SECTION 2 : PETROGRAPHIC EXAMINATION OF SAMPLES OF VOLCANIC ROCKS FROM ANDERSON ROAD QUARRIES

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This report was originally produced in March 1995 as GEO Special Project Report No. SPR 2/95

FOREWORD

In mid-1991, at the request of the Quarries Section of GEO, the Public Works Central Laboratory (PWCL) of the Materials Division commenced an investigation into the alkali-aggregate reaction potential of the volcanic rocks from the Anderson Road Quarries. The main objective of the investigation was to provide information for the evaluation of the suitability of the use of such rocks as aggregates in concrete. A report on the investigation was issued last year (Report No. SPR 10/94).

This report presents the detailed results of the petrographic examination which was carried out as part of the investigation. The petrographic examination included detailed thin section analyses and Scanning Electron Microscope (SEM), Energy Dispersive X-ray (EDX) and X-ray diffraction (XRD) analyses of a number of samples of tuff from Anderson Road Quarries.

The report was prepared by Mr S.T. Gilbert who carried out the thin section analyses. The SEM and EDX analyses were carried out by the Government Laboratory. The XRD analyses were carried out by the British Geological Survey in the UK.

The report was review by Mr H.H. CHOY, Dr R. Sewell and Dr R. Shaw of Planning Division and Dr T.Y. Irfan of Materials Division.

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ABSTRACT

A laboratory testing study has recently been carried out to provide information for the assessment of the alkali-aggregate reaction (AAR) potential of volcanic rocks at Anderson Road Quarries for concrete aggregates. As part of the study, a detailed petrographic examination was undertaken on a number of samples of tuff.

The petrographic examination included thin section analyses to assess the mineral composition and classify the rock type, Scanning Electron Microscope (SEM) and Energy Dispersive X-ray (EDX) analyses to assess the degree of crystallinity and chemical composition of the rock matrix, and X-ray Diffraction (XRD) analyses to confirm the presence and quantities of potentially reactive constituents.

All of the samples examined were found to contain one or more of the following potentially reactive materials:

(a) Microcrystalline to cryptocrystalline quartz.
(b) Strained quartz.
(c) Recrystallised fragments of volcanic glass.

The experience gained in the study indicates that petrographic examination is a useful preliminary screening test in AAR assessments of aggregate sources and in determining the extent and type of further testing needed.

CONTENTS

1. INTRODUCTION

The use of petrographic techniques to aid in the assessment of the suitability of aggregate materials has been recognised for many years. More recently growing importance has been placed on petrographic examination as both a qualitative and semi-quantitative means of assessing the alkali-aggregate reaction (AAR) potential of aggregate sources. Petrographic examination is now considered to be a key investigative technique in AAR assessment of concrete aggregates.

At the request of the Quarries Section of GEO, the Materials Division has recently carried out a laboratory testing study (Leung et al, 1994) to assess the AAR potential of the volcanic rocks at Anderson Road Quarries for concrete aggregates. As part of the study petrographic examination was carried out on a number of samples of tuff to determine the AAR potential of these rocks.

This report presents the detailed findings of the petrographic examination. The geological setting with respect to the proposed redevelopment of Anderson Road Quarries is also described.

2. GEOLOGY OF ANDERSON ROAD QUARRIES

The geology of Anderson Road Quarries has been mapped by the Hong Kong Geological Survey and is documented in Strange & Shaw (1986). The majority of the site of the quarries is underlain by fine-to medium-grained granites. Fine ash tuff of Upper Jurassic age (approx. 150 million years old) occupy the upper levels of the quarry. A prominent band of eutaxite within the tuff crosses the summit of the quarry. The eutaxite is formed by the flattening and stretching of glassy pumice clasts and other rock fragments within the tuff whilst the rock is still in a hot viscous state. Subsequently the clasts and fragments are "welded" together and the rock is left with a banded appearance.

The tuff when first formed contained abundant volcanic glass and possibly other silica phases such as tridymite and cristobalite which are thermodynamically unstable and devitrify or recrystallise with time. As a result of the great age of these rocks the recrystallisation process has proceeded to the point where little, if any, discernible volcanic glass is left (Workman, 1985).

Near the contact with the granite subsequent contact metamorphism has further recrystallised the tuff, resulting in coarsening of the crystal size, and has led to alteration of feldspars within the rock and growth of secondary minerals such as micas and chlorite. Thin quartz veinlets also cut through the tuff and have probably originated from the adjacent granite.

The geology of Anderson Road Quarries is shown in Figure 1. The mechanical properties of the volcanic tuff from Anderson Road are discussed in Gilbert & Irfan (1989).

3. REDEVELOPMENT OF ANDERSON ROAD QUARRIES

Anderson Road Quarries have been in operation since 1956. K. Wah Quarry Co. Ltd operates the northern part of the quarry area (Tai Sheung Tok Quarry) and Pioneer Quarries (HK) Ltd works the area to the south (Anderson Road Area 3 Quarry). The original contracts of these operators, which commenced in 1974 (Pioneer) and 1978 (K. Wah) respectively, were only for 12 years but have subsequently been extended. Quarrying is currently taking place to achieve a final landform specified by the contracts.

A study carried out by Ove Arup & Partners (Ove Arup & Ptns, 1993) contains recommendations which will permit the progressive restoration of the quarries and the handback of the restored area to Government for development through extended quarrying rights. The proposed final landform is required to satisfy both commercial and technical criteria. It is anticipated that 20 years will be required for these technical and commercial criteria to be met. The final landform will produce a total of about 43 million m^3 for K. Wah and 12 million m^3 for Pioneer. Of these quantities of material, approximately 0.9 million m^3 and 3.1 million m^3 of volcanic rock will be produced from the K. Wah and Pioneer operations respectively.

The proposed redevelopment boundary of Anderson Road Quarries is shown in Figure 1.

4. PETROGRAPHY OF VOLCANIC ROCKS WITH RESPECT TO ALKALI AGGREGATE REACTION

Certain types of volcanic rocks, particularly those of the acidic variety which have higher silica contents (as found in Hong Kong), are considered by many authors (Dolar-Mantuani, 1983; Sims, 1986; Wakizaka et al, 1986; Katayame & Kaneshige, 1986; French, 1992) to be potentially alkali-aggregate reactive when used for concrete aggregates. This is because they can often contain some of the more common forms of reactive minerals including opal, volcanic glass, tridymite, cristobalite, microcrystalline and cryptocrystalline quartz, chalcedony and strained quartz. Details of the occurrence of these potentially reactive constituents are given in Table 1. Some of these constituents, such as volcanic glass, cristobalite and tridymite, are thermodynamically unstable when first formed, but with the effect of geological processes during aging, they will invert to more stable forms of silica such as quartz. As a result, it can be expected that these reactive minerals are more likely to be present in volcanic rocks of younger geological ages than in older rocks (Katayama & Kaneshige, 1986).

Many authors have expressed opinions on the relative degree of reactivity of reactive forms of silica which depends principally on their grain size and the amount of disorder in their crystal structures. Opal, which is amorphous (i.e. non-crystalline) and has a highly disordered crystal structure, is considered to be the most reactive form of silica (Smith & Collis, 1993). At the other end of the scale, well order unstrained coarsely crystalline quartz is normally considered to have a low reactivity potential. The proportion of reactive silica present will have a major influence on the resulting expansion in concrete using rocks which contain this material as aggregates. For example, very small concentrations of opal in the aggregate may result in significant AAR expansion in the concrete (Building Research Establishment, 1988). For less reactive forms of silica, this concentration, known as the pessimum (French, 1980), occurs normally at higher proportions. National threshold limits of a number of countries for potentially reactive forms of silica are given in Table 2.

Rocks containing strained quartz have frequently been recognised as being potentially reactive and previous research has focused on developing quantitative petrographic methods to determine the degree of strain in individual quartz crystals. This has been carried out by measuring undulatory extinction angles in quartz crystals to assess potential reactivity (Dolar-Mantuani, 1983). More recent research (Anderson & Thaulow, 1989; Grattan-Bellew, 1992; Smith et al, 1992; and French, 1992) has suggested that the use of undulatory extinction angles alone to determine reactivity in strained quartz can be misleading. Additional factors such as grain size, degree of crystal disorder and texture of the strained quartz crystals are now considered to have a greater influence on the potential for reaction.

Grattan-Bellew (1992) has demonstrated that the reactivity of silica appears to increase with decreasing grain size and crystallinity. The solubility of quartz when exposed to alkalis is related to the amount and availability of free energy around and within the crystal. When a coarsely crystalline strained quartz crystal contains microcrystalline quartz (formed as a result of recrystallisation during straining) and/or internal defects such as strain lamellae or microcracks, the surface area of the strained crystal is increased and as such the amount of free energy available also increases. This consequently can increase the potential solubility of the crystal by allowing greater penetration of alkalis to unstable reaction centres within the strained quartz crystal.

5. TEST PROCEDURE AND RESULTS

5.1 Sampling

Six samples of tuff were collected from the upper quarry face at Anderson Road Quarry (Pioneer) on 20 April 1993. As the quarry operator is not yet producing volcanic aggregate from the quarry, the sampling procedure broadly followed the requirements of ASTM C295-85 (ASTM, 1985) for sampling from exposed faces of non-producing quarries.

