.4735	52	-	290		31				
79	WEST GERMANY	LAB-WARE			NIL	1.5146	22	190	93		82	25		115	
80	UK	LAB-WARE			NIL	1.4724	54	-	289						
81	AUSTR-ALIA	LAB-WARE			NIL	1.4732	52	-	481						
82	AUSTR-ALIA (VIC)	CONT-AINER			NIL	1.5154	31	81	90		29			79	

* high due to Mn (K)

TABLE C.1
ACCUMULATED DATA OF GLASS MUSEUM SAMPLES 1-172
THE RESULTS ARE ELEMENTAL PEAK MINUS BACKGROUND COUNTS OBTAINED FROM X-RAY INDUCED X-RAY SPECTRA

GLASS NO.	ORIGIN	TYPE	COLOUR Note 1	THICKNESS (mm) Note 2	FLUORES Note 3	REFRACTIVE INDEX	Fe(K_α)	Sr(K_α)	Sr(K_β) and/or ZR(K_α) Note 4	Zn(K_α)	As(K_α)	Rb(K_α)	Nb(K_α)	Ba(L_α)	OTHER PEAKS
83	ITALY	CONT-AINER	YELLOW		NIL	1.5206	28	185	95	28				43	Mo(K_α)161
84	AUSTR-ALIA (CORN-ING)	TABLE-WARE			NIL	1.5187	24	-	60		193				
85	USA (CROWN CORNING)	TABLE-WARE COOK-WARE			NIL	1.5325	49	153	1897						
86	WEST GERMANY	TABLE-WARE			NIL	1.5114	31	146	65					56	
87	ITALY	TABLE-WARE			NIL	1.5192	36	113	72	35				53	Mo(K_α)193
88	AUSTR-ALIA (CORN-ING)	TABLE-WARE			NIL	1.5163	35	27	97		265				
89	ITALY	TABLE-WARE			NIL	1.5222	33	83	-	30	77			35	
90	AUSTR-ALIA (CORNING)	TABLE-WARE			NIL	1.5168	27	-	100	41	253				
91	PHILIPS	LAMP BULB			NIL	1.5096	26	102	75						
92	UNKNOWN	LAMP BULB			NIL	1.5626	27	-							Mn(K_α)35, Pb(L_α)10831

TABLE C.1
ACCUMULATED DATA OF GLASS MUSEUM SAMPLES 1-172
THE RESULTS ARE ELEMENTAL PEAK MINUS BACKGROUND COUNTS OBTAINED FROM X-RAY INDUCED X-RAY SPECTRA

GLASS NO.	ORIGIN	TYPE	COLOUR Note 1	THICKNESS (mm) Note 2	FLUORES Note 3	REFRACTIVE INDEX	Fe(K_α)	Sr(K_α)	Sr(K_β) and/or ZR(K_α) Note 4	Zn(K_α)	As(K_α)	Rb(K_α)	Nb(K_α)	Ba(L_α)	OTHER PEAKS
93	UNKNOWN	LAMP BULB			NIL	1.5141	86	43	77		331				
94	USA (G.E.)	LAMP BULB			NIL	1.5140	63	63	63				57		
95	AUSTR-ALIA (NSW)	CONT-AINER	COLOUR LESS TO VERY PALE GREEN		NIL	1.5211	89	203	94		37		39		
96	AUSTR-ALIA (NSW)	CONT-AINER			NIL	1.5180	41	39	60	22			56		Mn(K_α)18, Mo(K_α)45.
97	AUSTR-ALIA (NSW)	CONT-AINER	BROWN		NIL	1.5203	112	30	76	34			52		Mn(K_α)26
98	AUSTR-ALIA (NSW)	CONT-AINER	BROWN		NIL	1.5198	120	53	90	24					Mn(k_α)29
99	AUSTR-ALIA (NSW)	CONT-AINER	YELLOW GREEN (PALE)		NIL	1.5200	56	44	88	24			51		Mn(K_α)24
100	AUSTR-ALIA (NSW)	CONT-AINER	GREEN		NIL	1.5208	123	223	69						Cr(K_α)56
101	AUSTR-ALIA (NSW)	CONT-AINER	YELLOW		NIL	1.5207	71	42	103						Mn(K_α)20

