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THIN SECTION PETROGRAPHY, SEM AND XRD  
ANALYSES OF CORE AND SIDEWALL CORE 8/86  
SAMPLES FROM PELICAN-5

Amoco Australia Petroleum Company

3/786/0-F6707/86&6709/86 April 1986

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F 6407/86, 6409/86

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REPORT F 6407/86 & 6409/86

YOUR REFERENCE: LPD 1094

TITLE: Thin section petrography, SEM and XRD  
analyses of core and sidewall core  
samples from Pelican-5, Misc-AUP 493-  
T-400-GMK

MATERIAL: Sandstones

LOCALITY: Pelican-5

DATE RECEIVED: 1 April 1986

WORK REQUIRED: Thin section petrography, SEM and XRD  
analyses

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## 1. INTRODUCTION

Thirty-five sandstone samples from Pelican-5 (12 core chips and 23 SWC's) were received for thin section petrography, SEM and XRD analyses. In some cases there was insufficient sample for XRD and SEM analyses.

## 2. RESULTS

XRD results for the thirteen sandstones analysed (2 core chips and 11 SWC's) are presented in Table 1 (Volume 1). SEM plates are presented in Volume 2 (Appendix 3 : Core 2 and Appendix 4 : sidewall cores). Thin section petrography is presented in Volume 1 (Appendix 1 : core chips, Appendix 2 : sidewall cores).

A discussion and summary of the data presented in this report follows.

## 3. SUMMARY AND DISCUSSION

### 3.1 Petrography and SEM

This is a summary of the petrography of 12 core chips and 23 SWC's from Pelican-5.

The rocks are generally litharenites which contain fairly well sorted sand-grade grains of quartz and lithic fragments. Feldspar, mica and heavy minerals are rare or absent. Sedimentary (shales, mudstones, chert) and metasedimentary (phyllites, schists) lithologies are by far the most abundant kinds of lithic clasts. Apart from chert (and possible rare limestones) they are deformable, soft fragments with fine-grained textures and abundant phyllosilicate minerals. Some retain vestiges of original outlines, others can be seen to have been squashed between adjacent quartz grains.

Long, curved and sutured grain boundaries are present in most samples.

Authigenesis is shown by quartz (epitaxial overgrowths), kaolinite (void filling aggregates) and carbonate (mostly partially replacing lithics).

There is no evidence of genuine, muddy matrix and the rocks therefore appear to be sedimentologically mature, although derived from a not-too-distant provenance of sedimentary terrain.

### 1. Porosity

Two dimensional sections (1" x 3") of rocks which have been cored, broken with a hammer, sawn with a diamond-impregnated blade, heated, impregnated and finally sliced and ground to a thickness of 0.03 mm are not the best medium from which to estimate the porosity of a reservoir quantitatively. SWC's are even worse. Microscopy can indicate the size of the larger pores (>0.01 mm) and sometimes, their mode of formation. No estimate is obtainable on microporosity. In all cases, physically measured porosity (or even log-derived values) should be regarded as definitive, at least as regards contrast with microscopically derived estimates.

SEM photography often shows microporosity which occurs within aggregates of clay (either authigenic clays or lithic fragments); such a feature would be invisible in most thin sections.

There has been considerable attention paid in recent years to the distinction between primary and secondary pores : primary pores can be related to the intergranular cavities in the sand (as deposited), secondary pores result from dissolution of minerals, fracturing, etc. Often primary pores are not larger than adjacent grains and are evenly distributed throughout the rock. Secondary pores have widely varying sizes - large pores are invariably of secondary origin and result from dissolution of framework grains. The decipherment of sequences of precipitation and solution of minerals at different stages of diagenesis (by SEM mainly) has led to a more complete understanding of the complexity of porosity formation and occlusion.

In the Pelican-5 samples there has been precipitation of quartz, carbonate, kaolinite and smectite. Quartz, and possibly carbonate, crystals have grown on a 'template' provided by pre-existing crystals whereas kaolinite and smectite have grown by direct precipitation from pore waters. Feldspars in these rocks appear to be fresh and not spatially associated with the kaolinite; it is therefore unlikely that kaolinite development is associated with alteration of detrital feldspar.

Primary porosity in these Pelican-5 sandstones was reduced initially by the deformation of soft lithic fragments between the more rigid quartz grains. The extent to which this primary porosity has been occluded by this process is proportional to the volume of lithic fragments in the sandstones. These volumes range from approximately 5-50% in the samples examined. Some microporosity remains in these lithic fragments (see SEM plates : Volume 2) although it is unlikely that much of this porosity is interconnected.

The small volumes of primary interconnected pore spaces remaining were then filled with authigenic quartz (mainly from quartz overgrowths), clays (kaolinite, smectite, smectite-illite, illite and chlorite) and finally carbonate (mainly dolomite). Some microporosity remains between these authigenic clays and much of this is likely to be interconnected (see SEM plates : Volume 2).

As a result of these diagenetic effects the majority of the resultant sandstones are tight. The sandstones with the best porosity contain few lithic fragments. Quartz overgrowths are extensive and authigenic clays are abundant in these sandstones. These more porous sandstones occur at 2881, 3891.5 and 3900.5 metres depth in Pelican-5.

## 2. Lithic Fragments

Fine-grained material in these rocks which is not attributable to authigenic carbonate or kaolinite is derived from sand-grade lithic clasts which were deposited with the quartz grains. This identification/interpretation is based on the fact that the material varies in nature (mineralogy and texture) on a scale of 0.1 to 0.4 mm. This variation reflects the different kinds of lithics incorporated into the sandstone. Had the clays been derived from a clay matrix (fine-grained detritus which infiltrated between the sand grains in the immediate environment of deposition) then they would be homogeneous over the whole area of the thin section. It is likely that the fine-grained sedimentary and metasedimentary lithics encountered in Pelican-5 are likely to contain mainly illitic and illite-smectite interstratified clays - derived from the alteration of sericite and micas in the original rocks.

Note that there is likely to be a variety of reactive minerals in these Pelican-5 reservoirs (carbonate, kaolinite, smectite and more than one clay from the lithics) and this should be considered in assessing, for example, stimulation proposals.

## 3. Diagenetic Model

It is not possible to evolve a full understanding of the diagenesis of these sandstones without more detailed study, but some comments can be made.

These are fluvial (non-marine) sandstones and are hence likely to have been saturated initially with low pH waters of low ionic strength. In these conditions, and given flushing with equally fresh water, kaolinite (and quartz) are stable mineral species and precipitate when the concentration of aluminum and silicon ions in the porewater is sufficient. Other authigenic clays (smectite, randomly interstratified smectite/illite and hairy illite) appear to form after the kaolinite and quartz and commonly coat these minerals. These authigenic clays are commonly associated with the lithic fragments, and probably form from the alteration of sericite and micas in the original sediments.

The authigenic clay minerals tend to be most abundant in samples and portions of samples, where some porosity has remained after the lithic fragments have been squashed between the quartz grains during compaction of these sandstones.

Carbonate cement is relatively late and could be formed from the influx of seawater into the system or by an increase in  $\text{CO}_2$  in the porewaters (from organic-matter diagenesis or perhaps from the diagenesis of adjacent shales). The advent of  $\text{CO}_2$  (increasing pH) may also be responsible for some mineral dissolution and an increase in (secondary) porosity.

### 3.2 X-Ray Diffraction

The XRD results illustrate that the clay fractions of these sandstones comprise of mixtures of ten different minerals, a large proportion of which are generally present in each sample. Barite is probably a contaminant in these samples derived from the drilling mud. The size of the  $-2 \mu\text{m}$  fraction relates to the proportion of clay minerals in each sample and in this case is largely dependent on the proportion of lithic fragments.

The most abundant clay minerals in the  $-2 \mu\text{m}$  fraction are kaolinite, randomly interstratified mixed-layer smectite-illite and mica/illite. Smectite occurs in the interval 2746.5-3098.5 metres depth and chlorite is present between 3155.5-3617 metres depth. Quartz and feldspars in this size range are most likely derived from the lithic fragments.

## MINERALOGY CLAY FRACTION OF 13 PELICAN-5 SAMPLES

F6409 - Pelican 5

Sample	2746.5m	2750m	2869m	2881m	3098.5m	3109m	3155.5m	
-2 $\mu$ m fract. %:	6	5	3	1	10	5	11	
Mineralogy:	K D ML A Q A M A Sm* A B Tr-A F'?	D Q K SD ML A M A Sm* A B Tr F' Tr	ML D K SD M A Q Tr-A	ML D M A-SD K A-SD Q Tr	B D MI A-SD M A Q A K A Sm* Tr-A	ML D Q SD B A M A K Tr F? Tr	B D ML A-SD M A K A Q A C Tr F? Tr	D A-SD M A K A A Tr C Tr F Tr
Sample	3159m	3194m	3198m	3442.5m	3447m	3617m		
-2 $\mu$ m fract. %:	10	11	11	11	13	2		
Mineralogy:	M D Q SD K A B A ML A C Tr F? Tr	ML CD M CD Q A K A B A C Tr F? Tr	ML D B A-SD M A Q A K A C Tr F? Tr	ML D M A-SD K A-SD Q A C Tr F Tr	ML D K SD M A Q A B Tr-A C Tr F Tr	M D Q SD K A ML A B A F Tr C F		

\* In these instances it was not possible to tell whether the smectite was interstratified.

Mineral Key

B Barite  
 C Chlorite  
 F Feldspar (plag., -albite)  
 F' K feldspar  
 K Kaolinite  
 M Mica/illite  
 Randomly-interstratified mixed-layer  
 smectite-illite with approx. equal  
 proportions of the two layer types.  
 Q Quartz  
 Sm Smectite  
 + Smectite with appreciable inter-  
 stratification of illite layers.

SEMIQUANTITATIVE ABBREVIATIONS:

D = Dominant. Used for the component apparently most abundant, regardless of its probable percentage level.  
 CD = Co-dominant. Used for two (or more) predominating components, both or all of which are judged to be present in roughly equal amounts.  
 SD = Sub-dominant. The next most abundant component(s) providing its percentage level is judged above about 20%.  
 A = Accessory. Components judged to be present between the levels of roughly 5 and 20%.  
 Tr = Trace. Components judged to be below about 5%.

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APPENDIX 1

CORES 1, 2 AND 3; PETROGRAPHY

Sample: TSC47080; Location: Pelican-5, Core 1; 2790.5 m

Rock Name:

Compact lithic sandstone

Thin Section:

An optical estimate of the constituents gives the following:

	%
Quartz	70
Pores	10
Lithic fragments	7
Authigenic kaolinite	5-7
Carbonate	3-5
Mica	1
Feldspar	1

In textural terms this sample appears to be a distinctly tight and compact sandstone in that it shows the presence of authigenic kaolinite and carbonate, a moderate amount of lithic fragments and noticeably compact and intergrown quartz grains; nevertheless, the thin section retains about 10% porosity and many of these pores are relatively large. This being the case, it seems likely that the porosity is of secondary origin and is in some way related to a relatively late stage of dissolution of some particular component from the rock leaving numerous pores up to about 0.2 mm in size.

Although the average grain size of the rock is about 0.2 mm there are some variations from place to place in the thin section and there are isolated grains as much as 0.8 mm in size. In pressolved zones the average grain size of the quartz appears to be about 0.15 mm and these zones are characterised by the abundance of sutured and curved contacts between the grains, relatively abundant fine-grained authigenic carbonate and moderate amounts of apparently insoluble clays and detrital mica. These pressolved zones are generally not more than about 1 to 2 mm in thickness.

In other parts of the thin section the rock has a somewhat cleaner and more open texture and contacts between the quartz grains are generally long, tangential or, in a few cases, sutured and curved. In these parts of the rock carbonate is relatively less abundant but there are some aggregates of kaolinite ranging in size from about 0.1 to 0.3 mm. The heterogeneous patchy distribution of clay can also be seen in the more open parts of the rock and it is clear that the fine-grained material is derived entirely from original lithic fragments. Most of these appear to be aluminous lithologies, probably sedimentary and metasedimentary rocks. In this part of the rock there are also isolated instances of overgrowths on the quartz grains whereas these are not seen in the pressolved zones.

This is a tight rock characterised by what appear to be conformable zones in which pressure solution of quartz has been particularly thorough; in general the rock contains isolated patches of authigenic kaolinite and widely distributed small granules of an authigenic carbonate mineral. These features, together with the presence of relatively soft lithic fragments, are conducive to a sandstone with rather poor reservoir quality.

Sample: TSC47081; Location: Pelican-5, Core 1; 2791.3 m

Rock Name:

Compact sandstone

Thin Section:

An optical estimate of the constituents gives the following:

	%
Quartz	75
Pores	7-10
Lithic fragments	5
Authigenic kaolinite	5
Carbonate	3
Feldspar	1
Mica	<1

In most mineralogical and textural features this sample is very similar to that from 2790.5 m. The rock shows authigenic carbonate and kaolinite which form widely dispersed small granules and isolated monomineralic patches, respectively. Zones of notably advanced pressure solution are present but they tend in this sample to be less well defined and possibly not continuous in a horizontal direction. The limited extent of these pressure solution zones in this sample means that the rock has a somewhat higher average grain size but, even in the zones which don't show pressure solution, the rocks are only moderately to moderately well sorted. In this sample there are many grains of the order of 0.3 to 0.6 mm in size. Some parts of the rock may have a bimodal grain size distribution.

Pores in this sample are probably essentially of secondary origin and tend to range in size commonly from about 0.1 mm to 0.5 mm. Where feldspar occurs it is fresh and it seems unlikely that either the large secondary pores (or for that matter aggregates of kaolinite) are derived from the alteration of feldspar. It seems likely that the pores represent a particular kind of lithic fragment which were susceptible to dissolution. In some cases the cavities remaining after this dissolution have been filled by authigenic kaolinite. As a result, there are well defined monomineralic patches of this mineral as much as 1 mm in size. There is some textural evidence to indicate that the deposition of the authigenic kaolinite preceded that of the fine-grained secondary carbonate mineral.

Sample: TSC47068; Location: Pelican-5, Core 2; 2869 m

Rock Name:

Compact lithic sandstone with microstylolites

Hand Specimens:

A buff to cream coloured fine-grained sandstone which contains discontinuous dark brown microstylolitic bands at right angles to the length of core.

Thin Sections:

An optical estimate of the constituents gives the following:

	%
Quartz	85
Lithic fragments	7
Pores	5
Carbonate	2
Feldspar	<1
Mica	Trace
Authigenic kaolinite	Trace

Rigid detrital grains of quartz and feldspar are well sorted about an average size of 0.15 to 0.2 mm. Grain boundaries show considerable modification by post-deposition effects and long and somewhat curved boundaries are fairly common. Overgrowths are seen on only a small proportion of the quartz grains and it is not likely that the development of these overgrowths has contributed much to the porosity reduction. The rock contains a significant proportion of clay and fine-grained constituents and these are interpreted as being derived entirely from original lithic fragments. Much of this material in the thin section is rather turbid and grey but shows variations in both the relative proportions of quartz and phyllosilicates and in average crystal size. There appears to be a considerable amount of fine-grained quartz-rich lithologies some of which are clearly chert but others are probably fine-grained metasediments with a relatively siliceous composition. Other lithic fragments are richer in mica and what appear to be illitic phases and some of these, particularly, show the effects of compression between the more rigid quartz grains. It is thought that the abundance of this clay and the clastic deformation during compaction have had relatively large effects in reducing the original porosity.

The rock does contain small amounts of authigenic kaolinite and of a carbonate mineral. The latter is also distinctly fine-grained and appears to form as a replacement product of some of the finer grained lithic fragments rather than being genuinely a pore fill constituent. The carbonate is particularly abundant in some of the microstylolitic zones where it occurs in fine-grained aggregates with micas and heavy minerals particularly.

Pores are generally relatively small and widely scattered but appear to be of secondary rather than primary origin. Apart from the possibility that they represent sites of preferential dissolution of clay, it is not clear what the origin of these secondary pores is.

Sample: TSC47069; Location: Pelican-5, Core 2; 2871 m

Rock Name:

Compact lithic sandstone

Hand Specimen:

A distinctly pale grey to creamy coloured rock with a small proportion of distinctive white spots. The rock is slightly friable.

Thin Section:

An optical estimate of the constituents gives the following:

	%
Quartz	80
Lithic fragments	15-20
Pores	<5
Feldspar	<1
Mica	<1
Authigenic kaolinite	<1

In this sandstone the average size of the quartz grains is of the order of 0.2 to 0.3 mm and the grains are moderately to well sorted. There is some development of long and curved contacts and overgrowths on the quartz grains, although not abundant are somewhat more common than in the sample described immediately above.

The most characteristic feature of the rock is a presence of a considerable amount of fine-grained material between the quartz grains. This is generally a mixture of fine-grained quartz and rather varied phyllosilicate minerals. The material is heterogeneous and is clearly derived probably entirely from original lithic clasts. It is the abundance of this material and its deformation and compaction during lithification of the rock which has resulted in reduction of the original porosity. This will also have been affected by the modifications to the quartz grains whereas the development of authigenic kaolinite will have done little to reduce the porosity. The pores themselves are generally at least 0.2 mm in size and are thought to be of secondary origin. Many have marginal areas of rather porous clay and hence it appears most likely that the pores have derived from dissolution or physical removal in some way of some of the intergranular clay component. As far as can be distinguished in the thin section it seems unlikely that the pores are well interconnected in three dimensions.

Sample: TSC47070; Location: Pelican-5, Core 2; 2873 m

Rock Name:

Lithic sandstone

Hand Specimen:

A slightly friable, pale grey sandstone with a small proportion of distinctive white spots.

Thin Sections:

An optical estimate of the constituents gives the following:

	%
Quartz	80-85
Lithic fragments	7
Pores	7(+)
Authigenic kaolinite	<1
Feldspar	Trace
Mica	Trace
Carbonate	Rare

This sandstone is a little cleaner than that described above and has, therefore, somewhat more porosity. There are fields of view in this thin section in which long and concavo-convex boundaries between the quartz grains are abundant and the low porosity stems from the pressure solution effects on the quartz grains. Considering the thin section overall, however, it is likely that an equally important effect has been the deformation of relatively soft lithic fragments during compaction and lithification. The distribution of these lithic clasts is somewhat patchy in the thin section and it seems likely that although the rock may have a reasonable porosity the permeability may be somewhat restricted. The lithic fragments themselves are extremely variable and include cherts, psammitic metamorphic rocks and distinctly more argillaceous sedimentary and metasedimentary varieties. Clay is also represented by small patches of authigenic kaolinite. These occur in this rock, as in others in this well, as isolated monomineralic patches which generally fill the intergranular space where they occur. The kaolinite invariably has a patchy distribution and the estimated proportion of this mineral in the rock is an indication of the extent to which it will have reduced the original porosity.

The pores in the thin section are generally about 0.1 to 0.4 mm in size and do not appear to well interconnected in three dimensions. There is somewhat more evidence in this rock of the pores being of primary origin in some cases and some, indeed, are small cusped or triangular patches surrounded by clean faces of quartz crystals or grains. Other areas of the thin section are somewhat more porous with a greater proportion of large secondary pores which appear to have been derived from the dissolution of original grains.

In brief, therefore, this sample shows rather more the effect of pressure solution having reduced the original porosity to a similar extent to the process of deformation of original lithic fragments.

Sample: TSC47071; Location: Pelican-5, Core 2; 2875.1 m

Rock Name:

Compact lithic sandstone

Hand Specimen:

A slightly friable cream to pale grey rock which appears to be massive in the hand specimen. The sandstone shows some spotting by rare white patches.

Thin Section:

An optical estimate of the constituents gives the following:

	%
Quartz	80
Lithic fragments	15
Pores	3
Mica	1
Authigenic kaolinite	<1
Carbonate	Rare

This is a somewhat coarser grained and distinctly tighter rock than many others from core 2; in fact the sample is characterised by abundant concavo-convex grain boundaries and by the paucity of pores. There are small amounts of authigenic kaolinite and very fine-grained aggregates of carbonate; however, the apparent impervious nature of the sample is a result of modifications to the quartz grains during diagenesis and to a somewhat smaller extent compaction and deformation of soft lithic clasts between the relatively rigid grains of quartz. Pores now appear to be not well interconnected in three dimensions and many are not more than about 0.1 mm in size. Most of these small pores could readily be interpreted as being of primary origin, slightly modified during compaction of the rock. There is a small proportion of somewhat larger pores very widely distributed over the area of the thin section. These may well be of secondary origin and related to the preferential dissolution of some types of argillaceous fragments. The clay material in the rock and other fine-grained constituents are notably heterogeneous and varied. There are some monomineralic cherts but most of the fine-grained material consists of quartz and phyllosilicate with varying relative proportions and crystal sizes. As well, there are patches in which argillaceous material forms a network between the grains and this, also, has probably resulted in a marked reduction of any original permeability.

Authigenic kaolinite forms small isolated patches which are relatively coarsely grained, clear and monomineralic and are thought to represent a precipitate from circulating pore waters. In this rock, as in others from this core, feldspar is relatively fresh and is not spatially associated with the kaolinite and hence the kaolinite is not thought to have been derived from alteration of detrital feldspar.

Carbonate forms patches up to as much as 0.4 mm in size which are extremely fine-grained and appear to be almost opaque in plane polarised light. This is an unusual habit for authigenic carbonate and it is possible that these aggregates of carbonate represent original limestone clasts probably somewhat recrystallised during diagenesis of the rock.

Sample: TSC47072; Location: Pelican-5, Core 2; 2877 m

Rock Name:

Compact lithic sandstone

Hand Specimen:

A very pale somewhat spotted fine-grained sandstone.

Thin Section:

An optical estimate of the constituents gives the following:

	%
Quartz	85
Lithic	7
Authigenic kaolinite	2
Carbonate	2
Pores	<2

This is a distinctly tight sandstone which shows numerous examples of most of the characteristics which are likely to lead to a reduction in porosity. The pores in the thin section are rather isolated from each other and tend to be not more than 0.2 mm in size. Most are interpreted as being probably of secondary origin.

The quartz grains are moderately to well sorted and have an average size of about 0.2 mm. Most of the grains are equant and compact in shape but many have slightly irregular and subangular outlines as a result of the development of concavo-convex boundaries and examples of suturing. Identifiable overgrowths on the quartz grains are present only to a relatively small extent.

When the sample is examined under high magnification and intense illumination it can be seen that there is a considerable amount of widely dispersed carbonate. This is invariably very fine-grained and ranges from almost opaque irregular patches up to 0.3 mm in size to a fine dusting of authigenic crystals within fine-grained patches of lithic material. Authigenic kaolinite is also somewhat more abundant in this rock than in most of the others from core 2 but it tends to form discrete monomineralic isolated patches and is not dispersed throughout every field of view. The kaolinite is well crystallised and appears to be a genuine precipitate from pore waters. Unlike the carbonate, the kaolinite tends to fill (on a microscopic scale) all of the intergranular space where it occurs.

As the list of minerals above indicate, the rock contains a fine-grained material which is interpreted as being of lithic origin. Much of this appears to be relatively quartz-rich and some grains are definitely cherty. Others have some clay or phyllosilicate content and are most likely to be rather altered and deformed sedimentary or metasedimentary rocks.

The sample shows more evidence of pressure solution effects (particularly suturing) and of the authigenic crystallisation of kaolinite and carbonate than any of the samples described above, consequently the rock has the lowest apparent porosity in thin section.

Sample: TSC47073; Location: Pelican-5, Core 2; 2878.9 m

Rock Name:

Very compact sandstone

Hand Specimens:

This is a compact apparently relatively thinly bedded sandstone which shows some evidence of incipient microstylolites. The core samples appears to have split along some of these better developed microstylolitic zones.

Thin Section:

An optical estimate of the constituents gives the following:

	%
Quartz	85
Carbonate	5
Lithic fragments	5
Mica	2
Authigenic kaolinite	1
Pores	<2

Sutured grain boundaries are amongst the commonest type present in this thin section and the sample therefore shows extreme effects of pressure solution and the reduction of porosity by localised dissolution of the quartz grains. As well as this, there is a relatively large amount of fine-grained authigenic carbonate which forms both discrete patches and in narrow intergranular spaces and within the sutured grain contacts. Pores in the thin section are isolated from each other but range in size occasionally to as much as 0.2 mm. These relatively large pores are commonly associated with rather loose aggregates of clay or have clay at their margins and hence appear to be most likely of secondary origin. Although there is clear evidence of the dissolution of quartz, optically continuous overgrowths are not at all abundant in the thin section.

The average grain size of this sample is about 0.2 mm but the shape of the grains has been affected by pressure solution and most grains, although equant in shape have distinctly irregular and rather angular outlines. In some of the incipient microstylolitic zones there appears to have been a genuine reduction in the average size of the quartz grains. The clay material is distinctly heterogeneous and is interpreted as having been derived entirely from original lithic fragments. Some of these are cherty but most are fine-grained quartz and clay aggregates which probably can be regarded as metasedimentary rocks. Some quartz-rich types have rather varying crystal sizes and spherulitic patches which may suggest their origin as acid igneous rocks.

The sample appears to have essentially similar mineralogical characteristics to most of those described above and it is not apparent from examination of this thin section alone, why this sample should show such marked suturing of the grain contacts; however, it is clear that this process has been the principal factor in reducing the original porosity. It seems likely that the suturing was a relatively late process in the diagenesis in that it has affected quartz overgrowths and the authigenic carbonate.

Sample: TSC47074; Location: Pelican-5, Core 2; 2881 m

Rock Name:

Compact lithic sandstone

Hand Specimen:

A friable very pale sandstone which appears to be essentially massive.

Thin Section:

An optical estimate of the constituents gives the following:

	%
Quartz	80
Lithic fragments	12
Pores	5-7
Authigenic kaolinite	1
Carbonate	Trace

This sandstone is somewhat more argillaceous and coarser grained than those described above; the rock is not well sorted but the average grain size is estimated to be about 0.3 mm and there are several grains up to about 0.8 mm in size. The sample probably also shows somewhat more evidence of quartz overgrowths than many in this collection. Grain boundaries are definitely concavo-convex but sutures are not abundant.

The intergranular material is at least as abundant as in any other rock from this core but it is in some ways less obviously derived from lithic fragments and is difficult to classify. This is probably because of the amount of quartz which has a crystal size of the order of 0.05 to 0.1 mm. This appears to occur in a fine-grained mosaic with indeterminate argillaceous material and hence to be of lithic origin but in some places there is a question whether such material is derived from fracturing of adjacent larger sand-grade grains. Elsewhere lithic material is better defined and clearly of metasedimentary origin and there are one or two fragments which are definitely chert. Authigenic kaolinite in this sample also forms both relatively large patches of distinctly well formed crystals. One such patch is about 0.5 mm in size and the kaolinite occurs adjacent to a fine-grained lithic fragment which contains finely dispersed authigenic carbonate. The kaolinite is slightly porous and a little blue stain can be seen within it.

Sample: TSC47082; Location: Pelican-5, Core 3; 2885.1 m

Rock Name:

Lithic sandstone

Thin Section:

An optical estimate of the constituent gives the following:

	%
Quartz	70
Lithic fragments	20-25
Pores	<5
Carbonate	5
Authigenic kaolinite	2
Mica	1
Feldspar	<1

As the list of minerals above indicates, the sample is characterised by the abundance of heterogeneous clay material which is clearly derived entirely from lithic fragments deposited essentially at the same time as those of quartz and feldspar. These fragments now occur as patches of clay similar in size to adjacent quartz grains and ranging widely in mineralogical characteristics, colour and crystal size. Some of the fragments clearly show the effect of being squeezed between the more rigid adjacent quartz grains but others show more evidence of an original compact outline. As well as wholly argillaceous varieties, the rock contains fine-grained metamorphic quartz-bearing lithologies and one or two apparently quartzofeldspathic rocks which may be high level, fine-grained volcanics. During compaction of the sandstone many of the lithic fragments were compressed so that they tended to squeeze into the interstices between the grains thereby reducing the porosity and permeability; this process was probably the most important in reducing the porosity from that of the original sand to the present level of probably less than 5%.

Carbonate is present in the rock as widely dispersed fine-grained material which also occurs as fine-grained monomineralic patches up to 0.2 mm in size. These latter may be derived from limestone detrital fragments which have been somewhat recrystallised and it seems likely, in any case, that the carbonate was derived from a relatively adjacent source within the sandstone body. Authigenic kaolinite forms isolated monomineralic patches similar to those in other rocks in this collection.

Sample: TSC47083; Location: Pelican-5, Core 3; 2886.5 m

Rock Name:

Argillaceous sandstone

Thin Section:

An optical estimate of the constituents gives the following:

	%
Quartz	65
Lithic fragments	20
Carbonate	7-10
Pores	5-7
Authigenic kaolinite	<2
Mica	<1
Feldspar	<1

In most features this sample is similar to that from 2885.1 m but carbonate tends to occur predominantly as monomineralic very fine-grained patches and the rock is probably a little more porous. The pores in this case are generally not more than about 0.1 to 0.15 mm in size and some appear to be associated with very porous aggregates of clay. To this extent, therefore, it seems likely that the pores are mainly of secondary origin and have been derived from recrystallisation, alteration or dissolution of clays in some of the lithic fragments. As in the sample described above, it is the abundance of lithic material which has been responsible for the apparent impervious nature of the sample; the lithic fragments comprise fully 20% of the volume of the rock and deformation of these during compaction has resulted in pore throats and original cavities being filled by the plastically deformed clay aggregates. In addition to this there is fine-grained authigenic carbonate which appears to be either derived from the recrystallisation of detrital limestone fragments or has been introduced into the system with circulating pore waters. This mineral forms either isolated patches or widely distributed small granules and crystals. As in other samples, however, the authigenic kaolinite forms distinct compact monomineralic patches.

The quartz grains are fairly well sorted about an average size of 0.15 to 0.2 mm and some show the presence of long or slightly curved boundaries; suturing is not present and it is thought likely that extreme modifications to the detrital quartz grains were inhibited by a relatively early process by which the lithic fragments choked off a considerable amount of the original permeability.

Sample: TSC47084; Location: Pelican-5, Core 3; 2888 m

Rock Name:

Porous clean sandstone

Thin Section:

An optical estimate of the constituents gives the following:

	%
Quartz	65
Pores	20(+?)
Lithic fragments	10
Carbonate	2
Authigenic kaolinite	1
Feldspar	1

This sandstone is distinctly different from the two described above in that it is coarser grained, cleaner (to the extent that it contains little lithic material) and distinctly more porous. It is thought that because of the relatively small amount of lithic fragments there was more circulation of pore waters during compaction and burial and consequently the rock contains much more evidence of the presence of overgrowths on the quartz grains and it is estimated that probably 30 to 50% of the quartz grains show some evidence of the presence of overgrowths.

The pores in this rock generally range in size from 0.1 to about 0.4 mm; many of the smaller pores are partially bounded by rational crystal faces of quartz and appear to be modified primary pores whereas the secondary pores (probably quantitatively not as abundant) are somewhat larger and are probably associated with the dissolution of original lithic fragments.

The quartz grains are well sorted about an average size of 0.25 mm and most appear to have shown reasonably well rounded outlines although these have been modified by overgrowths. Authigenic kaolinite forms well defined monomineralic patches which tend to fill the whole of the intergranular space where they occur whereas the carbonate is more widely distributed throughout the rock and is generally fine-grained.

APPENDIX 2

PETROGRAPHY

## 1. PETROGRAPHY

A portion of each sample was mounted after impregnation and stained with alizarin red-S. The thin sections were examined and descriptions are given below. As is commonly the case with sidewall cores there has been considerable damage to the rocks which can be attributed to the way in which the cores are collected. Consequently a detailed description of the quantitative mineralogy of the samples and, in some cases, of the textures have not been given but attention is focused in the descriptions on the overall characteristics of the sample which can be determined in spite of the damage caused by the sampling bullet.

Sample: TSC47102; Location: Sidewall Core 45, 2746.5 m

## Rock Name:

Compact sandstone

## Thin Section:

The average grain size of the quartz grains is about 0.2 mm and possibly about 10% of the grains appear to show overgrowths. Much more abundant, however, is the development of long and curved contacts between the grains and in some of the more undisturbed parts of the thin section there is even the development of triple-point junctions and small aggregates of essentially monomineralic quartz material. More generally, however, there are patches and thin lamellae of clay between the quartz grains and authigenic kaolinite and clay derived from lithic material perhaps comprise a 10% of the volume of the rock together. Authigenic kaolinite is relatively abundant and tends to form isolated monomineralic patches which fill the intergranular space where they occur.

Authigenic carbonate is significantly less abundant but is more widely scattered throughout the thin section where it forms very small crystals dotted along the margins of quartz grains and within aggregates of both kaolinite and other clays. There are rare fine-grained monomineralic aggregates of the carbonate which may well be derived from recrystallised original limestone fragments. Carbonate also occurs in one part of the thin section where there is a thin bed of silty material about 1 mm in width.

In brief, therefore, this is a tight sandstone characterised by modifications to original quartz grains during compaction and diagenesis and the crystallisation of authigenic kaolinite and carbonate; as well, the rock does contain a relatively small amount of lithic fragments and these have been compressed and squeezed as the rock was lithified. It is likely that the sample has moderate to poor reservoir qualities. The undisturbed parts of the thin section appear to show no porosity.

Sample: TSC47101; Location: Sidewall Core 44, 2750 m

Rock Name:

Compact sandstone

Thin Section:

This sample has been badly effected by the sampling bullet and the interpretation of the petrography should be regarded as tentatively only.

The sample contains about 10 to 15% of clay minerals of which probably about 3 to 5% is kaolinite and the remainder in all likelihood derived from original lithic clasts. As far as can be determined the sample now has a rather compact texture resulting both from the crystallisation of the kaolinite and deformation of the clays in the lithic fragments; more important still, however, has been the development of long and curved contacts between the quartz grains during compaction and lithification. The more coherent parts of the section show the development of triple-point junctions similar to those described in the sample immediately above. There are some instances of overgrowths on the quartz grains and these are somewhat more abundant in this rock than in that from 2746.5 m.

Authigenic carbonate comprises less than 2% of the volume of the rock and there are trace amounts of detrital feldspar and muscovite. The rock is well sorted and has an average grain size of about 0.2 to 0.3 mm.

The thin section contains a moderate amount of porosity but it is thought unlikely that much of this is integral to the originally undisturbed sandstone and it is likely that the rock has limited porosity and permeability but probably kaolinite is the principal clay mineral and reactive illites, smectites and chlorites are likely to be present only in very small amounts.

