SECTION 3: PETROGRAPHIC EXAMINATION OF CONCRETE SAMPLES FROM HILL ROAD FLYOVER (H114) FROM POK FU LAM TO CONNAUGHT ROAD WEST

S.D.G. Campbell

This report was originally produced in October 2000 as GEO Geological Report No. GR 4/2000

FOREWORD

This report describes the results of a petrographic examination of three thin sections of concrete to identify any potential Alkali Aggregate Reaction (AAR) constituents. The thin sections and polished slabs were prepared from samples taken from the Hill Road Flyover (H114), from Pok Fu Lam to Connaught Road West. The study has been carried out, wherever possible, in accordance with ASTM C856-95, and was written by Dr S.D.G. Campbell of the Geological Survey Section in the Planning Division. Dr R.J. Sewell, also of the Geological Survey Section, provided additional comments.

(H.N. Wong)
Chief Geotechnical Engineer/Planning

CONTENTS

		Page No.
	Title Page	46
	FOREWORD	47
	CONTENTS	48
1.	INTRODUCTION	49
2.	PETROGRAPHIC EXAMINATION OF HARDENED CONCRETE	49
3.	IDENTIFICATION OF ALKALI-AGGREGATE REACTION IN THIN SECTION AND POLISHED SLABS	49
4.	LABORATORY INVESTIGATION	49
	4.1 Description of Samples	49
	4.2 Petrographic Examination	50
	4.2.1 Sample No. C9	50
	4.2.2 Sample No. C16	52
	4.2.3 Sample No. C21	54
5.	CONCLUSIONS	56
6.	REFERENCES	56
	LIST OF PLATES	57

1. INTRODUCTION

Three concrete thin sections, and polished slabs of the same samples, were submitted to the Geological Survey Section of Planning Division by Materials Division for petrographic analysis in order to identify any potential Alkali-Aggregate Reaction (AAR) constituents. The thin sections and polished slabs were prepared from samples taken from the Hill Road Flyover (H114) from Pok Fu Lam to Connaught Road West. The findings of this report are based solely on the petrographic observations.

2. PETROGRAPHIC EXAMINATION OF HARDENED CONCRETE

Petrographic examination of concrete is now commonly used for identification of alkali-aggregate reaction products and the standard procedures for such examination are outlined in ASTM C856-95 (ASTM, 1996a). Alkali-aggregate reaction occurs when minerals in certain aggregates react with the soluble alkaline components of the cement paste. Two main forms of alkali-aggregate reaction have been recognised: alkali-silica reaction and alkali-carbonate reaction. Except where dolomitic limestone has been used as an aggregate, most alkali-aggregate reaction is between alkaline components in the cement paste and reactive silica-bearing minerals in the accompanying aggregate.

3. IDENTIFICATION OF ALKALI-AGGREGATE REACTION IN THIN SECTION AND POLISHED SLABS

The general procedures adopted in this report for identification of alkali-aggregate reaction involved examination of polished slabs with the naked eye and under a binocular microscope, followed by detailed examination of thin sections under a polarizing microscope. The examination of the polished slabs included inspection for any obvious deleterious effects such as cracking, bleeding, void infilling, and carbonation. In addition, the size range, shape and type of aggregate fragments were described, along with any unusual features in the aggregate, such as the presence or absence of foliation, strained quartz, recrystallization and/or mineralization. Thin section examination was undertaken to identify the different varieties of aggregate fragments, and to determine any microscopic evidence for alkali-aggregate reaction. Features used to confirm the presence of alkali-aggregate reaction included the presence of gel filling cracks through the cement paste, gel filling cracks across grain boundaries and gel filling cracks on the margins of aggregate fragments.

4. LABORATORY INVESTIGATION

4.1 Description of Samples

No details of the relative sample locations within the Hillroad Flyover were provided and the following descriptions are therefore based on petrographic examination only.

4.2 Petrographic Examination

4.2.1 Sample No. C9

(i) Visual and stereo-binocular examination of polished slab

Coarse aggregate
- comprises crushed rock, mainly fresh
- c. 15% of total concrete
- size range 10-20 mm but there is a size continuum with the fine aggregate
- the lithology is fine- to medium-grained granite, mostly pink, spotted grey white and black varying to white spotted light grey and black, with some grey to brownish grey quartz veins
- angular to subangular and occasionally subround clasts with uneven to smooth texture and low flakiness
- relatively evenly distributed throughout the concrete and mainly matrix-supported
- unevenly graded with no obvious preferred orientation

Fine aggregate
- comprises crushed rock, mainly fresh
- c. 15% of total concrete
- size range 2-10 mm but there is a size continuum with the coarse aggregate
- the lithology is fine- to medium-grained granite, mostly pink, spotted grey white and black varying to white spotted light grey and black, with some grey to brownish grey quartz veins
- angular to subangular and occasionally subround clasts with uneven to smooth texture and low to occasionally moderate flakiness
- relatively evenly distributed throughout the concrete and mainly matrix-supported
- unevenly graded with no obvious preferred orientation

Sand
- comprises crushed rock
- c. 15% of total concrete
- size range < 0.5-2 mm but there is a size continuum with the fine aggregate
- comprises individual crystals, or small clusters of crystals, of quartz with some feldspar, of the same grain size as that in the coarser aggregate
- angular to subangular and subround clasts with variably low to high flakiness, the latter mainly o quartz and biotite crystals
- appears evenly distributed through the matrix with no obvious preferred orientation

Matrix
- light brownish grey to grey
- c. 55% of total concrete
- generally even colour distribution except along occasional microcracks which are grey to dark grey
- no obvious possolanic additive