5.2 Petrographic Examination

Each sample was examined in hand specimen and described in accordance with Geoguide 3 (GCO, 1988). One thin section was prepared from each of the six samples of tuff and are numbered AR1-6. A petrographic examination, using an Olympus BH2 polarising microscope, was carried out on each thin section and, where possible, followed the procedural requirements of ASTM C295-85 for the petrographic examination of samples representative of materials proposed for use as aggregates in concrete, and in particular for the identification of potentially alkali-silica reactive constituents. The descriptions of the constituent minerals in each thin section followed the guidelines of ASTM C294-85 (ASTM, 1987). A micrometer eyepiece was used to determine the grain size of minerals within each thin section. Point count analyses of the matrix and crystal contents of samples AR1-6 were carried out using a Swift Model F Automatic Point Counter. A total of 1000 counts was carried out on each sample over a grid with a stepping interval of 0.5mm. Crystals were defined as individual grains with a size greater than or equal to 250μm.

In addition, a number of thin sections of tuff from Anderson Road Quarries, taken from the collection of the Hong Kong Geological Survey, were examined for comparative purposes to check the representative nature of the samples taken under this study. These are numbered HK1042 and HK1044, and HK7021, HK7022 and HK7024.

The samples of tuff from Anderson Road Quarries were found to consist mainly of fresh to slightly decomposed grey or light grey fine ash tuffs which were occasionally vitric in variety (Table 3).

The rocks are crystalline in nature and consist predominantly of poorly formed crystals of quartz and K-feldspar (up to 3 mm in size) set in a devitrified matrix of quartz, feldspar and mica which is predominantly microcrystalline in nature (Plate 1) but occasionally varies to very fine grained (Samples AR1, 3, 4, & HK7022), or cryptocrystalline in the more vitric samples (AR2, 5, 6 and HK7024) (Plate 2). The crystal content of these rocks is variable and ranges from around 5% to 30% of the rocks (Table 4).

The majority of the samples have been slightly metamorphosed which has resulted in some straining & recrystallisation of the quartz crystals and rock matrix and the development of secondary minerals such as mica and chlorite. HK 1042 is taken from the contact zone between the tuff and the adjacent granite and has undergone extensive recrystallisation of both the rock matrix and the crystal phases. Iron oxides/pyrites were observed as accessory minerals in most of the samples examined.

The petrographic examination revealed the presence of potentially reactive minerals in all of the thin sections. These included microcrystalline to cryptocrystalline quartz (Plates 1 and 2), fiamme (flattened recrystallised fragments of volcanic glass (pumice)) (Plate 3), and strained quartz crystals with internal defects and microcrystalline inclusions (Plates 4 and 5).

A summary of the petrographic examination results is given in Tables 3 & 4. Detailed petrographic descriptions of each sample examined are given in Appendix A.

5.3 Scanning Electron Microscope Analyses

Scanning Electron Microscope (SEM) and Energy Dispersive X-ray (EDX) analyses were carried out on two of the more vitric samples of tuff (AR5 and AR6) to assess the degree of crystallinity and composition of the matrix material.

The SEM permits high resolution images of the crystal structure of the matrix at very high magnifications (X50 - X50,000). The EDX allows the chemical analysis of very small volumes of the sample to be determined in terms of their elemental composition.

The SEM analyses of the two samples of tuff revealed that the matrix material is generally poorly crystalline to amorphous with individual crystals, where developed, with grain size between 2 μm and 10 μm (Plates 6 and 7).

The EDX analyses, although not able to determine mineral composition directly, suggest from the distribution and intensity of the element spectra (Figures 2 and 3) that the matrix of the two samples of tuff has a similar composition to the rocks themselves, i.e. being composed of quartz and feldspar with subordinate micas.

5.4 X-ray Diffraction Analyses

X-ray diffraction analyses were carried out by the British Geological Survey (BGS) in the UK on two of the more vitric samples of tuff (AR2 and AR5) to confirm the presence and quantity of potentially reactive constituents.

The samples were crushed and sub-samples (5g) were micronised to a fine powder. The samples were back-loaded into aluminium holders and analysed using a Philip PW 1700 X-ray diffractometer operating at 45 kV and 40 mA. Their bulk mineralogy was determined by scanning over an angular range of 3-50°2θ using Co-Kα radiation and the X-ray diffraction traces were interpreted with reference to the JCPDS database. The total quartz content of each sample was determined by scanning over the 4.26A peak and comparing the peak intensities to a series of calibration standards. The relative quartz crystal size of each sample was determined by measurement of the 4.26A peak width (in °2θ at half height and comparing them with those for an Arkansas stone standard (peak width 0.13°2θ).

The results of the XRD analyses of the two samples of volcanic tuff agreed with the findings of the petrographic examination (Tables 3 & 5). The quartz content of the samples examined varied from 29% (AR2) to 40% (AR5) by weight. The analyses suggest that much of the quartz is microcrystalline to cryptocrystalline in grain size. The presence of more reactive forms of silica such as opal, cristobalite, tridymite and chalcedony was not identified.

6. DISCUSSION OF RESULTS

The most common forms of potentially reactive silica (Table 1) can be found as primary or secondary phases in volcanic rocks as discussed in Section 4. The petrographic examination of the Anderson Road tuffs has therefore focused on identifying the presence of these silica phases.

Quantitative determination of potentially reactive components of aggregates is important to allow the proportions of these constituents to be compared against established national threshold limits for assessing the degree of potential reactivity. The most commonly used method for determining the proportions of mineral constituents in aggregate is by point counting mineral constituents in thin sections to establish the percentage of each mineral present. However, careful consideration should be given to the extent of the point counting coverage in relation to the grain size of the samples, otherwise the assessment will not be statistically representative. Although point count analysis has been used in this study to determine the ratio of crystals to matrix in some of the samples examined, this method is, however, not suited for the quantitative assessment of the poorly crystalline matrix of the tuff from Anderson Road Quarries. This is because the mineral constituents of the tuff are too small to be quantitatively assessed in thin section using a conventional polarising microscope.

Some success has been gained during the study in determining the quantitative proportions of reactive constituents present in the tuffs using X-ray diffraction methods. However, some difficulties have arisen in the resolution of reactive components which are present in very low quantities (<2%). It is, therefore, considered that the ASTM C295 method of petrographic examination in conjunction with X-ray diffraction analysis, for quantitative assessment, is the most appropriate petrographic method for the assessment of the AAR potential of the tuffs at Anderson Road.

The petrographic examination of thin sections of the tuff from Anderson Road Quarries indicated the presence of potentially reactive microcrystalline to cryptocrystalline quartz and strained quartz in all of the samples examined (Plates 1, 2 and 4). In addition, the presence of fiamme (flattened recrystallised fragments of volcanic glass (pumice)) was identified in two of the samples of vitric tuff examined. However, any remnant glass present in the fiamme appears to have devitrified (or recrystallised) to microcrystalline to cryptocrystalline quartz.

The results of the X-ray diffraction analyses indicated total quartz contents, for the samples examined, of 29% and 40% which, as a result of the very low quartz crystal contents of these rocks (Table 4), can be assumed to represent the quantity of microcrystalline to cryptocrystalline quartz in the rock matrix. These quantities of microcrystalline to cryptocrystalline quartz are well in excess of recognised national threshold limits for potential reactivity of these constituents (Table 2). However, the effects of subsequent metamorphism on these tuffs has resulted in a partial coarsening of the grain size of the matrix which may have lessened its potential for reaction. Other known forms of reactive silica such as opal, chalcedony, cristobalite and tridymite were not identified in thin section or by the X-ray diffraction analyses.

Frequent evidence of strained quartz was observed within larger quartz crystals in most of the samples examined (Plates 4 & 5) and was also observed occasionally in larger partially formed quartz crystals in the rock matrix. It was not possible with the conventional polarising microscope to quantify the degree of potential reactivity of strained quartz, present in both the crystals and the matrix of all of the thin sections examined. This is because of the low quartz crystal content and the very fine grained nature of the rocks, which was at times beyond the resolution of the petrographic microscope used in the examination.

Many of the strained quartz crystals examined have subsequently recrystallised to finer grained quartz sub-crystals, which as a result has increased the surface area and amount of available free energy around and within the strained quartz crystals, thus enhancing the potential for reaction (Plate 8). In addition, some of the strained quartz crystals also contain internal cracks (Plate 4) which may act as pathways for alkalis within the cement to migrate to unstable reaction centres within strained quartz crystals. Some quartz crystals within some of the samples examined were also observed to contain small inclusions of microcrystalline material probably absorbed from the matrix during formation (Plate 5). These inclusions, when associated within internal defects within the crystal, may constitute potential unstable reaction centres within the quartz crystals.

7. CONCLUSIONS AND RECOMMENDATIONS

As a result of the work carried out, the following conclusions can be made:

(a) The petrographic examination of thin sections of tuff from Anderson Road Quarries indicated the presence of potentially reactive microcrystalline to cryptocrystalline quartz, flattened recrystallised fragments of volcanic glass and strained quartz in the samples examined.

(b) The X-ray diffraction analyses results carried out on two samples of the tuff indicated that the quantity of microcrystalline to cryptocrystalline quartz in the tuff exceeded the established national threshold limits for alkali-aggregate reaction potential.

(c) Because of the very fine grain sizes of the tuff of Anderson Road Quarries and the difficulties encountered in quantifying the reactive minerals in such rocks, it is clear that the petrographic examination should only be used as a preliminary screening test for identifying the presence of potentially reactive minerals. The results of petrographic examination will assist in determining the extent and type of further testing that needs to be carried out.

Examination of the geology with respect to the proposed redevelopment of Anderson Road Quarries reveals that in addition to the tuff, an extensive band of eutaxite will be included in the quarried material resulting from the proposed redevelopment of the quarries. During the present study it was not possible to sample the eutaxite as a result of access difficulties. The likelihood of the presence of potentially reactive remnant volcanic glass in the eutaxite is considered to be higher than in the volcanic host rock due to the predominance of flattened glassy pumice fragments within the eutaxite. It is recommended that petrographic examination and appropriate testing be carried out on the band of eutaxite to assess its potential for alkali-aggregate reaction if this rock is to be considered for use as aggregates in concrete.