Sample: TSC47100; Location: Sidewall Core 55, 3093 m

Rock Name:

Dolomitic compact sandstone

Thin Section:

It is estimated that authigenic carbonate comprises about 10 to 15% of the volume of this rock; the carbonate has not been stained by alizarin red-S and does not appear to be associated with ferruginous staining and therefore is most likely to be dolomite. This mineral is generally distinctly fine-grained and evenly and widely scattered over the area of the thin section. There are some crystals and aggregates up to about 0.1 mm in size and some of these could be derived from limestone fragments which were recrystallised in situ. The wide distribution of the dolomite, however, suggests that it may well be a mineral introduced into the rock and probably relatively late in the diagenetic process.

For the remainder, the rock is a somewhat lithic sandstone in which the quartz grains are well sorted about an average size of 0.1 to 0.15 mm. Clays derived from lithic fragments are rather difficult to estimate but probably do not exceed 5% of the volume of the rock. There are small amounts of detrital feldspar and mica and both of these minerals appear to be fresh. Kaolinite is essentially absent.

Most parts of the thin section show evidence of the development of long and concavo-convex boundaries between the quartz grains and it is likely that modifications to these grains during compaction, together with the crystallisation of dolomite, has been the main factor in lithifying the rock and in reducing the original permeability of the sand as it was deposited. The thin section does contain a small amount of porosity but the more compact and less damaged parts of the sandstone appear to be essentially impervious and it is likely that the rock has rather poor permeability and porosity. Reactive clays are probably present to a relatively small extent. The presence of the dolomite would have to be taken into account in designing any stimulation of the reservoir.

Sample: TSC47099; Location: Sidewall Core 54, 3098.5 m

Rock Name:

Compact lithic sandstone

Thin Section:

This is a relatively coarse grained sandstone and it appears to be well sorted about an average grain size of about 0.3 to possibly 0.4 mm. The rock shows considerable evidence of modifications of the detrital grains during compaction and there are places where sutured contacts are well developed and there is a tendency towards microstylolitic features. The rock contains about 15 to 20% of relatively birefringent clays (sericite, illite?) and these form both coherent patches and, more commonly, contiguous intergranular films. It is likely that these clays are derived from lithic fragments although this is less evident in this sample than in most others described from this well. For the most part the clay appears to be monomineralic material probably derived from original shales or mudstones but there are places where fine-grained quartz is intergrown with the illitic material. For the most part, therefore, the sample is a totally impervious aggregate of quartz grains with intervening patches and seams of this illitic material. Elsewhere in the thin section there are very small amounts of authigenic kaolinite and fine-grained ?dolomite. The rock does contain detrital feldspar and in one instance there appear to be overgrowths on a rather altered plagioclase grain.

Many fields of view contain no porosity which can be identified in the thin section but there are places where there are pores up to about 0.4 mm in size. Some of these may well be secondary pores which are integral to the rock as a whole and may be derived from the dissolution of particular kinds of lithic fragments. These pores are unlikely to be interconnected in three dimension.

Sample: TSC47098; Location: Sidewall Core 52, 3109 m

Rock Name:

Coarse grained compact lithic sandstone

Thin Section:

This sandstone, also, is distinctly coarse grained and appears to be well sorted. Most of the grains range in size from 0.2 mm to 0.5 mm. The rock has been extensively damaged during collection but more compact areas of the thin section show abundant development of long and concavo-convex boundaries between the quartz grain and as much as 20 to 30% of fine-grained material derived from lithic clasts. The latter generally fill the spaces between the quartz grains as a result of deformation during squeezing and only rare chert grains retain their original rounded outline. One or two exceptionally large detrital flakes of mica also show the effects of distortion during compaction between the lithic quartz grains. All these features have contributed to the impervious nature of the sample and most of the more coherent parts of the thin section contain no visible porosity.

The sample does not appear to contain any authigenic kaolinite but there are isolated patches of what appears to be authigenic ?dolomite and some of the larger patches of this material could be derived from the localised recrystallisation of original limestone or dolomite fragments.

In places in the thin section there are incipient microstylolites and some fine-grained carbonate tends to be present in the sutures of insoluble material in the microstylolites.

Sample: TSC47103; Location: Sidewall Core 48, 3155.5 m

Rock Name:

Compact lithic sandstone

Thin Section:

There has been considerable damage to this sample and the quartz grains in many areas are fractured and fine-grained seams are thought to be derived from this disturbance of the original sandstone. In most places, however, the quartz grains appear to show moderate to good sorting and have an average grain size of the order of 0.2 to 0.3 mm. Clay comprises approximately 25% of the volume of the rock and most of this is heterogeneous material derived from original lithic fragments. This now occurs as discrete aggregates which fill the whole of the intergranular space where they occur and the heterogeneity is the essential indicator of the derivation from lithic fragments rather than from an original argillaceous matrix. The squeezing and deformation of the soft lithic clast during compaction has been one of the principal factors resulting in the apparently impervious nature of the sample.

As well as the clay derived from lithic fragments the sample does contain isolated monomineralic pools of kaolinite and there is a small amount of widely dispersed carbonate. The latter probably comprises 3 to 5% of the volume of the rock and, as well as an unstained variety there is a small amount of calcite. The carbonate is clearly authigenic in origin and there are some moderately well formed rhombs. The carbonate is present generally as very small crystals but some larger aggregates also tend to fill the space between the quartz grains.

The rock contains small amounts of detrital feldspar and colourless mica. As far as can be determined the rock is essentially impervious and hence has very poor reservoir properties.

Sample: TSC47108; Location: Sidewall Core 47, 3159 m

Rock Name:

Compact lithic sandstone

Thin Section:

Fine-grained clays and minor carbonate comprise fully 25% of the volume of this rock. Amongst this material there is a minor amount of kaolinite which forms compact monomineralic aggregates between the quartz grains but most of the material is heterogeneous and thought, therefore, to have been derived from lithic fragments which were deposited at the same time as the abundant quartz grains. This lithic material ranges from fairly well defined fine-grained aggregates of quartz and oriented phyllosilicates, which are clearly of metasedimentary origin, to more indeterminate aggregates of very fine-grained clay which commonly have been markedly distorted by squeezing between the quartz grains during compaction. Many of these more indeterminate clay aggregates show moderate birefringence and are likely to be illitic in character. There is a small proportion of chert grains and these tend to retain compact detrital outlines.

The quartz grains are well sorted and have an average size of 0.3 mm. Most show some evidence of the development of long and curved contacts and in some instances they are separated from each other by films of clay material. Overgrowths are not common but the shape of the grains is a clear indication of the extent of pressure solution and porosity reduction by modification of the quartz grains.

The thin section contains a very small proportion of pores which are interpreted as being integral to the sandstone; these are up to 0.2 mm in size and are probably of secondary origin. Taken overall, however, the sample is probably impermeable and has poor reservoir qualities. As well as containing abundant clay, it is likely that there is a considerable range of clay minerals in rocks such as this, in that there is heterogeneous lithic material as well as apparently well crystallised authigenic kaolinite.

Sample: TSC47107; Location: Sidewall Core 42, 3194 m

Rock Name:

Dolomitic lithic sandstone

Thin Section:

Approximately 15% of the volume of this rock consists of fine-grained authigenic carbonate and there is a similar or possibly somewhat smaller amount of clay derived from lithic fragments. Authigenic kaolinite appears to be essentially absent. As far as can be determined the sandstone consists of well sorted grains which range from about 0.1 to 0.25 mm in size. Where the sandstone is relatively well preserved, there is evidence of the presence of long and curved contacts between the grains and rare instances of overgrowths. For the most part, however, intergranular space is relatively abundant and is filled either with distorted heterogeneous remnants of original lithic fragments or with fine-grained patches and porous aggregates of ?dolomite. It is the abundance of these fine-grained constituents which has lead to the apparently impervious and impermeable nature of the sandstone. Modifications to the quartz grains appear to be locally significant and there is an inverse relationship between the amount of clay in the rock and the extent of pressure solution of the quartz.

The sample has been considerably damaged during collection of the sidewall core but it seems likely that it is amongst the more carbonate-rich and lithic sandstones in this group. Its reservoir properties include not only meagre porosity and permeability but also wide varieties of potentially active minerals including carbonate as well as, probably, a range of phyllosilicates.

Sample: TSC47106; Location: Sidewall Core 41, 3198.5 m

Rock Name:

Compact lithic sandstone

Thin Section:

Lithic fragments comprise about 20% of the volume of this sandstone and the remainder is comprised very largely of quartz grains with a moderate proportion of authigenic carbonate. Authigenic kaolinite is present only to a very small extent. The rock appears to be impervious as a result of modifications to the original quartz grains, distortion of the lithic fragments and the crystallisation of the authigenic carbonate mineral.

The quartz grains are moderately well sorted and commonly range in size from 0.15 mm to about 0.4 mm. In some places there are long and curved contacts between the grains with some incipient suturing but for the most part the grains are separated by aggregates or thin films of fine-grained material and it is likely that the abundance of this has somewhat inhibited free circulation of pore waters which would enhance the development of pressure solution effects.

The lithic material is heterogeneous and ranges from rare siliceous rocks (both of metamorphic origin and chert) to apparently monomineralic aggregates of fine-grained birefringent clay (probably illitic) many of these illitic fragments have been markedly distorted and now form cusped and irregular aggregates or, in some instances, films and seams between the quartz grains.

Carbonate is present both as relatively large aggregates and widely disseminated crystals and it is sufficiently abundant to have been a major influence in reducing the original porosity. In contrast, authigenic kaolinite, although it is present and forms some relatively large monomineralic aggregates, is quantitatively less abundant than the carbonate.

The thin section does show some porosity but it is thought that the bulk of this has been induced by collection of the sidewall core and preparation of the thin section. The rock is likely to be distinctly impervious and impermeable. There is some evidence of ferruginous staining in the sample and some of the clays have a distinctly yellow colour. There is also a little opaque and semi-opaque material which is present both in incipient microstylolite zones and as rare, apparently detrital, fragments.

Sample: TSC47105; Location: Sidewall Core 17, 3442.5 m

Rock Name:

Dolomitic lithic sandstone

Thin Section:

The average grain size is approximately 0.25 mm and the quartz grains for the most part retain their original subround to subangular detrital outlines. There is little development of long contacts in places where there is a relative paucity of clay. In most fields of view, however, fine-grained constituents comprise 30 to 50% of the volume of the rock. Most of this material is rather heterogeneous and fine-grained and consists mainly of phyllosilicate minerals with intergrown fine-grained quartz and small amounts of carbonate and secondary ferruginous phases. The heterogeneity of the material is a clear indication of its derivation from lithic fragments and the abundance of this material and the way in which it has been compressed and squeezed between the more rigid quartz grains is responsible for the apparently impervious nature of the sample in thin section.

As well as this clay the rock does contain, in places, rather large aggregates of extremely fine-grained carbonate. The largest of these is about 1 cm in size but there are several which are of the order of about 0.2 mm in width and 1 mm in length. The largest of these fragments could well be some kind of concretion which has been caught up in the sandstone but the smaller aggregates of carbonate may well be derived from recrystallisation and deformation of original limestone fragments. Also present in one part of the thin section, particularly, are elongate and irregular aggregates of opaque material which could well be of plant origin.

This is a distinctly lithic sandstone which has, probably, extremely poor petrophysical characteristics. These result from the abundance of the lithic materials and hence from the sedimentological maturity of the sandstone. As well as low porosity and permeability it should be noted that this sample (like many others from this well) is likely to contain a wide variety of reactive minerals including several types of phyllosilicates as well as carbonate and kaolinite derived from authigenesis.

In one place in the thin section there is a small aggregate of a green mineral tentatively interpreted as glauconite.

Sample: TSC47104; Location: Sidewall Core 16, 3447 m

Rock Name:

Compact lithic sandstone

Thin Section:

This sample is similar to many other lithic sandstones in this collection but this one contains probably 15 to 25% of carbonate and only less than 2% of authigenic kaolinite. Fine-grained material thought to have been derived from lithic fragments comprises perhaps about 20 to 25% of the volume of the rock. The fine-grained clay material both forms irregular patches between the quartz grains and also in intergranular films so that there is limited evidence of the pressure solution effects on the quartz grains. These are confined to a few small patches where the clays are relatively less abundant. The carbonate forms many irregular porous patches in which it appears to have partially replaced some of the lithic fragments. As well, the carbonate occurs as small crystals, particularly along quartz grain boundaries. Overall the abundance of clay and of the carbonate means that the sample has an apparently impervious and impermeable nature.

Authigenic kaolinite is a minor constituent of the rock and there are traces of detrital mica and slightly turbid feldspar.

Sample: TSC47109; Location: Sidewall Core 4, 3592 m

Rock Name:

Compact lithic sandstone

Thin Section:

The average grain size of the quartz in this rock is approximately 0.3 mm and the sample appears to be well sorted. The shapes of the quartz grains have been effected by pressure solution and most fields of view show numerous long and curved contacts and even a few somewhat sutured contacts between the grains. Where the quartz grains are not in contact with each other there are patches of clay which essentially completely fill the spaces where they occur. The heterogeneity of this clay is taken as an indication that it is derived essentially entirely from lithic fragments. Some of these were cherty but most are aluminous lithologies of sedimentary or metasedimentary origin. During compaction these have been compressed and squeezed between the more rigid quartz grains and, by this mechanism, much of the porosity and permeability have been occluded.

The lithic fragments probably comprise 20 to 25% of the volume of the rock and the sample also contains a small amount (less than 3%) of authigenic kaolinite which forms monomineralic patches. Carbonate is also present as an authigenic phase to the extent of about 3 to 5% and forms both isolated crystals and some distinctly irregular fine-grained monomineralic patches.

The thin section contains a little porosity but it is thought that this is a function of disturbance of the sample; it seems more likely that, as far as can be determined in thin section, the rock is impervious and impermeable.

Sample: TSC47114; Location: Sidewall Core 3, 3609.5 m

Rock Name:

Lithic sandstone

Thin Section:

Fine-grained constituents comprise at least 40% of the volume of this rock and there is a correspondingly small proportion of sand-grade quartz grains. The latter are well sorted and most grains are 0.15 to 0.3 mm in size. There is some evidence of pressure solution effects from these grains but in general the compaction forces on the rock have been absorbed by the clastic deformation of the lithic fragments rather than by dissolution of the stressed quartz grains. A small proportion of the grains show overgrowths and these are notably smooth in a few places against kaolinite.

The lithic fragments generally show fine-grained textures and clay and phyllosilicate are the predominant constituents. A small proportion contain abundant sericitic or illitic material but most of the lithic fragments are less well defined and probably contain very fine-grained intergrowths of quartz, phyllosilicates and authigenic carbonate.

Authigenic kaolinite and authigenic carbonate are both present but the kaolinite, although it forms discrete patches, is not abundant in the rock whereas the carbonate is widely dispersed and most fields of view contain porous aggregates of this material where it appears to have partly replaced some of the lithic fragments.

This appears to be an essentially impervious sandstone which not only shows an apparent absence of porosity in thin section but also contains several potentially reactive minerals (carbonate, kaolinite and various clays in lithic fragments). To this extent, artificial stimulation of the reservoir by chemical means would be a complicated job.

Sample: TSC47113; Location: Sidewall Core 1, 3617 m

Rock Name:

Compact lithic sandstone

Thin Section:

This sample is similar in many respects to those described above in that it contains a relatively large proportion of clay material most of which has been derived from lithic fragments which were deposited at the same time as the sand-grade quartz grains. Occlusion of the original porosity and permeability of the sand has occurred mainly by physical squeezing and distortion of the relatively soft lithic clasts between the more rigid quartz grains. Many fields of view in the thin section simply consist of a randomly oriented aggregate of quartz grains and fine-grained patches on a scale of about 0.2 to 0.3 mm.

The lithic fragments range from siliceous types which are probably cherty through fairly well defined foliated schistose and slaty rock to very fine-grained argillaceous lithologies which are probably shales or their metamorphic equivalents. The more quartz-rich fragments retain a compact detrital outline but many of the softer fragments can be seen to be conformable to the shape of the adjacent quartz grains.

The lithic fragments probably comprise about 30 to 35% of the volume of the rock but authigenic kaolinite is present only to a very small extent and probably comprises not more than about 2%. Even so, the kaolinite does tend to form well defined monomineralic patches up to about 0.2 mm in overall size.

Some parts of the thin section contain rather large aggregates of a completely opaque constituent which may well represent plant debris. The largest aggregates of this material are several millimetres in length and up to about 1 mm in width.

The thin section contains some porosity but it is likely that this is a result of preparation of the sample before microscopy and it seems unlikely that the reservoir at this depth has good petrophysical properties both in terms of the overall amount of porosity and permeability and also in view of the wide variety of potentially reactive minerals present.

Sample: TSC47112; Location: Sidewall Core 62, 3663.6 m

Rock Name:

Compact lithic sandstone

Thin Section:

This sample is a little different from the few described immediately above in that it is a little finer grained and there appears to be an opaque or semi-opaque authigenic phase which rims and outlines many of the quartz grains. The rock shows an equally compact texture in that there are concavo-convex and sutured margins between the grains but these are marked both by the authigenic mineral referred to above and by thin smears of clays derived from adjacent deformed lithic fragments.

The average grain size of the quartz and lithic fragments appears to be about 0.15 to 0.2 mm and the lithic material probably comprises fully 20 to 25% of the volume of the rock. There are some well rounded chert grains but most of the lithic fragments are fine-grained lithologies generally consisting of phyllosilicates with or without small amounts of fine-grained quartz. Most of these rocks are probably of metasedimentary origin. There is a little detrital muscovite but feldspar is very rare.

There appears to be little or no authigenic kaolinite but the rock contains widely dispersed authigenic ?dolomite and this may comprise possibly as much as 5% of the volume of the sample. The dark granular authigenic phase referred to above may be an iron oxide or hydroxide mineral derived from the alteration of original pyrite or it may represent tiny aggregates of dolomite or siderite (which are so small that they appear to be opaque).

The least disturbed parts of this thin section contain no visible porosity and permeability and this has resulted from the abundance of clay, modification of some quartz grains and the presence of incipient microstylolitic zones.

Sample: TSC47111; Location: Sidewall Core 61, 3673 m

Rock Name:

Compact lithic sandstone

Thin Section:

This sample has been extensively damaged during collection of the sidewall core but it appears to be similar in many respects to other sidewall core sandstones in this well. The average grain size is of the order of 0.2 to 0.3 mm and there is evidence of pressure solution having acted upon the quartz grains leading to the formation of long and concavo-convex grain boundaries.

The overall proportion of clay in the rock is rather difficult to determine but it is probably not more than 15 to 20%. Authigenic kaolinite can only be identified positively in a few places and it seems likely that the bulk of the fine-grained material in the rock is heterogeneous clays, mica and quartz in sedimentary and metasedimentary fragments. These have clearly been compressed between the quartz grains and this process, also, has occluded much of the original porosity and permeability.

Sample: TSC47110; Location: Sidewall Core 19, 3684 m

Rock Name:

Compact lithic sandstone

Thin Section:

Collection of the sidewall core has caused considerable and extensive damage to this sandstone and there are some zones in which the average size of the quartz crystals/grains is not more than 0.1 mm. Less damaged areas have an average grain size of approximately 0.25 mm and these are taken to be more indicative of the nature of the original sandstone. These latter areas also contain about 25 to 30% of lithic fragments which occur as rather heterogeneous fine-grained aggregates between the quartz grains. There are some clearly cherty fragments and numerous argillaceous lithologies which probably contain abundant sericitic and illitic material. Most of the latter are probably metasedimentary rocks of some kind. In one or two instances in this sample there are fine-grained, possibly quartzofeldspathic, lithologies which may be of volcanic origin.

Authigenic kaolinite is present in the sample but it has rather a patchy distribution and it is difficult to estimate the proportion present with precision but it is thought to be less than 5%. The aggregates of kaolinite are commonly not more than 0.1 mm in size and although some fill all the intergranular space where they occur others are associated with patches of lithic fragments. A process may have occurred whereby there was partial dissolution of the lithic material and the cavities thus formed were subsequently filled with kaolinite precipitates.

There are thin films of fine-grained carbonate around some of the quartz grains and as partial replacements of some lithic material but the carbonate, although widespread, is not a quantitatively important constituent of this rock.

The sample appears to be impervious in thin section and it is thought likely that it has distinctly poor reservoir properties.

Sample: TSC47115; Location: Sidewall Core 59, 3688 m

Rock Name:

Compact lithic sandstone

Thin Section:

This sample has been extremely badly damaged during collection of the sidewall core and a detailed description will not be attempted. The rock appears to contain more than 20% of lithic fragments and it seems likely that the rock is similar in many respects to others described in this collection. There is evidence of pressure solution on some of the quartz grains and the rock contains readily identifiable grains of chert. Amongst the finer grained material there is clearly some carbonate which has partly replaced some of the clay in the lithic fragments and partly formed irregular fine-grained monomineralic patches. Authigenic kaolinite was identified but it is thought that this mineral and the carbonate are neither as significant in reducing the porosity as the deformation of the lithic fragments and modifications to the original quartz grains.

Sample: TSC47120; Location: Sidewall Core 58, 3692.5 m

Rock Name:

Compact lithic sandstone

Thin Section:

The better preserved parts of this thin section contain about 15 to 20% of lithic material and there are patches where quartz grains are relatively abundant and show curved boundaries and some overgrowths. In these parts of the rock the lithic fragments tend to be isolated as discrete patches similar in size to adjacent quartz grains. As well as distinctly deformed and squashed fragments of phyllosilicates the rock contains more compact lithic fragments which contain a higher proportion of quartz.

This sample appears to be somewhat more feldspathic than many in this collection and there are feldspar grains as much as 0.4 mm in size. Most of the feldspar appears to be a potassic variety but a little plagioclase was identified also. All of the feldspars are fresh and there is no evidence that, for example, the authigenic kaolinite has been derived from dissolution of feldspar grains.

The best-preserved parts of the thin section show no porosity whatsoever but there are somewhat more damaged areas with small pores and fractures; however, these are thought to have been derived from the collection of the sidewall core and the thin sectioning process.

The rock does contain a siltstone ?fragment which is about 1 cm in size overall. This contains a minor amount of detrital siltgrade quartz in an abundant dark matrix which presumably consists of clays extensively stained by ferruginous material.

Sample: TSC47119; Location: Sidewall Core 18, 3697 m

Rock Name:

Compact lithic sandstone

Thin Section:

In the better preserved parts of this thin section, this sandstone shows most of the textural features common to the majority of samples from Pelican-5. The rock is particularly characterised by the development of concavo-convex and sutured contacts between the grains.

Fine-grained components comprise about 30% of the volume of the rock and most of these are birefringent phyllosilicates with a rather characteristic brown colour. Some of the material may even be fine-grained biotite possibly derived from neomorphism of clays originally in lithic clasts. The material shows considerable evidence of having been deformed and compressed between the more rigid quartz grains. As in other rocks, the lithic material is distinctly heterogeneous and ranges from quartz-rich varieties (mainly cherts) to grains which appear to be monomineralic phyllosilicates.

The rock contains traces of authigenic kaolinite and of fine-grained carbonate but the crystallisation of these phases has probably been much less important in occluding original porosity than has the development of pressure solution on the quartz grains and deformation of the soft lithic clasts.

The sample does show microstylolitic zones and these are particularly characterised in some areas by the presence of irregular networks of opaque material which may well be of plant origin. The thin section contains hardly any porosity which can be regarded as integral to the original sandstone.

Sample: TSC47118; Location: Sidewall Core 14, 3891.5 m

Rock Name:

Compact lithic sandstone

Thin Section:

Most of the sample in the thin section has been extremely damaged by collection of the sidewall core and now consists of broken fragments of quartz grains in a melange of comminuted fragments of quartz, clay and carbonate. There are, however, more compact and less damaged patches and these contain approximately 30% of fine-grained material which is heterogeneous on a scale of 0.2 to 0.4 mm and is thought to have been derived from lithic fragments. The quartz grains in this part of the rock are moderately well sorted and have an average size of 0.25 mm. Where several quartz grains occur together they show well developed concavo-convex boundaries but in most parts of the sandstone the quartz grains are more or less rimmed by clay material derived from compressed and deformed lithic fragments. Overgrowths are not common on the quartz grains and it appears likely that the principal process involved in reducing the porosity of original sand was the compaction and deformation of the relatively soft clay lithic fragments.

This part of the rock contains traces of authigenic kaolinite and approximately 5 to 10% of fine-grained authigenic carbonate. Most of the latter is widely distributed and is present either as individual crystals or as rather porous patches where the carbonate appears to have partially replaced lithic material. Unusually, there are one or two relatively coarse grained patches of calcite, also. In view of the scarcity of this mineral and its very different texture (compared to the fine-grained authigenic carbonate) it seems likely that this has been derived from a limestone detrital fragment.

The sample is essentially impervious in thin section.

Sample: TSC47117; Location: Sidewall Core 48, 3900.5 m

Rock Name:

Lithic sandstone

Thin Section:

The sample consists of about 50% of quartz grains which range in size from 0.1 to 0.2 mm with the remainder of the rock being rather dark and indeterminate fine-grained material which forms a contiguous network around and between the quartz fragments. It seems likely that the rock has in fact been completely shattered by the sidewall coring bullet and that the texture as now seen is not a reflection of that of the original sandstone; however, it is likely that the original rock did contain the large proportion of fine-grained material seen in the thin section and the sandstone was presumably impervious and impermeable as a result of this.

Amongst the fine-grained material there is a small proportion of extremely fine-grained carbonate (about 10% of the rock as a whole) and in some places this appears almost certainly to have partly replaced some of the lithic fragments. Authigenic kaolinite is not present (it may have been broken up and removed during collection of the sidewall core).

There are traces of fresh feldspar and detrital muscovite and it seems likely that the sample is, in general terms, similar to many of those described above but more details cannot be given because of the nature of the sandstone preserved in the sidewall core.

Sample: TSC47116; Location: Sidewall Core 12, 3928.5 m

**Rock Name:**

Ferruginous siltstone with lithic sandstone

**Thin Section:**

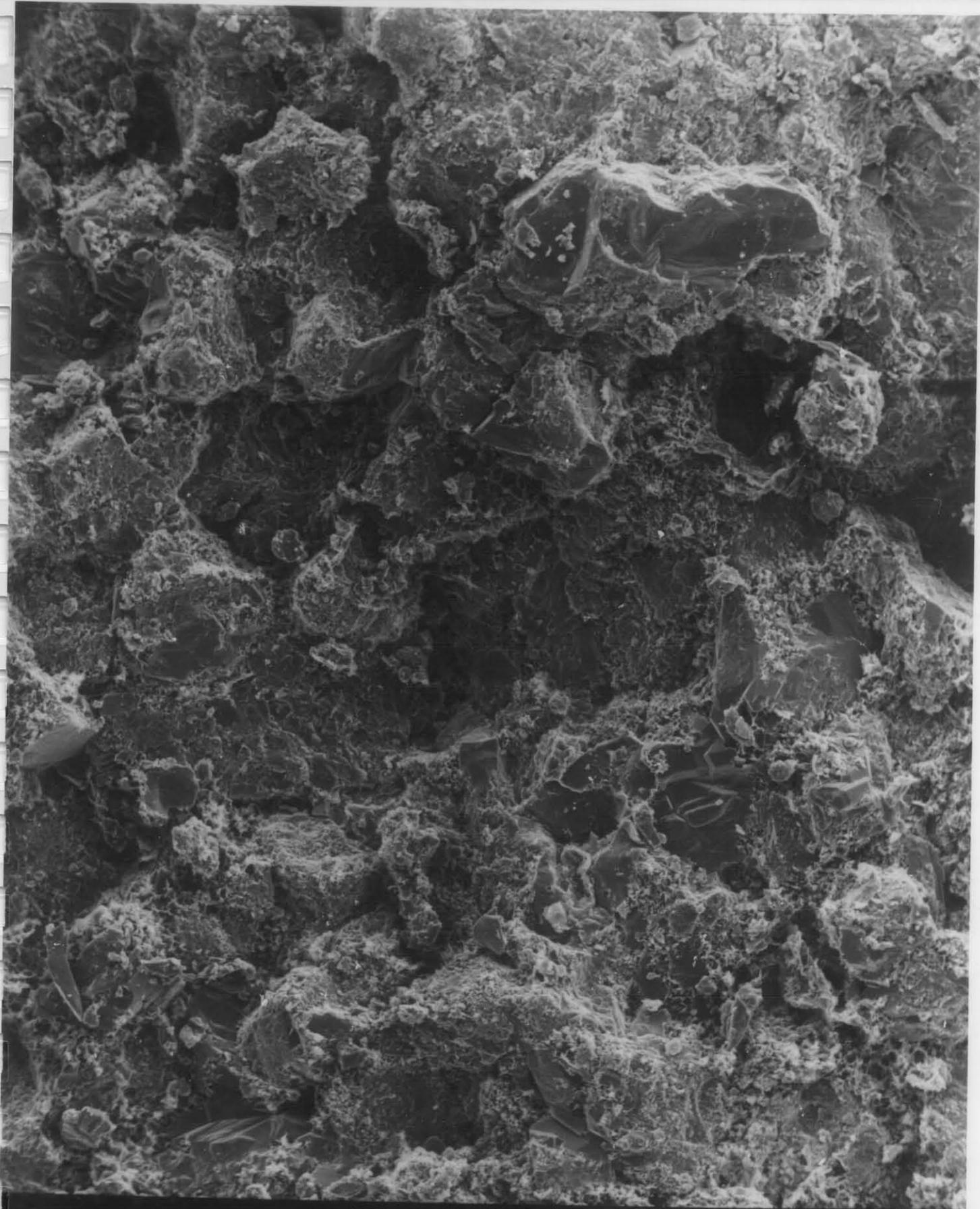
Most of the thin section consists of a homogeneous dark siltstone which contains about 50% of quartz grains up to 0.1 mm in size in a homogeneous matrix of dark material which has been obscured by abundant secondary ferruginous staining. This material is, needless to say, apparently totally impervious.

The adjacent sandstone is a rather broken remnant but it contains quartz grains commonly up to 0.3 mm in size. There is some evidence of the development of long contacts between the grains but in rare instances there are examples of what appear to be smoothly curved detrital outlines. The material between the quartz grains partly consists of broken fragments of quartz (which were not integral to the original sandstone) and indeterminate heterogeneous fine-grained material thought to have been derived from lithic fragments. This probably comprises of the order of 20 to 35% of the volume of the rock. The sample also contains a little authigenic carbonate and some, at least, of this is calcite. Authigenic kaolinite was not specifically identified in this sandstone.

453046

APPENDIX 3

CORE 2; SEM PLATES



100 10 u |-----|  
06-1 20 10 19 000 027

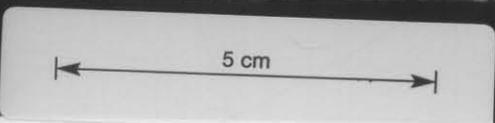


PLATE 1: 2869 m, Core 2  
Porosity in this sample is low due to the high proportion of lithic fragments and authigenic minerals (quartz overgrowths and authigenic clays; kaolinite, illite, ?chlorite and ?smectite).

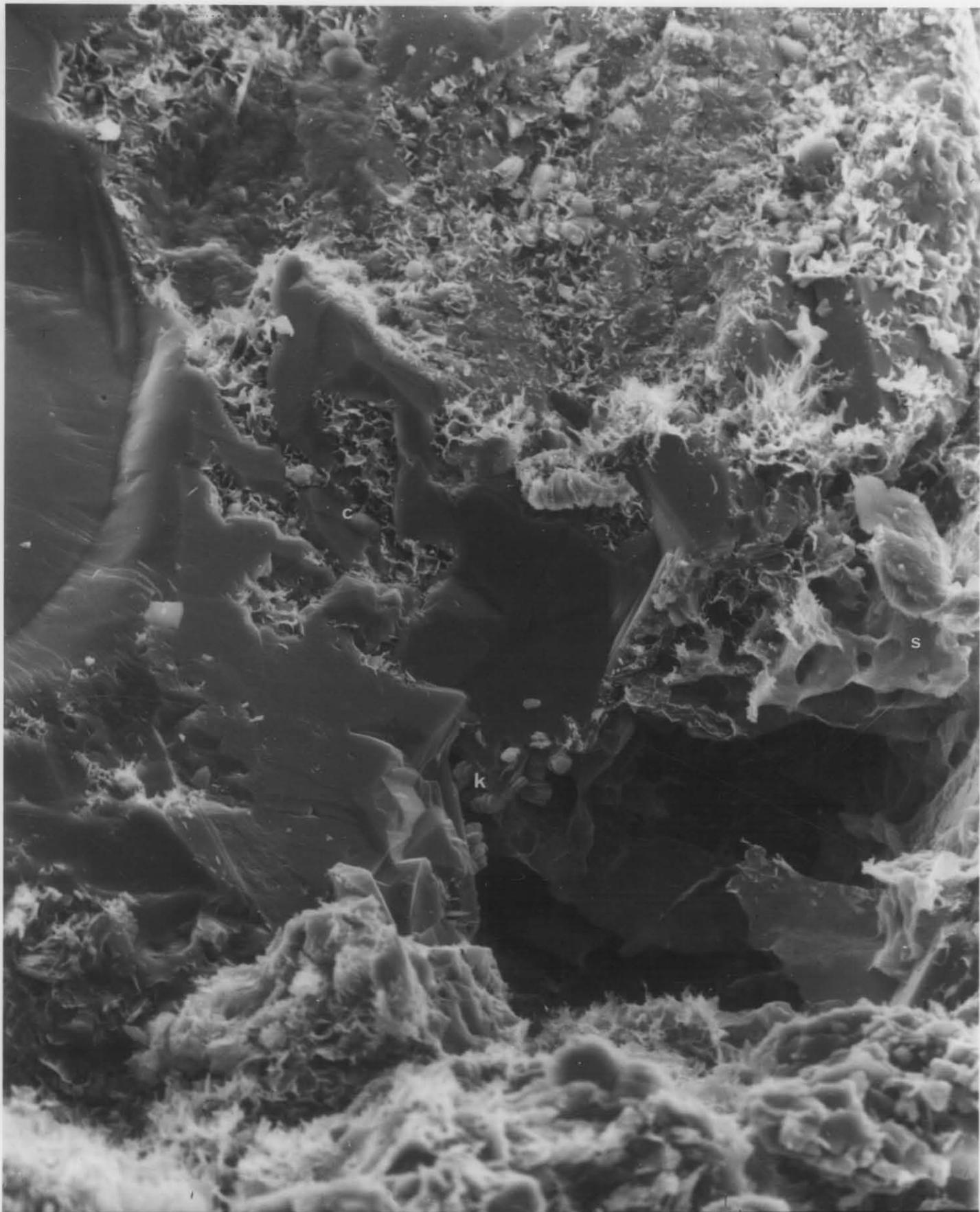


PLATE 2: 2869 m, Core 2

The authigenic quartz in this plate is growing over authigenic ?chlorite (C) and kaolinite (K). Authigenic illite is mainly associated with the lithic fragments (lower field). Authigenic ?smectite (S) occurs mainly on the pore spaces and appears to be a late diagenetic phase.