Cracks

- very occasional infilled cracks, c. 0.1 mm wide
- mainly extend from, and occasionally between, aggregate into the matrix
- only readily visible on the unvarnished surface where they appear dark grey
- diffuse margins suggesting alteration associated with the development of the cracks
- slightly sinuous
- generally widest adjacent to aggregate but cracks appear not to extend through the aggregate

Voids

- occasional subspherical to non-spherical voids around aggregate peripheries, sometimes associated with infilled cracks that extend a short distance into the matrix, and subspherical voids up to 2.5 mm diameter in matrix (c. 1% of total)

Embedded items

- none observed

Comments

- occasional plucking of matrix and aggregate during sawing
- gives a slight ringing sound when hit lightly by a hammer

(ii) Petrological microscope examination of thin sections

Aggregate

- both coarse and fine aggregate comprise mainly slightly porphyritic fine-grained granite
- quartz shows some slight undulose extinction
- plagioclase is partly sericitised, but there is no zoning
- K-feldspar is slightly to highly perthitic
- some biotite and occasional pyrite (?)

Sand

- generally individual crystals liberated from fine-grained granite aggregate, including quarts, K-feldspar, plagioclase and biotite

Matrix

- there are occasional unreacted cement grains comprising alite, belite and ferrite, and small cement grain fragments (< 0.05 mm) mainly of ferrite and alite
- several microcracks up to 0.01 mm wide, occur especially around the peripheries of individual crystals and aggregate particles, extend into the paste, and rarely across aggregate particles, some containing infill with a slightly greenish and yellowish hue in PPL and low birefringence in XPL, although occasionally a higher birefringence infill has been observed, and rarely, portlandite is present in the cracks
- portlandite is present but relatively uncommon
- there are occasional shrinkage cracks up to 0.2 mm wide, which are empty or resin filled, and which have associated symmetrical carbonation of the paste on either side of the crack. The carbonation (slightly brownish in PPL) has diffuse limits.

Carbonation also occurs around the peripheries of some aggregate. The shrinkage cracks appear to provide a conduit for reaction with atmospheric carbon dioxide.

- no obvious possolanic additive
- aggregate/binder ratio c. 30/70
- water/cement ratio 0.45-0.50

4.2.2 Sample No. C16

(i) Visual and stereo-binocular examination of polished slab

Coarse aggregate

- comprises crushed rock, mainly fresh
- c. 15% of total concrete
- size range to 10 to 20 mm but there is a size continuum with the fine aggregate
- the lithology is fine- to medium-grained granite, mostly pink, spotted grey white and black, varying to light red, reddish yellow and light grey, spotted grey and black, with some grey to light brownish grey quartz veins
- angular to subangular and subround with uneven to smooth texture and low to occasionally moderate flakiness
- relatively evenly distributed and mainly matrix-supported
- unevenly graded with no obvious preferred orientation

Fine aggregate

- comprises crushed rock, mainly fresh
- c. 15% of total concrete
- size range to 2 to 10 mm but there is a size continuum with the coarse aggregate
- lithology is fine- to medium-grained granite, mostly pink, spotted grey white and black, varying to light red, reddish yellow and light grey, spotted grey and black, with some grey to light brownish grey quartz veins
- angular to subangular and subround with occasionally rough, to uneven and smooth texture and low to moderate flakiness
- relatively evenly distributed throughout the concrete and mainly matrix-supported
- unevenly graded with no obvious preferred orientation

Sand

- comprises crushed rock
- c. 15% of total concrete
- size range < 0.5-1 mm generally
- comprises individual crystals, or small clusters of crystals, of quartz with some feldspar, of the same grain size as that in the aggregate
- angular to subangular and subround with flakiness varying with mineralogy from low to moderate for feldspar crystals, to low to high for quartz crystals and high for biotite crystals
- appears evenly distributed throughout the matrix
- no preferred orientation

Matrix
- grey to light brownish grey and light grey
- c. 55% of total
- uneven colour distribution consistent with general alteration of the matrix in some areas and along some short microcracks which are grey to dark grey
- no obvious possolanic additive

Cracks
- some sealed cracks, typically < 0.5 mm wide, and generally short (< 10 mm)
- extend around and between some aggregate clasts, and into the matrix
- only readily visible on the unvarnished surface where they appear dark grey
- diffuse margins suggesting alteration associated with the development of the cracks
- some sinuosity
- generally widest adjacent to aggregate
- cracks appear not to extend through the aggregate

Voids
- occasional spherical voids, up to 4 mm diameter ($< 1\%$ of total), rarely partly filled with resin

Embedded items
- none observed

Comments
- aggregate did not tear in sawing
- the concrete gives a slight ringing sound when hit lightly by a hammer

(ii) Petrological microscope examination of thin sections

<u>Aggregate</u>
- both coarse and fine aggregate comprise mainly fine- to medium-grained granite
- quartz shows slightly undulose extinction locally and commonly has sutured boundaries
- plagioclase is very prone to sericitization but there is no zoning
- K-feldspar is perthitic
- opaque minerals occur locally in clusters
- some biotite

<u>Sand</u>
- generally individual crystals liberated from fine-grained granite aggregate during crushing, including quartz, K-feldspar, plagioclase and biotite

<u>Matrix</u>
- there are several large unreacted cement grains up to 0.3 mm, comprising belite, ferrite and some alite, and common smaller cement grains (< 0.1 mm) mainly of alite and ferrite, with some belite
- occasional portlandite, some around the peripheries of fine aggregate quartz grains and some within the paste