8. REFERENCES

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Table 1 - Varieties of Potentially Reactive Silica and their Geological Occurrence (after Smith & Collis, 1993)

Variety of Silica	Common Geological Occurrence
Opal	Vein material and vugh filling in a variety of rock types, a constituent of some types of chert, a replacement for siliceous fossil material and a cementing material in some sedimentary rocks.
Volcanic glass	A constituent of some igneous volcanic rocks ranging from acid to basic composition. Volcanic glass devitrifies over geological time and devitrified glass may also be potentially reactive.
Tridymite and cristobalite	High temperature metastable polymorphs of silica found as a minor constituent in some acid and intermediate volcanic rocks.
Microcrystalline and cryptocrystalline quartz	The principal constituent of most cherts and flint. Vein material and vugh fillings in a variety of rock types, groundmass mineral in some igneous and metamorphic rocks, cementing material in some sedimentary rocks.
Chalcedony	A fibrous variety of microcrystalline quartz found as a constituent of some cherts and flint. Vein materials and vugh fillings in a variety of rock types, cementing material in some sedimentary rocks.
Strained quartz	Found especially in metamorphic rocks, but also in some igneous rocks, subjected to high stresses. Also occurs as a detrital mineral in clastic sediments. Current opinion is that strained quartz itself is probably not reactive and reactivity may be associated with poorly ordered silica at the highly sutured grain boundaries commonly associated with strained quartz.

Table 2 - National Threshold Values of Potentially Reactive Forms of Silica (after RILEM, 1993)

Country	Potentially Reactive Forms of Silica Found in Aggregates	Threshold of Reactivity (% of Rock Material)
Belgium	Opal, chalcedony, microcrystalline & cryptocrystalline quartz.	<2%
Canada	Opal, tridymite, cristobalite volcanic glasses, beekite. Chalcedony, microcrystalline to cryptocrystalline quartz, macrogranular quartz with deformed crystal lattice.	As little as 1% As little as 5%
Denmark	Opal, cryptocrystalline quartz.	<2%
Ireland	Opal, cristobalite and tridymite chalcedony, microcrystalline & cryptocrystalline quartz, volcanic glass.	Opal, cristobalite and tridymite = 0% Chalcedony, microcrystalline quartz, volcanic glass <0.5% Strained quartz <30%
Norway	Microcrystalline quartz.	<2%
Russia	Opal, microcrystalline quartz, volcanic glass, cristobalite, tridymite, chalcedony.	<5%
UK	Opal, cristobalite and tridymite. Microcrystalline & cryptocrystalline quartz, strained quartz, opal, chalcedony, volcanic glass. Strained quartz.	Opal, cristobalite and tridymite = 0% Microcrystalline to cryptocrystalline quartz (in flint) <2% and >60% in coarse aggregate; <5% in fine aggregate. Strained quartz <30%

Table 3 - Summary of Petrographic Examination Results on Rock Samples from Anderson Road Quarries

Specimen/Thin Section No.	Rock Type	Major Constituents	Minor Constituents	Potentially Reactive Constituents
AR1	Fine ash TUFF	Quartz (dominant) K-feldspar	Mica, chlorite, iron pyrites/oxides	Microcrystalline quartz in matrix Strained quartz in crystals
AR2	Fine ash vitric TUFF	K-feldspar (dominant) Quartz	Mica, chlorite, iron pyrites/oxides	Microcrystalline to cryptocrystalline quartz in matrix. Fiammi (Flattened recrystallised fragments of volcanic glass (pumice))
AR3	Fine ash TUFF	Quartz, K-feldspar plagioclase	Mica, chlorite	Microcrystalline quartz in matrix Strained quartz and microcrystalline inclusions in crystals
AR4	Fine ash TUFF	Quartz, K-feldspar	Mica, chlorite, iron pyrites/oxides	Microcrystalline quartz in matrix Strained quartz with internal defects and microcrystalline inclusions in crystals
AR5	Fine ash vitric TUFF	K-Feldspar (dominant) quartz, mica	Mica, chlorite, iron pyrites/oxides	Microcrystalline to cryptocrystalline quartz in matrix Strained quartz in crystals
AR6	Fine ash vitric TUFF	K-Feldspar (dominant) quartz, mica	Mica, chlorite, iron pyrites/oxides	Microcrystalline to cryptocrystalline quartz in matrix Fiammi (Flattened recrystallised fragments of volcanic glass (pumice))

Table 3 - Summary of Petrographic Examination Results on Rock Samples from Anderson Road Quarries (Cont'd)

Specimen/Thin Section No.	Rock Type	Major Constituents	Minor Constituents	Potentially Reactive Constituents
HK 1042	HORNFELS	--	--	Microcrystalline quartz in matrix Strained quartz in crystals
HK 1044	Fine ash TUFF	Quartz and K-feldspar (dominant) plagioclase	Chlorite, mica, iron pyrites/ oxides, zircon	Microcrystalline quartz in matrix Strained quartz with microcrystalline inclusions in crystals
HK 7021	Fine ash TUFF	Quartz, K-feldspar (dominant) plagioclase	Chlorite, mica, iron pyrites/ oxides, zircon	Microcrystalline to cryptocrystalline quartz in matrix Microcrystalline inclusions in crystals
HK 7022	Fine ash TUFF	Quartz & K-feldspar (dominant) mica	Chlorite, mica, iron pyrites/ oxides, zircon	Microcrystalline quartz in matrix
HK 7024	Fine ash vitric TUFF	K-Feldspar (dominant) quartz	Mica, chlorite, iron oxides	Microcrystalline to cryptocrystalline quartz in matrix
Note : Specimen No. HK 1042, 1044, 7021, 7022 and 7024 were sample specimens obtained by Hong Kong Geological Survey				

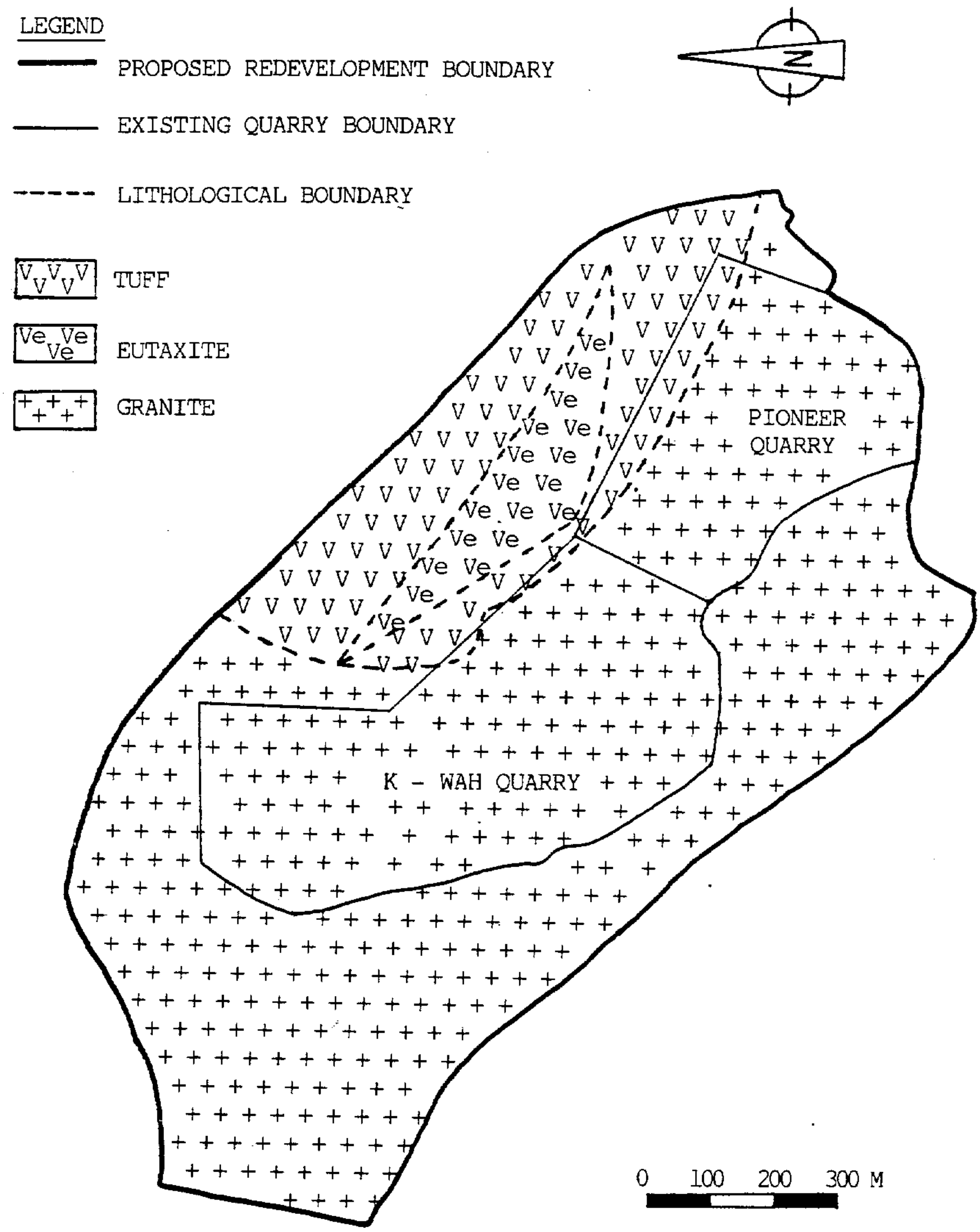
Table 4 - Results of Point Count Analyses

Sample No.	MATRIX (%)	CRYSTALS						
		Quartz (%)	Orthoclase Feldspar (%)	Plagioclase Feldspar (%)	Mica (%)	Chlorite (%)	Iron Oxides (%)	Accessories (%)
AR1	83.2	8.1	7.0	0	0.6	0.7	0	0.4
AR2	69.1	0.9	26.0	0.4	0	1.8	1.8	0
AR3	88.5	6.7	3.6	0.8	0.3	0.1	0	0
AR4	76.8	5.7	14.6	0.6	1.7	0.3	0.3	0
AR5	95.6	0.4	3.7	0	0	0	0	0
AR6	71.1	0	23.3	0.1	0.1	2.5	2.9	0

Table 5 - X-ray Diffraction Analysis Results of Volcanic Aggregates

Specimen No.	X-Ray Diffraction Results
AR2	Contains dominant quartz (29 wt%), major Na-feldspar and K-feldspar, minor chlorite and mica and trace magnetite. The presence of pyrite was not confirmed. The 4.26A peak width was 0.16°2θ.
AR5	Contains dominant quartz (40 wt%), major K-feldspar and Na-feldspar, and minor chlorite and mica. The presence of pyrite and iron oxides was not confirmed. The 4.26A peak width was 0.15°2θ.