453088

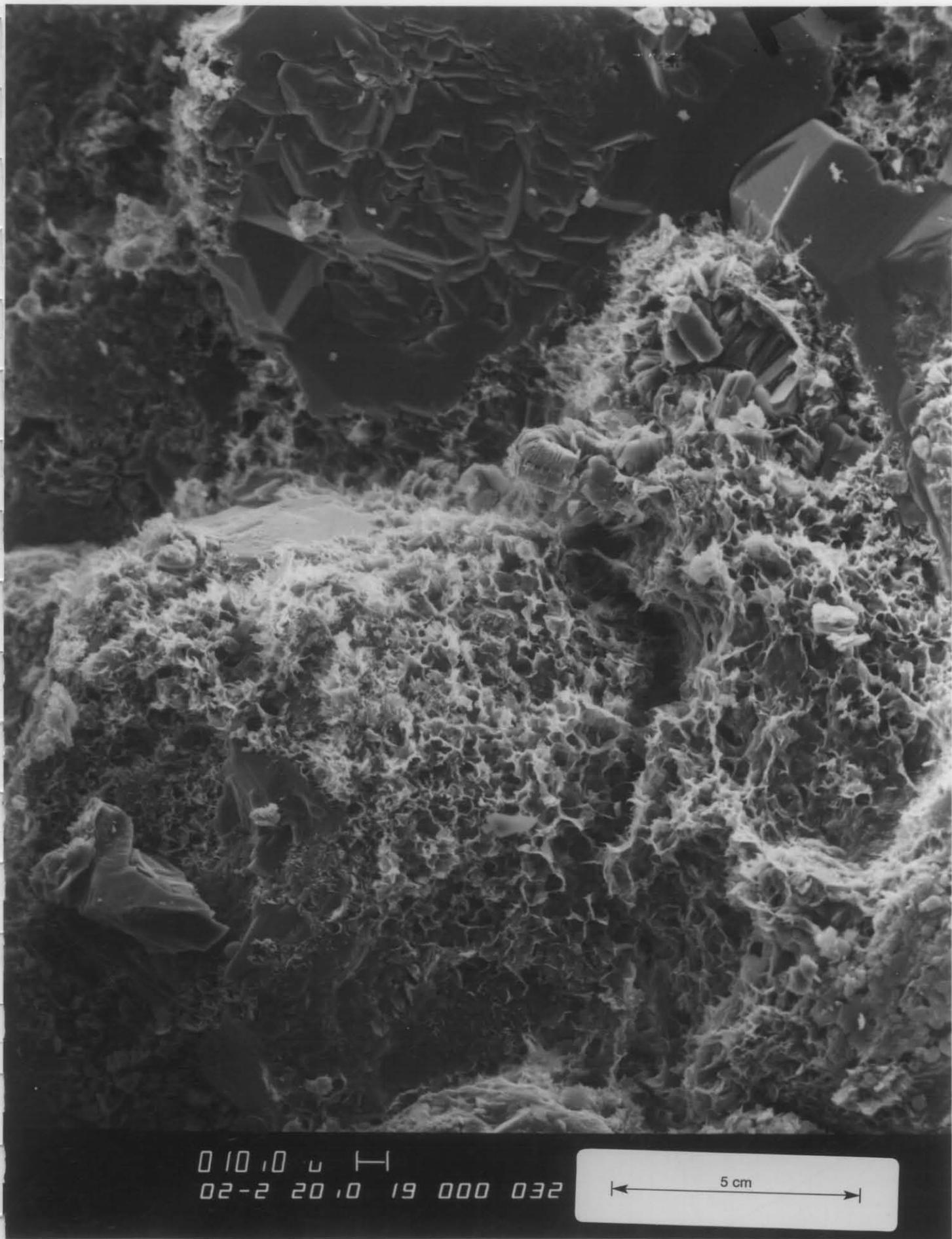
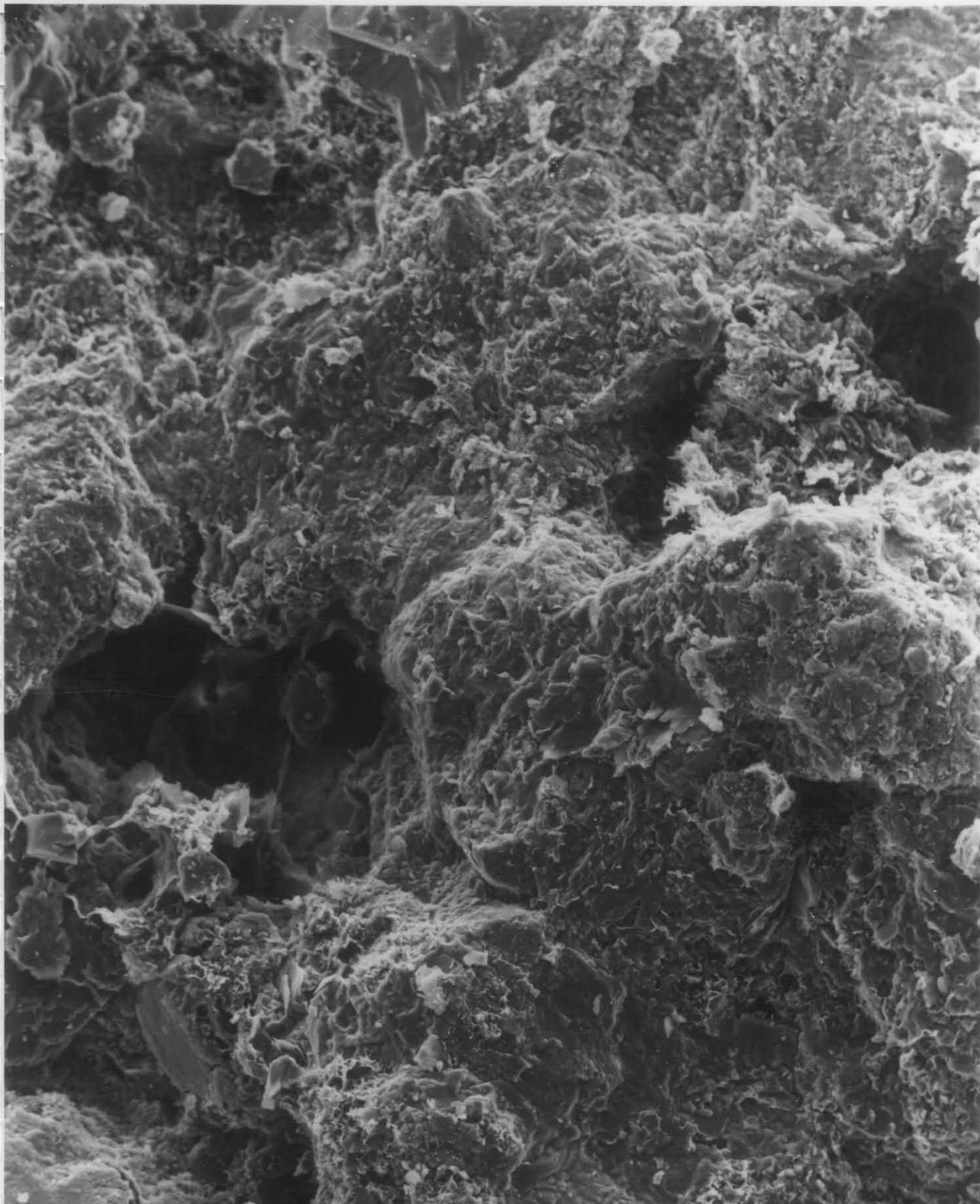


PLATE 3: 2869 m, Core 2  
Some porosity remains between the authigenic clays (randomly interstratified smectite/illite overgrowing kaolinite) at the interstices of these overgrown quartz grains.



01010 u H  
01-2 20.0 19 000 033

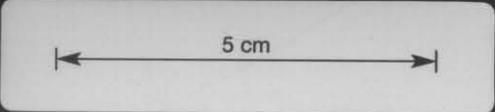


PLATE 4: 2869 m, Core 2  
Authigenic clays are much less abundant in these pore spaces possibly due to differences in permeability.

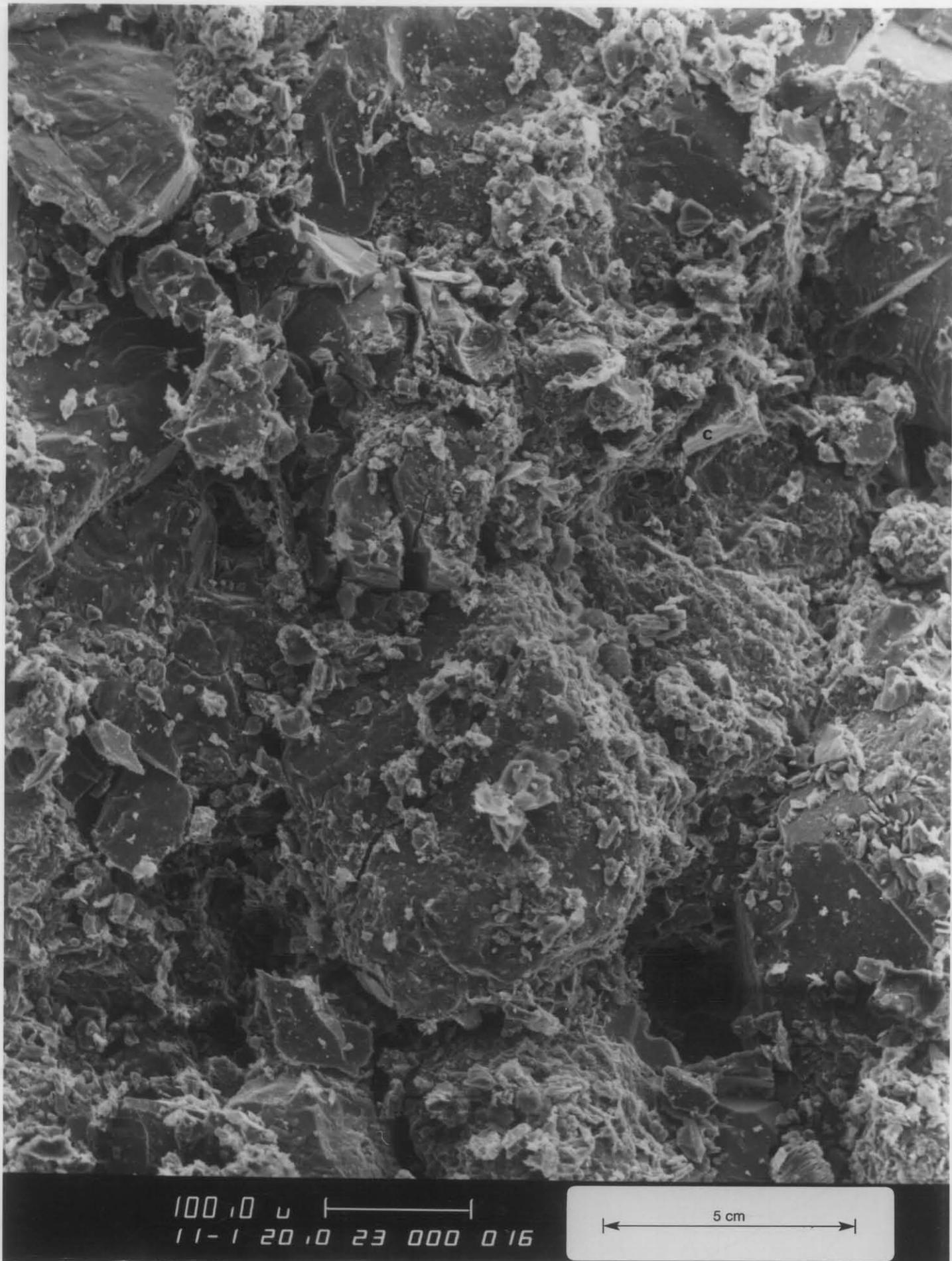
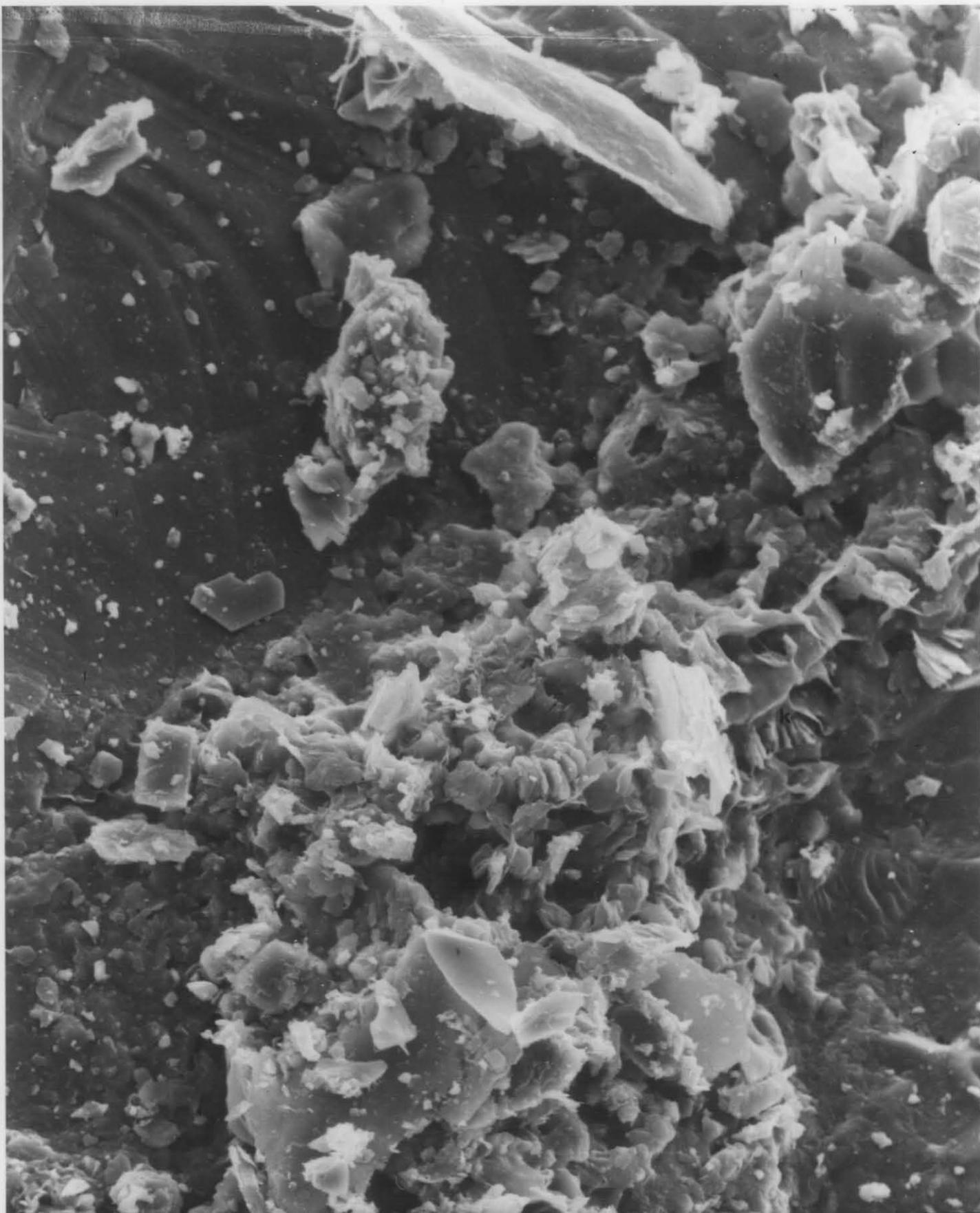


PLATE 5: 2871 m, Core 2  
Lithic fragments are less abundant than in Plate 1. However, porosity is still low due to the abundance of authigenic minerals (mainly quartz, kaolinite and carbonate (C)).

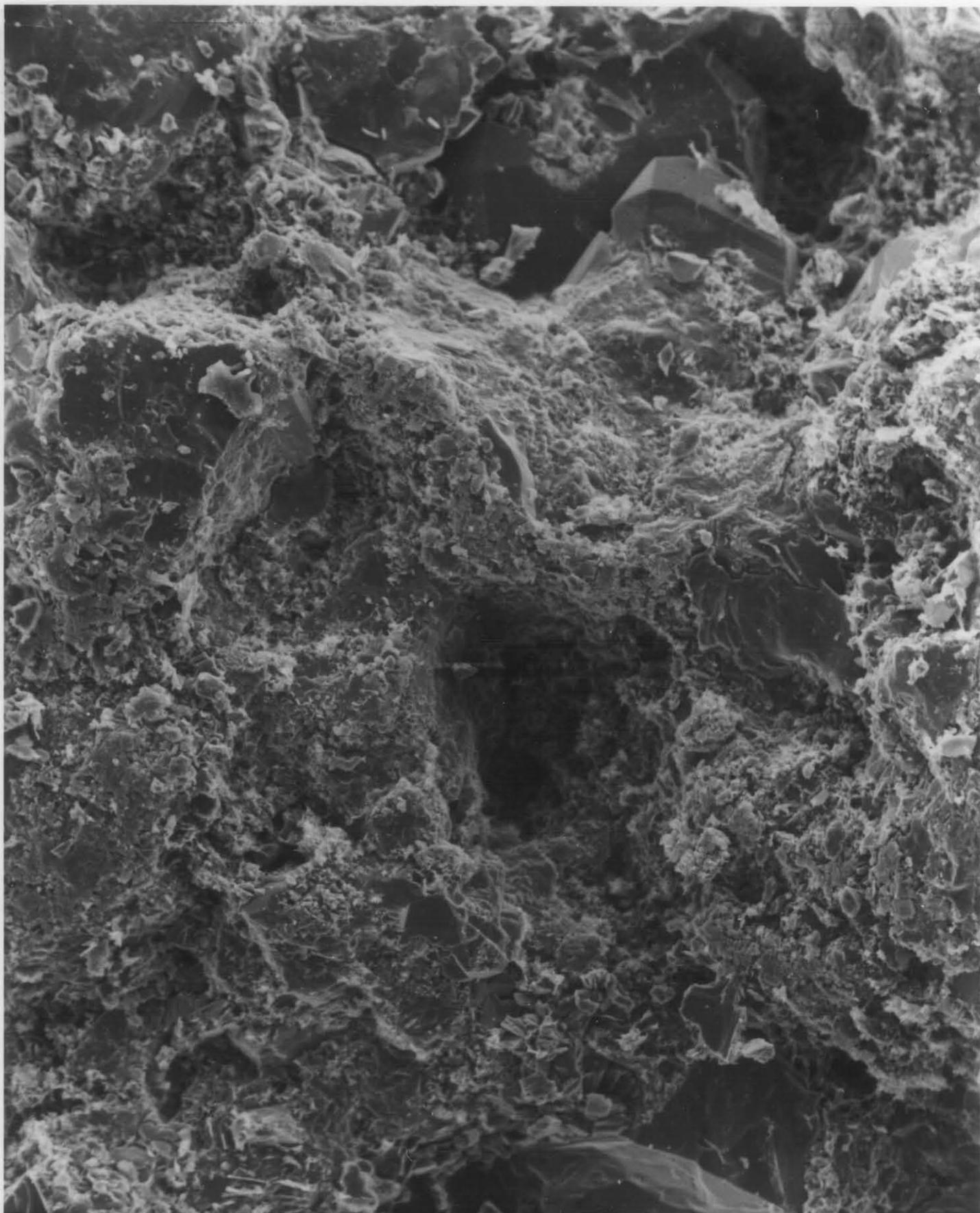


0 10 10 u |  
05-2 20 10 23 000 0 17

5 cm

PLATE 6: 2871 m, Core 2

Some porosity remains between the kaolinite (centre) which fills this pore space interstitial to overgrown quartz grains. Authigenic quartz has grown over some of the kaolinite (K). Minor amounts of authigenic illite are also present.

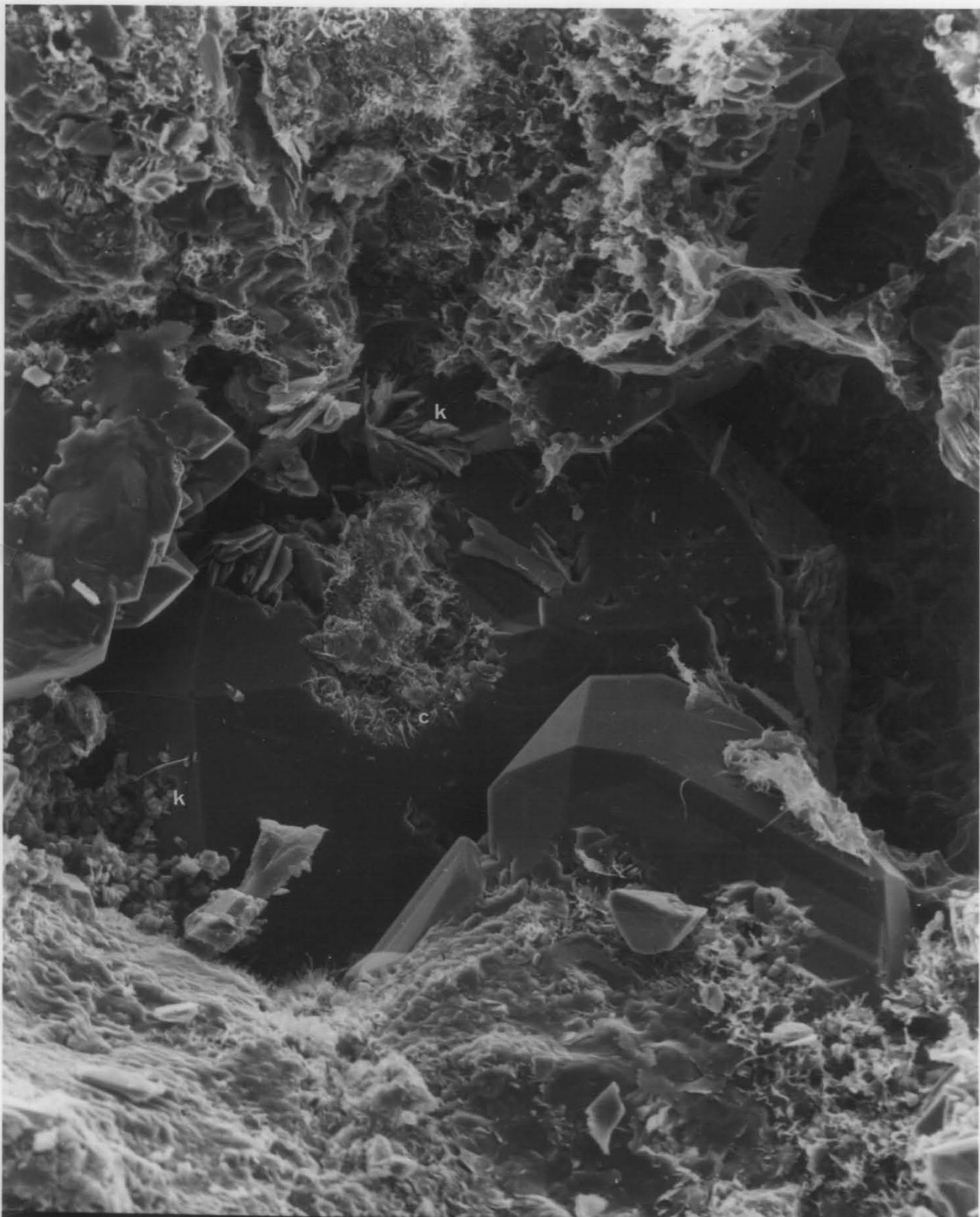


100 .10 u |-----|  
10-1 20 .10 20 000 0 19

5 cm

PLATE 7: 2873 m, Core 2  
This sandstone is very similar to that from 2871 metres depth. Crystal faces on the quartz overgrowths are quite well developed and authigenic clays are common.

453053



0 10 10 u |  
02-2 20 10 20 000 020

5 cm

PLATE 8: 2873 m, Core 2

Authigenic quartz overgrowths have continued after the formation of authigenic kaolinite (K) and ?chlorite (C). Hairy illite (lower left) appears to be a late stage phase.

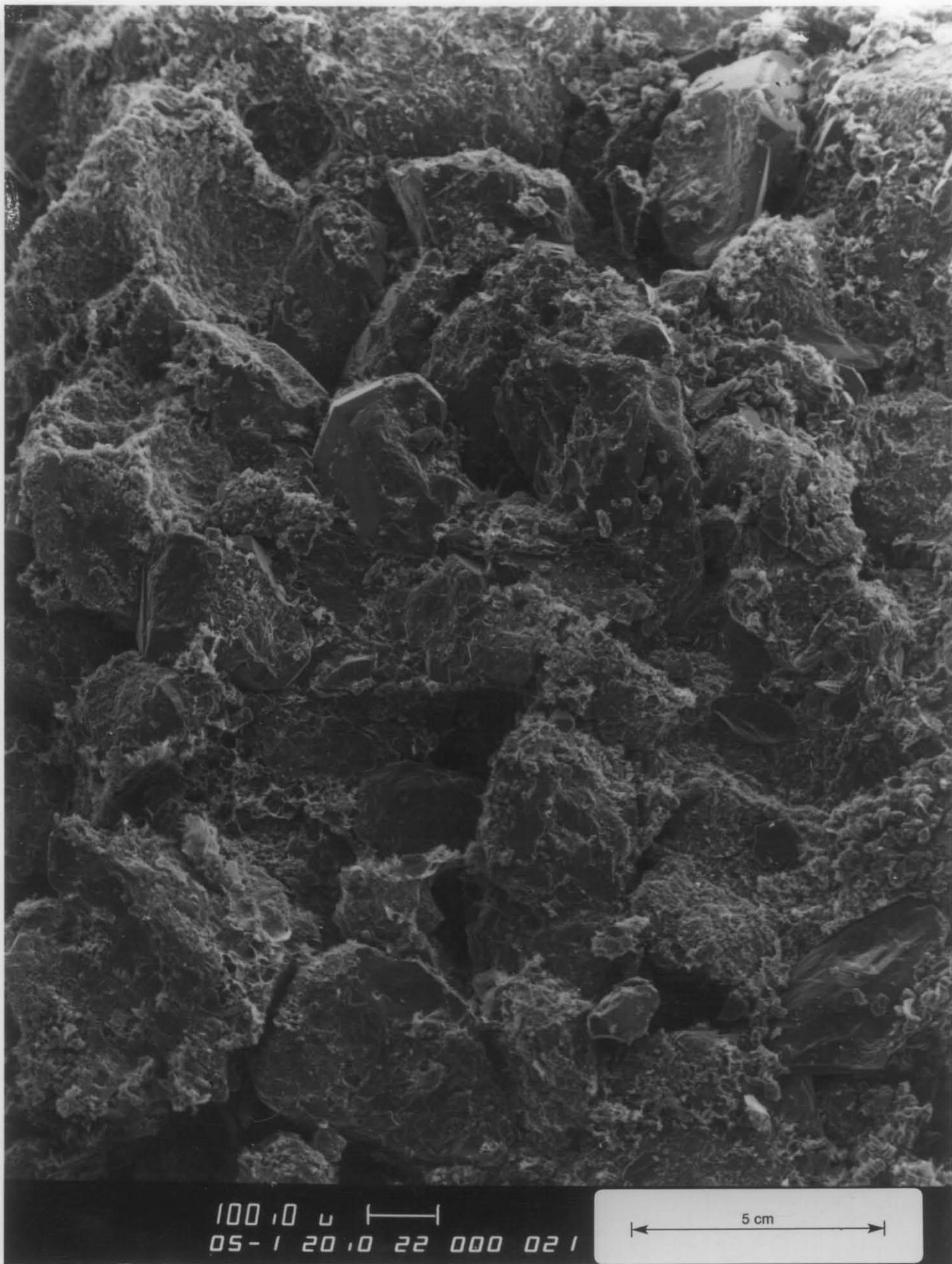
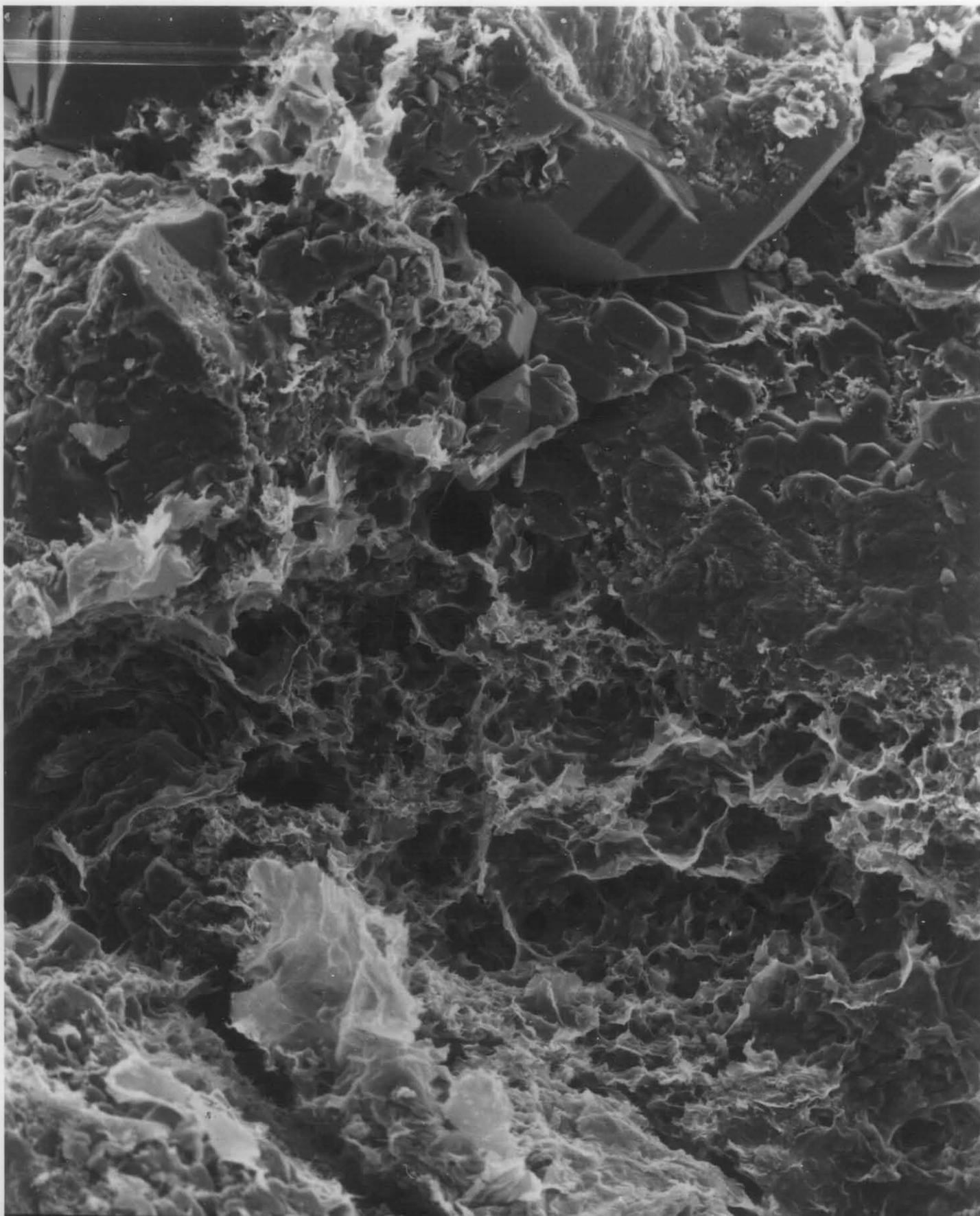


PLATE 9: 2875 m, Core 2  
Lithic fragments are less abundant in this sample although porosity is still fairly low.

453055

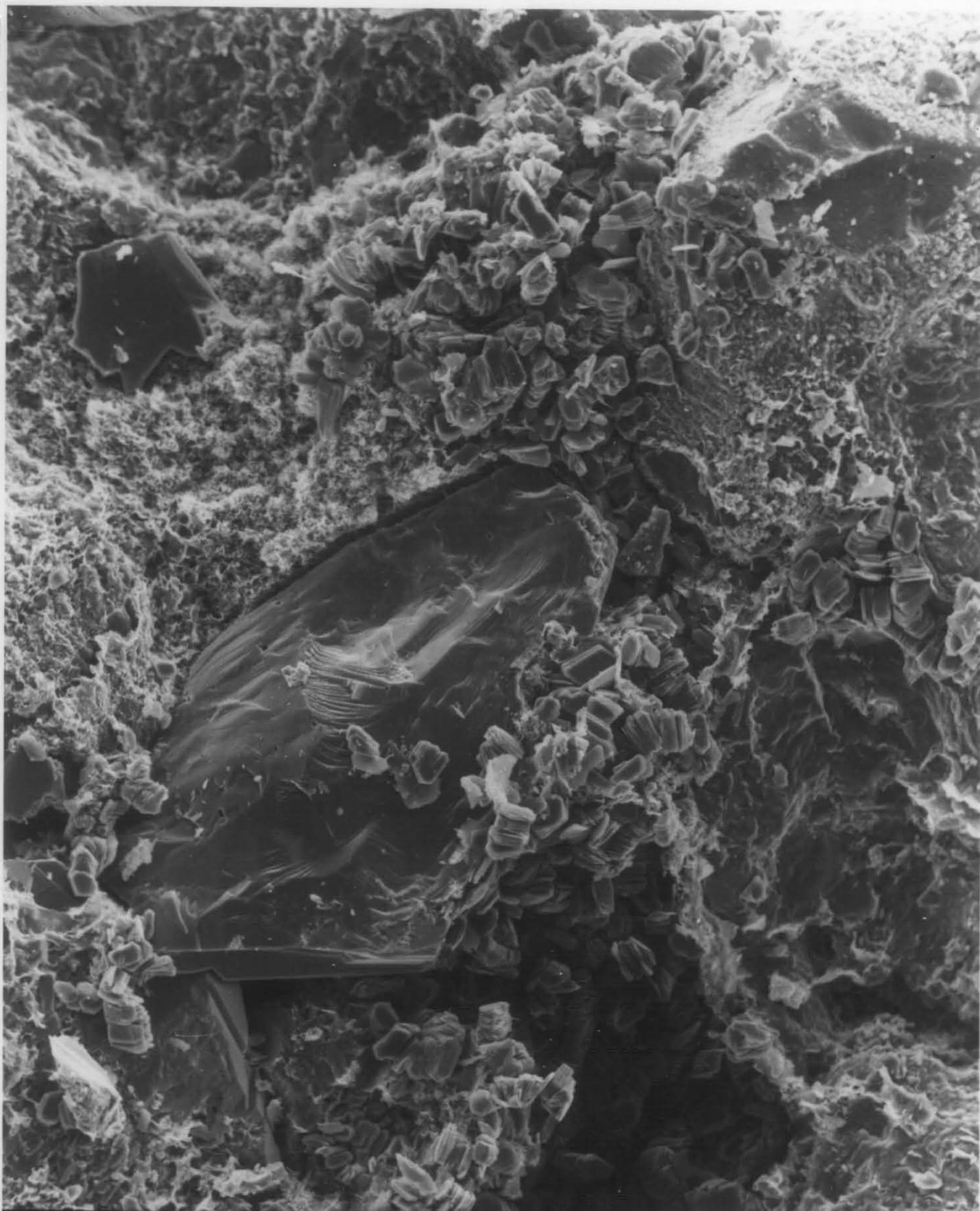


01010 u H  
02-2 20.0 22 000 022

5 cm

PLATE 10: 2875 m, Core 2  
Some porosity remains between the ?smectite (centre). Authigenic quartz has overgrown clay ?illite (upper left hand corner). Illite (top right) appears to be a late stage phase.