- there are some microcracks up to 0.02 mm wide, often with a slightly greenish or yellowish (in PPL) infill (low birefringence in XPL), around the peripheries of some aggregate particles and extending into the paste, and occasionally into aggregate particles, along grain boundaries
- only local carbonation
- no obvious possolanic additive
- aggregate/binder ratio c. 30/70
- water/cement ratio c. 0.45

4.2.3 <u>Sample No. C21</u>

(i) Visual and stereo-binocular examination of polished slab

Coarse aggregate
- comprises crushed rock, variably fresh to slightly, and possibly moderately, decomposed
- c. 25-30% of total concrete
- size range typically 10-38 mm
- the lithology is slightly quartzphyric fine-grained granite, mostly pink, spotted grey white and black, indicating fresh rock, but some discoloured by weathering to an orangish brown, spotted grey and buff
- angular to subangular and occasionally subround with rough to uneven and smooth texture and moderate flakiness
- unevenly distributed and occasionally clast-supported
- unevenly graded with a moderate preferred orientation of larger aggregate clasts in particular

Fine aggregate
- comprises crushed rock, variably fresh to slightly, and possibly moderately, decomposed
- c. < 5% of total concrete
- size range typically 6-10 mm
- the lithology is slightly quartzphyric fine-grained granite, mostly pink, spotted grey white and black, indicating fresh rock, but some discoloured by weathering to an orangish brown, spotted grey and buff
- angular to subangular and occasionally subround with uneven to smooth texture and moderate flakiness
- unevenly distributed and occasionally clast-supported
- unevenly graded with moderate preferred orientation

Sand
- comprises crushed rock
- 15-20% of total concrete
- size range < 0.1-1 mm generally, occasionally up to 2 mm, median 0.25 mm
- comprises individual crystals, or small clusters of crystals, of quartz and feldspar of the same grain size as that in the aggregate
- angular to subangular and subround with very variable flakiness depending on mineralogy: low to moderate for feldspars, low to high for quartz, and high for biotite

- appears evenly distributed with no preferred orientation
- relatively fewer sand particles than in samples C9 and C16

Matrix

- grey
- c. 65% of total concrete
- even colour distribution except along microcracks which are dark grey
- no obvious possolanic additive

Cracks

- several sealed cracks, typically 0.5-1 mm wide, along the boundaries of, and extending between, individual aggregate constituents
- only readily visible on the unvarnished surface where they appear dark grey
- diffuse margins suggesting alteration associated with the development of the cracks
- some sinuosity and occasional bifurcations
- most clearly extend outwards from aggregate boundaries into the matrix or outwards from larger cracks between aggregate clasts into the matrix
- generally widest adjacent to aggregate
- cracks appear not to extend through the aggregate

Voids

- none observed, therefore low porosity

Comments

- aggregate did not tear in sawing
- gives a slightly flatter sound when hit lightly by a hammer than samples C9 and C16 (which more clearly ring)

(ii) Petrological microscope examination of thin sections

<u>Aggregate</u>

- both coarse and fine aggregate comprise mainly slightly porphyritic fine-grained granite
- relatively little fine aggregate
- quartz commonly has sutured boundaries
- plagioclase is slightly sericitised but there is no zoning
- K-feldspar
- relatively common biotite

<u>Sand</u>

- generally individual crystals liberated from fine-grained granite aggregate during crushing, including quartz, K-feldspar, plagioclase and biotite

<u>Matrix</u>

- contains common unreacted cement grains and small cement grain fragments comprising alite, belite and ferrite
- there is relatively little portlandite
- there are occasional microcracks up to 0.01 mm wide, slightly yellowish in hue in

PPL and mainly low birefringence in XPL, around the peripheries of some aggregate particles, some extending into the paste and rarely some extending into aggregate clasts

- no obvious possolanic additive
- aggregate/binder ratio c. 30/70
- water/cement ratio c. 0.40-0.42

5. CONCLUSIONS

The petrographic examination of the samples has established that C21 differs from C9 and C16 in several respects. The principal aggregate component of C21 is a slightly porphyritic fine-grained granite that shows signs of slight to moderate decomposition in some clasts. This contrasts with the generally fresh, slightly porphyritic fine- to medium-grained granite aggregate in C9 and C16. C21 also contains far fewer fine aggregate particles and voids than C9 and C21 and has a lower water/cement ratio. C9, and to a lesser extent C16, show some evidence of shrinkage cracking and associated carbonation.

All of the samples show microcracking. C9 contains the most microcracks whereas C21 has the fewest. The microcracks often contain a slightly greenish to yellowish infill (in PPL, generally low birefringence in XPL) that may be silica gel formed as a result of alkali-silica reaction. Potential ingredients for alkali-aggregate reaction (DOT, 1991; RILEM, 1993) have not been identified with confidence, although some microcracks are associated with quartz crystals within aggregate particles. There is some evidence, therefore, of alkali-silica reaction, but at this stage, the evidence is not entirely conclusive. Therefore, it is recommended that further thin sections should be obtained and that these should, if possible, be stained to highlight the presence of any silica gel.

6. REFERENCES

ASTM (1996a). Standard Practice for Petrographic Examination of Hardened Concrete. Test Designation: C856-95. American Society for Testing Materials.

ASTM (1996b). Standard Descriptive Nomenclature for Constituents of Natural Mineral Aggregates. Test Designation: C294-86 (Reapproved 1991). American Society for Testing Materials.