TABLE C.1
ACCUMULATED DATA OF GLASS MUSEUM SAMPLES 1-172
THE RESULTS ARE ELEMENTAL PEAK MINUS BACKGROUND COUNTS OBTAINED FROM X-RAY INDUCED X-RAY SPECTRA

GLASS NO.	ORIGIN	TYPE	COLOUR Note 1	THICKNESS (mm) Note 2	FLUORES Note 3	REFRACTIVE INDEX	Fe(K_α)	Sr(K_α)	Sr(K_β) and/or ZR(K_α) Note 4	Zn(K_α)	As(K_α)	Rb(K_α)	Nb(K_α)	Ba(L_α)	OTHER PEAKS
102	AUSTR-ALIA (TAS)	CONT-AINER			NIL	1.5220	38	37	103				30		
103	AUSTR-ALIA (TAS)	CONT-AINER	BROWN		NIL	1.5212	122	48	102				52		
104	AUSTR-ALIA (TAS)	CONT-AINER	GREEN		NIL	1.5235	87	42	113						Cr(K_α)55
105	PHILI-PPINES	SHEET		2.87		1.5136	84	65	76				31		
106	BELGIUM	PATTERNED	YELLOW BROWN			1.5196	49	35	104	55			51		
107	POLAND	SHEET		4.0	NIL	1.5164	76	-	93				64		
108	USA (PPG)	FLOAT		5.87	ONE SURFACE	1.5196	78	49					50		
109	USA (PPG)	FLOAT	GREY	5.58	ONE SURFACE	1.5196	175	34	38				26		
110	JAPAN	SHEET		4.01		1.5148	78	33	54				46		
111	CANADA (LUCAS)	HEAD-LAMP			NIL	1.4783	46	-	94		25				
112	AUSTR-ALIA (LEYLAND)	WIND-SCREEN TOUGHENED		5.91		1.5186	72	28	51				27		
113	JAPAN (MAZDA)	WIND-SCREEN		-	-	1.5179	78	24	35						

TABLE C.1
ACCUMULATED DATA OF GLASS MUSEUM SAMPLES 1-172
THE RESULTS ARE ELEMENTAL PEAK MINUS BACKGROUND COUNTS OBTAINED FROM X-RAY INDUCED X-RAY SPECTRA

GLASS NO.	ORIGIN	TYPE	COLOUR Note 1	THICKNESS (mm) Note 2	FLUORES Note 3	REFRACTIVE INDEX	Fe (K_α)	Sr (K_α)	Sr (K_β) and/or ZR (K_α) Note 4	Zn (K_α)	As (K_α)	Rb (K_α)	Nb (K_α)	Ba (L_α)	OTHER PEAKS
114	JAPAN KOTO	HEAD-LAMP			NIL	1.4778	43	-	344		1805				
115	DATSUN	WIND-SCREEN LAMI NATED			NIL	1.5166	68	36	35						
116	JAPAN TOSHIBA	HEAD-LAMP			NIL	1.4765	36	-	96						
117	AUSTR-ALIA (GMH)	WIND-SCREEN TOUGH-ENED		4.99		1.5166	60	38	49						
118	AUSTR-ALIA LEYLAND	WIND-SCREEN TOUGH-ENED		4.92		1.5186	63	29	46						
119	BOSCH	HEAD-LAMP			BULK	1.5203	20	232	164					127	
120	DATSUN	WIND-SCREEN LAMI-NATED				1.5233	48	-	53		411				
121	JAPAN (KOTO)	HEAD-LAMP				1.4751	35	-	218						
122	AUSTR-ALIA (WA)	CONT-AINER	GREEN			1.5221	40	303	92						Cr (K_α) 48

TABLE C.1
ACCUMULATED DATA OF GLASS MUSEUM SAMPLES 1-172
THE RESULTS ARE ELEMENTAL PEAK MINUS BACKGROUND COUNTS OBTAINED FROM X-RAY INDUCED X-RAY SPECTRA