453056



0 10 10 u H  
0 1-2 20 10 21 000 023

5 cm

PLATE 11: 2875.1 m, Core 2  
Authigenic kaolinite occurs interstitially to overgrown quartz grains and lithic fragments. Authigenic illite and randomly interstratified smectite/illite are mainly associated with the lithic fragments (upper left).

453057

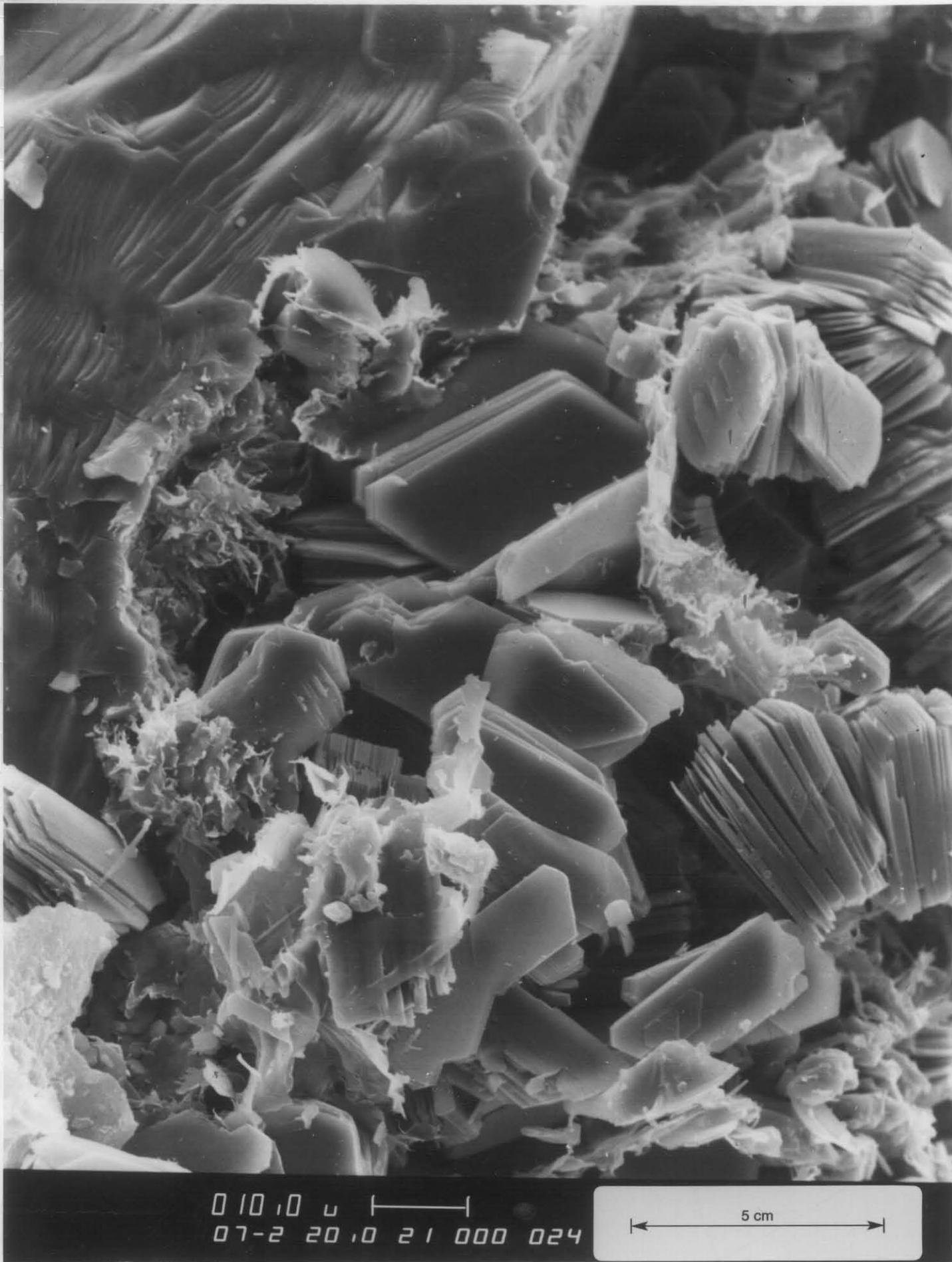


PLATE 12: 2875.1 m, Core 2  
Authigenic kaolinite and authigenic illite occur adjacent to a fractured overgrown quartz grain.

453058

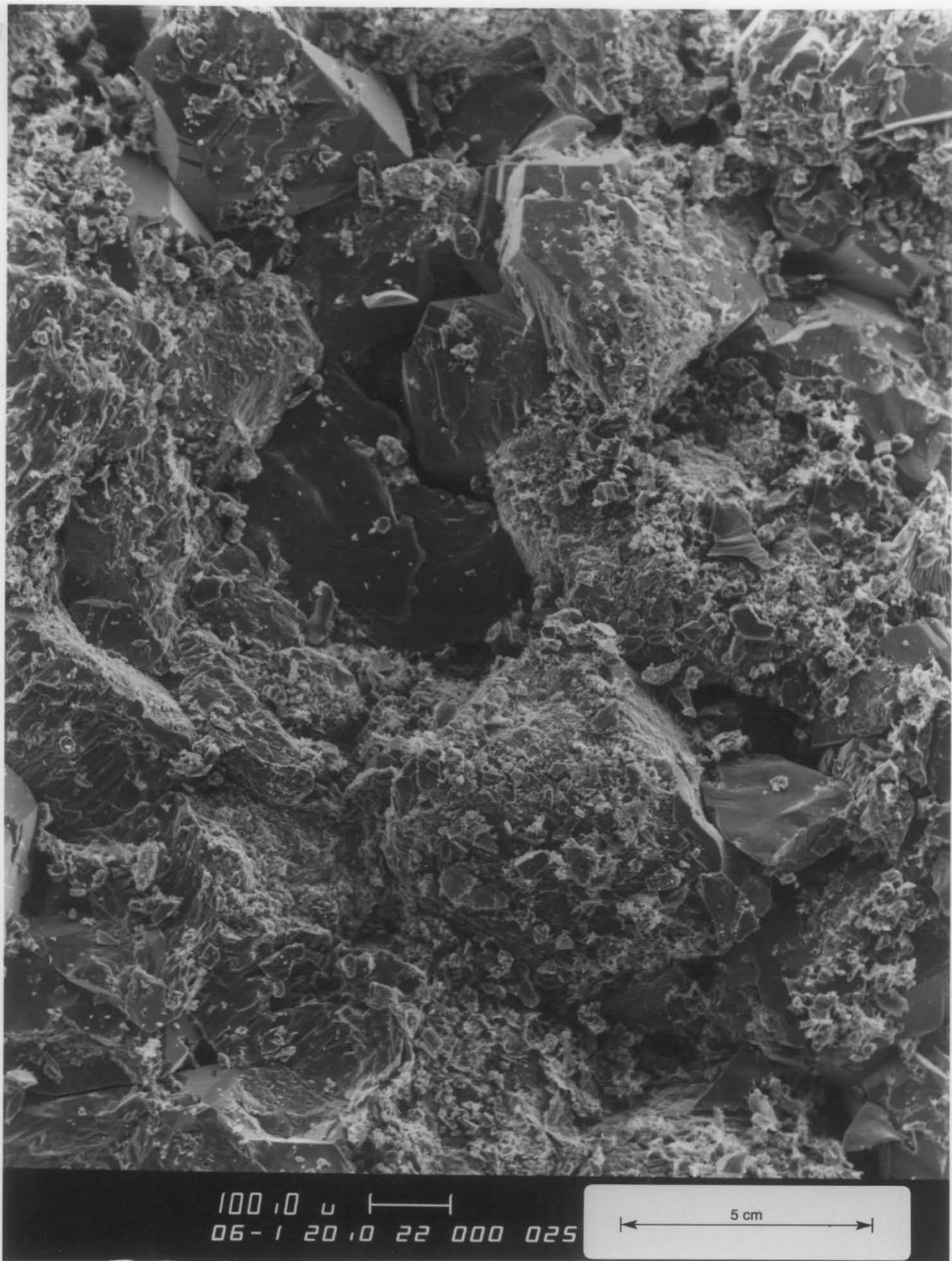
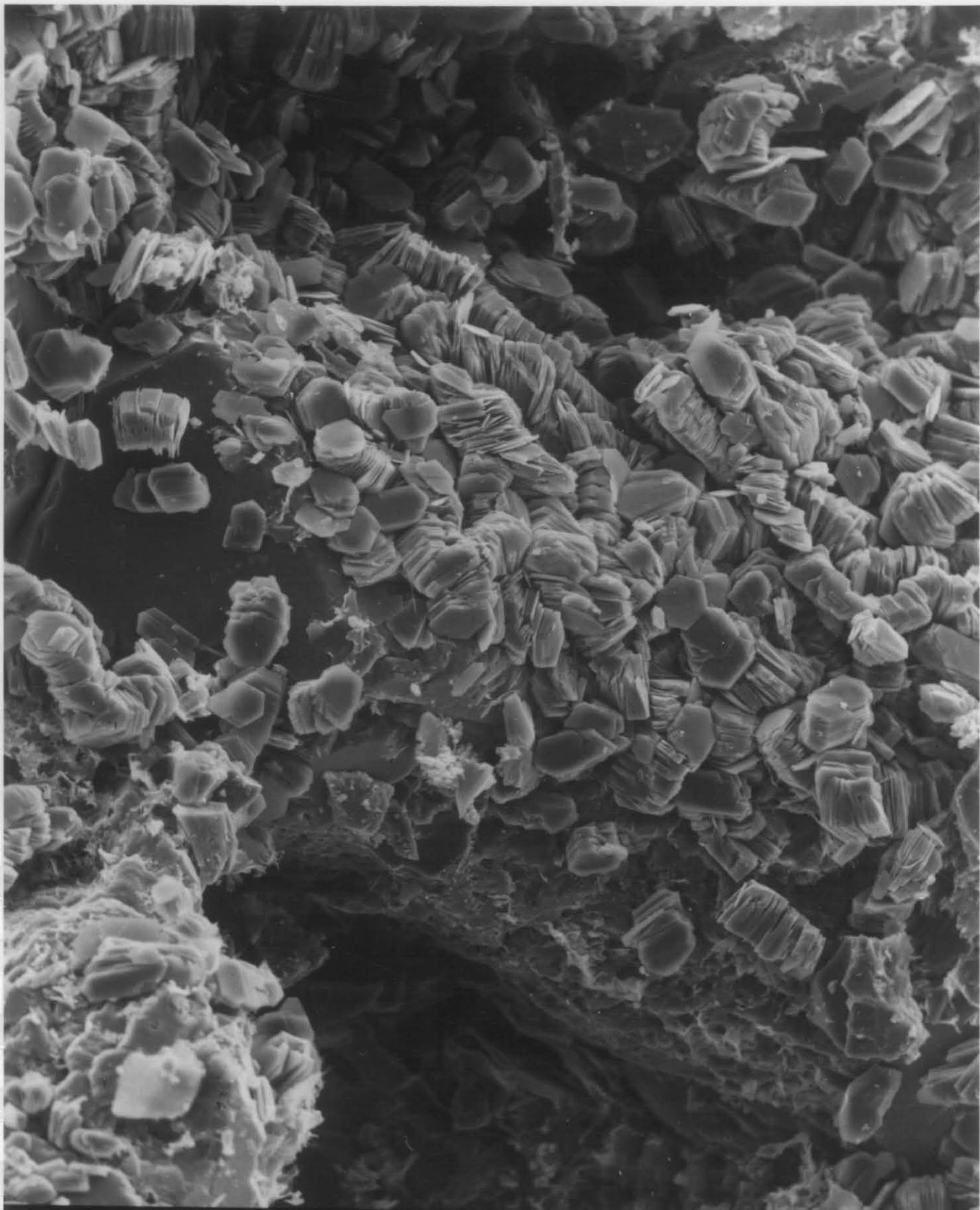


PLATE 13: 2877 m, Core 2  
Most of the porosity in this sandstone occurs at the interstices of the overgrown quartz grains.

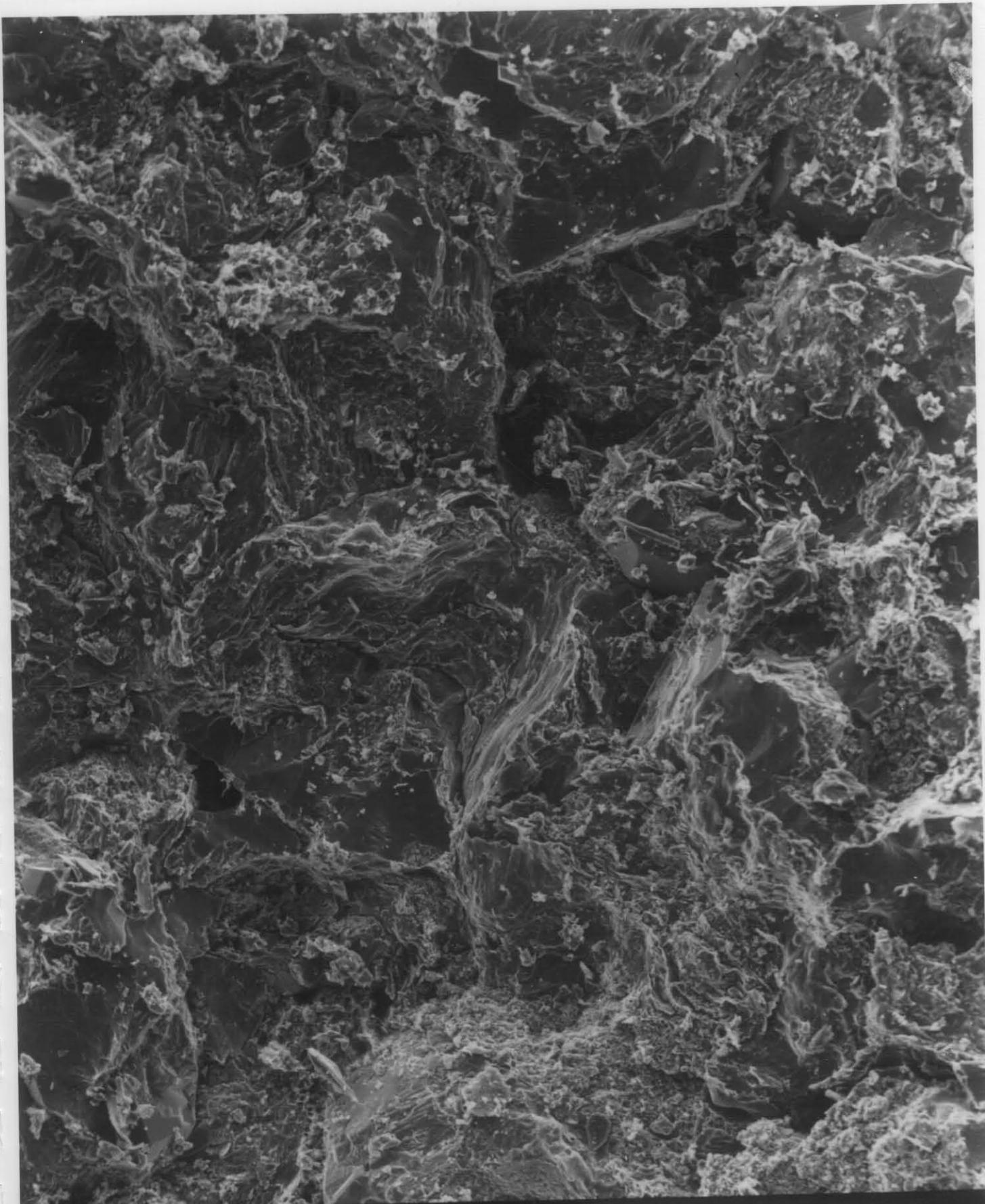
453059



01010 u H  
02-2 20.0 23 000 026

5 cm

PLATE 14: 2877 m, Core 2  
Pore spaces in this sandstone are commonly lined with authigenic kaolinite.



100 10  $\mu$  |-----|  
06-1 20 10 22 000 028

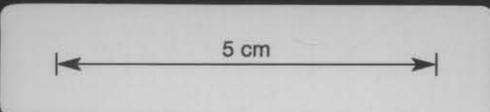
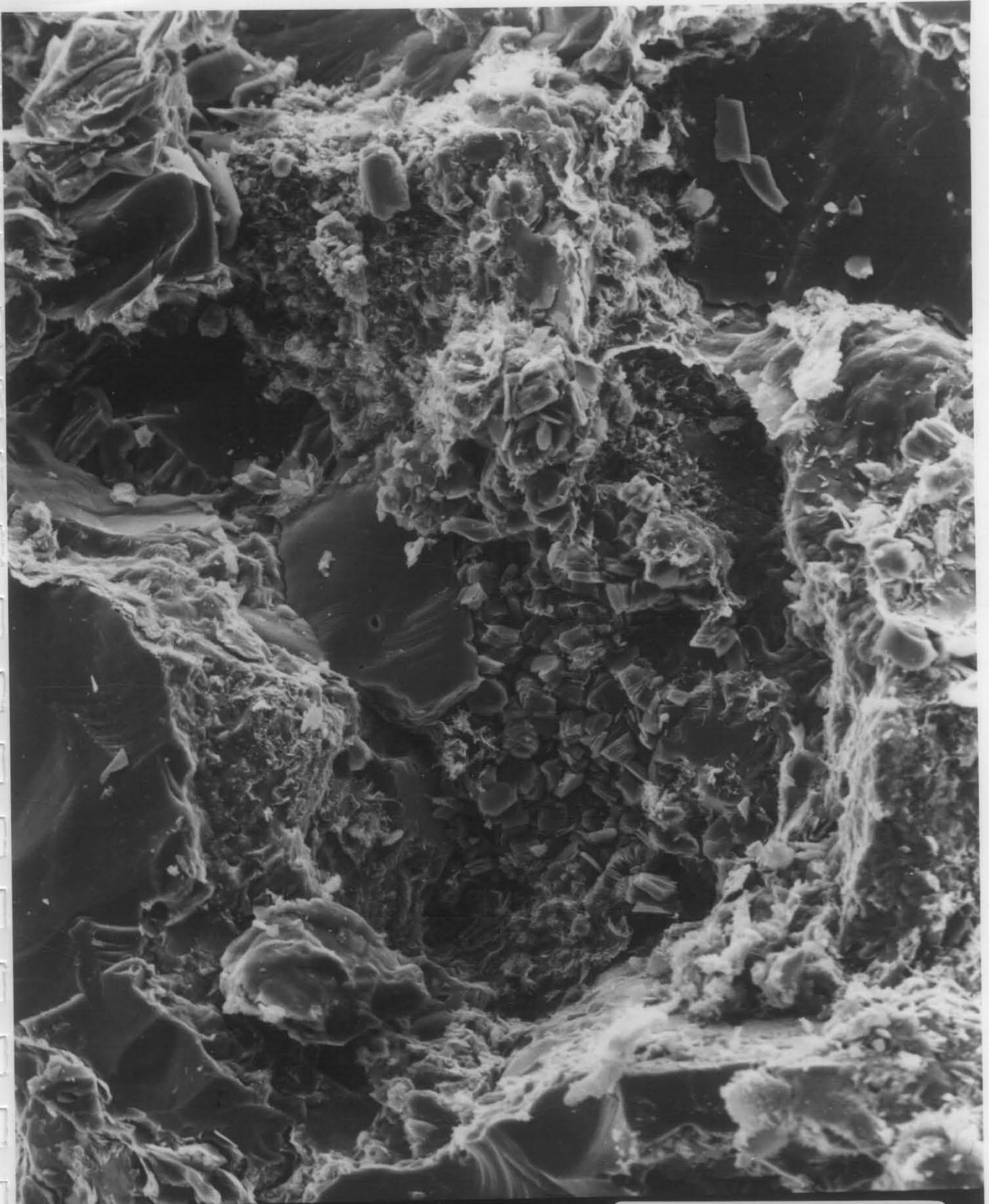


PLATE 15: 2878.9 m, Core 2  
This sandstone appears to be "tighter" than previous samples. This is primarily due to the continued development of quartz overgrowths.

453061

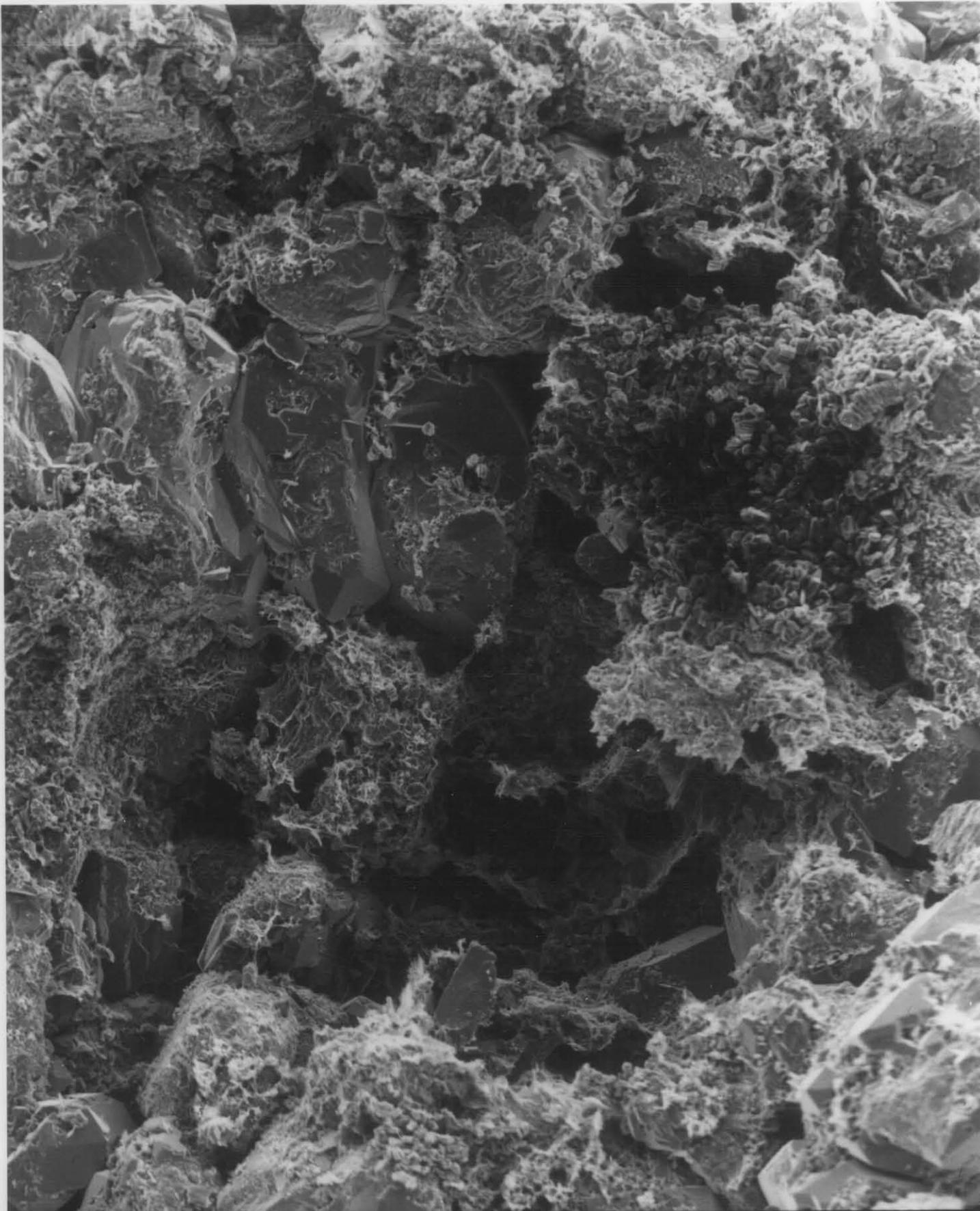


0 10 10 u |  
02-2 20 10 22 000 029

5 cm

PLATE 16: 2878.9 m, Core 2  
Authigenic kaolinite and minor authigenic illite fill what remains of the pore spaces. Quartz overgrowths have continued to grow after the formation of kaolinite. (Kaolinite imbedded in quartz; centre right).

453062



100 10 u |——|  
05-1 20 10 21 000 030

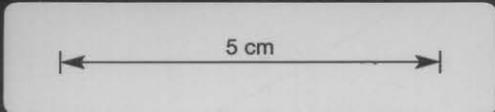
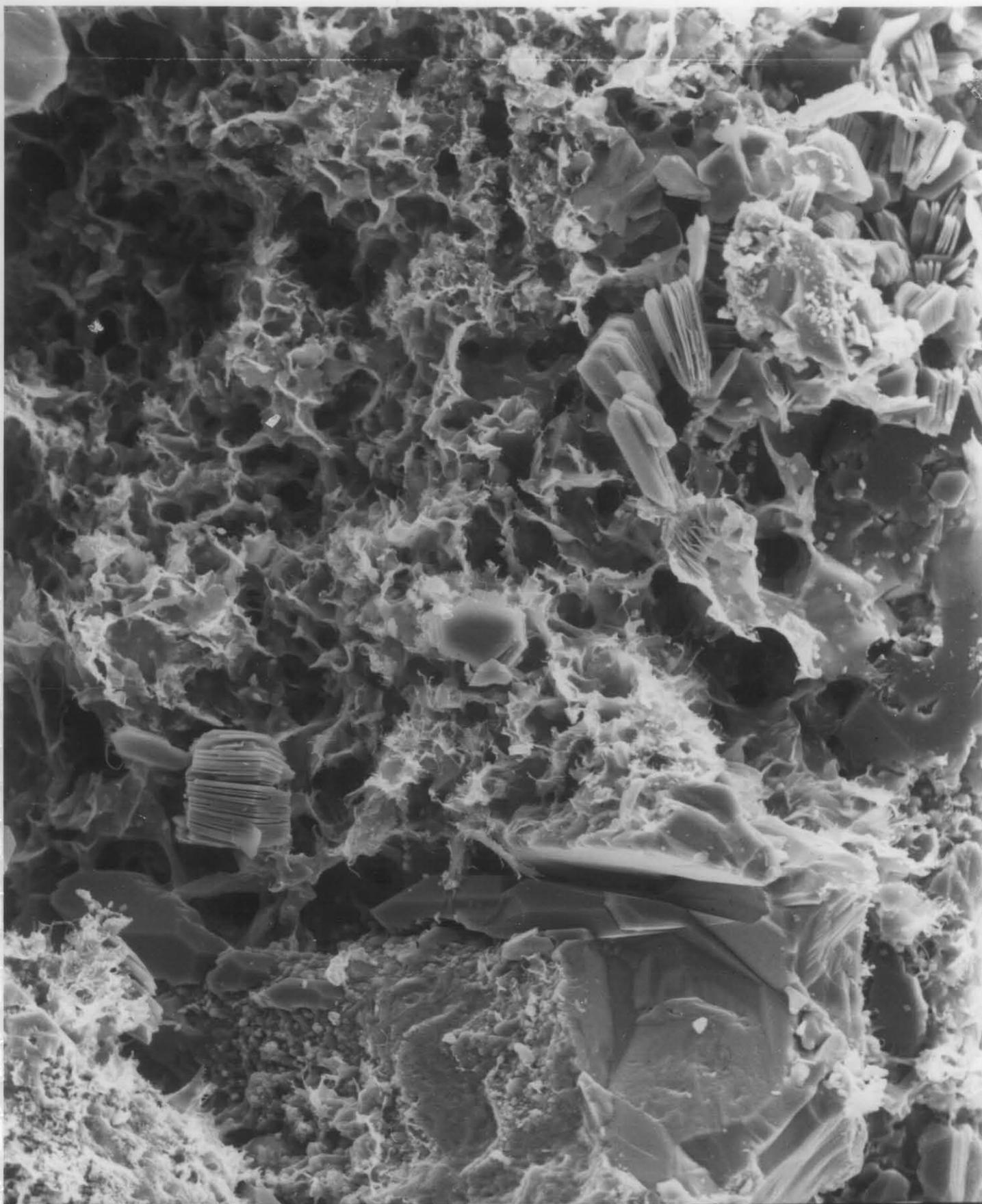


PLATE 17: 2881 m, Core 2  
This sandstone appears to be more porous as lithic fragments are not as common. Authigenic kaolinite and randomly interstratified smectite/illite are common.

453063



0 10 .0 u | |  
03-2 20 .0 20 000 031

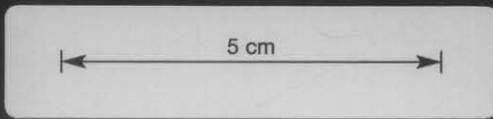


PLATE 18: 2881 m, Core 2  
This plate illustrates the porous and permeable nature of the authigenic clays (randomly interstratified smectite/illite, upper left and kaolinite). Minor authigenic illite is associated with the lithic fragment (lower left corner).

453064

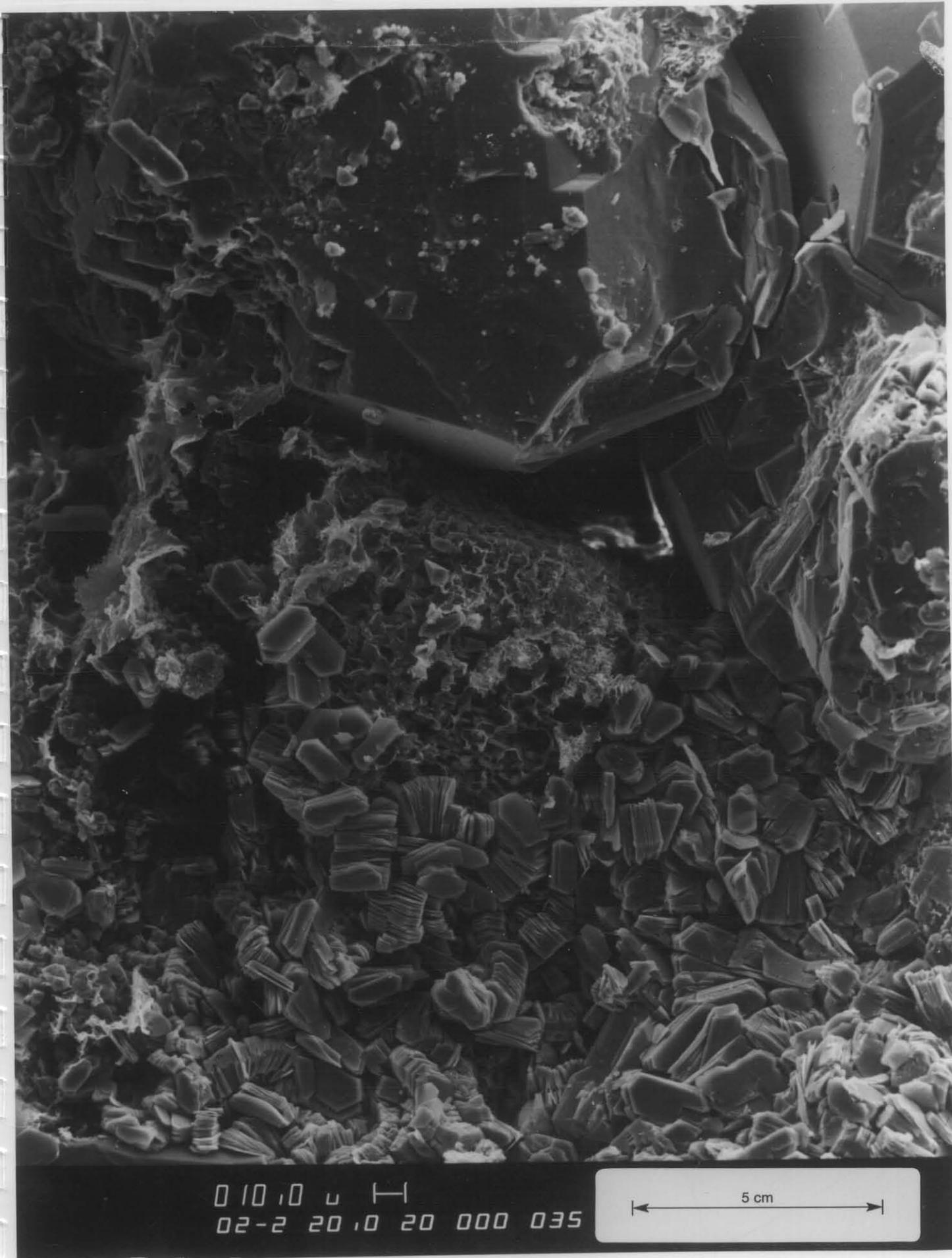
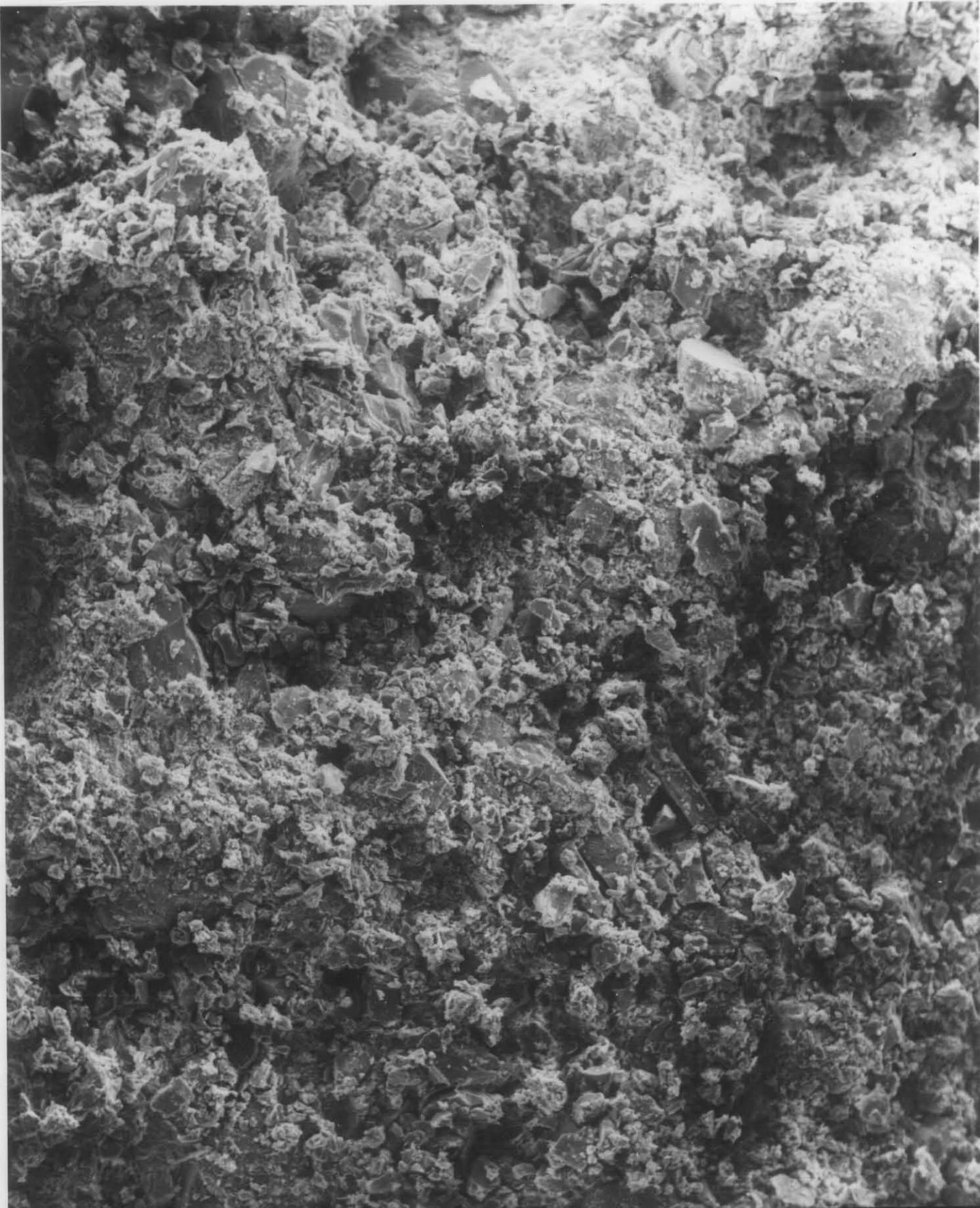


PLATE 19: 2881 m  
Authigenic kaolinite and authigenic smectite occur interstitially to overgrow quartz grains. The smectite appears to be a late stage phase.