DOT (1991). Notes for Guidance on the Specification for Highway Works. Department of Transport, UK, 31 p.

RILEM (1993). Petrographic Working Group Report No. RILEM/TC - 106/93/08. RILEM (The International Union of Testing and Research Laboratories for Materials and Structures), 11 p.

LIST OF PLATES

Plate No.		Page No.
1	Polished Surface of Sample C9 (CLROC000001A1, Field of View 60 mm, i.e. x 2 Magnification)	58
2	Microcrack Partly Infilled with Pale Green, Possible Silica Gel, Sample C9 (CLROC000001A1, PPL, Field of View = 1.8 mm)	58
3	Multiple Microcracks Possibly Partly Infilled with Silica Gel, Sample C9 (CLROC000001A1, PPL, Field of View = 1.8 mm)	59
4	Multiple Microcracks Partly Infilled with Possible Silica Gel, Sample C9 (CLROC000001A1, PPL, Field of View = 1.8 mm)	59
5	Polished Surface of Sample C16 (CLROC000001A2, Field of View 60 mm, i.e. x 2 Magnification)	60
6	Microcrack Partly Infilled with Pale Green, Possible Silica Gel, Sample C16 (CLROC000001A2, PPL, Field of View = 1.8 mm)	61
7	Microcrack Partly Infilled with Possible Silica Gel, Sample C16 (CLROC000001A2, PPL, Field of View = 1.8 mm)	61
8	Polished Surface of Sample C21, Showing Dark Grey Alteration along Shrinkage Cracks (CLROC000001A3, Field of View 60 mm, i.e. x 2 Magnification)	62
9	Microcrack Partly Infilled with Pale Green, Possible Silica Gel, Sample C21 (CLROC000001A3, PPL, Field of View = 1.8 mm)	62
10	Microcrack Partly Infilled with Possible Silica Gel, Sample C21 (CLROC000001A3, PPL, Field of View = 1.8 mm)	63
11	Microcrack Partly Infilled with Pale Yellow, Possible Silica Gel, Sample C21 (CLROC000001A3, PPL, Field of View = 1.8 mm)	63

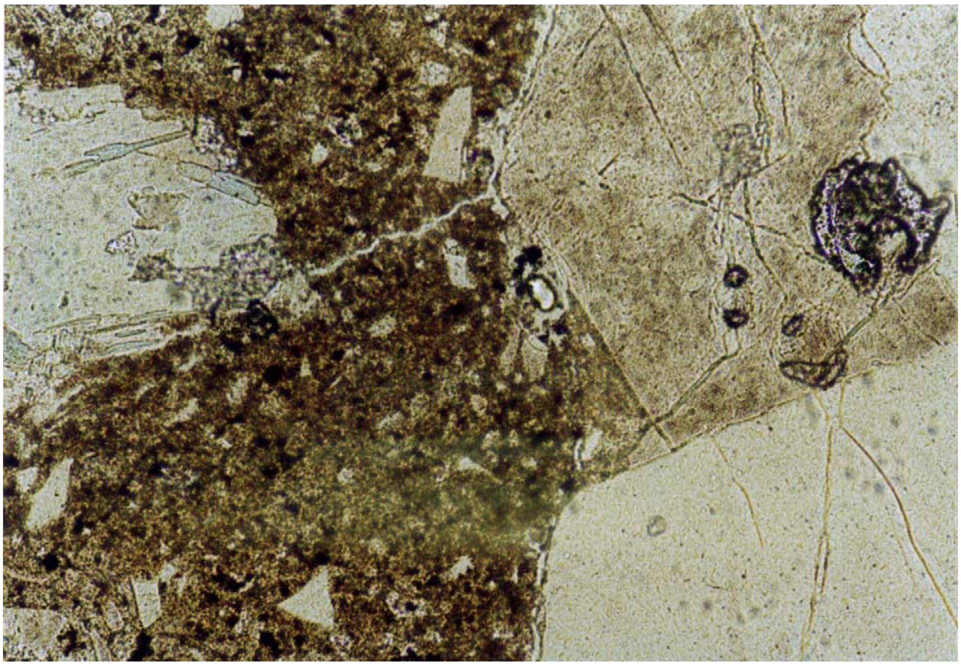

Plate 1 - Polished Surface of Sample C9 (CLROC000001A1, Field of View 60 mm, i.e. x 2 Magnification) (GS00/58C/06) (taken on 3.4.00)