GLASS NO.	ORIGIN	TYPE	COLOUR Note 1	THICKNESS (mm) Note 2	FLUORES Note 3	REFRACTIVE INDEX	Fe(K_α)	Sr(K_α)	Sr(K_β) and/or ZR(K_α) Note 4	Zn(K_α)	As(K_α)	Rb(K_α)	Nb(K_α)	Ba(L_α)	OTHER PEAKS
123	PORTU-GAL	CONT-AINER	GREEN			1.5225	150	45	74	22		27			Cr(K_α)49
124	ITALY	CONT-AINER	GREEN			1.5236	250	47	84		37				Cr(K_α)29
125	SOUTH AFRICA	CONT-AINER	YELLOW TO OLIVE			1.5154	65	78	57				28		Y(K_α)36
126	SPAIN	CONT-AINER	GREEN			1.5246	151	48	57			26			Cr(K_α)44, Mo(K_α)35.
127	FRANCE	CONT-AINER	GREEN			1.5255	269	36	66						Cr(K_α)35, Mn(K_α)33.
128	AUSTR-ALIA (SA)	CONT-AINER	LIGHT GREEN			1.5212	49	49	69		15	35			
129	AUSTR-ALIA (SA)	CONT-AINER	GREEN			1.5224	103	229	87		21				Cr(K_α)41
130	AUSTR-ALIA (SA)	CONT-AINER				1.5201	38	222	128		29				
131	AUSTR-ALIA (SA)	CONT-AINER	BROWN			1.5215	142	312	107				34		
132	UK	CONT-AINER	GREEN			1.5230	165	47	46			32			Cr(K_α)44
133	AUSTR-ALIA (WA)	CONT-AINER	PALE GREEN			1.5211	43	325	99						

TABLE C.1
ACCUMULATED DATA OF GLASS MUSEUM SAMPLES 1-172
THE RESULTS ARE ELEMENTAL PEAK MINUS BACKGROUND COUNTS OBTAINED FROM X-RAY INDUCED X-RAY SPECTRA

GLASS NO.	ORIGIN	TYPE	COLOUR Note 1	THICKNESS (mm) Note 2	FLUORES Note 3	REFRACTIVE INDEX	Fe(K_α)	Sr(K_α)	Sr(K_β) and/or ZR(K_α) Note 4	Zn(K_α)	As(K_α)	Rb(K_α)	Nb(K_α)	Ba(L_α)	OTHER PEAKS
134	AUSTR-ALIA (SA)	CONT-AINER	BROWN			1.5213	103	259	83		29				
135	AUSTR-ALIA (VIC)	CONT-AINER			NIL	1.5154	50	60	87		69		67	134	
136	AGM	CONT-AINER				1.5196	36	46	31				28		Mn(K_α)23
137	UK	LAMP BULB	SEMI-OPAQUE			1.5138	121	-	47	153	62				
138	USA	CONT-AINER				1.5177	36	25	75	13					
139	ITALY	CONT-AINER				1.5296	247	49	88						Cr(K_α)15
140	UK	CONT-AINER				1.5221	142	36	42						
141	UK	CONT-AINER				1.5189	197	60	61	19		21	38		
142	SPAIN	CONT-AINER				1.5244	146	51	60		21	32			Cr(K_α)43
143	AUSTR-ALIA (AGM)	CONT-AINER				1.5205	40	41	44						Mn(K_α)16
144	AUSTR-ALIA	FLOAT				1.5197	76	26	36						
145		LAB WARE				1.5115	52	125	68		96	29		107	

TABLE C.1

ACCUMULATED DATA OF GLASS MUSEUM SAMPLES 1-172

THE RESULTS ARE ELEMENTAL PEAK MINUS BACKGROUND COUNTS OBTAINED FROM X-RAY INDUCED X-RAY SPECTRA

GLASS NO.	ORIGIN	TYPE	COLOUR Note 1	THICKNESS (mm) Note 2	FLUORES Note 3	REFRACTIVE INDEX	$Fe(K_\alpha)$	$Sr(K_\alpha)$	$Sr(K_\beta)$ and/or $ZR(K_\alpha)$ Note 4	$Zn(K_\alpha)$	$As(K_\alpha)$	$Rb(K_\alpha)$	$Nb(K_\alpha)$	$Ba(L_\alpha)$	OTHER PEAKS
146						1.5162	40	175	125		146			101	
147	BELGIUM	PATTERNED				1.5248	62	34	43	20					
148	WEST GERMANY	LAB WARE				1.4723	24	-	172						
149	AUSTR-ALIA	PATTERNED				1.5235	51	-	47						
150	USA	LAB WARE				1.5158	30	27	98		744				
151	CASE					1.5083	36	-	50	20					
152	CASE		BROWN			1.5216	88	225	86						
153	CASE					1.5165	59	28	32						
154	CASE					1.5083	38	-	-						
155	CASE					1.5136	64	25	45						
156	CASE					1.5201	30	31	51	26	117		31		
157	CASE					1.5136	58	32	43			29			
158	CASE					1.5086	38	-	-						
159	CASE					1.5090	36	-	-		59				
160	CASE					1.5168	89	29	35						
161	CASE					1.5168	37	37	-				12		
162	CASE					1.5189	64	31	25						
163	CASE					1.5189	59	33							