453065

APPENDIX 4

SIDEWALL CORES; SEM PLATES



100 10 u |——|  
06-1 20 10 24 000 025

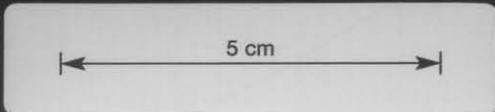
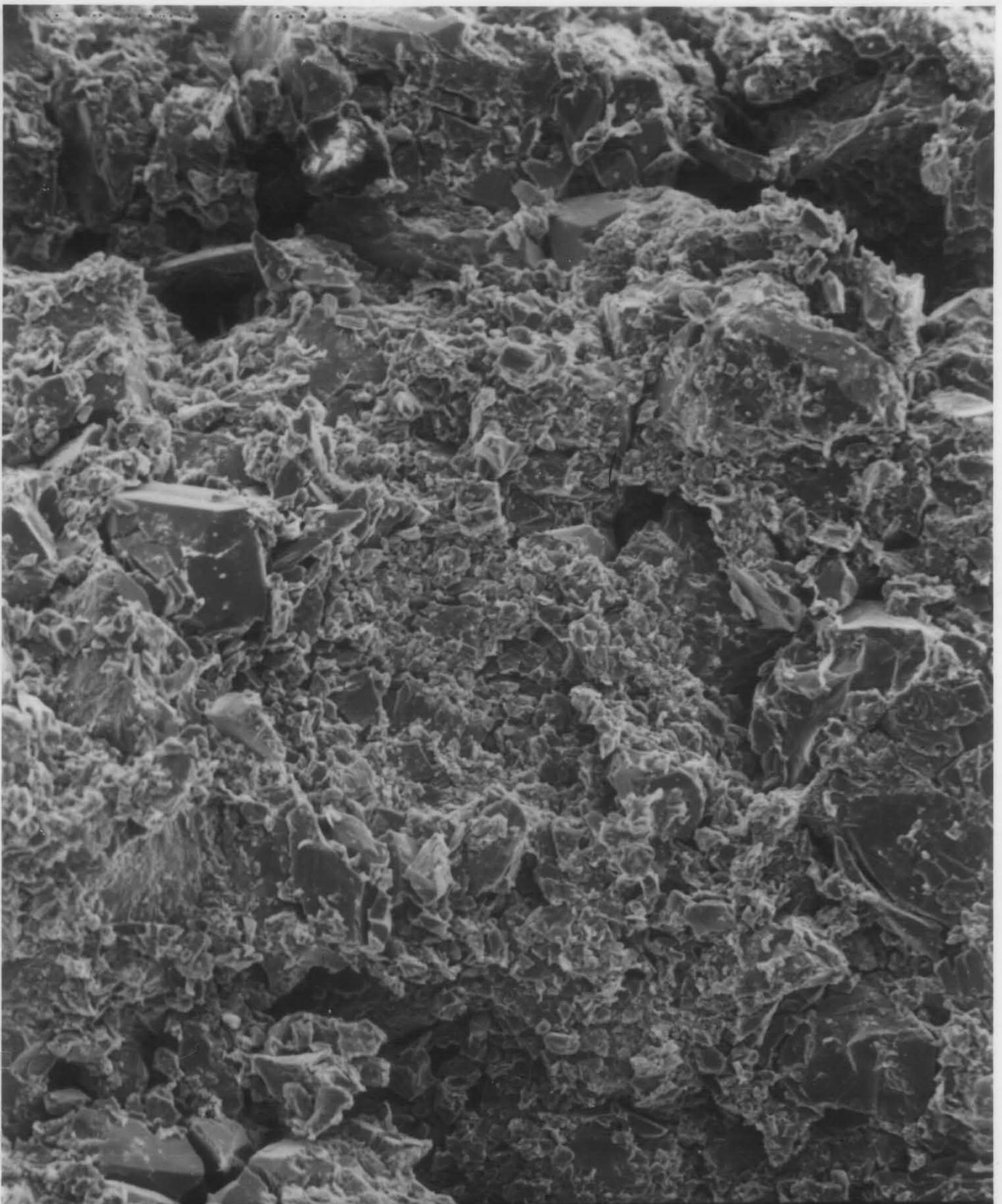


PLATE 1: 2746.5 m  
Porosity is minimal in this sample due to the abundance of lithic fragments and quartz overgrowths. Authigenic clays do not appear to be common.

453067



100 10 u |-----|  
10-1 20 10 21 000 025

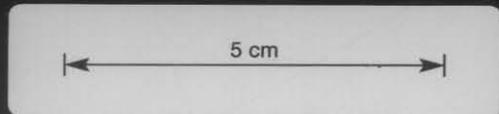
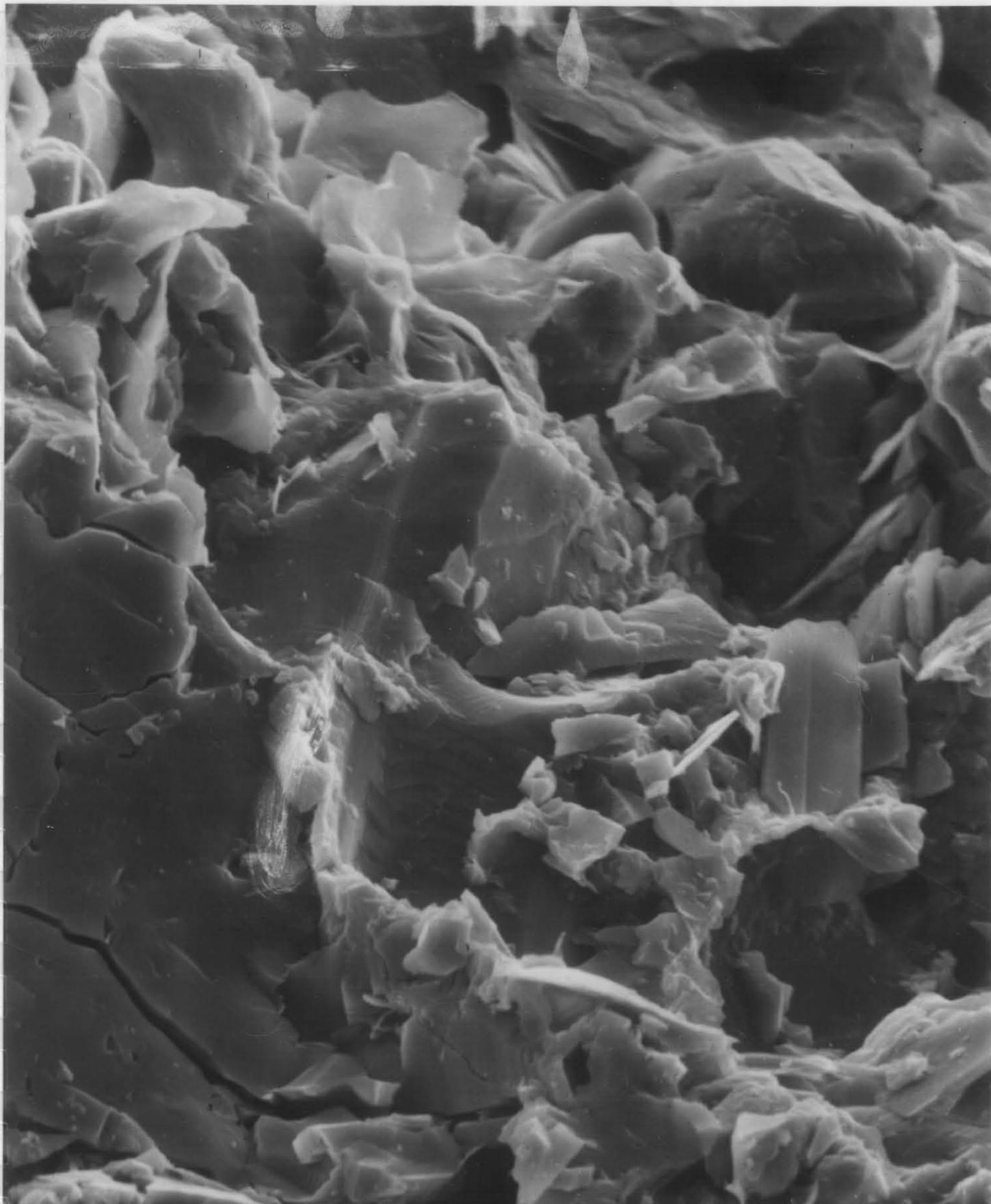


PLATE 2: '2750' m

Lithic fragments do not appear to be quite as abundant in this sandstone and quartz overgrowths are very well developed. However, some porosity remains at the interstices of the quartz grains.

453068



0 10 10  $\mu$  |—————|  
09-2 20 10 22 000 028

5 cm

PLATE 3: 2750 m

Some porosity remains in the lithic fragments (right) however this porosity does not appear to be interconnected. Authigenic kaolinite (K) has been overgrown by quartz. Trace amounts of authigenic illite and smectite occur in the lithic fragments.

453069



100 10 u | |  
04-1 20 10 23 000 029

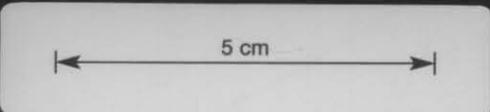


PLATE 4: 3098.5 m  
Quartz grains in this sandstone are cemented by carbonate (?dolomite).  
Lithic fragments and authigenic clays are rare.

453070

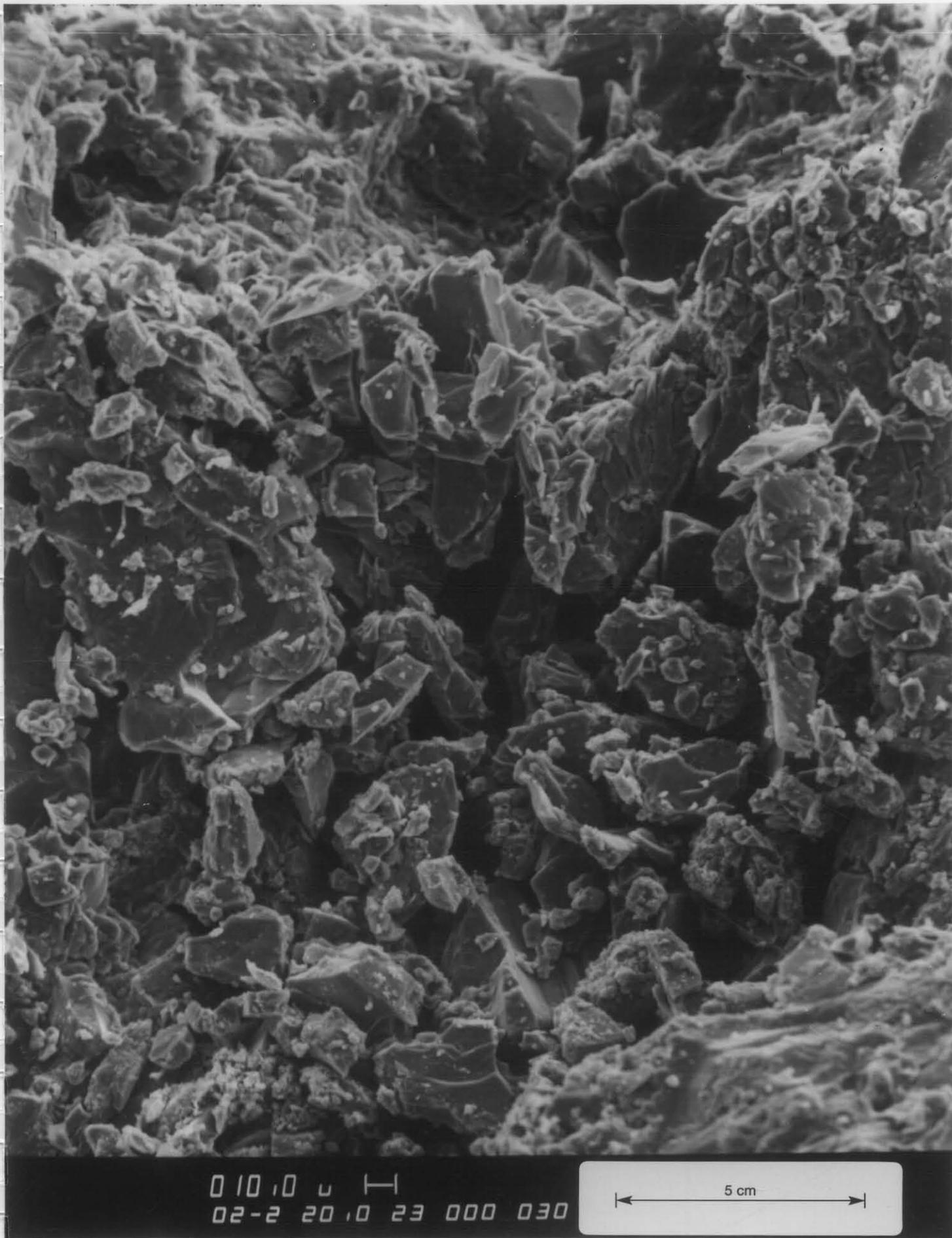


PLATE 5: 3098.5 m  
Pores at the interstices of the overgrown quartz grains are filled with fine-grained quartz and carbonate, however some porosity remains. This porosity may have been enlarged by fracturing during collection of the sidewall core.

453071

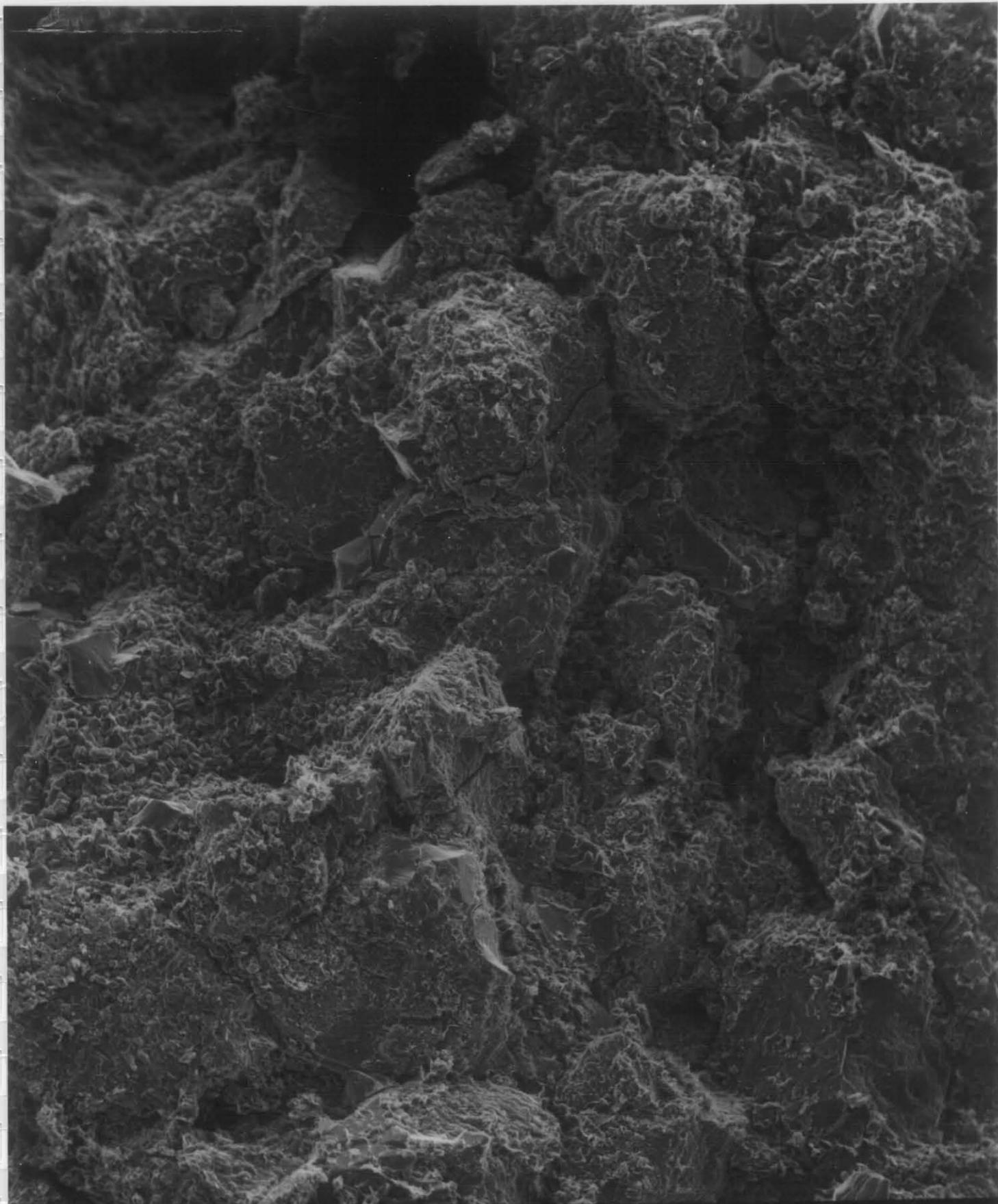


100 10 u |——|  
05-1 20 10 20 000 036

5 cm

PLATE 6: 3109 m  
This appears to be a poorly-sorted sediment containing abundant fine-grained quartz and lithic fragments. Minor amounts of fine-grained carbonate are also present.

453072



100 10 u |-----|  
07-1 20 10 19 000 040

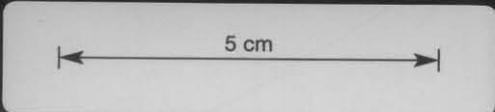
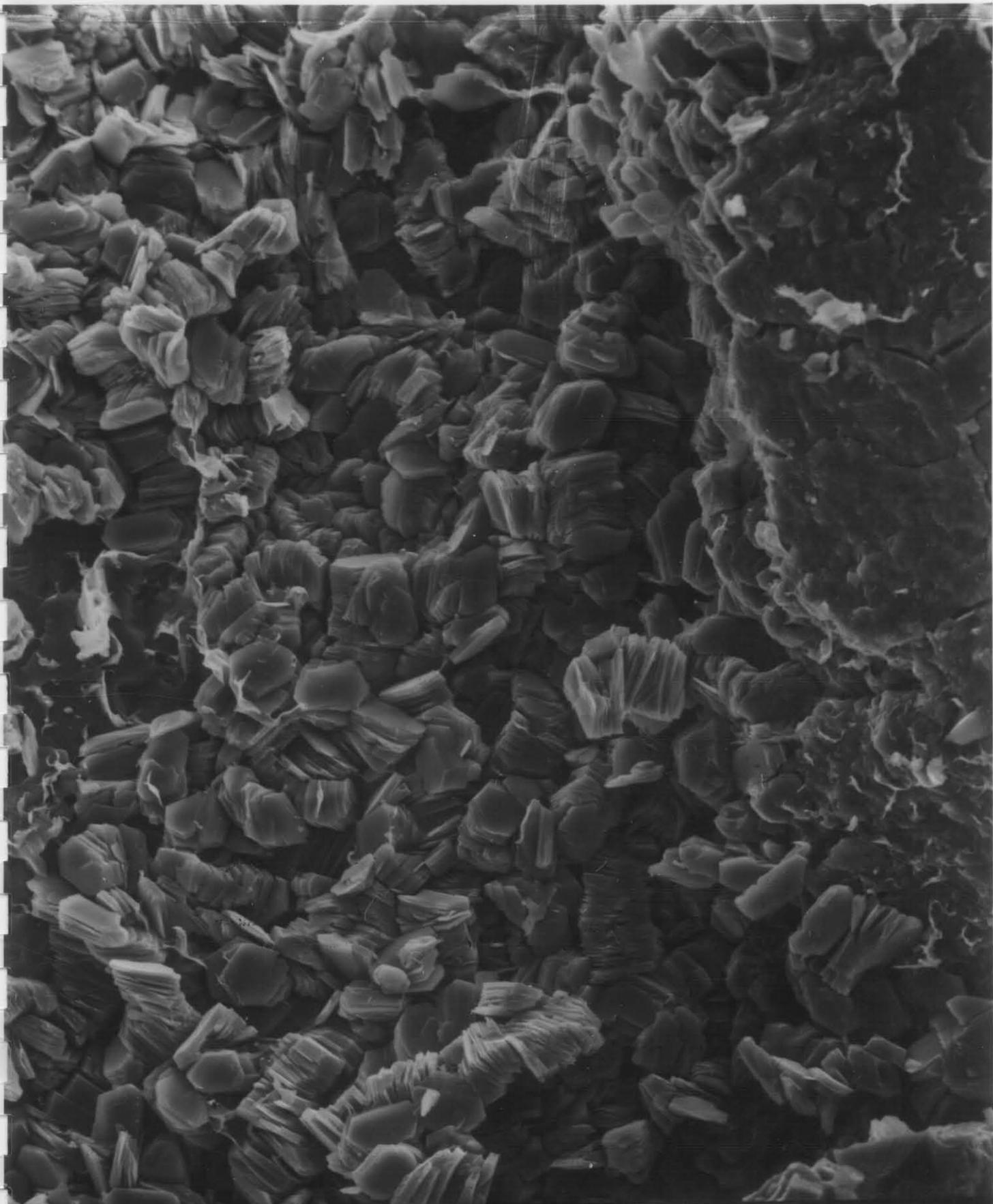


PLATE 7: 3109 m  
Authigenic randomly interstratified ?smectite/illite occurs interstitially to overgrown quartz grains in this plate.

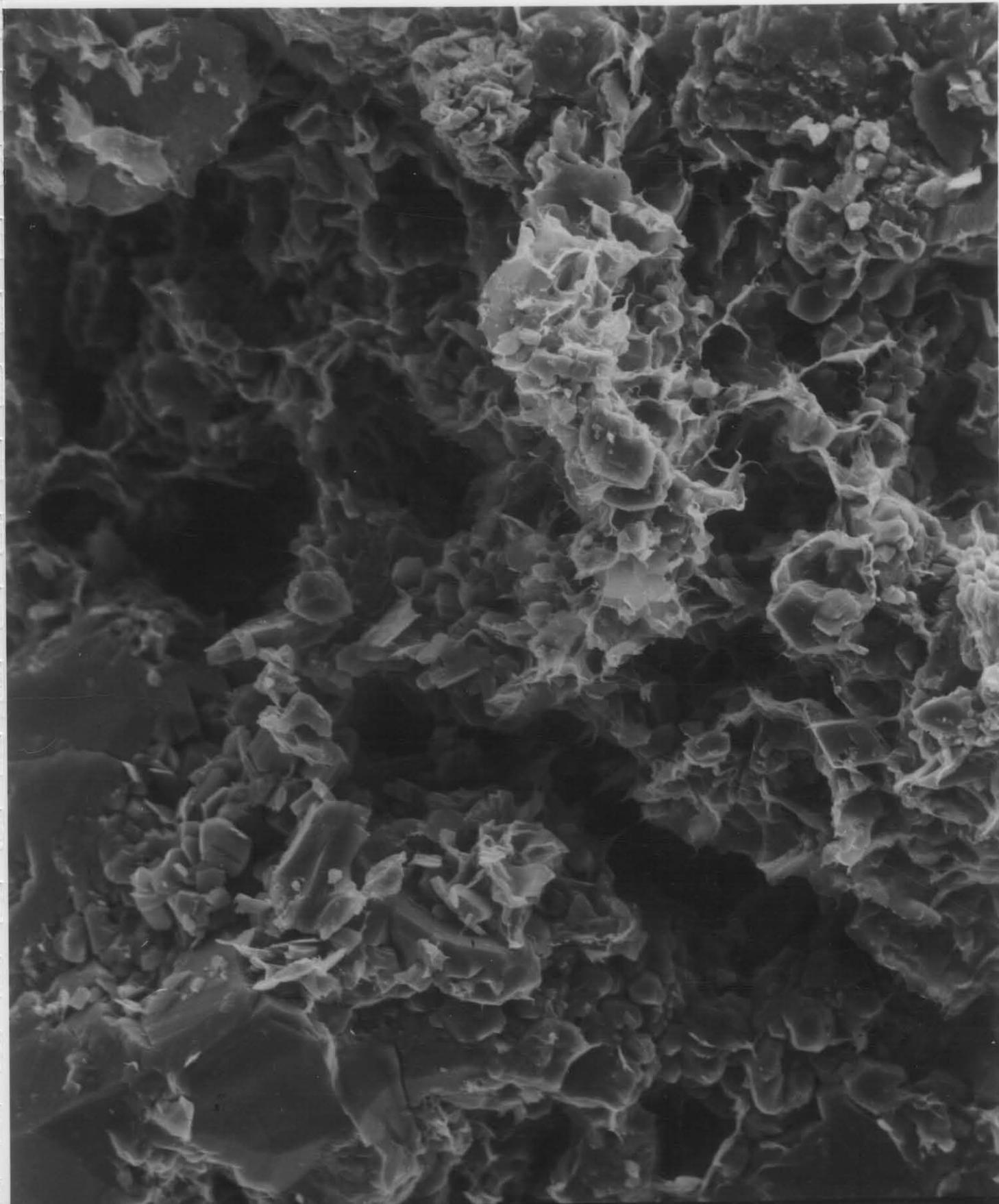


0 10 10 u |——|  
05-2 20 10 19 000 041

5 cm

PLATE 8: 3155.5 m  
This plate shows a coarse-grained portion of this sediment. Lithic fragments are abundant and fine-grained authigenic carbonate is rare.

453074

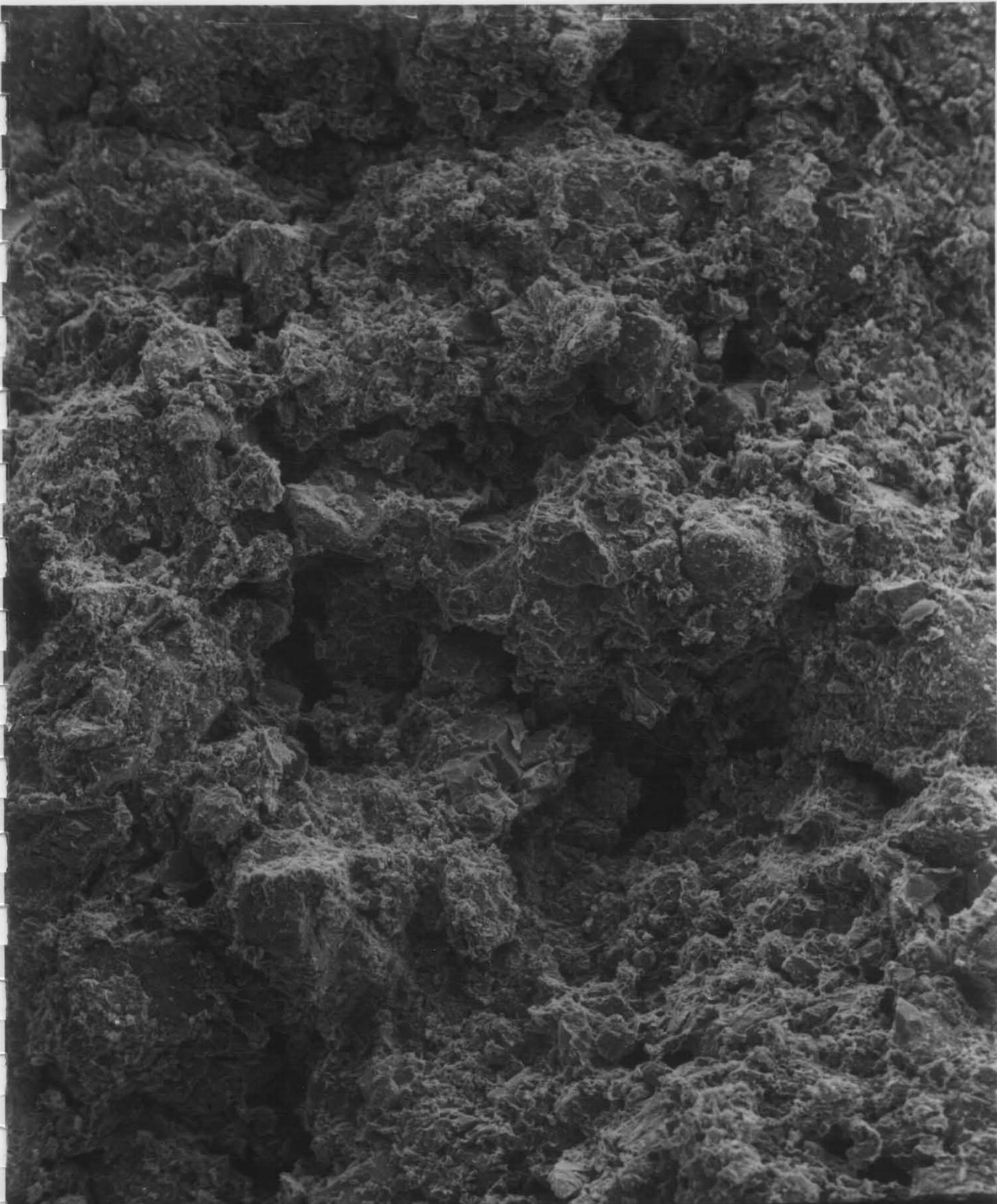


01010 u | |  
05-2 20.0 18 000 042

5 cm

PLATE 9: 3155.5 m  
?Zeolite crystals are growing from a lithic fragment adjacent to an overgrown quartz grain. Some small pore spaces ( $\sim 10 \mu\text{m}$ ) are preserved in this sediment.

453075



100.0 u |——|  
05-1 20.0 17 000 043

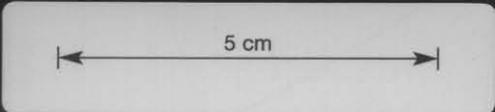
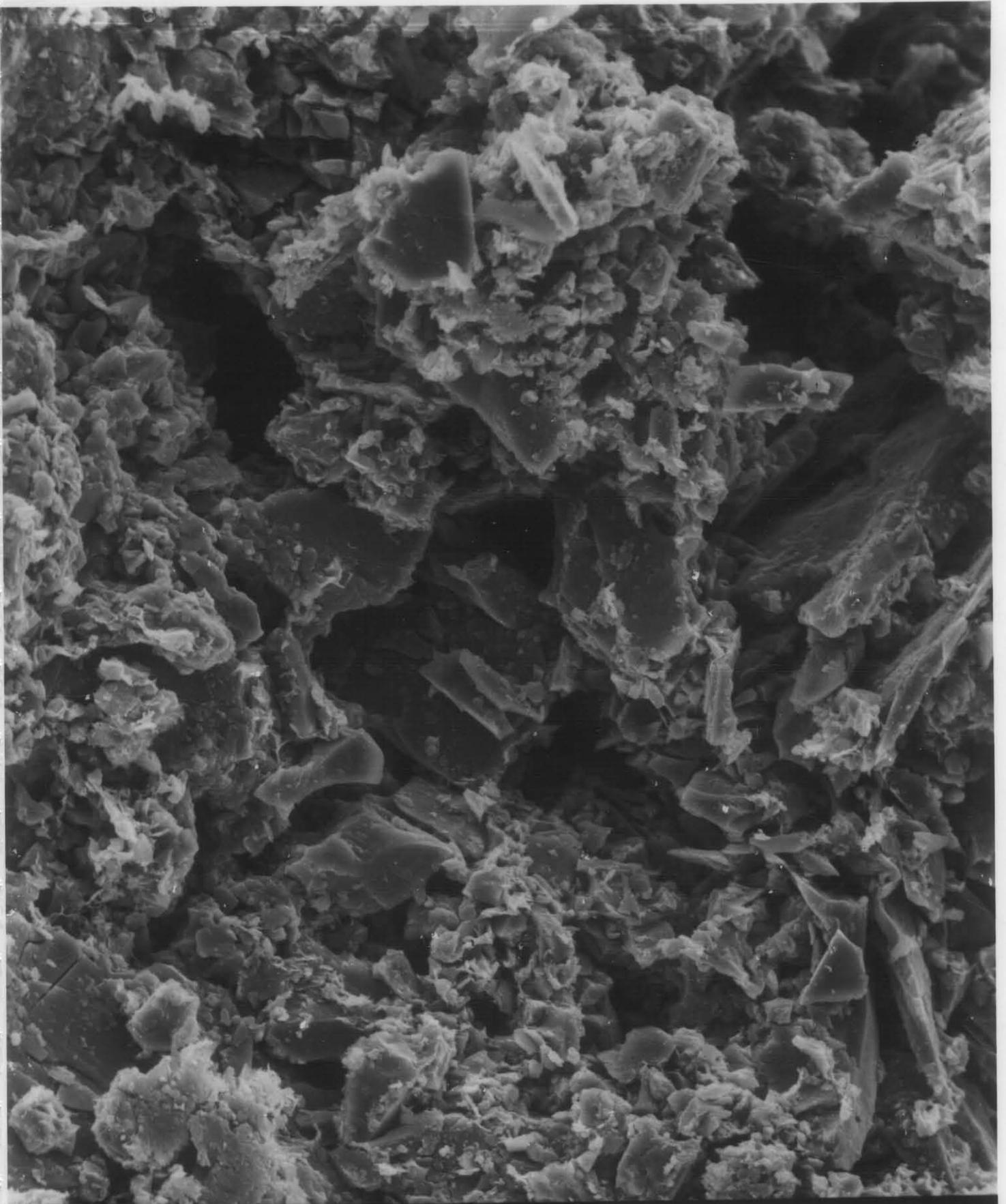


PLATE 10: 3159 m  
Lithic fragments are again abundant in this sediment. However some primary porosity remains between overgrown quartz grains.