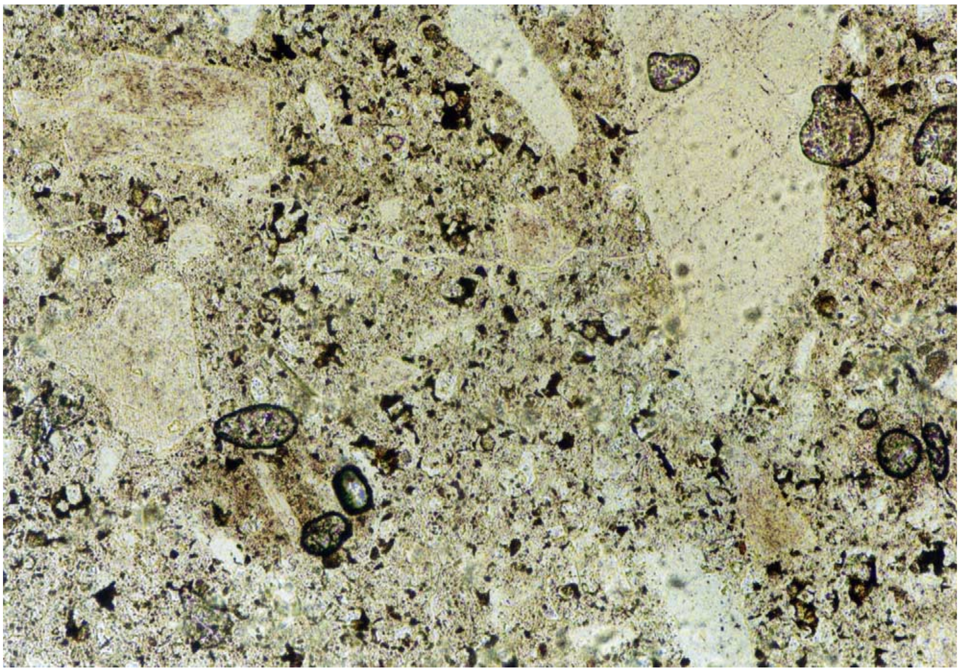

Plate 2 - Microcrack Partly Infilled with Pale Green, Possible Silica Gel, Sample C9 (CLROC000001A1, PPL, Field of View = 1.8 mm) (GS00/58C/22) (taken on 3.4.00)

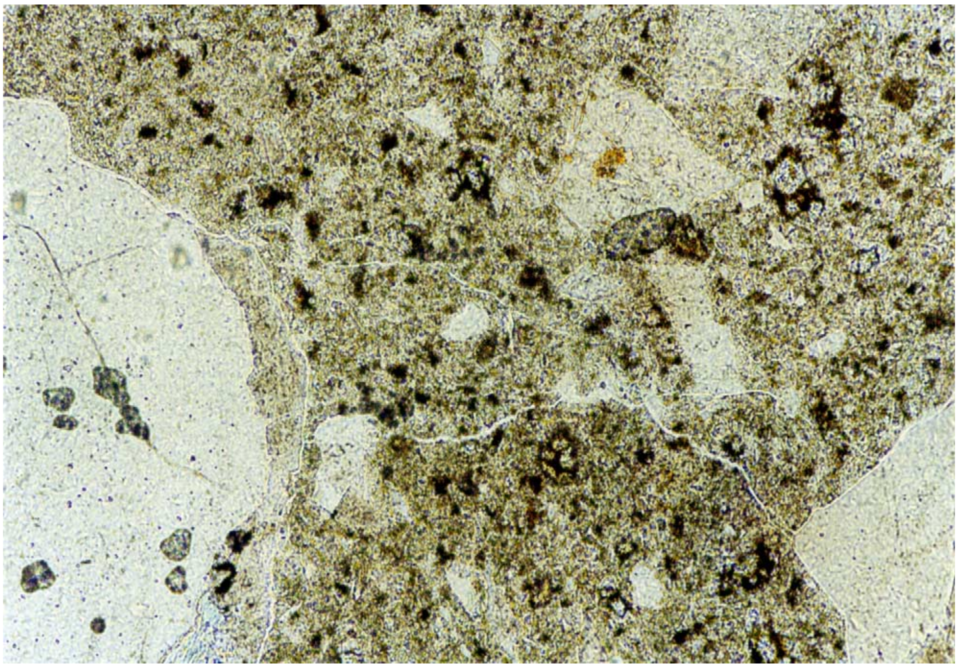

Plate 3 - Multiple Microcracks Possibly Partly Infilled with Silica Gel, Sample C9 (CLROC000001A1, PPL, Field of View = 1.8 mm) (GS00/58C/25) (taken on 3.4.00)

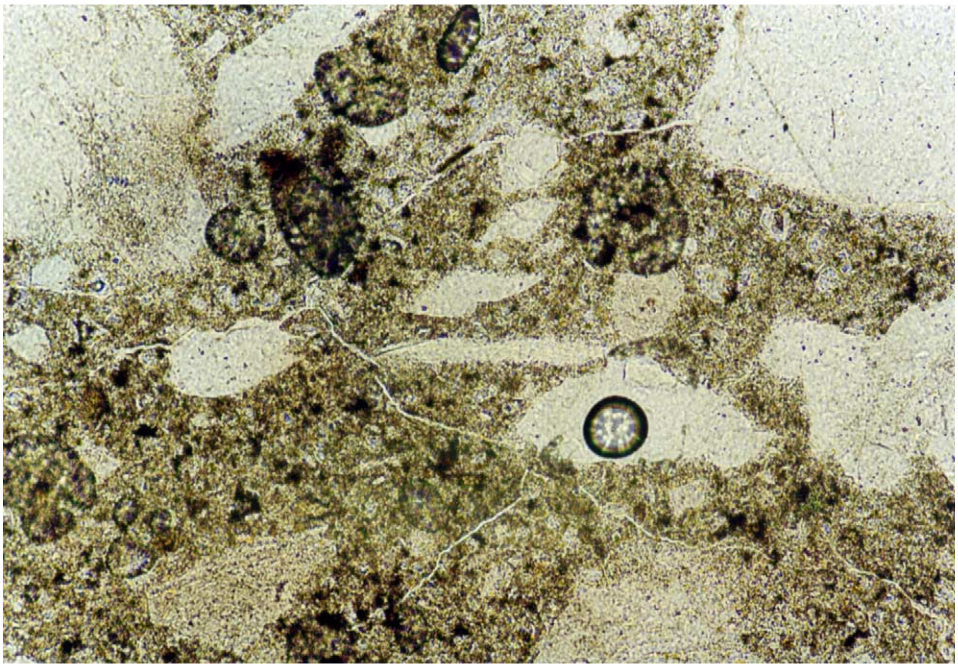

Plate 4 - Multiple Microcracks Partly Infilled with Possible Silica Gel, Sample C9 (CLROC000001A1, PPL, Field of View = 1.8 mm) (GS00/58C/02) (taken on 3.4.00)