TABLE C.1
ACCUMULATED DATA OF GLASS MUSEUM SAMPLES 1-172
THE RESULTS ARE ELEMENTAL PEAK MINUS BACKGROUND COUNTS OBTAINED FROM X-RAY INDUCED X-RAY SPECTRA

GLASS NO.	ORIGIN	TYPE	COLOUR Note 1	THICKNESS (mm) Note 2	FLUORES Note 3	REFRACTIVE INDEX	$Fe(K_\alpha)$	$Sr(K_\alpha)$	$Sr(K_\beta)$ and/or $ZR(K_\alpha)$ Note 4	$Zn(K_\alpha)$	$As(K_\alpha)$	$Rb(K_\alpha)$	$Nb(K_\alpha)$	$Ba(L_\alpha)$	OTHER PEAKS
164	CASE					1.5083	-	-	-		THIN SAMPLE NO WELL DEFINED PEAKS				
165	CASE					1.5164	57	25	54						
166	CASE					1.5164	58	-	46			32			
167	CASE					1.5197	58	60	47				33		
168	CASE					1.5180	55	31	33				38		
169	CASE					1.5179	42	32	47						
170	CASE					1.5178	44	-	-		233	139	37		
171	CASE					1.5197	66	31	36				56		
172	CASE					1.5178	34	-	-			28	73	THIN SAMPLE	

NOTE 1. No entry indicates uncoloured glass.

NOTE 2. Only flat window glass are accurate thickness measurements. Remainder are nearest approximations. No entry indicates sample unsuitable for thickness measurement.

NOTE 3. Fluorescence with 253.7 nm light (U.V.).

NOTE 4. When the ratio of Sr(K)/Sr (K) falls below a value of 3 it indicates the presence of Zr as the Zr(K) overlaps the Sr K peak.

TABLE C.2 FLOAT GLASSES

GLASS NO.	ORIGIN	REFRACTIVE INDEX	Fe(K_α)	Zn(k_α)	As(K_α)	Rb(K_α)	Sr(K_α)	Sr(K_β) and/or Zr(K_α)	Nb(K_α)	Ba(L_α)	OTHER PEAKS
9	USA	1.5198	252				35	47	32		
10	USA	1.5238	207				20	32			
11	USA	1.5198	230				24	50			
12	USA	1.5241	48				27	58			Ni(K_α)128
13	AUSTRALIA	1.5198	93				41	26			
14	AUSTRALIA	1.5198	74				41	28			
15	AUSTRALIA	1.5199	84				35	-			
16	AUSTRALIA	1.5198	81				35	-			
19	USA	1.5199	243				33	37			
20	USA	1.5186	48				44	52			Ni(K_α)119
21	USA	1.5198	200				-	-			
23	BELGIUM	1.5194	174				31	35			Ni(K_α)18
27	AUSTRALIA	1.5197	98				34	-			
28	AUSTRALIA	1.5189	63				-	138			
31	AUSTRALIA	1.5189	57				34	143			
40	USA	1.5233	206				33	-			
41	AUSTRALIA	1.5193	79				43	-			
43	AUSTRALIA	1.5183	83				35	-			
108	USA	1.5196	78				49	-	50		
109	USA	1.5196	175				34	38	26		
144	AUSTRALIA	1.5197	76				26	36			

TABLE C.3 SHEET GLASSES

GLASS NO.	ORIGIN	REFRACTIVE INDEX	$Fe(K_\alpha)$	$Zn(K_\alpha)$	$As(K_\alpha)$	$Rb(K_\alpha)$	$Sr(K_\alpha)$	$Sr(K_\beta)$ and/or $Zr(K_\alpha)$	$Nb(K_\alpha)$	$Ba(L_\alpha)$	OTHER PEAKS
7	JAPAN	1.5143	82				38	74			
22	JAPAN	1.5144	96				34	52			
30	JAPAN	1.5144	73				45	78			
34	JAPAN	1.5148	81			26	27	59			
105	PHILI-PPINES	1.5136	84				65	76	31		
107	POLAND	1.5164	76				-	93	64		
110	JAPAN	1.5148	78				33	54	46		