453076



01010 u |—|  
04-2 20.0 17 000 044

5 cm

PLATE 11: 3159 m

Minor authigenic kaolinite occurs adjacent to an overgrown quartz grain (centre). Fine-grained carbonate occurs towards the top of the plate (top centre).

453077



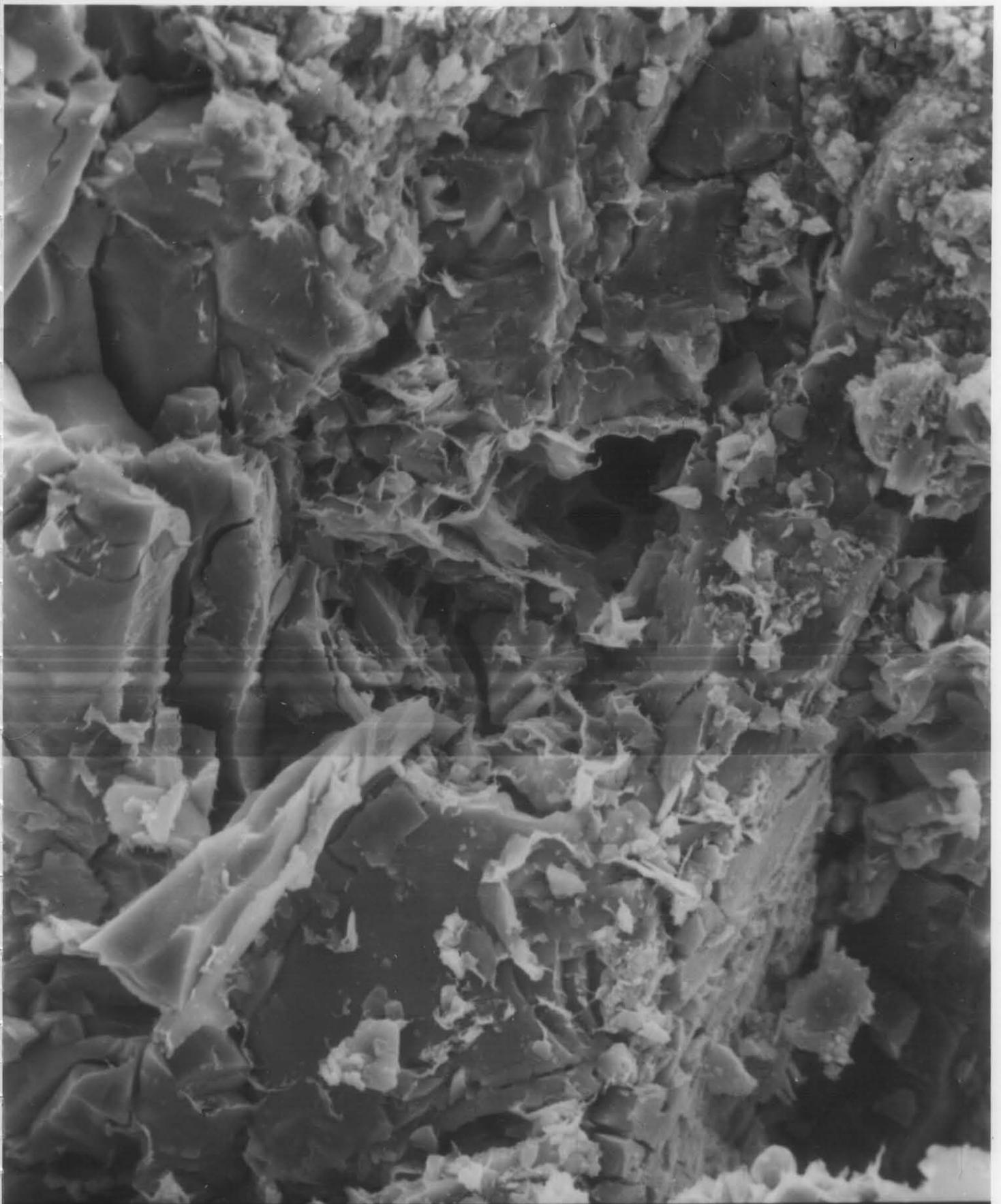
100 10 u |——|  
07-1 20 10 24 000 031

5 cm

PLATE 12: 3194 m

This sandstone is also well cemented by carbonate (top centre) but contains considerably more lithic fragments than the previous sample. Pore spaces are rare but occur both at the interstices of the quartz grains (top centre) and in the lithic fragments (top right).

453078



0 10 10 u |-----|  
07-2 20 10 20 000 032

5 cm

PLATE 13: 3194 m  
Traces of authigenic clay (randomly interstratified smectite/illite) occur in this pore space. Authigenic carbonate (bottom right) appears to be banded.

453079



100 10 u |——|  
05-1 20 10 21 000 002

5 cm

PLATE 14: 3198.5 m  
This sample is similar to the previous sample but contains a high proportion of lithic fragments. Some porosity remains at the interstices of the quartz grains and within the lithic fragments.

453080

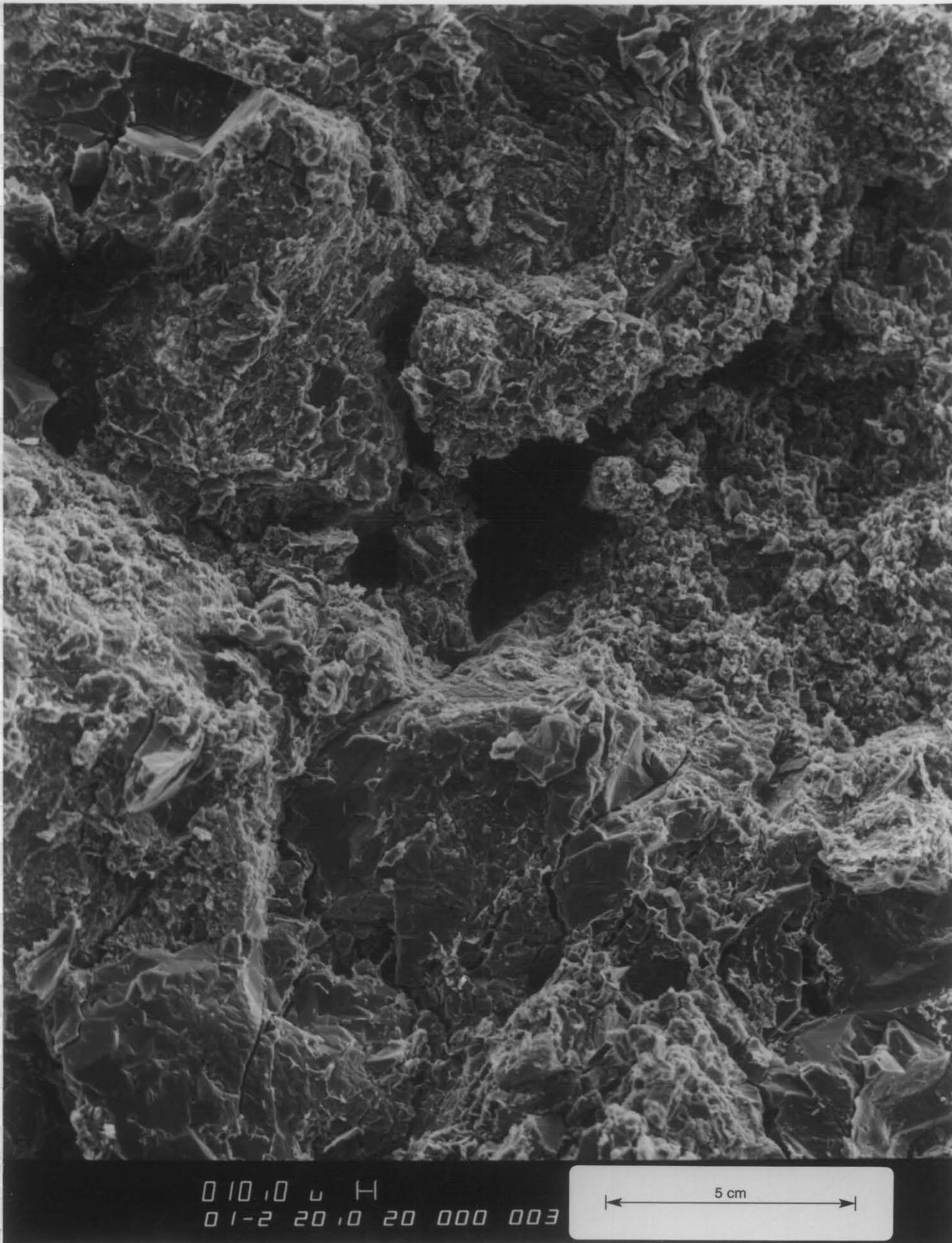
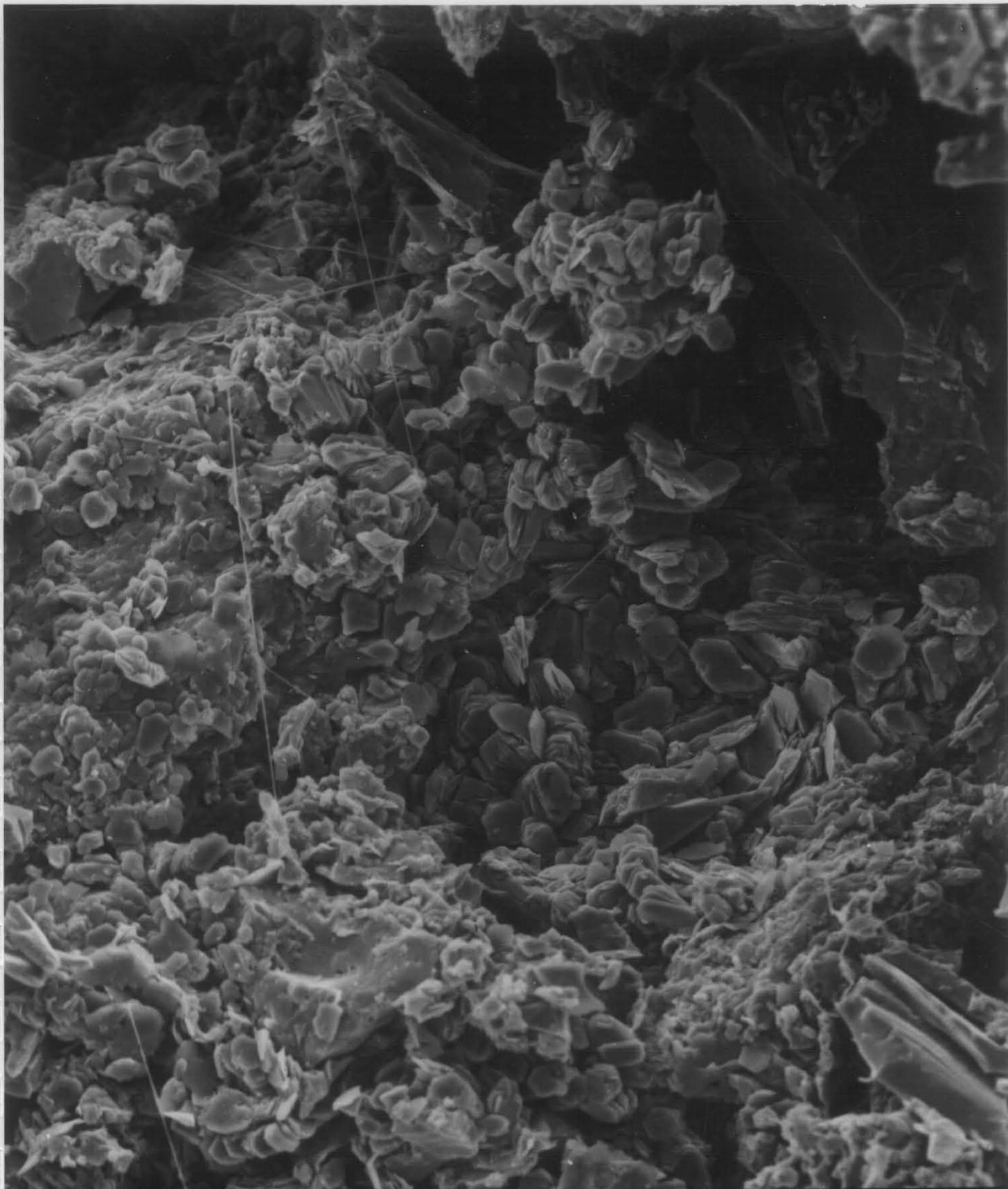


PLATE 15: 3198.5 m

Authigenic carbonate (top left) has filled much of the pore spaces in this sandstone. However some porosity remains interstitial to the overgrown quartz grains and squashed lithic fragments.

453081

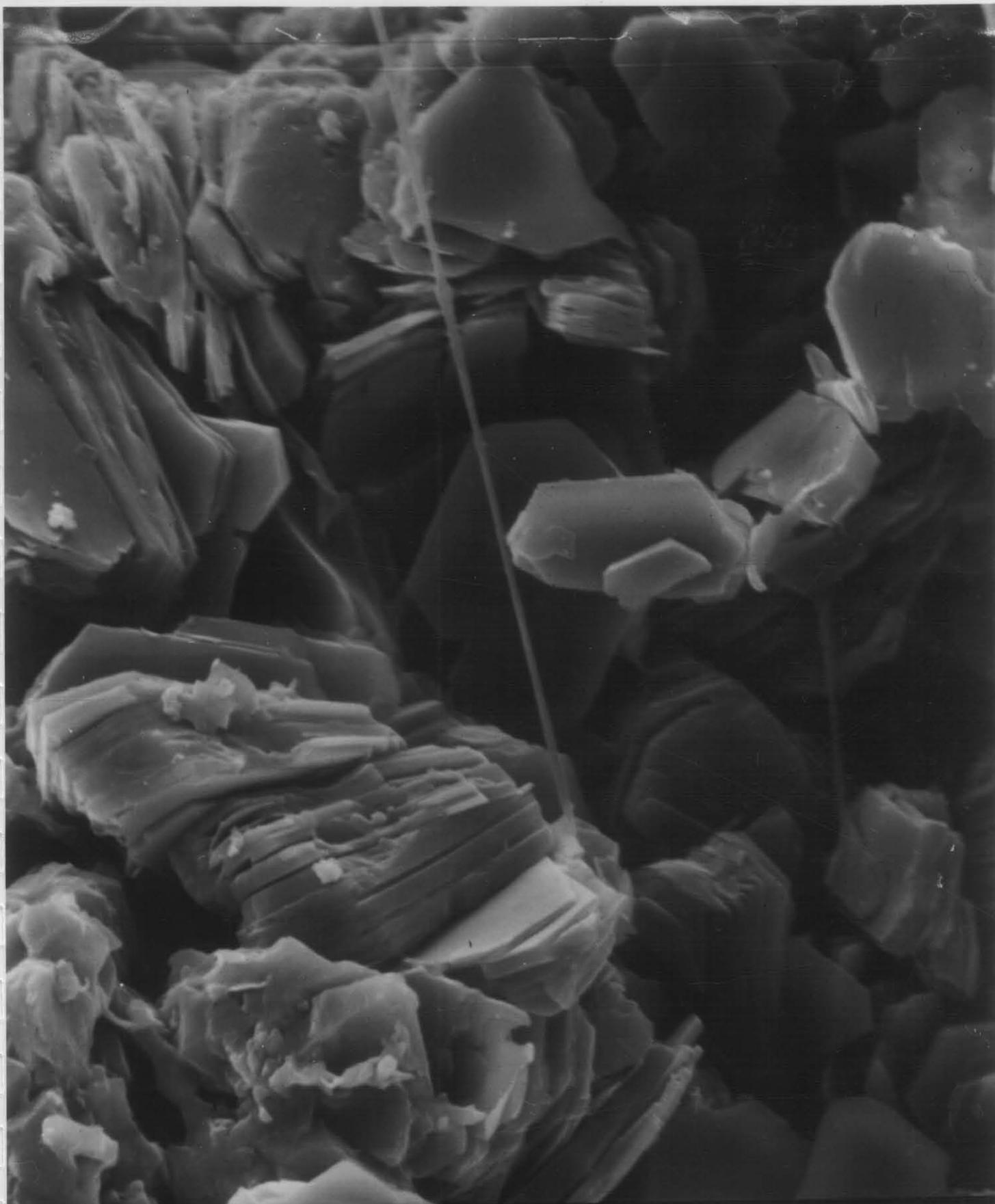


010.0 u H  
02-2 20.0 19 000 038

5 cm

PLATE 16: 3442.5 m  
Quartz grains in this sandstone are rounded to sub-angular. ?Lithic fragments containing fine-grained quartz constitute a major proportion of this rock and porosity is minimal.

453082

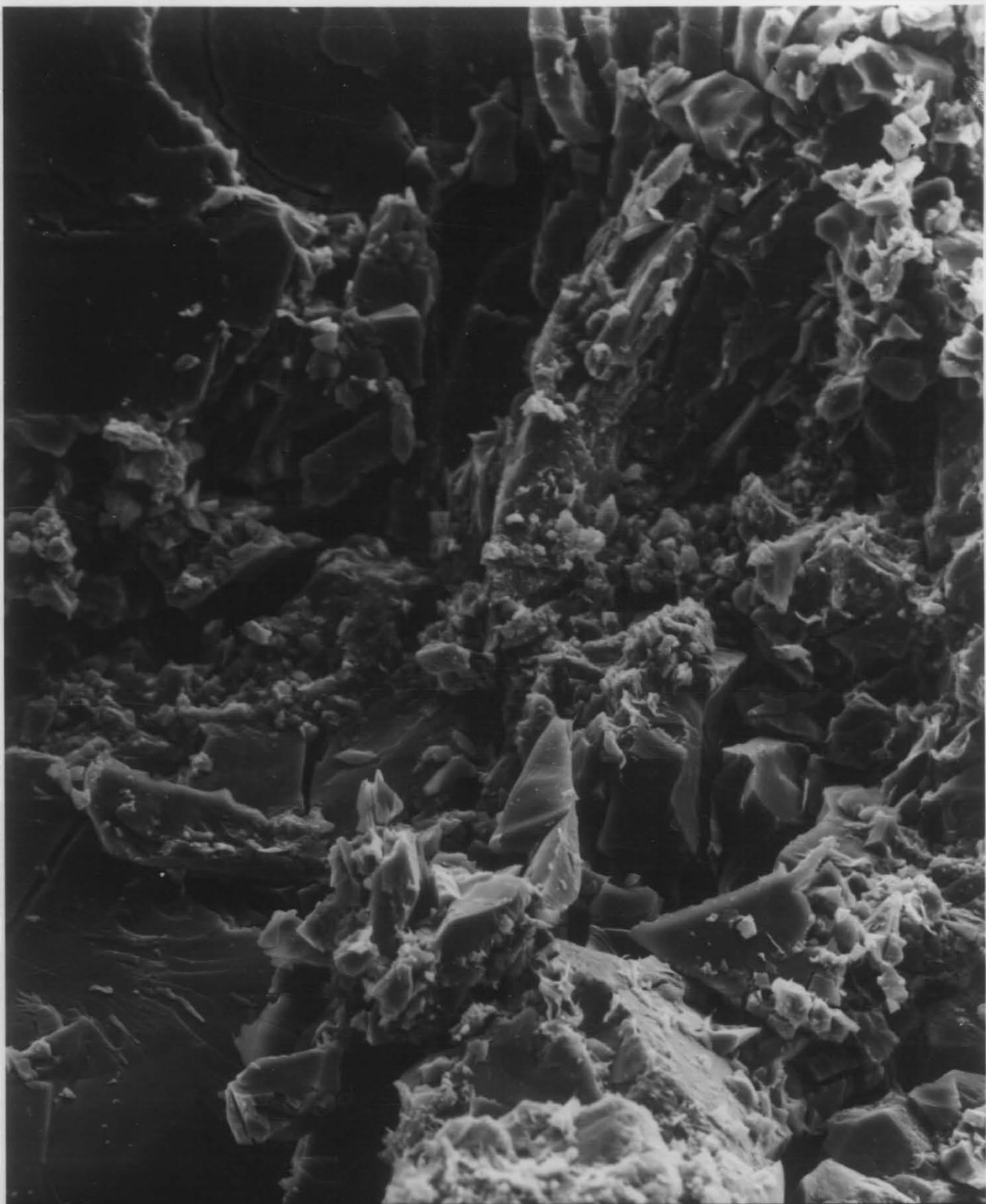


0 10 10 μ |-----|  
15-2 20 10 19 000 039

5 cm

PLATE 17: 3442.5 m  
Authigenic kaolinite and illite fills this pore space which occurs at the interstices of lithic fragments (left) and quartz (right).

453083



0 10 10 u |  
04-2 20 10 20 000 037

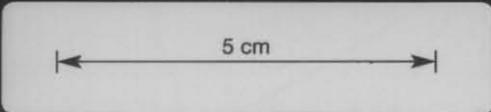
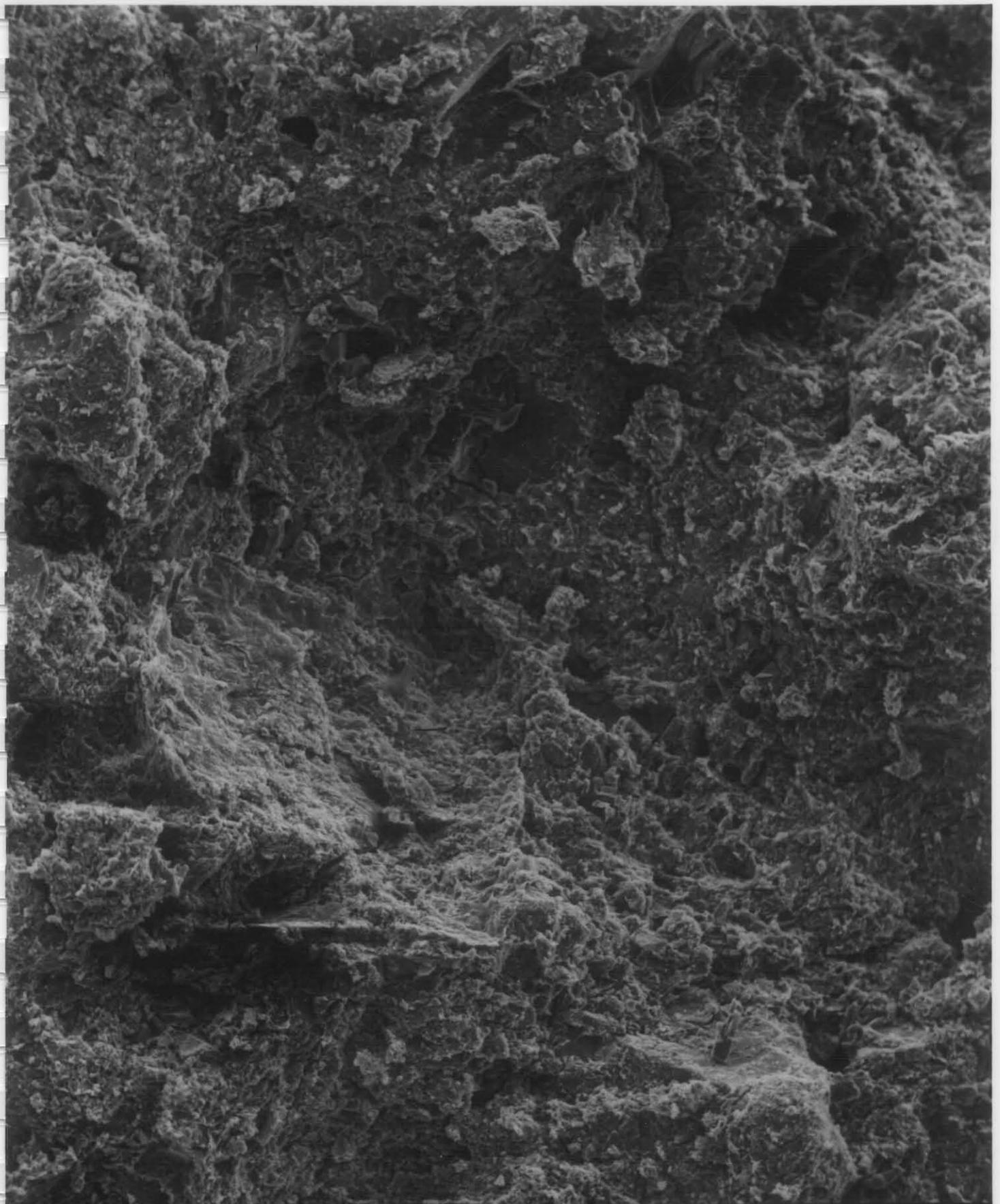


PLATE 18: 3442.5 m  
The fibrous illite is attached to the kaolinite and hence must have formed after the kaolinite.



100 10 u |-----|  
08-1 20 10 21 000 004

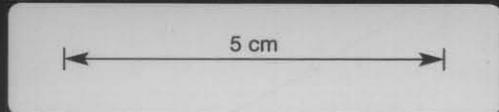
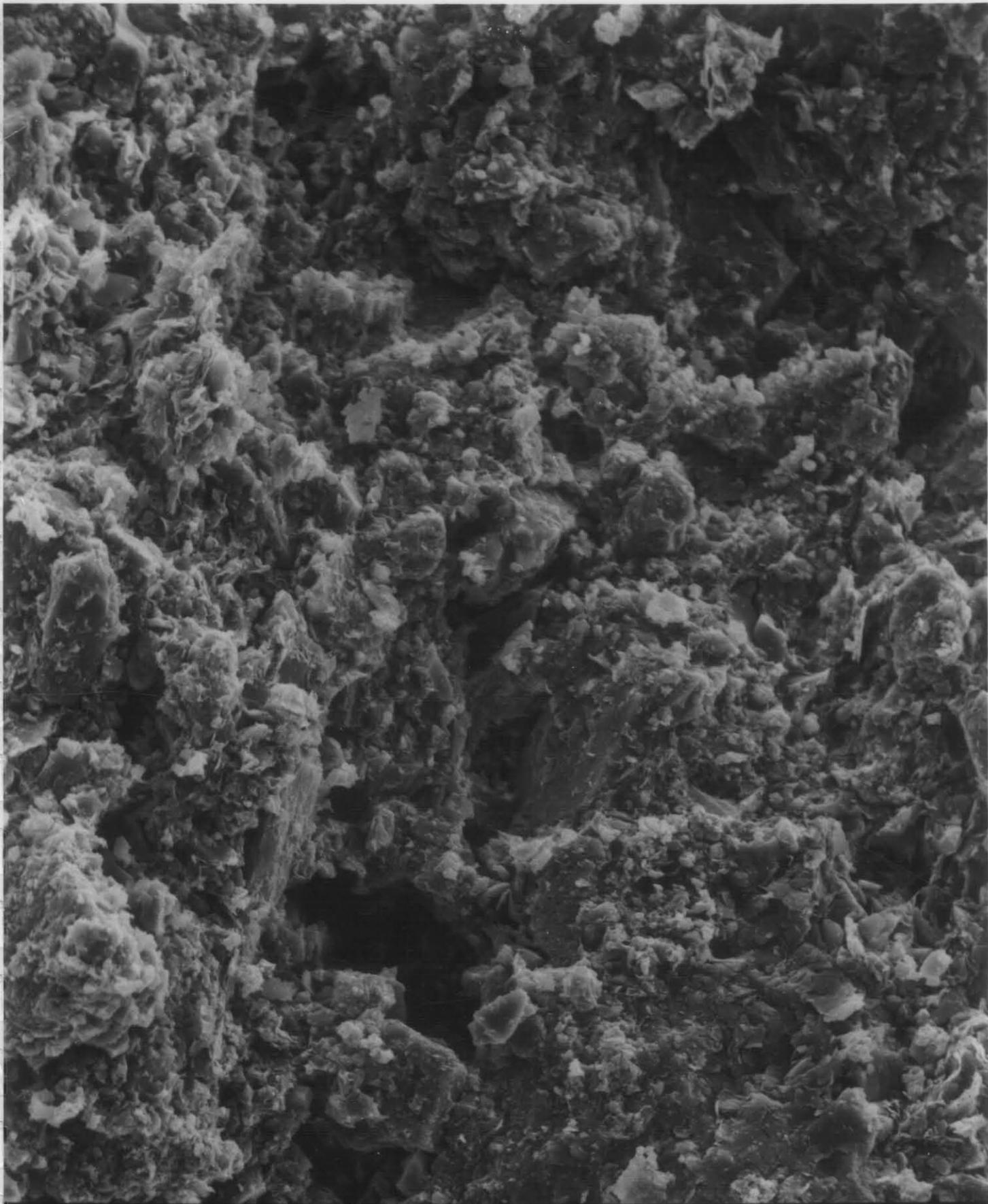


PLATE 19: 3447 m  
Lithic fragments again constitute a major proportion of this sandstone and carbonate is abundant. A large proportion of the pore spaces occur within the lithic fragments.



0 10 10 u |——|  
05-2 20 10 21 000 005

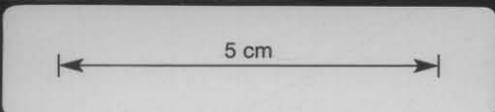
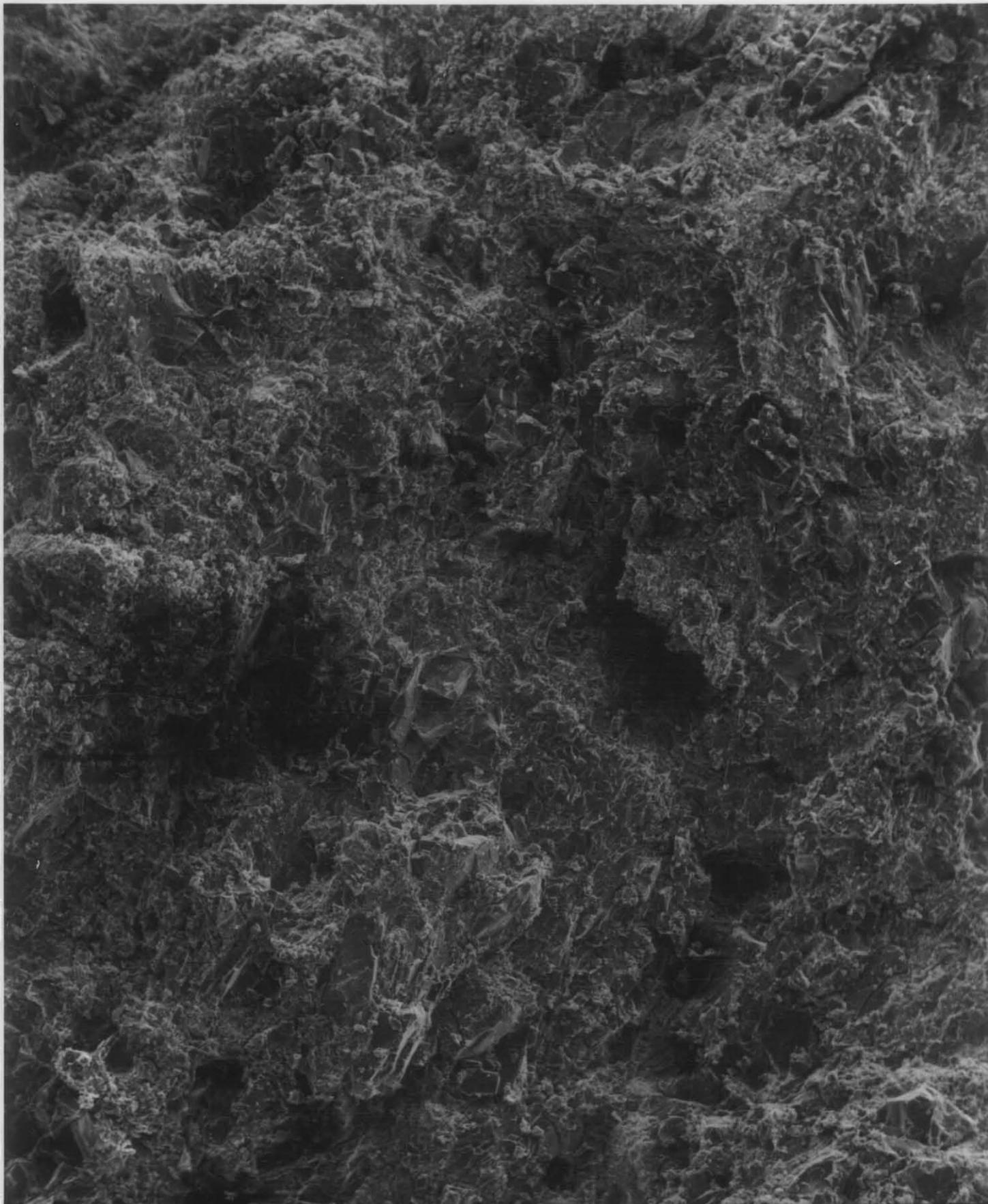


PLATE 20: 3447 m  
This is one of the smaller pore spaces in this rock which has been partially filled by carbonate.