LIST OF FIGURES



(Adapted from Choy et al, 1987 and Ove Arup & Ptns, 1993)

Figure 1 - Geology and Proposed Redevelopment of Anderson Road Quarries

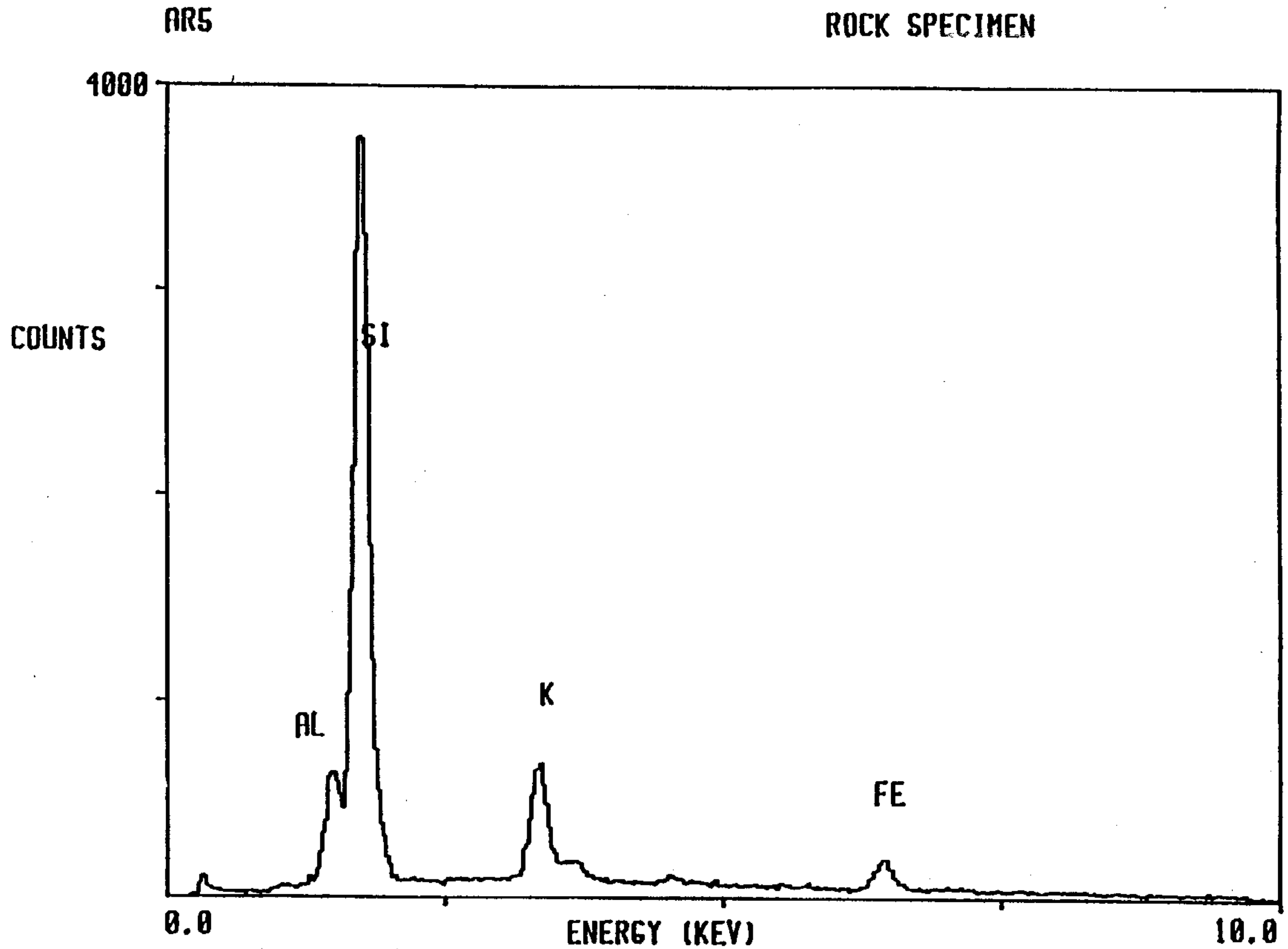


Figure 2 - EDX Analysis Results of Sample AR5

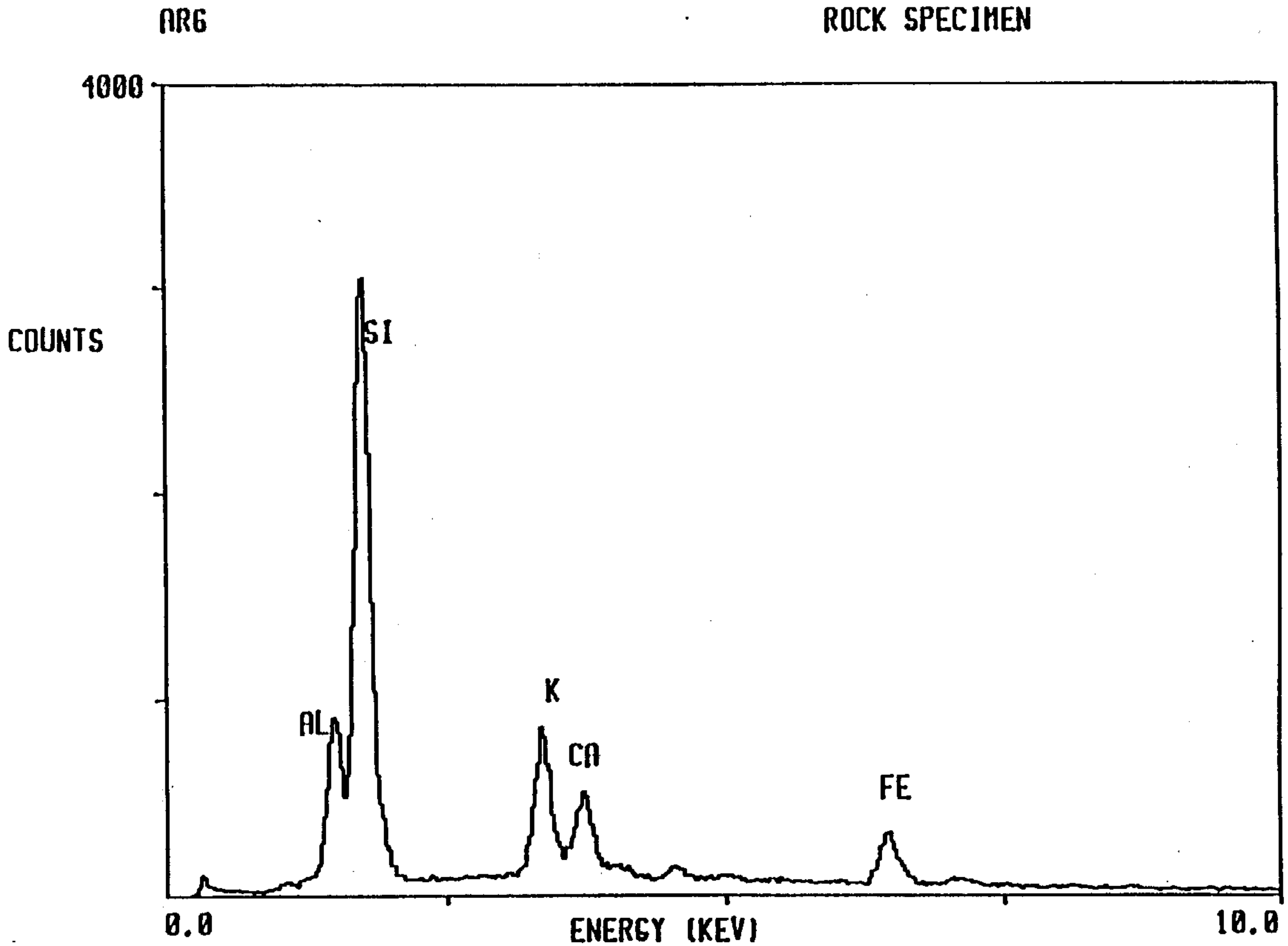


Figure 3- EDX Analysis Results of Sample AR6

LIST OF PLATES

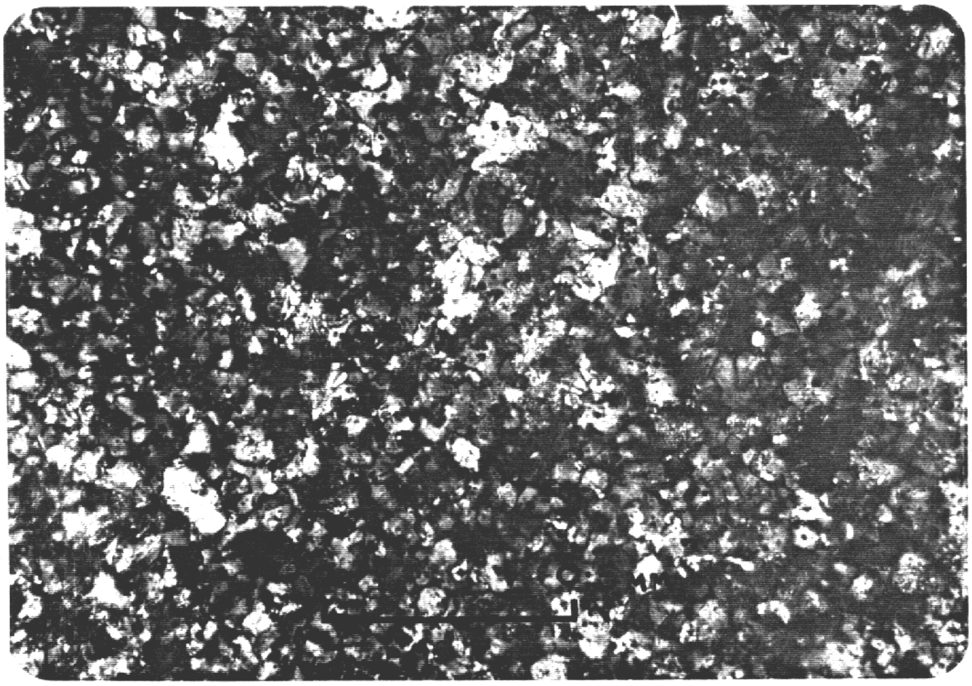


Plate 1 - Microcrystalline Quartz in Rock Matrix (Thin Section Photomicrograph in Cross Polarised Light - Sample AR2)