TABLE C.4 ROLLED (OTHERS)

GLASS NO.	ORIGIN	REFRACTIVE INDEX	Fe(K_α)	Zn(K_α)	As(K_α)	Rb(K_α)	Sr(K_α)	Sr(K_β) and/or ZR(K_α)	Nb(K_α)	Ba(L_α)	OTHER PEAKS
1	JAPAN	1.5195	86				57	68			
3	JAPAN	1.5188	83				40	98			
5	JAPAN	1.5227	71				-	47			
6	JAPAN	1.5232	105			20	39	38			
24	W. GERMANY	1.5252	68				-	41			
26	JAPAN	1.5186	74				38	54			

TABLE C.5 NON FLOAT FLAT (AUSTRALIAN, 3.6% MgO)

GLASS NO.	ORIGIN	REFRACTIVE INDEX	Fe(K)	Zn(K)	As(K)	Rb(K)	Sr(K)	Sr(K) and/or Zr(K)	Nb(K)	Ba(L)	OTHER PEAKS
17	AUSTRALIA	1.5193	98				34	80			
25	AUSTRALIA	1.5196	125				46	61			
29	AUSTRALIA	1.5188	89				31	86			
37	AUSTRALIA	1.5166	90				39	50			
39	AUSTRALIA	1.5199	179				34	63			

TABLE C.6 NON FLOAT FLAT (AUSTRALIAN, 3.1% MgO)

GLASS NO.	ORIGIN	REFRACTIVE INDEX	Fe(K)	Zn(K)	As(K)	Rb(K)	Sr(K)	Sr(K) and/or Zr(K)	Nb(K)	Ba(L)	OTHER PEAKS
18	AUSTRALIA	1.5199	81				33	81			
33	AUSTRALIA	1.5196	77				28	88			
38	AUSTRALIA	1.5200	87				38	66			

TABLE C.7 ROLLED (JAPAN, 0.5% MgO)

GLASS NO.	ORIGIN	REFRACTIVE INDEX	Fe(K_α)	Zn(K_α)	As(K_α)	Rb(K_α)	Sr(K_α)	Sr(K_β) and/or Zr(K_α)	Nb(K_α)	Ba(L_α)	OTHER PEAKS
2	JAPAN	1.5227	90				116	110			
4	JAPAN	1.5229	84				44	80			
8	JAPAN	1.5228	81				132	133			

TABLE C.8 ROLLED (BELGIUM, 4.5% MgO)

GLASS NO.	ORIGIN	REFRACTIVE INDEX	Fe(K)	Zn(K)	As(K)	Rb(K)	Sr(K)	Sr(K) and/or Zr(K)	Nb(K)	Ba(L)	OTHER PEAKS
32	BELGIUM	1.5248	72				27	54			
35	BELGIUM	1.5247	175				43	63			Se(K)18
36	BELGIUM	1.5250	157		26		-	38			Se(K)30
42	BELGIUM	1.5247	57				31	46			
106	BELGIUM	1.5196	49	55			35	104	51		

TABLE C.9 WINDSCREEN GLASSES

GLASS NO.	ORIGIN	REFRACTIVE INDEX	Fe (K_α)	Zn (K_α)	As (K_α)	Rb (K_α)	Sr (K_α)	Sr (K_β) and/or Zr (K_α)	Nb (K_α)	Ba (L_α)	OTHER PEAKS
56	LEYLAND	1.5232	69		232		30	41			
57	LEYLAND	1.5177	80								
58	TOYOTA	1.5210	67				39				
59	GMH	1.5169	68				35				
60	GMH	1.5167	58				33	73			
61	BMW	1.5147	191				32	40			
62	FORD	1.5161	65				42	45			
63	CHRYSLER	1.5175	65				34	74			
112	LEYLAND	1.5186	72				28	51	27		
113	MAZDA	1.5179	78				24	35			
115	DATSUN	1.5166	68				36	35			
117	GMH	1.5166	60				38	49			
118	LEYLAND	1.5186	63				29	46			
120	DATSUN	1.5233	48		411			53			