453086



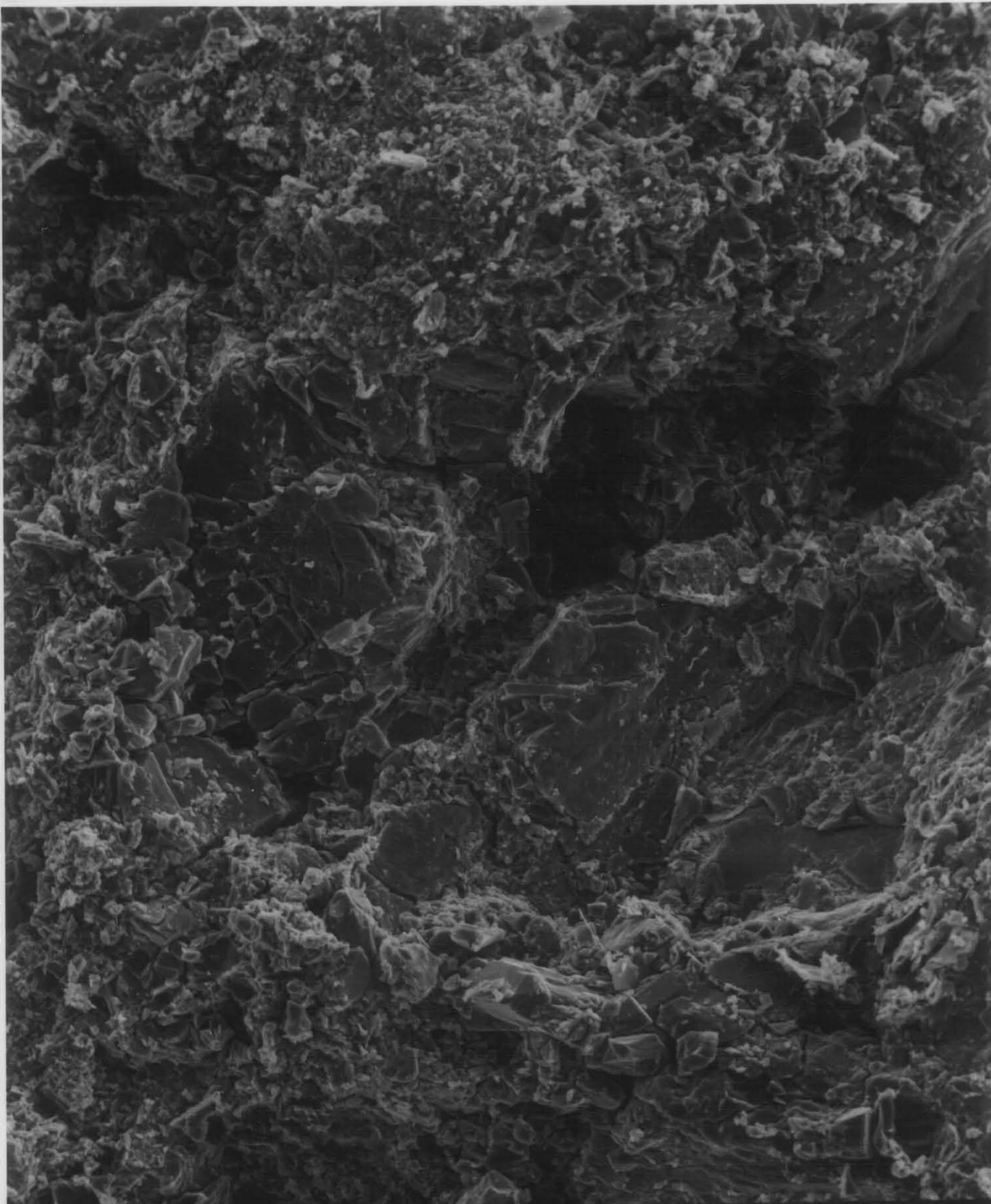
100 10 u |—|  
04-1 20 10 21 000 006

5 cm

PLATE 21: 3592 m

This rock appears to be surprisingly porous considering the high proportion of lithic fragments, quartz overgrowths and carbonate. Pore spaces occur both at the interstices of the quartz grains and within the lithic fragments.

453087



0 10 10 u H  
0 1-2 20 10 21 000 007

5 cm

PLATE 22: 3592 m

The large pore space in this plate is partially filled by carbonate and does not appear to be interconnected. Smaller pore spaces occur in the lithic fragment (lower left).

453088

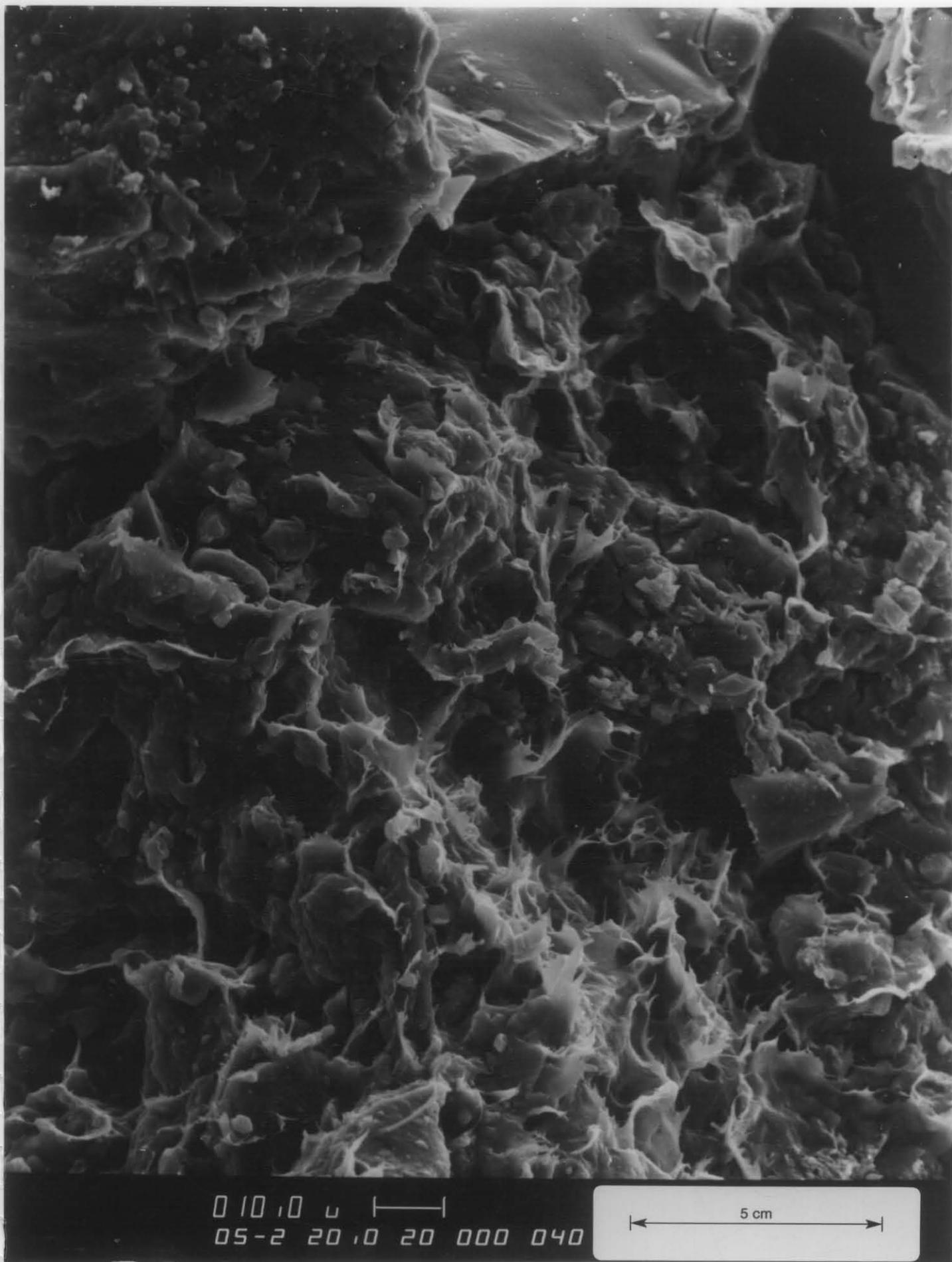
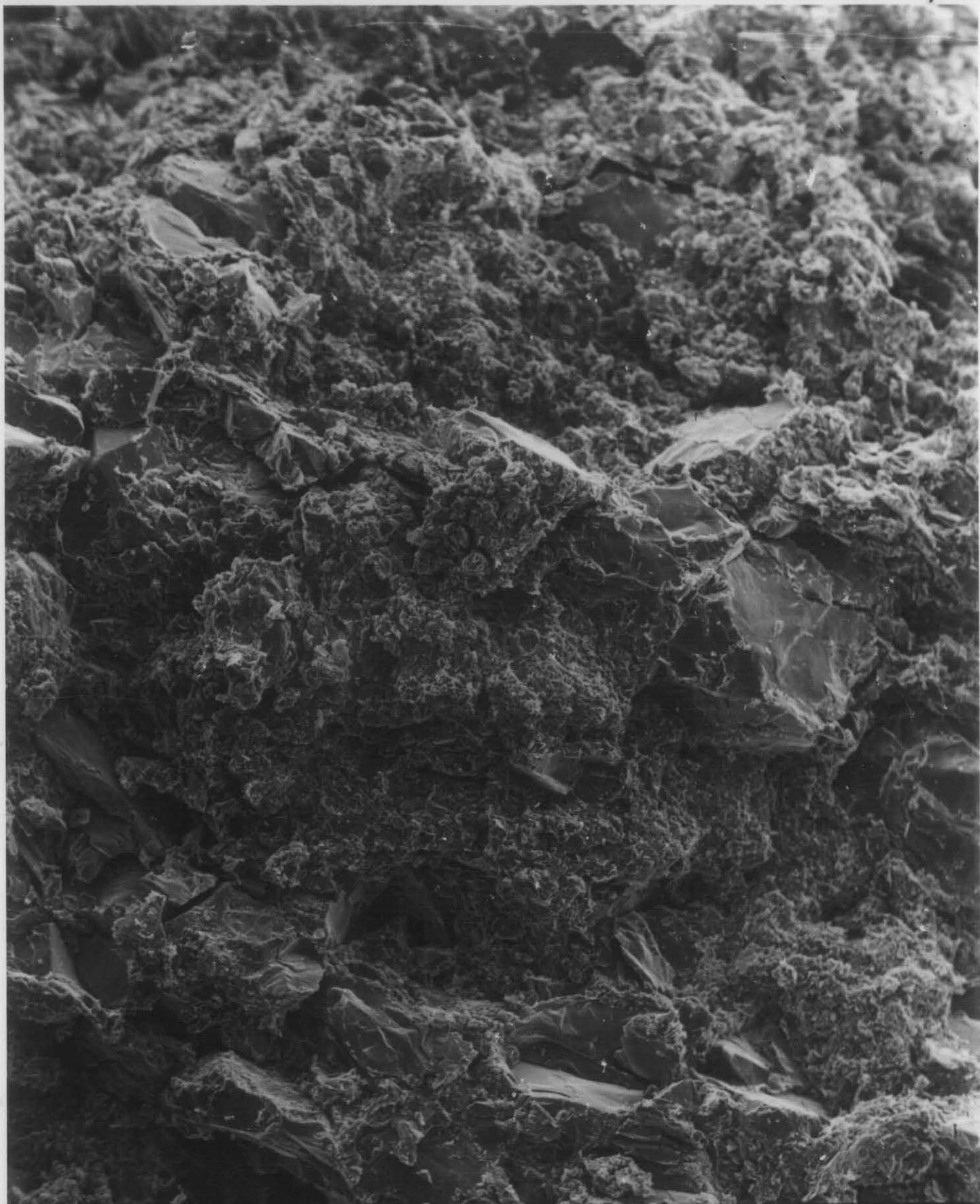


PLATE 23: 3609.5 m.  
The quartz grains in this sandstone are generally sub-angular. Porosity is minimal and generally occurs where the interstices of the larger grains have not been completely filled by squashed lithic fragments or authigenic clays.

453089



100.0 μ |  
05-1 20.0 19 000 041

5 cm

PLATE 24: 3609.5 m  
Authigenic kaolinite almost completely fills this pore space between quartz grains. Authigenic ?smectite/illite is overgrown by quartz at the edge of these grains.

453090

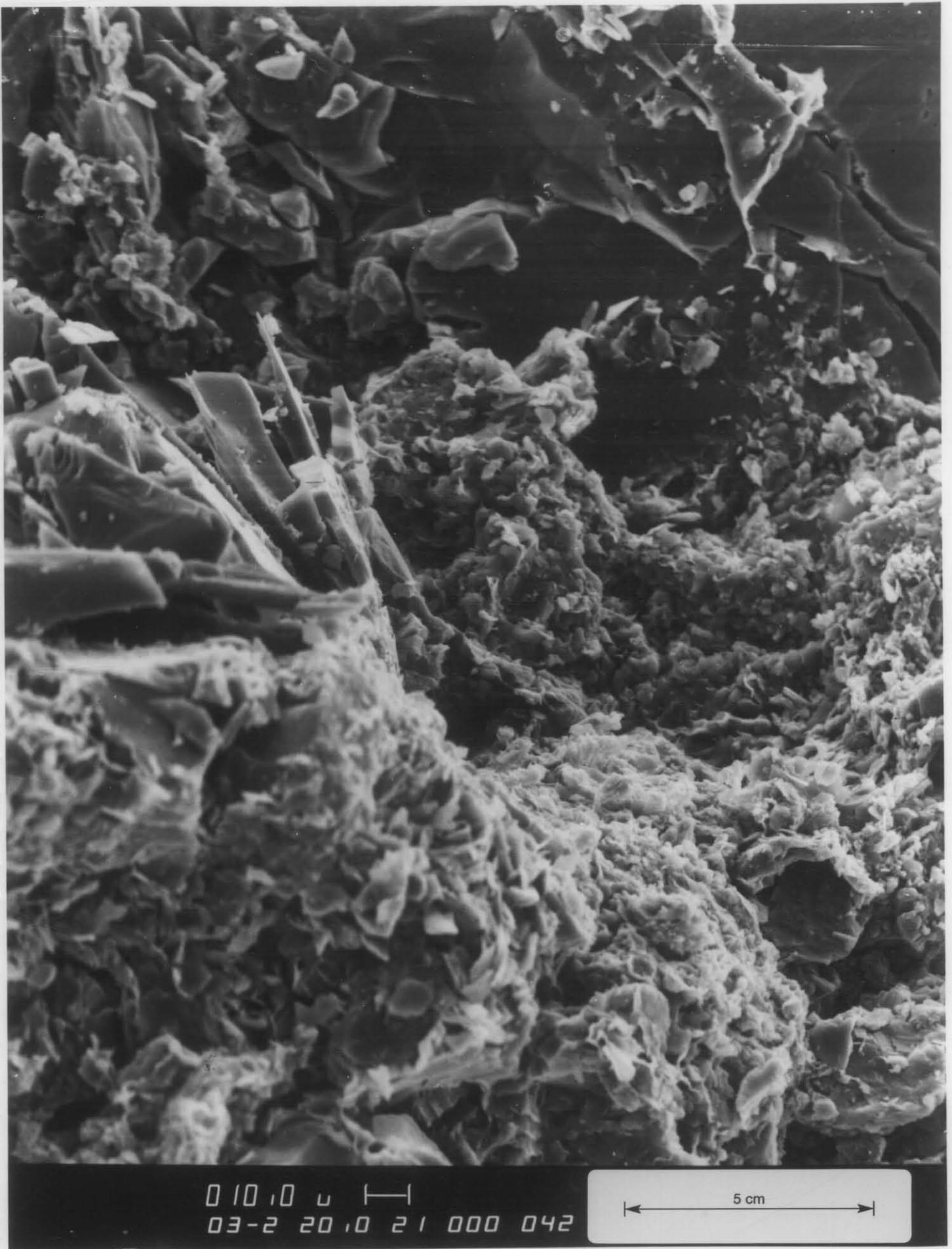
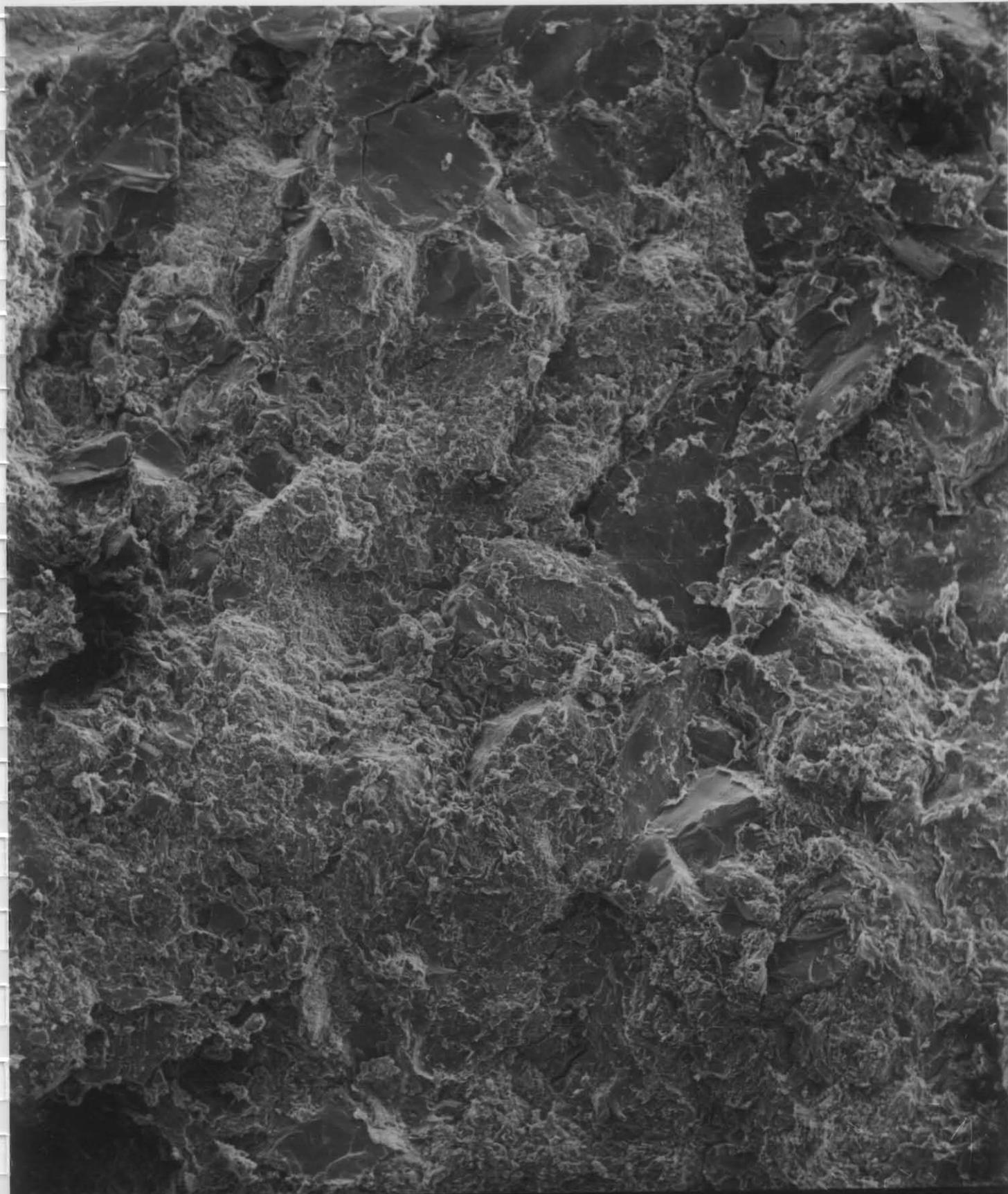


PLATE 25: 3607.5 m  
Authigenic smectite/illite and quartz fill the majority of this pore space.

453091



100 10 μ |  
03-1 20 10 23 000 008

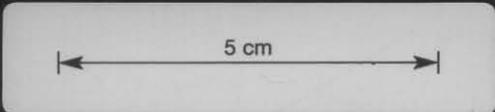


PLATE 26: 3617 m  
Porosity is minimal in this sandstone. Lithic fragments comprise about one third of the rock volume. Quartz grains are extensively overgrown.

453092

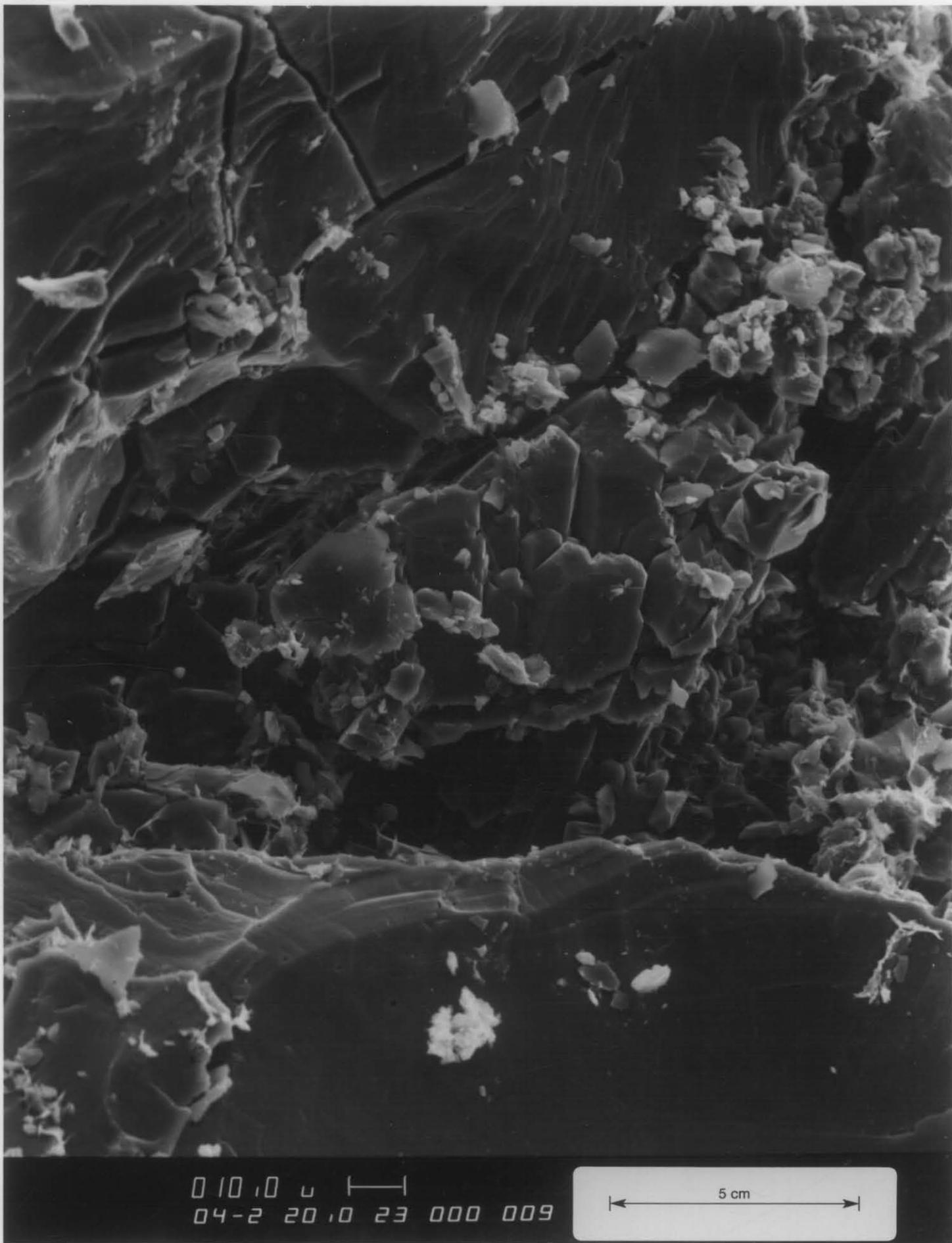
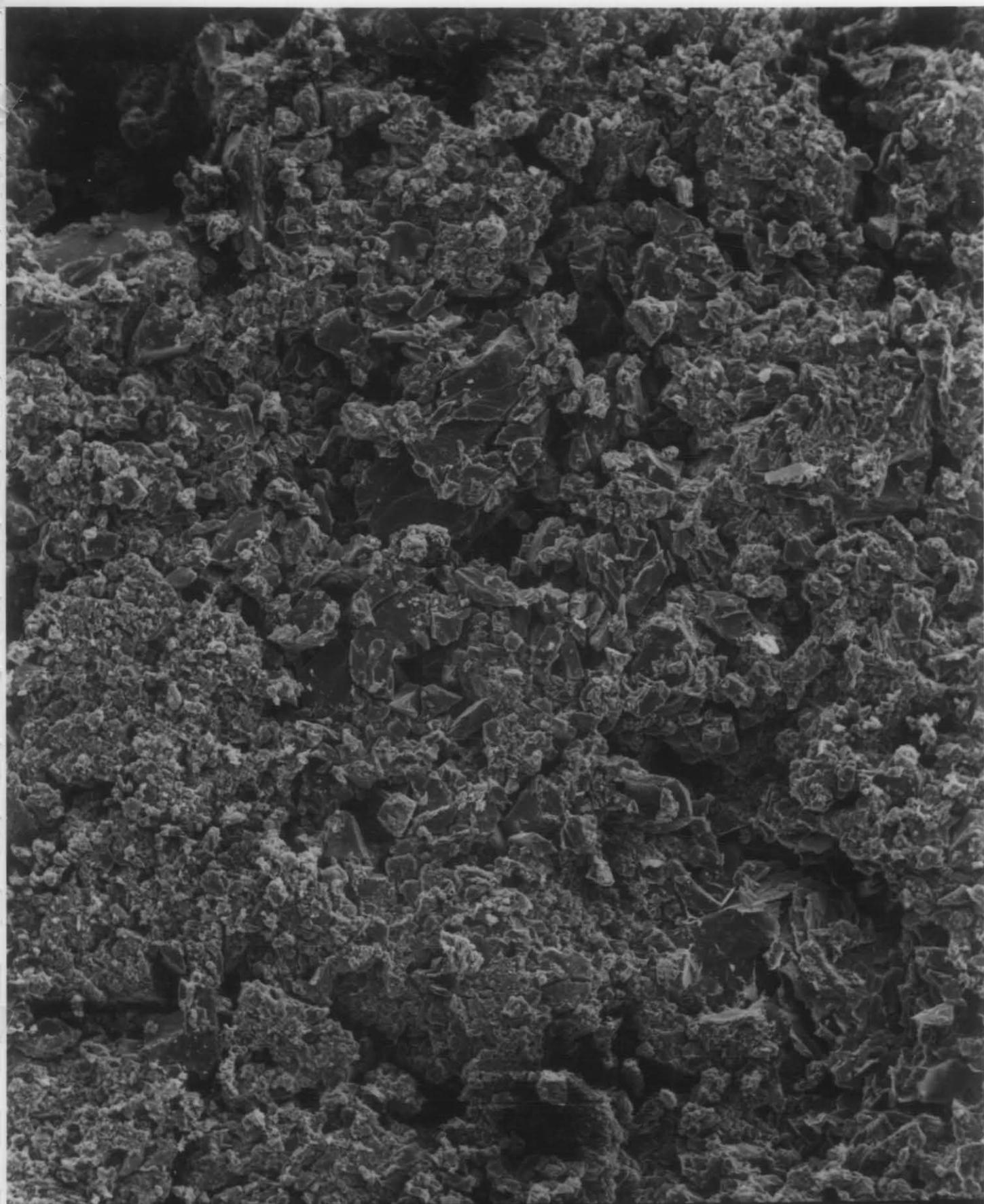


PLATE 27: 3617 m  
Authigenic clays (illite; lower left, illite/smectite; centre right) occur  
in trace amounts in this pore space between overgrown quartz grains.

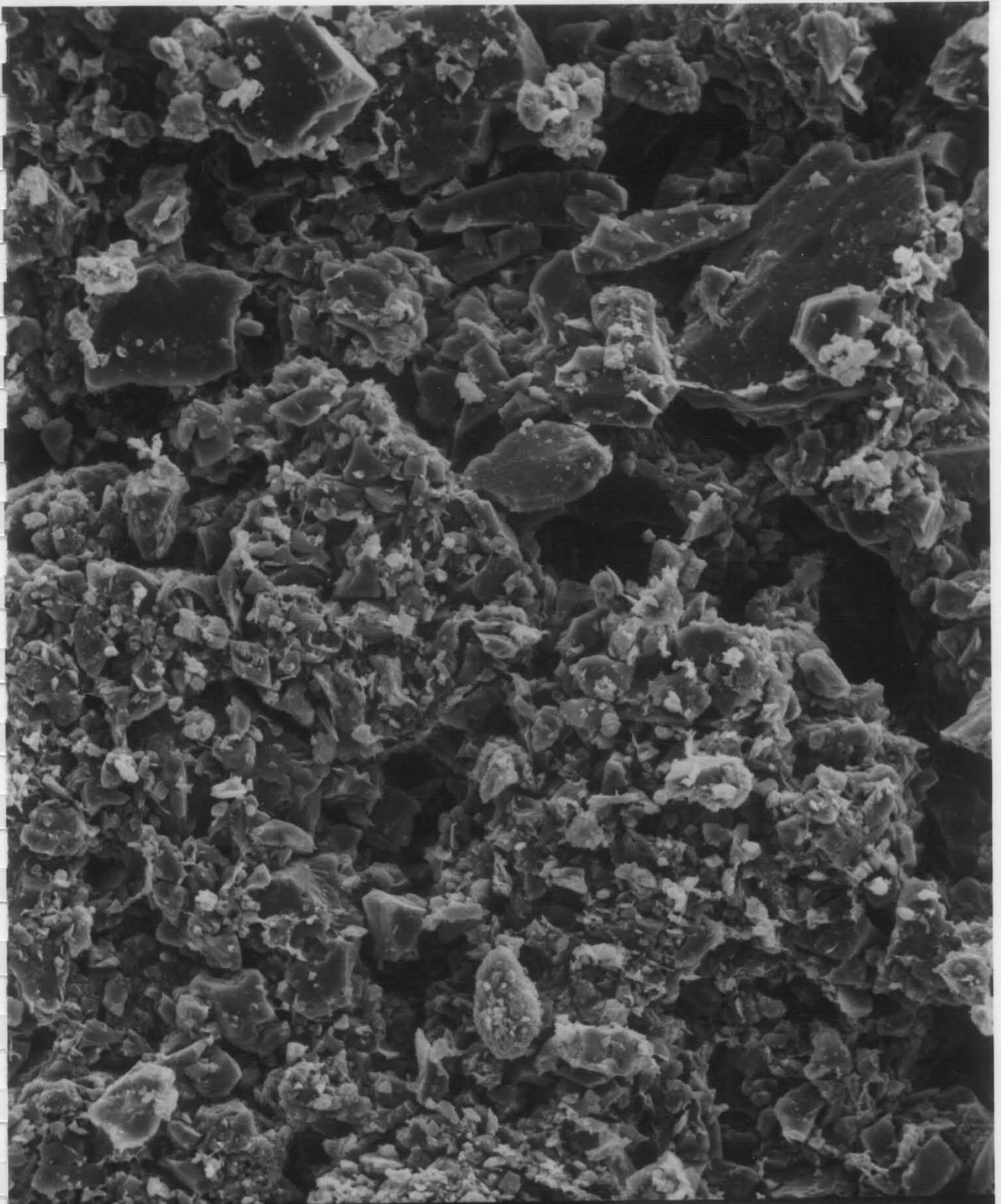
453093



100 10 u |——|  
07-1 20 10 23 000 0 10

5 cm

PLATE 28: 3663.6 m  
Lithic fragments are much less abundant in this sample and porosity appears to be fair. However, this apparent porosity may be a result of fracturing of rock during sample collection.



0 10 10 u |  
03-2 20 10 23 000 0 1 1

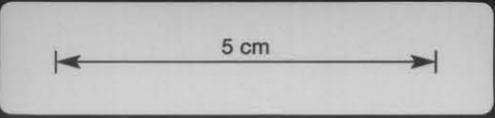
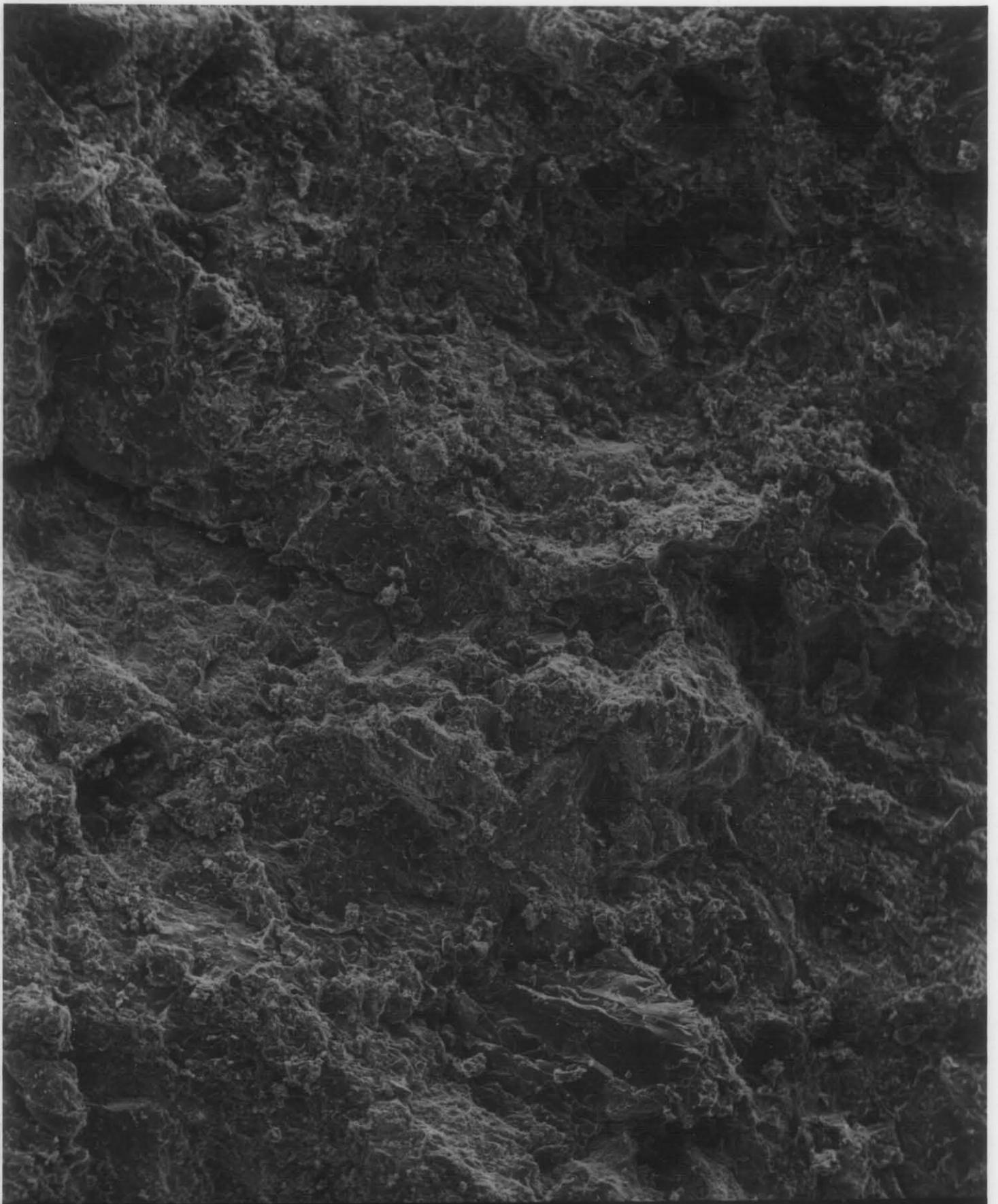


PLATE 29: 3663.6 m  
Authigenic clays occur in only trace amounts in this sandstone.