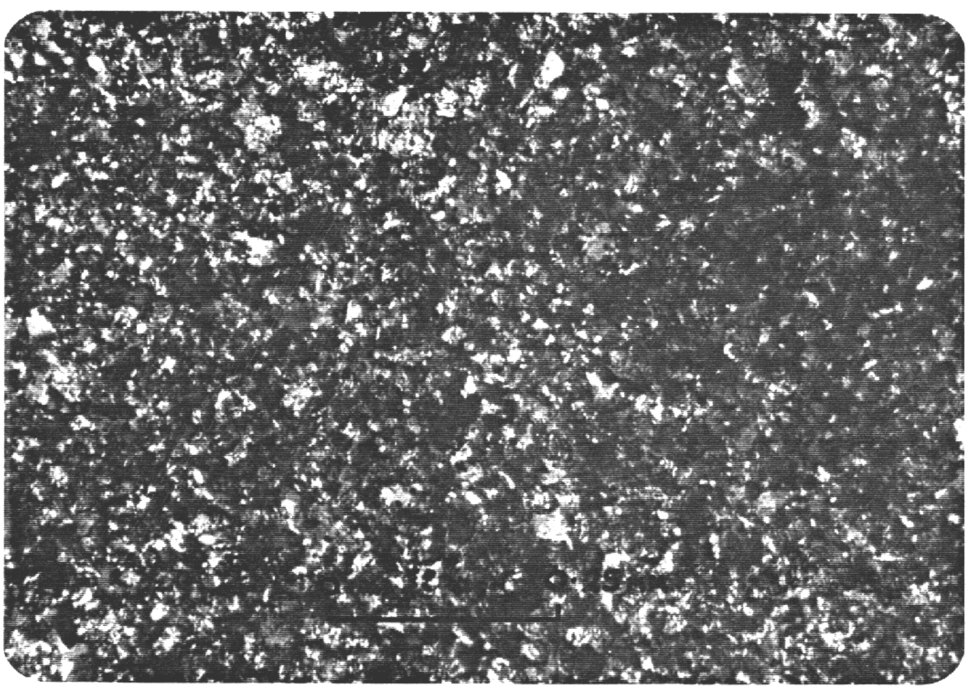


Plate 2 - Cryptocrystalline Quartz in Rock Matrix (Thin Section Photomicrograph in Cross Polarised Light - Sample AR6)

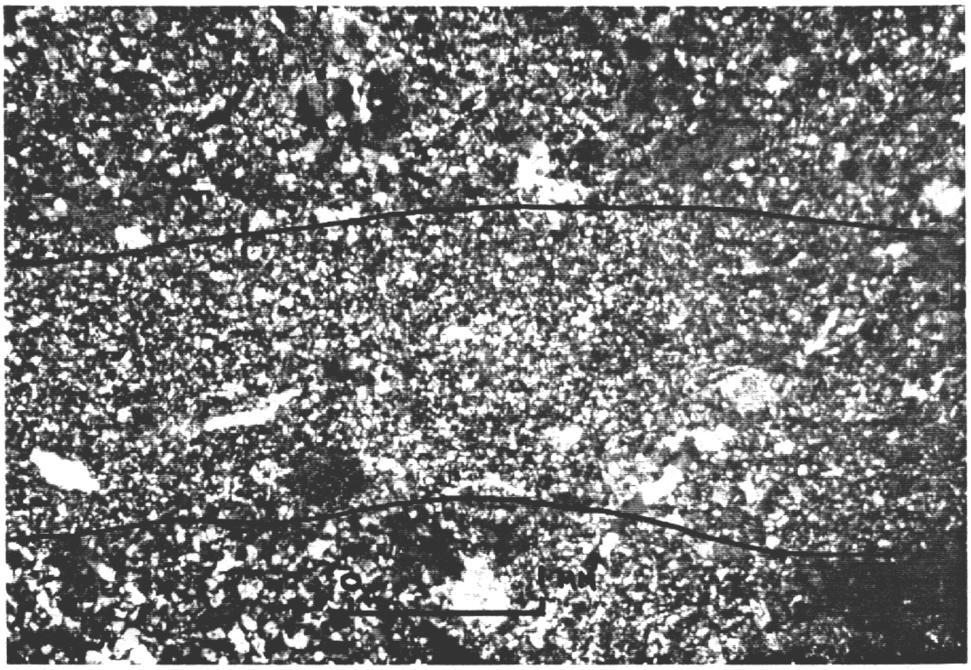


Plate 3 - Fiamme in Volcanic Tuff
(Thin Section Photomicrograph in Cross
Polarised Light - Sample AR6)

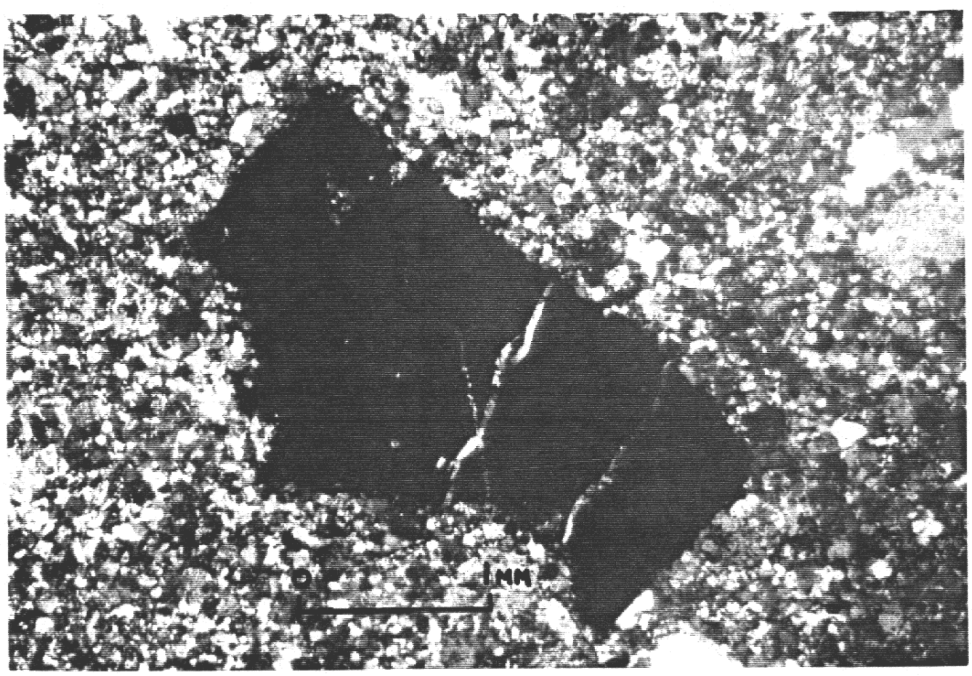


Plate 4 - Strained Quartz Crystals with Internal Cracks
(Thin Section Photomicrograph in Cross
Polarised Light - Sample AR4)