TABLE C.10 HEADLAMP GLASSES

GLASS NO.	ORIGIN	REFRACTIVE INDEX	Fe(K_α)	Zn(K_α)	As(K_α)	Rb(K_α)	Sr(K_α)	Sr(K_β) and/or Zr(K_α)	Nb(K_α)	Ba(L_α)	OTHER PEAKS
54	GE	1.4783	33				-	596			
55	LUCAS	1.5188	23		59		111	267		147	
111	LUCAS	1.4783	46		25		-	94			
114	KOTO	1.4778	43		1805			344			
116	TOSHIBA	1.4765	36					96			
119	BOSCH	1.5203	20				232	164		127	
121	KOTO	1.4751	35					218			

TABLE C.11 LIGHT BULB GLASSES

GLASS NO.	ORIGIN	REFRACTIVE INDEX	Fe(K_α)	Zn(K_α)	As(K_α)	Rb(K_α)	Sr(K_α)	Sr(K_β) and/or Zr(K_α)	Nb(K_α)	Ba(L_α)	OTHER PEAKS
91	UNKNOWN	1.5096	26				102	75			
92	UNKNOWN	1.5626	27								Mn(K_α)35, Pb(L_α)10831
93	UNKNOWN	1.5141	86		331		43	77			
94	USA	1.5140	63				63	63	57		
137	UK	1.5138	121		153	62		47			

TABLE C.12 SPECTACLE GLASSES

GLASS NO.	ORIGIN	REFRACTIVE INDEX	Fe (K_α)	Zn (K_α)	As (K_α)	Rb (K_α)	Sr (K_α)	Sr (K_β) and/or Zr (K_α)	Nb (K_α)	Ba (L_α)	OTHER PEAKS
44	UNKNOWN	1.5230	15	4849	172						
45	USA	1.5232	23				74	3035		335	Ce(L_α)57, Cu(K_α)49, Pb(L_α)3679
46	UK	1.5228	2249		273		131	49			
47	UK	1.5236	15	105	34		151	78		107	Cu(K_α)118
48	USA	1.5237		4109	643		32	62		21	
49	UK	1.5229	48								Ce(L_α)248, Sm(M_α)74, Mn(K_α)143, Y(K_α)101, Mo(K_α)32
50	CANADA	1.5246	1308	64			45	47			Mo(K_α)99
51	THAILAND	1.5229		3296			60	67			Ti(K_α)126, Nd(L_α)38

TABLE C.13 TABLEWARE GLASSES

GLASS NO.	ORIGIN	REFRACTIVE INDEX	$Fe(K_\alpha)$	$Zn(K_\alpha)$	$As(K_\alpha)$	$Rb(K_\alpha)$	$Sr(K_\alpha)$	$Sr(K_\beta)$ and/or $Zr(K_\alpha)$	$Nb(K_\alpha)$	$Ba(L_\alpha)$	OTHER PEAKS
52	CZECHO-SLOVAKIA	1.5488	18	1204				62			$Pb(L_\alpha)$ 9116
53	AUSTRALIA	1.5178	19		242		33	59			
83	ITALY	1.5206	28	28			185	95		43	$Mo(K_\alpha)$ 161
84	AUSTRALIA	1.5187	24		193			60			
85	USA	1.5325	49				153	1897			
86	WEST GERMANY	1.5114	31				146	65		56	
87	ITALY	1.5192	36	35			113	72		53	$Mo(K_\alpha)$ 193
88	AUSTRALIA	1.5163	35		265		27	97			
89	ITALY	1.5222	33	30	77		83	-		35	
90	AUSTRALIA	1.5168	27	41	253			100			

TABLE C.14 LABWARE GLASSES

GLASS NO.	ORIGIN	REFRACTIVE INDEX	Fe(K_α)	Zn(K_α)	As(K_α)	Rb(K_α)	Sr(K_α)	Sr(K_β) and/or Zr(K_α)	Nb(K_α)	Ba(L_α)	OTHER PEAKS
76	CHINA	1.4751	80	418	380						
77	ARGENTINA	1.4938	45		45	73	567	189		111	
78	CZECHO-SLOVAKIA	1.4735	52		31			290			
79	WEST GERMANY	1.5146	22		82	25	190	93		115	
80	UK	1.4724	54					289			
81	AUSTRALIA	1.4732	52					481			
145		1.5115	52		96	29	125	68		107	
148	WEST GERMANY	1.4723	24					172			
150	USA	1.5158	30		744		27	98			