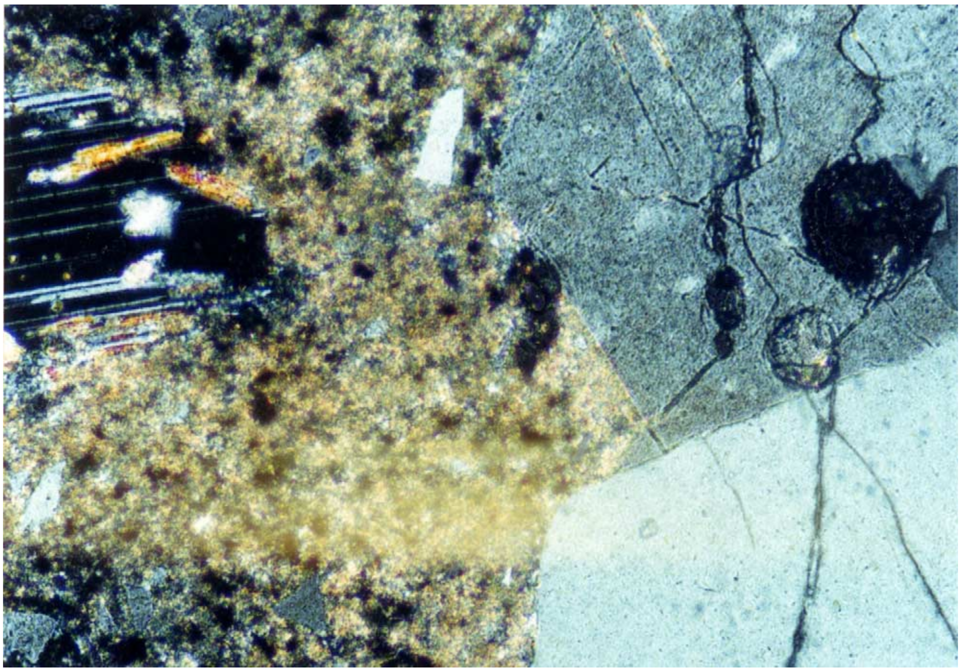

Plate 5 - Polished Surface of Sample C16 (CLROC000001A2, Field of View 60 mm, i.e. x 2 Magnification) (GS00/58C/07) (taken on 13.4.00)

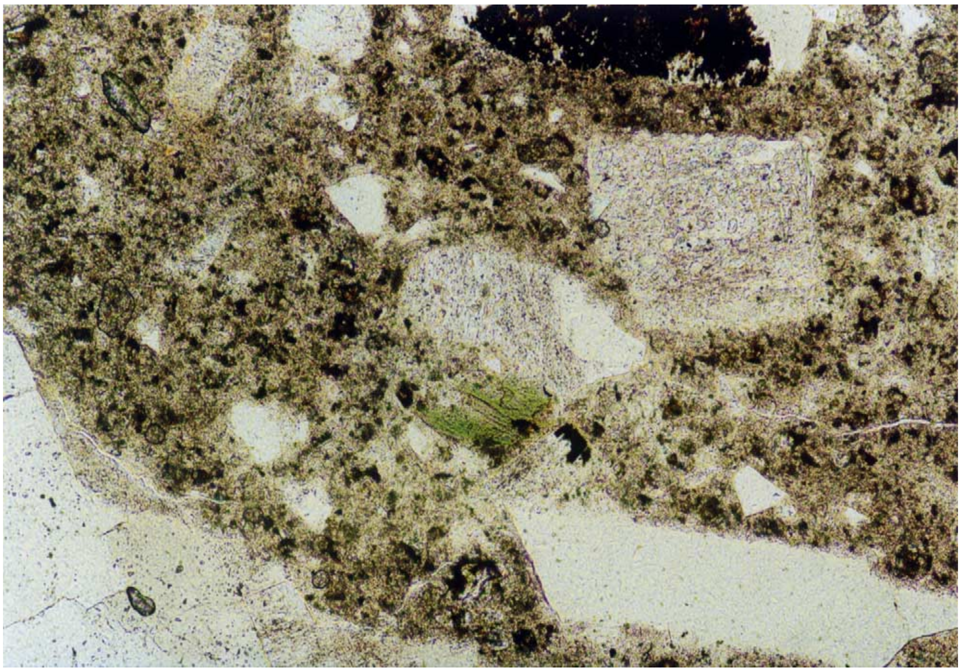

Plate 6 - Microcrack Partly Infilled with Pale Green, Possible Silica Gel, Sample C16 (CLROC000001A2, PPL, Field of View = 1.8 mm) (GS00/58C/11) (taken on 3.4.00)