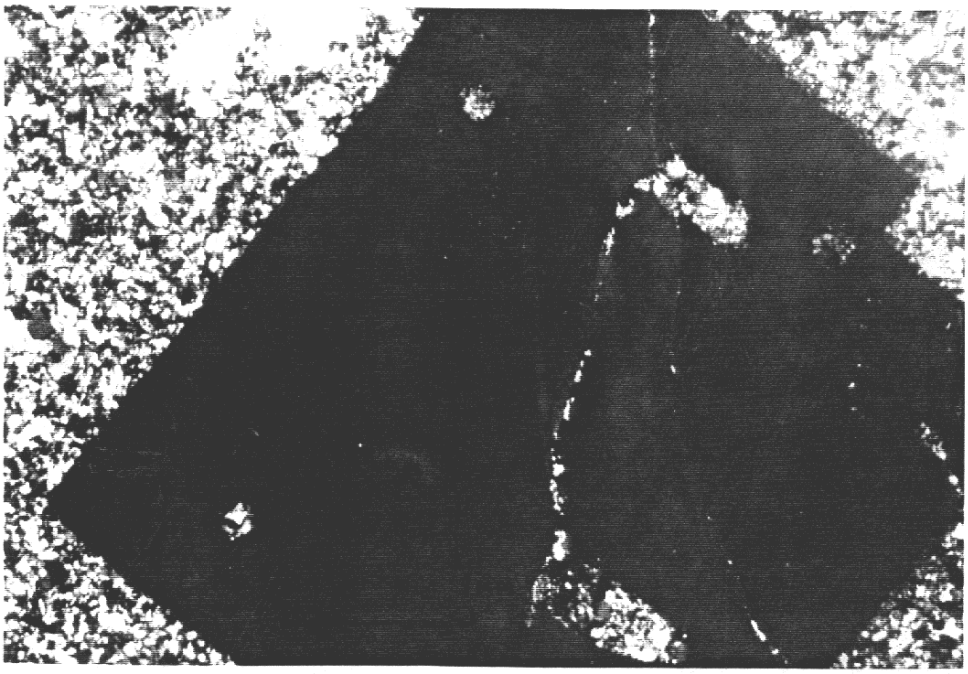


Plate 5 - Strained Quartz Crystals with Microcrystalline Inclusions (Thin Section Photomicrograph in Cross Polarised Light - Sample AR3)

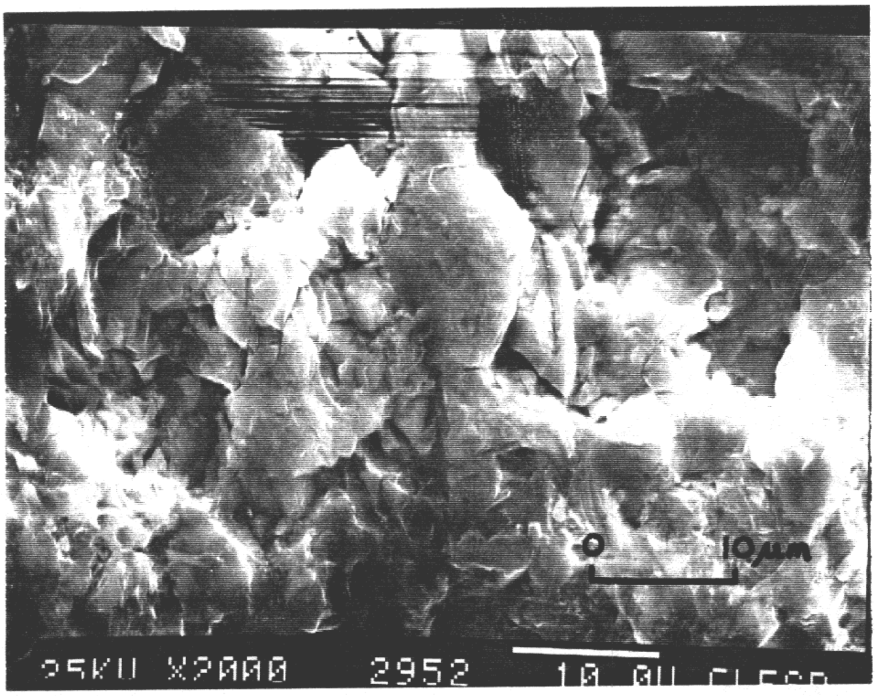


Plate 6 - SEM Photomicrograph of Rock Matrix in Sample AR5

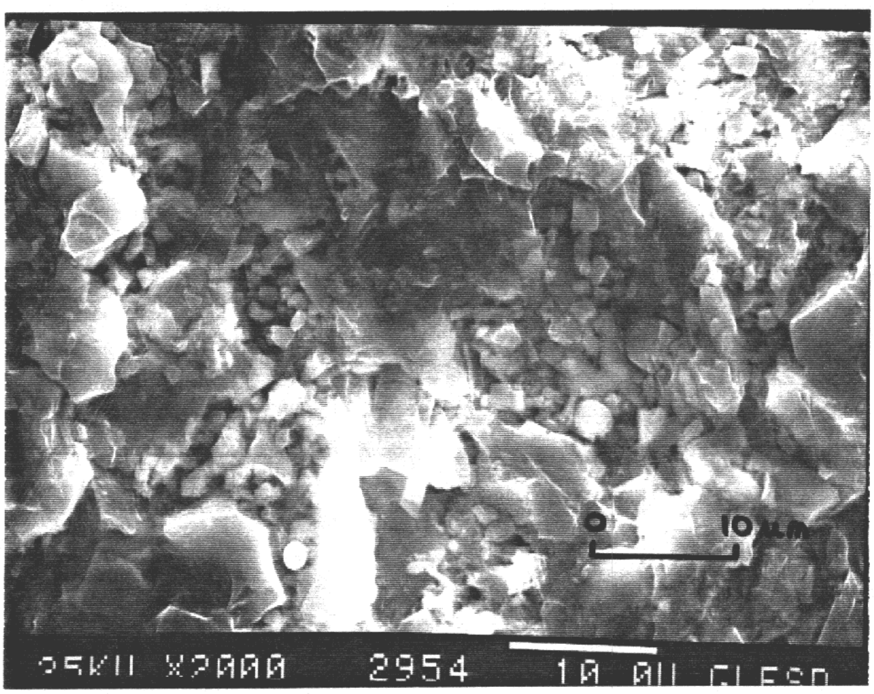


Plate 7 - SEM Photomicrograph of Rock Matrix in Sample AR6

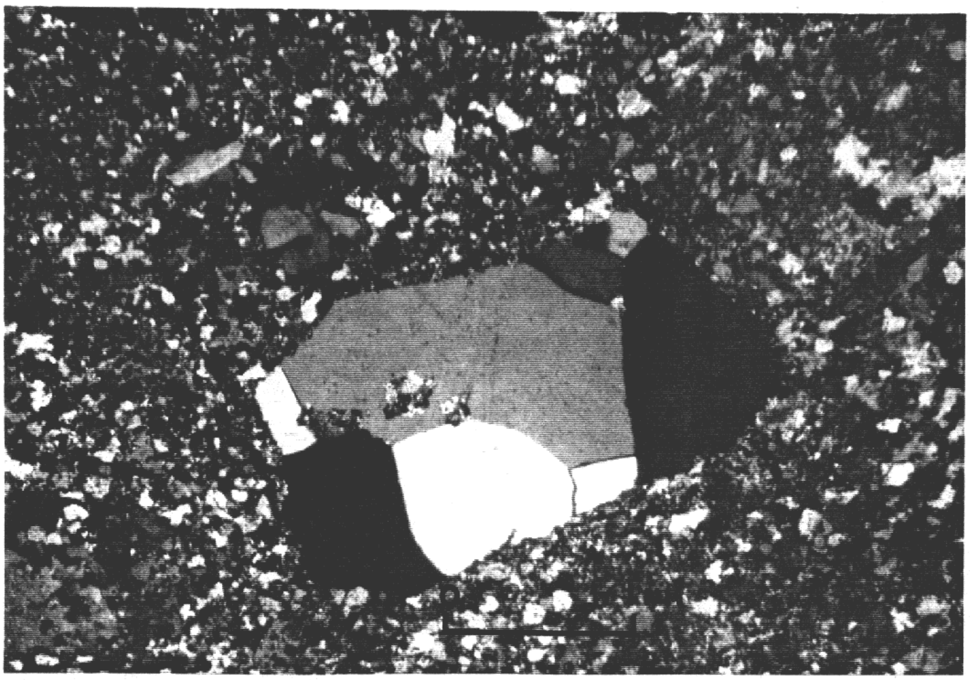


Plate 8 - Recrystallisation of Strained Quartz Crystal (Thin Section Photomicrograph in Cross Polarised Light - Sample AR1)

APPENDIX A

RESULTS OF PETROGRAPHIC EXAMINATION

OF SAMPLES OF TUFF

PETROGRAPHIC EVALUATION OF AGGREGATES FOR ASR

SAMPLE REGISTRATION

SAMPLE NO	AR1	LOCATION	ANDERSON ROAD QUARRY (PIONEER)
SAMPLE TYPE	QUARRY FACE	SAMPLING DATE	20.4.93
SAMPLE DESCRIPTION (HAND SPECIMEN)	FRESH GREY FINE GRAINED VOLCANIC ROCK	SAMPLE SIZE	50 mm (nominal)

PETROGRAPHIC INFORMATION

THIN SECTION NO	ROC 950006A	PREPARATION DATE	10.5.93
ROCK TYPE (GSS CLASSIFICATION)	FINE ASH TUFF (JSM)		
MINERALOGY MAJOR CONSTITUENTS	CRYSTALS - PREDOMINANTLY QUARTZ BETWEEN 0.5 mm TO 3 mm EXHIBITING OCCASIONAL PARTIAL RECRYSTALLISATION AND MINOR STRAINING. SUB-ORDINATE FELDSPARS (K - FELDSPAR) ARE SLIGHTLY ALTERED. OCCASIONAL BIOTITE CRYSTALS REPLACED BY CHLORITE AND IRON OXIDES. MATRIX - PREDOMINANTLY MICROCRYSTALLINE TO VERY FINE GRAINED QUARTZ AND FELDSPAR. MATRIX EXTENSIVELY ALTERED TO SERICITE, BIOTITE AND CHLORITE.		
MINOR CONSTITUENTS	MUSCOVITE, IRON PYRITES/OXIDES, BIOTITE, CHLORITE, SERICITE		
PRESENCE OF REACTIVE MINERALS	MICROCRYSTALLINE QUARTZ IN MATRIX, STRAINED QUARTZ IN CRYSTALS		
REMARKS	ROCK HAS BEEN SLIGHTLY METAMORPHOSED	Compiled by	S. GILBERT
		Date	26.5.93