TABLE C.15 CONTAINER GLASSES

GLASS NO.	ORIGIN	REFRACTIVE INDEX	Fe(K_α)	Zn(K_α)	As(K_α)	Rb(K_α)	Sr(K_α)	Sr(K_β) and/or Zr(K_α)	Nb(K_α)	Ba(L_α)	OTHER PEAKS
64	AUSTRALIA	1.5208	23				313	102			
65	AUSTRALIA	1.5217	29				341	95			
66	AUSTRALIA	1.5209	88				296	114			
67	AUSTRALIA	1.5214	100				295	88			
68	PHILI-PPINES	1.5201	124				87	81			Pb(L_α)64
69	THAILAND	1.5205	161				46	68			
70	UK	1.5193	31				77	56			
71	CHINA	1.5164		NO SPECTRUM AVAILABLE							
72	JAPAN	1.5197	136*	764			54	119			Mn(K_α)124, Pb(L_α)268, Y(K_α)34
73	AUSTRALIA	1.5219	83				288	108			
74	AUSTRALIA	1.5154	40				141	110			Pb(L_α)123
75	UK	1.5198	30				78	141			
82	AUSTRALIA	1.5154	31		29		81	90		79	
95	AUSTRALIA	1.5211	89		37		203	94	39		
96	AUSTRALIA	1.5180	41	22			39	60	56		Mn(K_α)18, Mo(K_α)45
97	AUSTRALIA	1.5203	112	34			30	76	52		Mn(K_α)26
98	AUSTRALIA	1.5198	120	24			53	90			Mn(K_α)29
99	AUSTRALIA	1.5200	56	24			44	88	51		Mn(K_α)24

* High due to Mn(K)

TABLE C.15 (CONT'D) CONTAINER GLASSES

GLASS NO.	ORIGIN	REFRACTIVE INDEX	Fe (K_α)	Zn (K_α)	As (K_α)	Rb (K_α)	Sr (K_α)	Sr (K_β) and/or Zr (K_α)	Nb (K_α)	Ba (L_α)	OTHER PEAKS
100	AUSTRALIA	1.5208	123				223	69			Cr (K_α) 56
101	AUSTRALIA	1.5207	71				42	103			Mn (K_α) 20
102	AUSTRALIA	1.5220	38				37	103	30		
103	AUSTRALIA	1.5212	122				48	102	52		
104	AUSTRALIA	1.5235	87				42	113			Cr (K_α) 55
122	AUSTRALIA	1.5221	40				303	92			Cr (K_α) 48
123	PORTUGAL	1.5225	150	22		27	45	74			Cr (K_α) 49
124	ITALY	1.5236	250		37		47	84			Cr (K_α) 29
125	S. AFRICA	1.5154	65				78	57	28		Y (K_α) 36
126	SPAIN	1.5246	151			26	48	57			Cr (K_α) 44, Mo (K_α) 35
127	AUSTRALIA	1.5255	269				36	66			Cr (K_α) 35, Mn (K_α) 33
128	AUSTRALIA	1.5212	49		15	35	49	69			
129	AUSTRALIA	1.5224	103		21		229	87			Cr (K_α) 41
130	AUSTRALIA	1.5201	38		29		222	128			
131	AUSTRALIA	1.5215	142				312	107	34		
132	UK	1.5230	165			32	47	46			Cr (K_α) 44
133	AUSTRALIA	1.5211	43				325	99			
134	AUSTRALIA	1.5213	103		29		259	83			
135	AUSTRALIA	1.5154	50		69		60	87	67	134	

TABLE C.15 (CONT'D) CONTAINER GLASSES

GLASS NO.	ORIGIN	REFRACTIVE INDEX	Fe(K_α)	Zn(K_α)	As(K_α)	Rb(K_α)	Sr(K_α)	Sr(K_β) and/or Zr(K_α)	Nb(K_α)	Ba(L_α)	OTHER PEAKS
136	AGM	1.5196	36				46	31	28		Mn(K_α)23
138	USA	1.5177	36	13			25	75			
139	ITALY	1.5296	247				49	88			Cr(K_α)15
140	UK	1.5221	142				36	42			
141	UK	1.5189	197	19		21	60	61	38		
142	SPAIN	1.5244	146		21	32	51	60			Cr(K_α)43
143	AUSTRALIA	1.5205	40				41	44			Mn(K_α)16

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