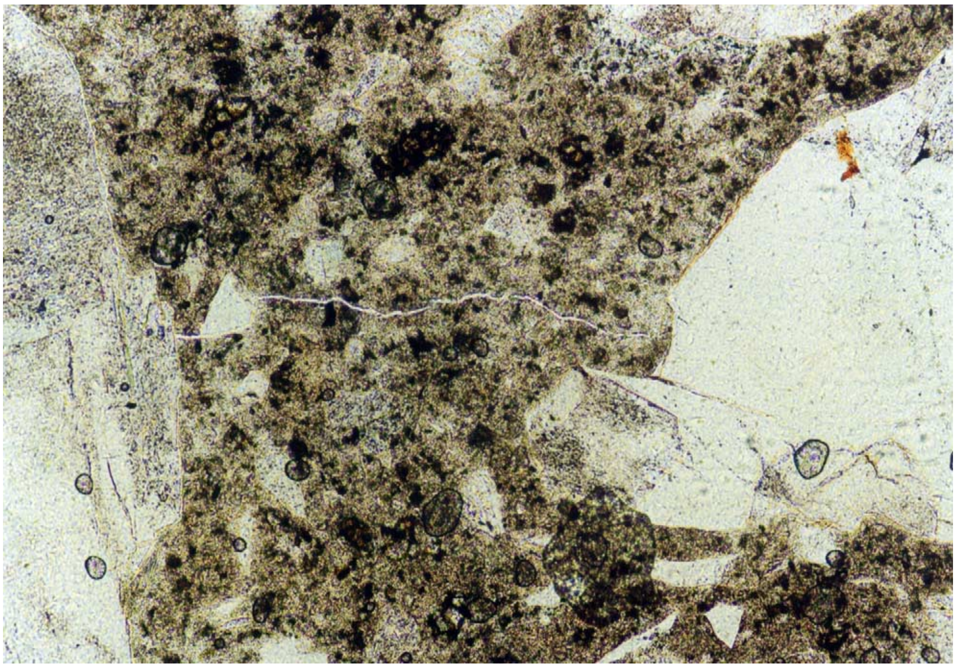

Plate 7 - Microcrack Partly Infilled with Possible Silica Gel, Sample C16 (CLROC000001A2, PPL, Field of View = 1.8 mm) (GS00/58C/09) (taken on 3.4.00)

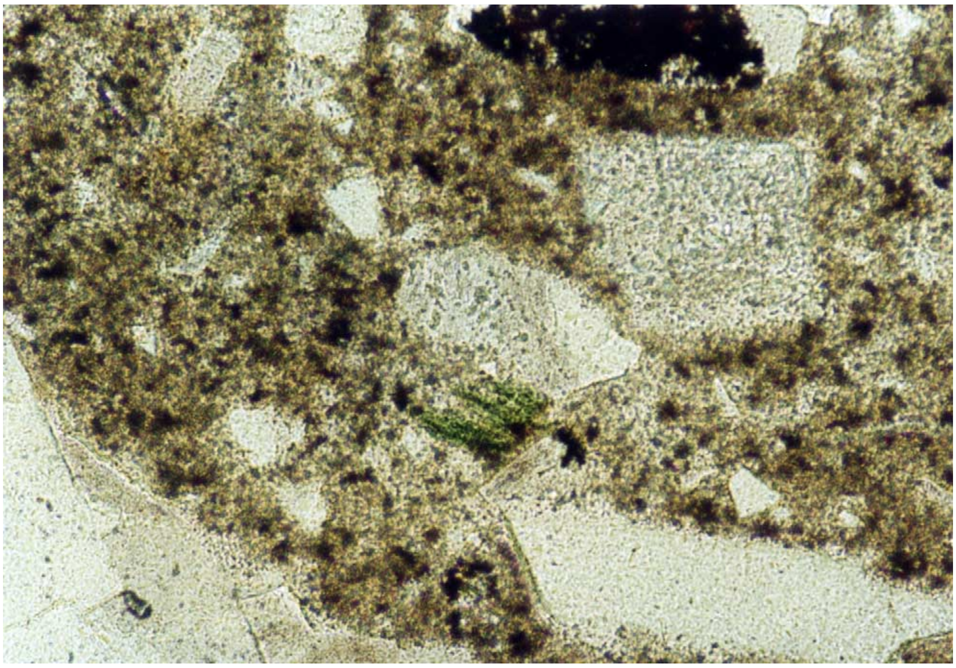

Plate 8 - Polished Surface of Sample C21, Showing Dark Grey Alteration along Shrinkage Cracks (CLROC000001A3, Field of View 60 mm, i.e. x 2 Magnification) (GS00/58C/10) (taken on 3.4.00)