PETROGRAPHIC EVALUATION OF AGGREGATES FOR ASR

SAMPLE REGISTRATION

SAMPLE NO	AR2	LOCATION	ANDERSON ROAD QUARRY (PIONEER)
SAMPLE TYPE	QUARRY FACE	SAMPLING DATE	20.4.93
SAMPLE DESCRIPTION (HAND SPECIMEN)	FRESH GREY FINE GRAINED SLIGHTLY VITRIC VOLCANIC ROCK	SAMPLE SIZE	80 mm (nominal)

PETROGRAPHIC INFORMATION

THIN SECTION NO	ROC 95007A	PREPARATION DATE	10.5.93
ROCK TYPE (GSS CLASSIFICATION)	FINE ASH VITRIC TUFF (JAC)		
MINERALOGY MAJOR CONSTITUENTS	CRYSTALS - PREDOMINANTLY FELDSPAR (K - FELDSPAR) BETWEEN 0.5 mm TO 2 mm, PARTIALLY ALTERED TO SERICITE. SUB-ORDINATE QUARTZ, 1-2 mm, WHICH ARE MAINLY RECRYSTALLISED. OCCASIONAL IRON OXIDE AND CHLORITE MATRIX - PREDOMINANTLY MICROCRYSTALLINE TO CRYPTOCRYSTALLINE QUARTZ AND FELDSPAR. MATRIX EXTENSIVELY ALTERED TO CHLORITE AND SERICITE		
MINOR CONSTITUENTS	CHLORITE, IRON PYRITES/OXIDES, SERICITE , FIAMMÉ (2-4 mm long fragments of flattened pumice, now recrystallised)		
PRESENCE OF REACTIVE MINERALS	MICROCRYSTALLINE TO CRYPTOCRYSTALLINE, QUARTZ IN MATRIX, FIAMMÉ (flattened pumice)		
REMARKS		Compiled by	S. GILBERT
		Date	26.5.93

PETROGRAPHIC EVALUATION OF AGGREGATES FOR ASR

SAMPLE REGISTRATION

SAMPLE NO	AR3	LOCATION	ANDERSON ROAD QUARRY (PIONEER)
SAMPLE TYPE	QUARRY FACE	SAMPLING DATE	20.4.93
SAMPLE DESCRIPTION (HAND SPECIMEN)	FRESH TO SLIGHTLY DECOMPOSED LIGHT GREY FINE GRAINED VOLCANIC ROCK	SAMPLE SIZE	70 mm (nominal)

PETROGRAPHIC INFORMATION

THIN SECTION NO	ROC 950006B	PREPARATION DATE	10.5.93
ROCK TYPE (GSS CLASSIFICATION)	FINE ASH TUFF (JSM)		
MINERALOGY MAJOR CONSTITUENTS	CRYSTALS - PREDOMINANTLY QUARTZ AND FELDSPAR, QUARTZ CRYSTALS BETWEEN 200 μm and 3 mm, OCCASIONAL EMBAYED (REACTION WITH MATRIX). MINOR UNDULOSE EXTINCTION IN SOME OF THE QUARTZ CRYSTALS. FELDSPARS (K - FELDSPAR AND PLAGIOCLASE) 1-2 mm, PARTIALLY TO EXTENSIVELY ALTERED TO SERICITE MATRIX - PREDOMINANTLY VERY FINE GRAINED TO MICROCRYSTALLINE QUARTZ AND FELDSPAR. SOME ELOGATION OF MICROCRYSTALS IN MATRIX, SLIGHT ALTERATION TO CHLORITE AND SERICITE		
MINOR CONSTITUENTS	CHLORITE, SERICITE, MUSCOVITE		
PRESENCE OF REACTIVE MINERALS	MICROCRYSTALLINE QUARTZ IN MATRIX, STRAINED QUARTZ IN CRYSTALS		
REMARKS	ROCK HAS BEEN SLIGHTLY METAMORPHOSED	Compiled by S. GILBERT Date 26.5.93	

PETROGRAPHIC EVALUATION OF AGGREGATES FOR ASR

SAMPLE REGISTRATION

SAMPLE NO	AR4	LOCATION	ANDERSON ROAD QUARRY (PIONEER)
SAMPLE TYPE	QUARRY FACE	SAMPLING DATE	20.4.93
SAMPLE DESCRIPTION (HAND SPECIMEN)	FRESH TO SLIGHTLY DECOMPOSED LIGHT GREY FINE GRAINED VOLCANIC ROCK	SAMPLE SIZE	50 mm (nominal)

PETROGRAPHIC INFORMATION

THIN SECTION NO	ROC 950006C	PREPARATION DATE	10.5.93
ROCK TYPE (GSS CLASSIFICATION)	FINE ASH TUFF (JSM)		
MINERALOGY MAJOR CONSTITUENTS	CRYSTALS - PREDOMINANTLY QUARTZ AND FELDSPAR. FELDSPARS (K - FELDSPAR) 1-3 mm, PARTIALLY TO EXTENSIVELY ALTERED TO SERICITE. QUARTZ, 500 μm to 1 mm, OCCASIONAL EMBAYED (REACTION WITH MATRIX), FREQUENTLY CRACKED AND OCCASIONALLY RECRYSTALLISED. MINOR EVIDENCE OF STRAINING. OCCASIONAL SHARDIC CRYSTALS OF QUARTZ. MINOR CRYSTALS OF MUSCOVITE MATRIX - PREDOMINANTLY VERY FINE GRAINED TO MICROCRYSTALLINE QUARTZ AND FELDSPAR, SLIGHT ALTERATION TO SERICITE		
MINOR CONSTITUENTS	CHLORITE, IRON PYRITES/OXIDES, MUSCOVITE		
PRESENCE OF REACTIVE MINERALS	MICROCRYSTALLINE QUARTZ IN MATRIX, STRAINED QUARTZ IN CRYSTALS		
REMARKS		Compiled by	S. GILBERT
		Date	26.5.93

PETROGRAPHIC EVALUATION OF AGGREGATES FOR ASR

SAMPLE REGISTRATION

SAMPLE NO	AR5	LOCATION	ANDERSON ROAD QUARRY (PIONEER)
SAMPLE TYPE	QUARRY FACE	SAMPLING DATE	20.4.93
SAMPLE DESCRIPTION (HAND SPECIMEN)	GREEN-GREY SLIGHTLY DECOMPOSED FINE GRAINED VITRIC VOLCANIC ROCK	SAMPLE SIZE	80 mm (nominal)

PETROGRAPHIC INFORMATION

THIN SECTION NO	ROC 950007B	PREPARATION DATE	10.5.93
ROCK TYPE (GSS CLASSIFICATION)	FINE ASH VITRIC TUFF (JAC)		
MINERALOGY MAJOR CONSTITUENTS	CRYSTALS - PREDOMINANTLY FELDSPARS (K - FELDSPAR) 1-2 mm, EXTENSIVELY ALTERED TO SERICITE. MINOR QUARTZ PRESENT, 500 μm, WITH SOME RECRYSTALLISATION AND STRAINING MATRIX - PREDOMINANTLY MICROCRYSTALLINE TO CRYPTOCRYSTALLINE QUARTZ AND FELDSPAR, EXTENSIVELY ALTERED TO SERICITE, CHLORITE AND IRON OXIDES. EXTENSIVE STRAINING AND ELONGATION OF MICROCRYSTALS		
MINOR CONSTITUENTS	SERICITE, CHLORITE, IRON PYRITES/OXIDES		
PRESENCE OF REACTIVE MINERALS	STRAINED QUARTZ IN CRYSTALS AND IN MATRIX, MICROCRYSTALLINE TO CRYPTOCRYSTALLINE QUARTZ IN MATRIX		
REMARKS	ROCK HAS BEEN SLIGHTLY TO MODERATELY METAMORPHOSED	Compiled by S. GILBERT	Date 26.5.93

PETROGRAPHIC EVALUATION OF AGGREGATES FOR ASR

SAMPLE REGISTRATION

SAMPLE NO	AR6	LOCATION	ANDERSON ROAD QUARRY (PIONEER)
SAMPLE TYPE	QUARRY FACE	SAMPLING DATE	20.4.93
SAMPLE DESCRIPTION (HAND SPECIMEN)	FRESH GREY FINE GRAINED VITRIC VOLCANIC ROCK	SAMPLE SIZE	50 mm (nominal)

PETROGRAPHIC INFORMATION

THIN SECTION NO	ROC 950007C	PREPARATION DATE	10.5.93
ROCK TYPE (GSS CLASSIFICATION)	FINE ASH VITRIC TUFF (JAC)		
MINERALOGY MAJOR CONSTITUENTS	CRYSTALS - PREDOMINANTLY FELDSPAR (K - FELDSPAR), 1-2 mm, FREQUENTLY REPLACED OR PSEUDOMORPHED BY CHLORITE AND IRON OXIDES, EXTENSIVELY ALTERED TO SERICITE. MINOR QUARTZ CRYSTALS, MAINLY RECRYSTALLISED. SOME ELONGATED CHLORITE CRYSTALS (REPLACING BIOTITE) MATRIX - PREDOMINANTLY MICROCRYSTALLINE TO CRYPTOCRYSTALLINE QUARTZ AND FELDSPAR. MATRIX HAS BEEN EXTENSIVELY ALTERED TO CHLORITE AND SERICITE. SOME ELONGATED MICROCRYSTALS IN MATRIX		
MINOR CONSTITUENTS	SERICITE, CHLORITE, IRON OXIDES/PYRITES, FIAMME (2-4 mm long fragments of flattened pumice, now recrystallised)		
PRESENCE OF REACTIVE MINERALS	MICROCRYSTALLINE TO CRYPTOCRYSTALLINE QUARTZ IN MATRIX, FIAMME (flattened pumice)		
REMARKS	ROCK IS CUT BY MICRO VEINS (200 - 300 μm WIDE) FILLED WITH VERY FINE GRAINED QUARTZ. ROCK HAS BEEN SLIGHTLY METAMORPHOSED	Compiled by Date	S. GILBERT 26.5.93

PETROGRAPHIC EVALUATION OF AGGREGATES FOR ASR

SAMPLE REGISTRATION

SAMPLE NO	PS 250	LOCATION	ANDERSON ROAD QUARRY
SAMPLE TYPE	--	SAMPLING DATE	--
SAMPLE DESCRIPTION (HAND SPECIMEN)	--	SAMPLE SIZE	--

PETROGRAPHIC INFORMATION

THIN SECTION NO	HK 1042	PREPARATION DATE	--
ROCK TYPE (GSS CLASSIFICATION)	GRANITE/VOLCANIC CONTACT		
MINERALOGY MAJOR CONSTITUENTS	--		
MINOR CONSTITUENTS	--		
PRESENCE OF REACTIVE MINERALS	STRAINED QUARTZ IN CRYSTALS, MICROCRYSTALLINE QUARTZ IN MATRIX		
REMARKS	SAMPLE FROM HONG KONG GEOLOGICAL SURVEY COLLECTION	Compiled by	S. GILBERT
		Date	29.9.93

PETROGRAPHIC EVALUATION OF AGGREGATES FOR ASR

SAMPLE REGISTRATION

SAMPLE NO	PS 252	LOCATION	ANDERSON ROAD QUARRY,
SAMPLE TYPE	--	SAMPLING DATE	--
SAMPLE DESCRIPTION (HAND SPECIMEN)	--	SAMPLE SIZE	--

PETROGRAPHIC INFORMATION

THIN SECTION NO	HK 1044	PREPARATION DATE	--
ROCK TYPE (GSS CLASSIFICATION)	FINE ASH TUFF (JSM)		
MINERALOGY MAJOR CONSTITUENTS	CRYSTALS/MATRIX : C 10%/90% CRYSTALS - PREDOMINANTLY QUARTZ AND K-FELDSPAR BETWEEN 0.5 MM AND 2 MM. QUARTZ CRYSTALS ARE FREQUENTLY EMBAYED WITH INCLUSIONS OF MICROCRYSTALLINE QUARTZ AND OCCASIONALLY SHARDIC, LARGER QUARTZ CRYSTALS EXHIBIT SLIGHT STRAINING AND OCCASIONAL RECRYSTALLISATION. K-FELDSPARS ARE ALTERED AND EXTENSIVELY SERICITISED. OCCASIONAL SMALLER CRYSTALS OF PLAGIOCLASE. MATRIX - PREDOMINANTLY VERY FINE GRAINED TO MICROCRYSTALLINE QUARTZ AND FELDSPAR. MATRIX ALTERED TO SERICITE AND CHLORITE.		
MINOR CONSTITUENTS	CHLORITE, SERICITE, IRON PYRITES/OXIDES, ZIRCON		
PRESENCE OF REACTIVE MINERALS	MICROCRYSTALLINE QUARTZ IN MATRIX AND AS INCLUSIONS IN QUARTZ CRYSTALS. SLIGHT STRAINING IN QUARTZ CRYSTALS		
REMARKS	%CRYSTALS/MATRIX ESTIMATED VISUALLY SAMPLE FROM HONG KONG GEOLOGICAL SURVEY COLLECTION	Complied by	S. GILBERT
		Date	29.9.93

PETROGRAPHIC EVALUATION OF AGGREGATES FOR ASR

SAMPLE REGISTRATION

SAMPLE NO	--	LOCATION	ANDERSON ROAD QUARRY
SAMPLE TYPE	--	SAMPLING DATE	--
SAMPLE DESCRIPTION (HAND SPECIMEN)	--	SAMPLE SIZE	--

PETROGRAPHIC INFORMATION

THIN SECTION NO	HK 7021	PREPARATION DATE	--
ROCK TYPE (GSS CLASSIFICATION)	FINE ASH TUFF (JSM)		
MINERALOGY MAJOR CONSTITUENTS	CRYSTALS/MATRIX : C 5%/95% CRYSTALS - PREDOMINANTLY QUARTZ AND K-FELDSPAR 0.5 MM TO 2.0 MM IN SIZE. QUARTZ CRYSTALS ARE FREQUENTLY EMBAYED AND CONTAIN SMALL INCLUSIONS OF MICROCRYSTALLINE QUARTZ. LARGER QUARTZ CRYSTALS OCCASIONALLY EXHIBIT PARTIAL OR TOTAL RECRYSTALLISATION. K-FELDSPARS ARE ALTERED SLIGHTLY SERICITISED AND DISPLAY MICROPERTHITE TEXTURE. MATRIX - PREDOMINANTLY MICROCRYSTALLINE TO CRYPTOCRYSTALLINE QUARTZ AND FELDSPAR ALTERED TO CHLORITE AND SERICITE.		
MINOR CONSTITUENTS	CHLORITE, BIOTITE, SERICITE, IRON OXIDES/PYRITES, ZIRCON, FIAMMI (FEW MM LONG FRAGMENTS OF FLATTENED PUMICE, NOW RECRYSTALLISED)		
PRESENCE OF REACTIVE MINERALS	MICROCRYSTALLINE TO CRYPTOCRYSTALLINE QUARTZ IN MATRIX AND AS INCLUSIONS IN QUARTZ CRYSTALS		
REMARKS	% CRYSTALS/MATRIX ESTIMATED VISUALLY SAMPLE FROM HONG KONG GEOLOGICAL SURVEY COLLECTION. ROCK HAS BEEN METAMORPHOSED.	Compiled by	S. GILBERT
		Date	29.9.93

PETROGRAPHIC EVALUATION OF AGGREGATES FOR ASR

SAMPLE REGISTRATION

SAMPLE NO	--	LOCATION	ANDERSON ROAD QUARRY
SAMPLE TYPE	--	SAMPLING DATE	--
SAMPLE DESCRIPTION (HAND SPECIMEN)	--	SAMPLE SIZE	--

PETROGRAPHIC INFORMATION

THIN SECTION NO	HK 7022	PREPARATION DATE	--
ROCK TYPE (GSS CLASSIFICATION)	FINE ASH TUFF (JSM)		
MINERALOGY MAJOR CONSTITUENTS	CRYSTALS/MATRIX : C 5%/95% CRYSTALS - PREDOMINANTLY QUARTZ AND K - FELDSPAR, 0.5 - 2 MM IN SIZE. QUARTZ CRYSTALS FREQUENTLY EMBAYED AND OCCASIONALLY RECRYSTALLISED. FELDSPAR CRYSTALS ARE ALTERED AND SERICITISED WITH OCCASIONAL MICROPERTHITE TEXTURE. NUMEROUS ABRADED CRYSTALS OF MUSCOVITE AROUND 1 MM IN SIZE. MATRIX - PREDOMINANTLY MICROCRYSTALLINE TO VERY FINE GRAINED QUARTZ AND FELDSPAR ALTERED TO SERICITE AND CHLORITE.		
MINOR CONSTITUENTS	CHLORITE, SERICITE, IRON PYRITES/OXIDES		
PRESENCE OF REACTIVE MINERALS	MICROCRYSTALLINE QUARTZ IN MATRIX		
REMARKS	%CRYSTALS/MATRIX ESTIMATED VISUALLY SAMPLE FROM HONG KONG GEOLOGICAL SURVEY COLLECTION	Compiled by Date	S. GILBERT 29.9.93

PETROGRAPHIC EVALUATION OF AGGREGATES FOR ASR

SAMPLE REGISTRATION

SAMPLE NO	--
LOCATION	ANDERSON ROAD QUARRY
SAMPLE TYPE	--
SAMPLING DATE	--
SAMPLE DESCRIPTION (HAND SPECIMEN)	--
SAMPLE SIZE	--

PETROGRAPHIC INFORMATION

THIN SECTION NO	HK 7024
PREPARATION DATE	--
ROCK TYPE (GSS CLASSIFICATION)	FINE ASH VITRIC TUFF (JAC)
MINERALOGY MAJOR CONSTITUENTS	CRYSTALS/MATRIX : C 10%/90% CRYSTALS - PREDOMINANTLY K-FELDSPAR BETWEEN 250 μM AND 500 μM, OCCASIONALLY UP TO 1 MM IN SIZE AND EXTENSIVELY ALTERED TO SERICITE. SUBORDINATE QUARTZ CRYSTALS. MATRIX - MICROCRYSTALLINE TO CRYPTOCRYSTALLINE QUARTZ AND FELDSPAR EXTENSIVELY ALTERED TO SERICITE, CHLORITE AND IRON OXIDE.
MINOR CONSTITUENTS	MICA, CHLORITE, IRON OXIDES/PYRITES
PRESENCE OF REACTIVE MINERALS	MICROCRYSTALLINE TO CRYPTOCRYSTALLINE QUARTZ IN MATRIX
REMARKS	%CRYSTALS/MATRIX ESTIMATED VISUALLY SAMPLE FROM HONG KONG GEOLOGICAL SURVEY COLLECTION
Compiled by	S. GILBERT
Date	29.9.93