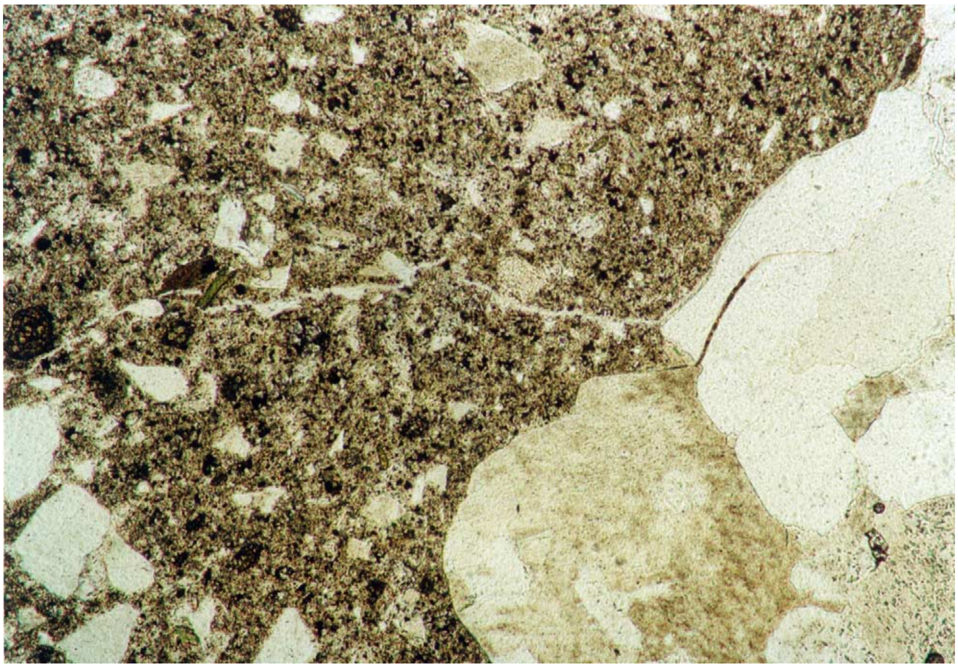

Plate 9 - Microcrack Partly Infilled with Pale Green, Possible Silica Gel, Sample C21 (CLROC000001A3, PPL, Field of View = 1.8 mm) (GS00/58C/17) (taken on 3.4.00)

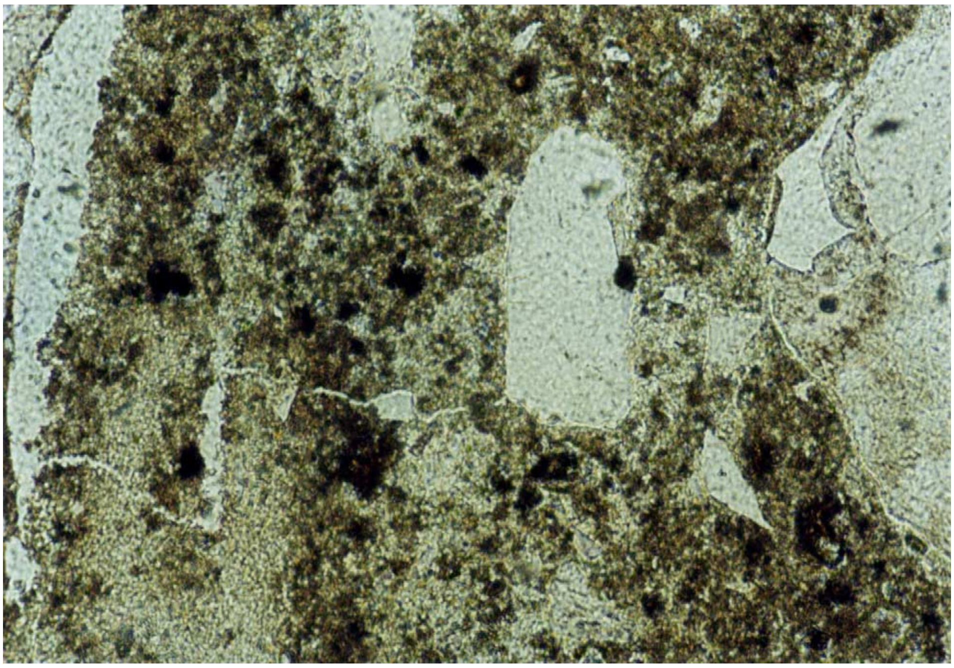

Plate 10 - Microcrack Partly Infilled with Possible Silica Gel, Sample C21 (CLROC000001A3, PPL, Field of View = 1.8 mm) (GS00/58C/15) (taken on 3.4.00)

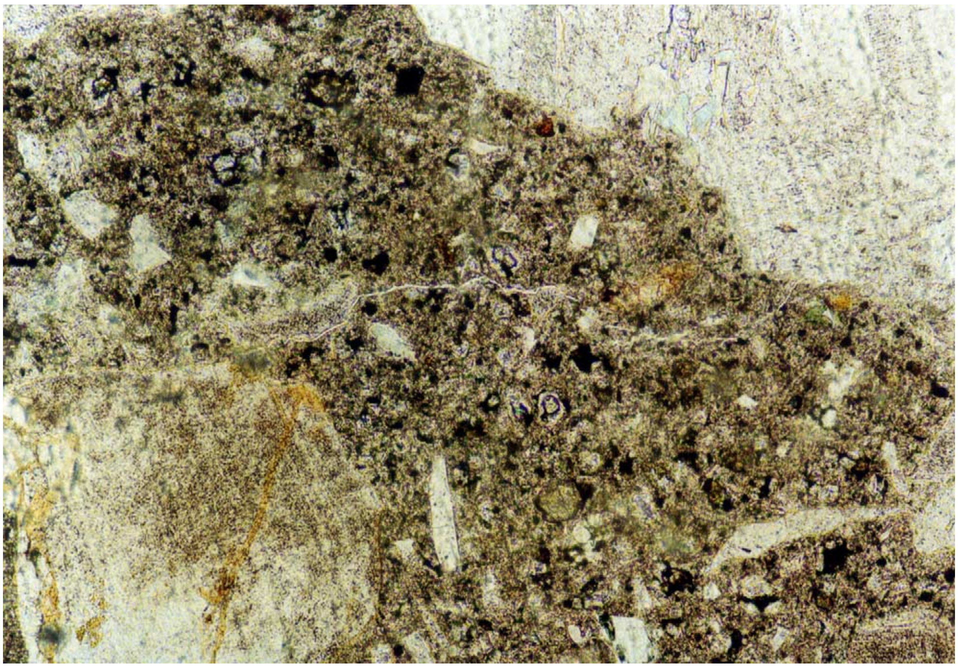

Plate 11 - Microcrack Partly Infilled with Pale Yellow, Possible Silica Gel, Sample C21 (CLROC000001A3, PPL, Field of View = 1.8 mm) (GS00/58C/14) (taken on 3.4.00)