453095



100 10 u |—|  
04-1 20 10 21 000 0 12

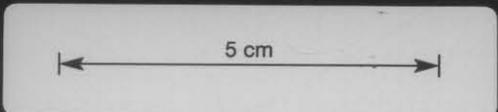


PLATE 30: 3684 m  
Porosity is again minimal in this sandstone although small pores occur adjacent to some quartz grains and in some lithic fragments.

453096



PLATE 31: 3684 m

This plate shows small pore spaces ( $\sim 10 \mu\text{m}$  in diameter) occurring in lithic fragments adjacent to a quartz grain. Authigenic minerals are rare. Authigenic ?smectite occurs in this plate and small patches of kaolinite occur elsewhere in this sandstone.

453097



100 10 μ |—|  
04-1 20 10 25 000 0 15

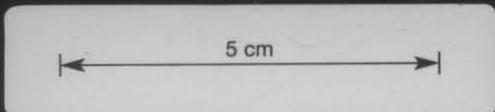


PLATE 32: 3688 m  
Lithic fragments are slightly less abundant in this sandstone but porosity is still minimal. Quartz grains are extensively overgrown and authigenic carbonate is fairly common.

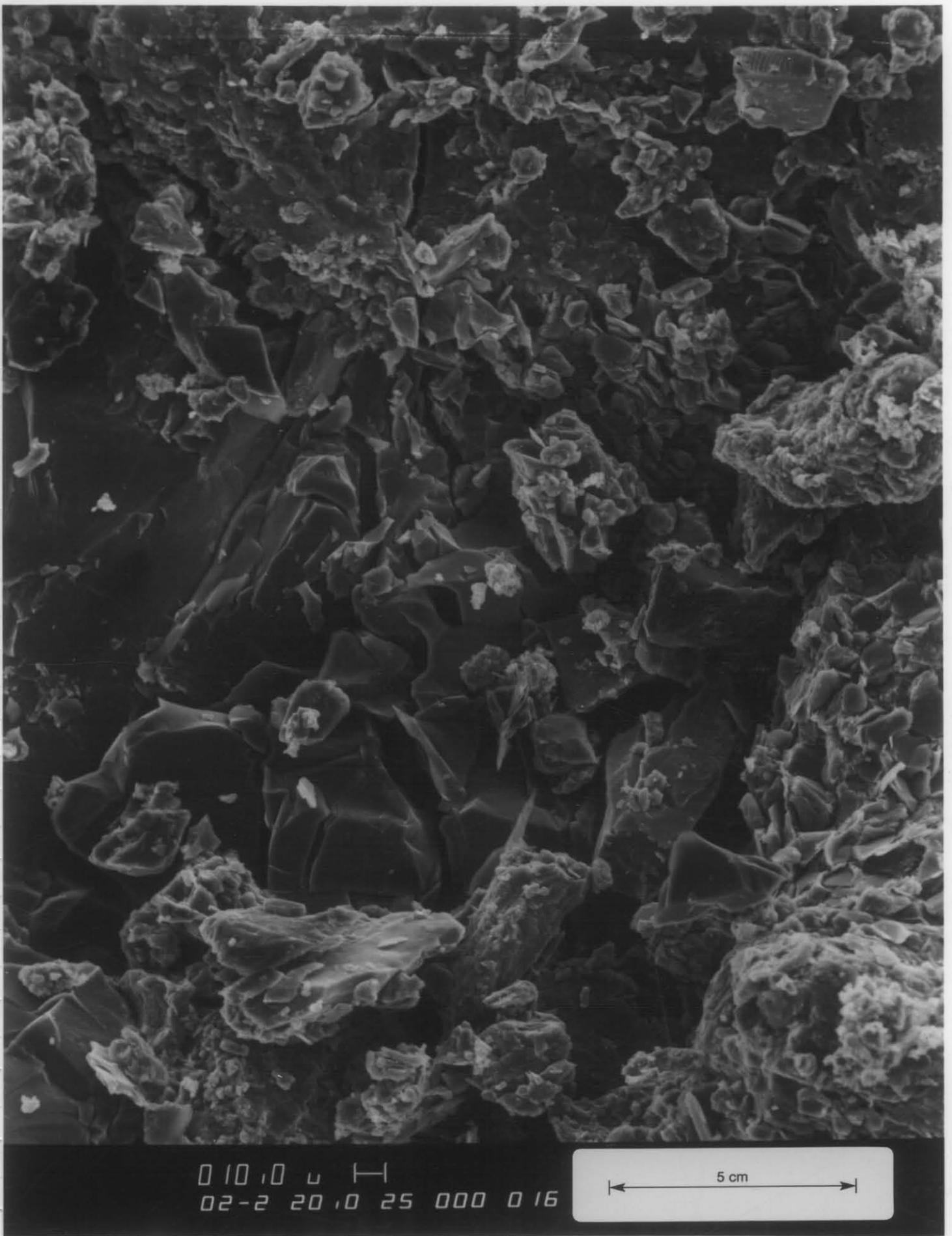
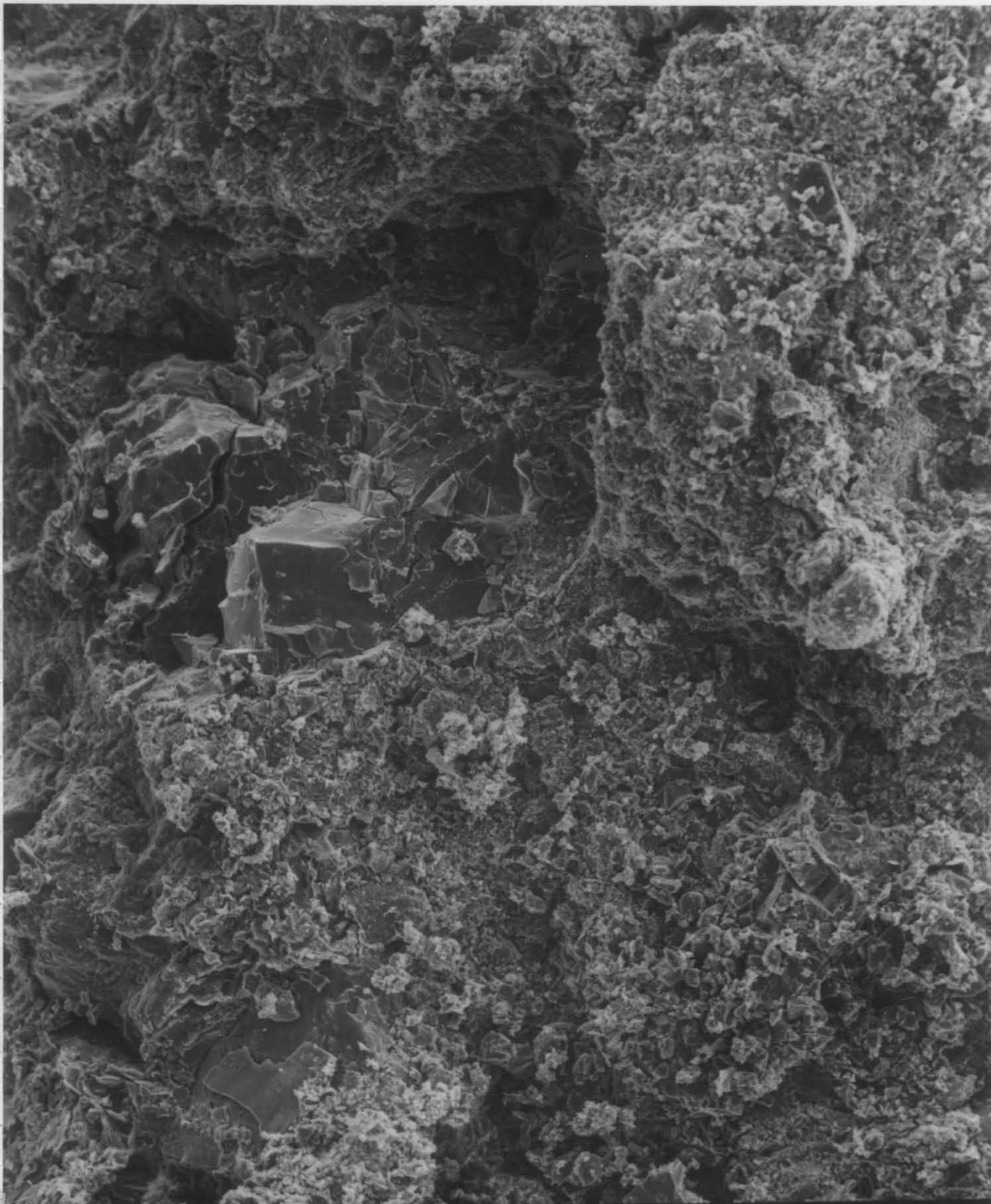


PLATE 33: 3688 m

This apparent pore space is probably a result of fracturing of the rock during sample collection. However this plate illustrates how the lithic fragments (right) fill the pore spaces between the quartz grains (top and left).

453099



100.0 u |-----|  
07-1 20.0 24 000 017

5 cm

PLATE 34: 3692.5 m  
Quartz grains are extensively overgrown in this sandstone (top left) filling most of the primary interstitial porosity. However some small pores appear to have been preserved in the lithic fragments.

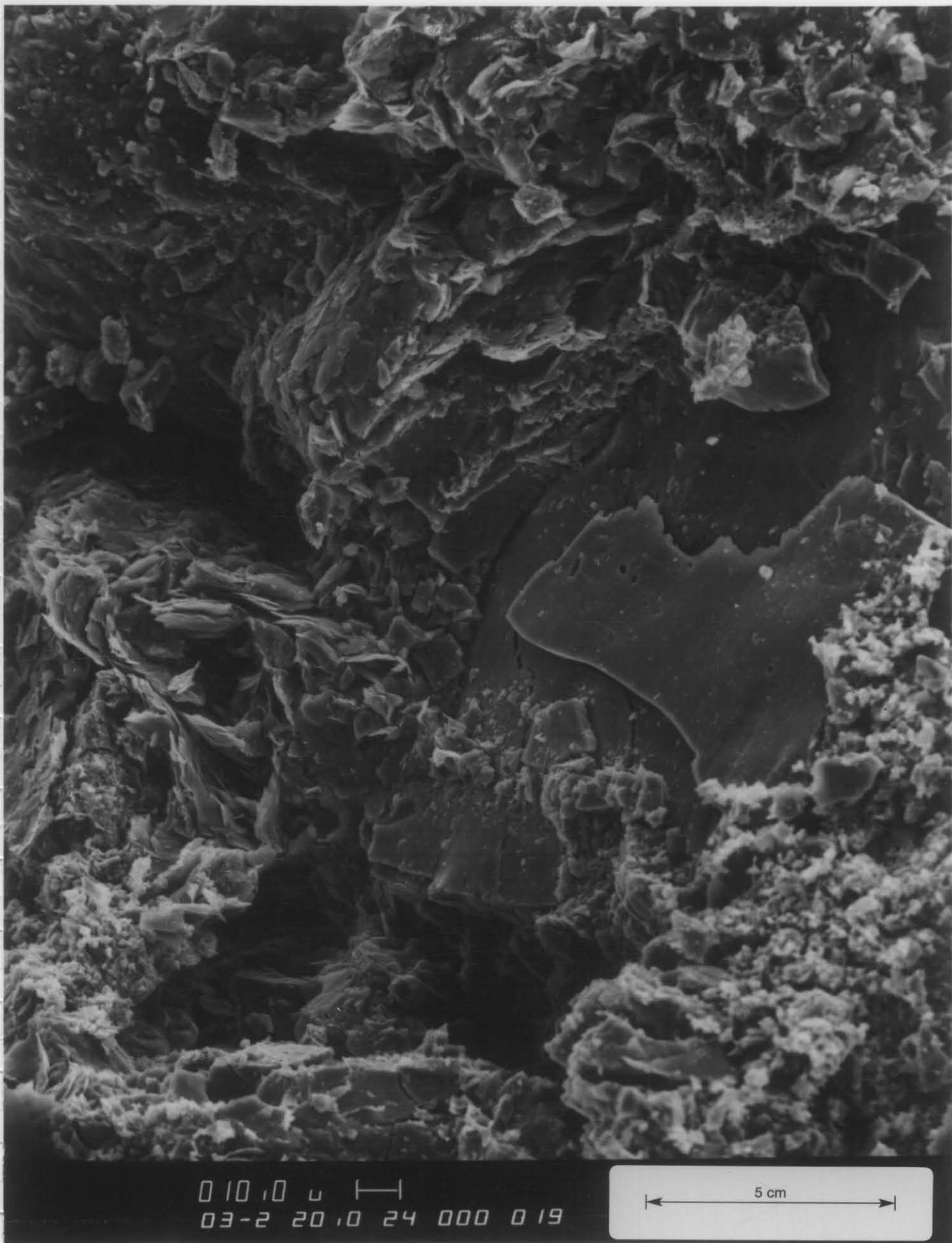


PLATE 35: 3692.5 m

Small pore spaces occur between quartz grains and a squashed lithic fragment in this sandstone. The folded structure of the lithic fragment (centre left) suggests that this fragment was fairly rigid prior to compaction.



100 10 u |—|  
04-1 20 10 22 000 020

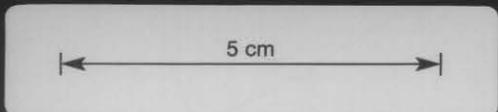
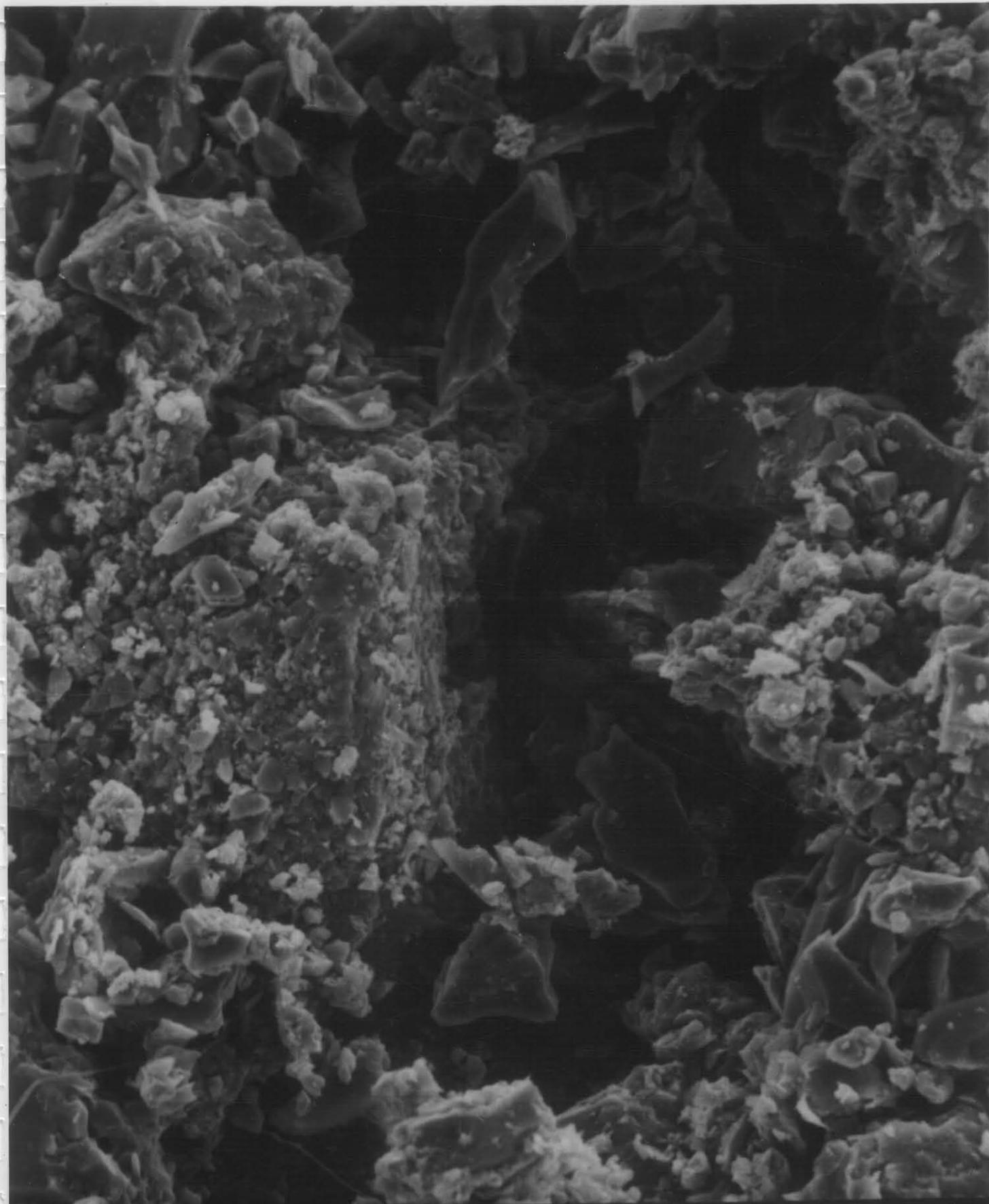


PLATE 36: 3697 m  
This rock appears to have been extensively fractured by the collection of the sidewall core but appears to be similar to the sediments previously described.

453102



01010 u | |  
04-2 20 10 22 000 021

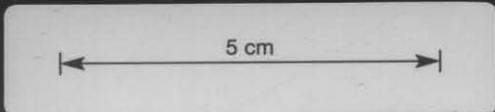


PLATE 37: 3697 m  
This fracture has been partially filled with fractured quartz. The fracture may have occurred through preserved pore spaces (lower right).

453103



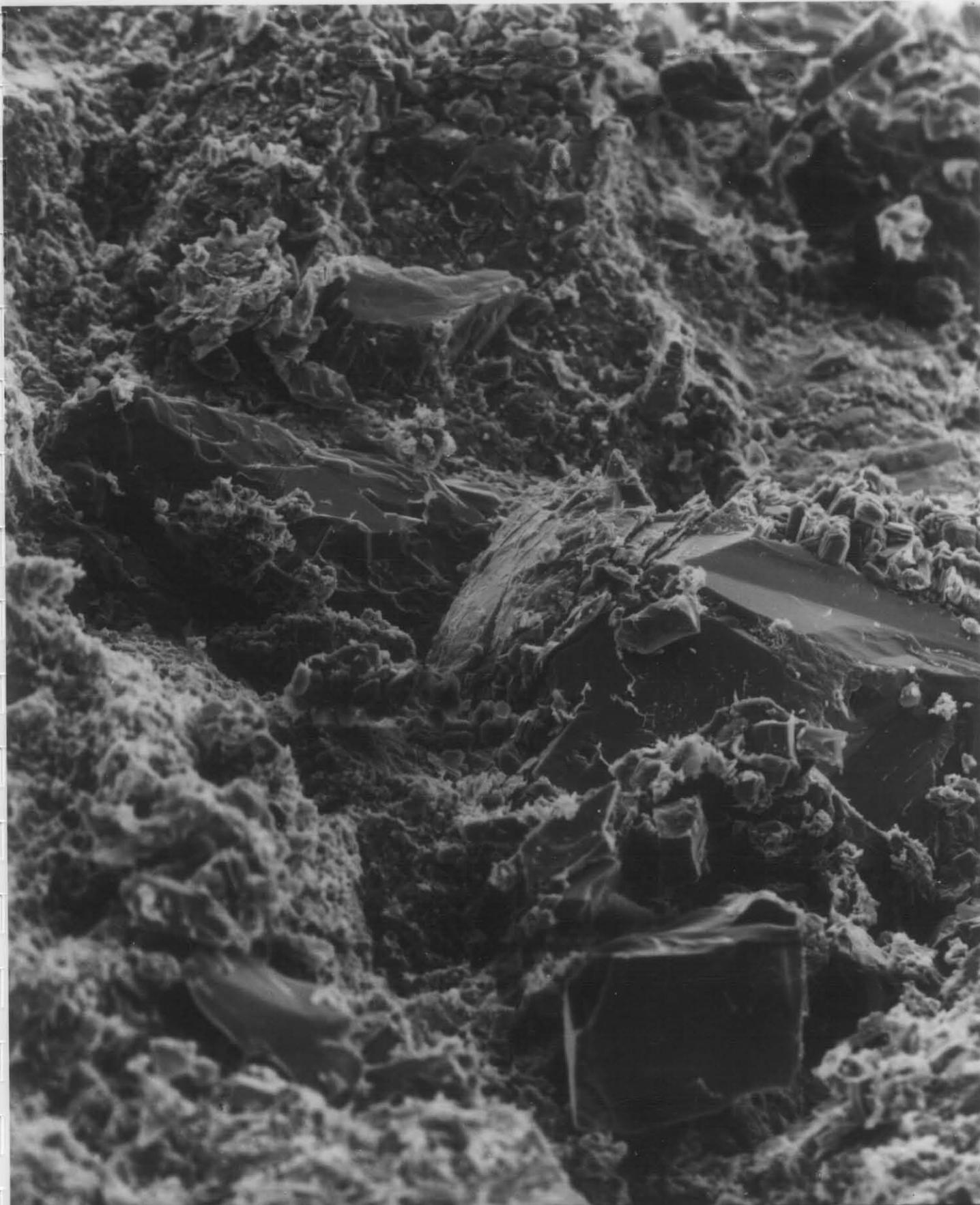
100 10 u |——|  
05-1 20 10 21 000 043

5 cm

PLATE 38: 3891.5 m

This sandstone (although extensively fractured during collection) appears to be slightly more porous than the previous few sandstones. Pores generally occur in lithic fragments adjacent to quartz grains.

453104



0 10 10 u H  
0 1-2 20 10 22 000 044

5 cm

PLATE 39: 3891.5 m  
This pore space appears to be fracture induced but may bear some relationship to original porosity.

453105

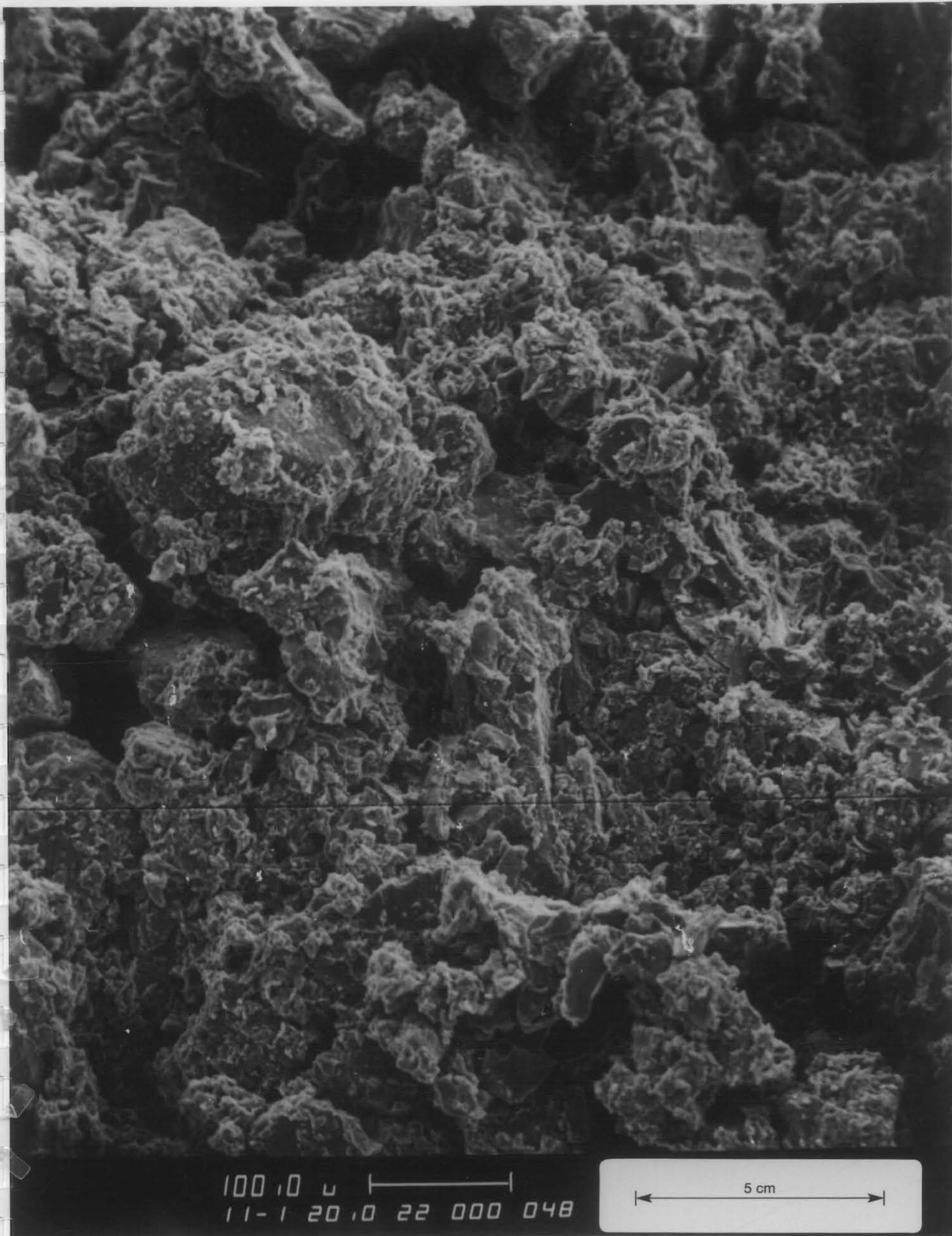
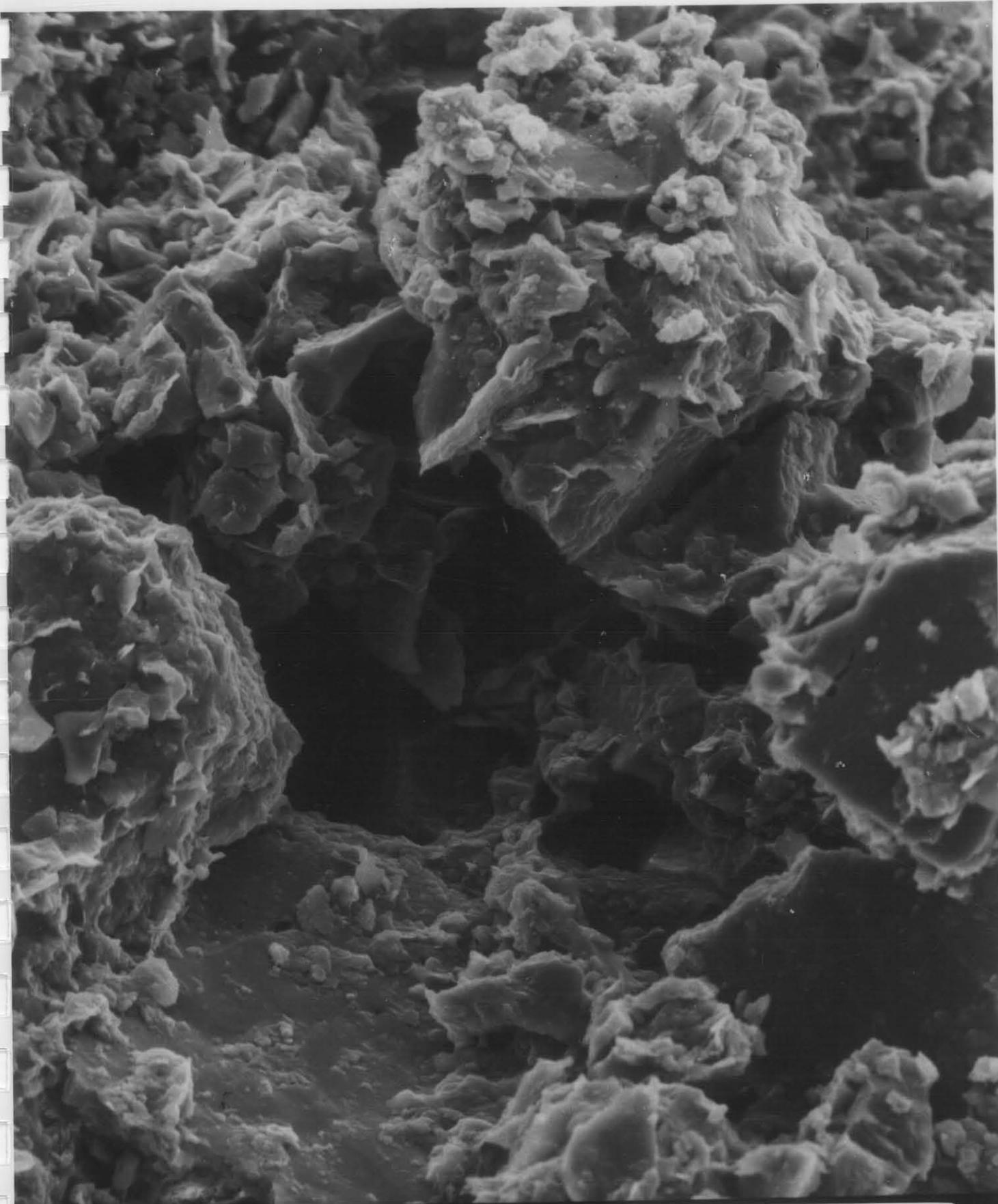


PLATE 40: 3900.5 m  
This sandstone appears to be quite porous and permeable although is at least partially due to fracturing (top left).

453106



0 10 10 u |-----|  
05-2 20 10 22 000 049

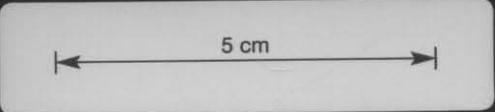
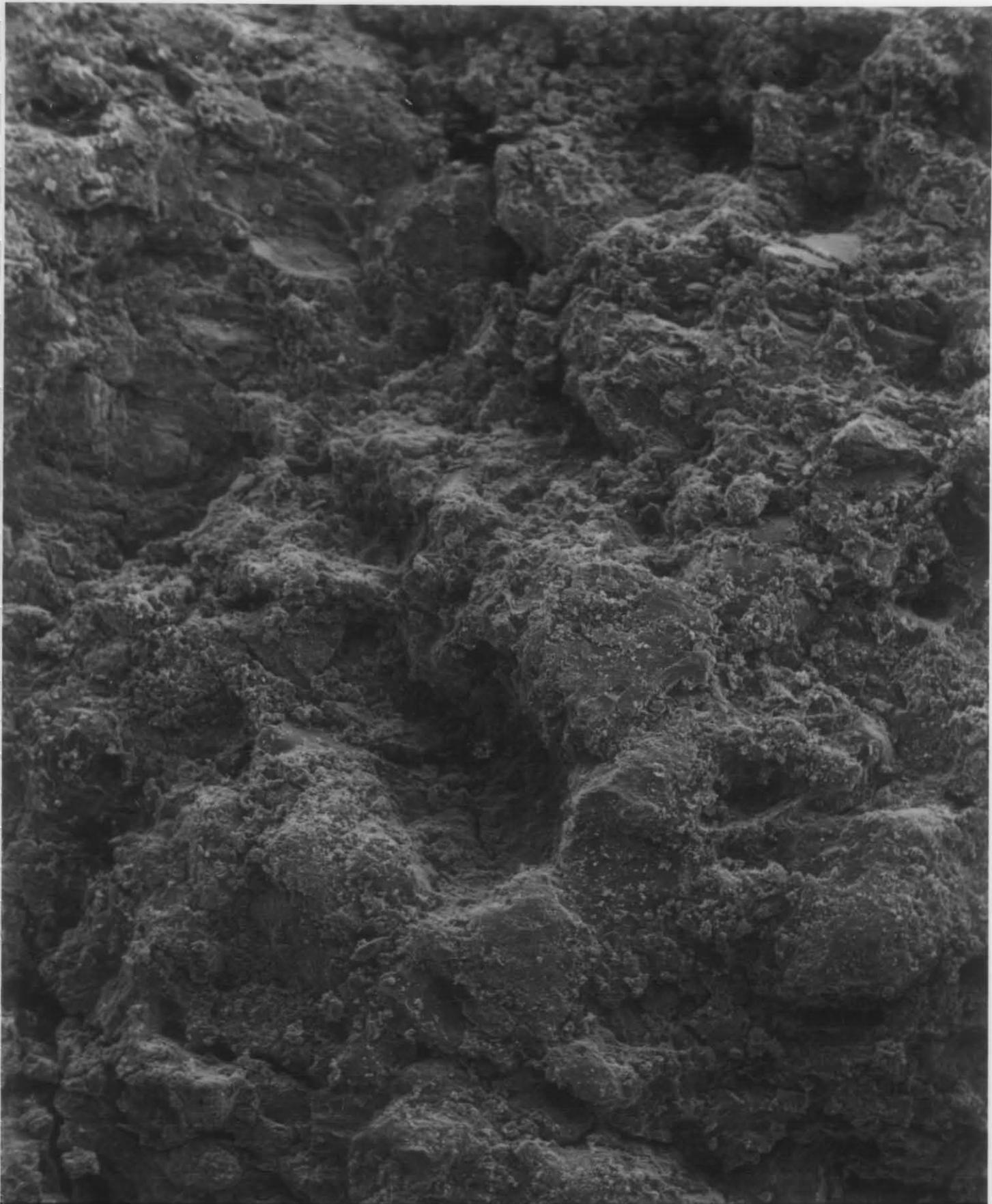


PLATE 41: 3900.5 m  
Authigenic clay minerals are essentially absent from this sandstone and pore spaces are fairly clean.

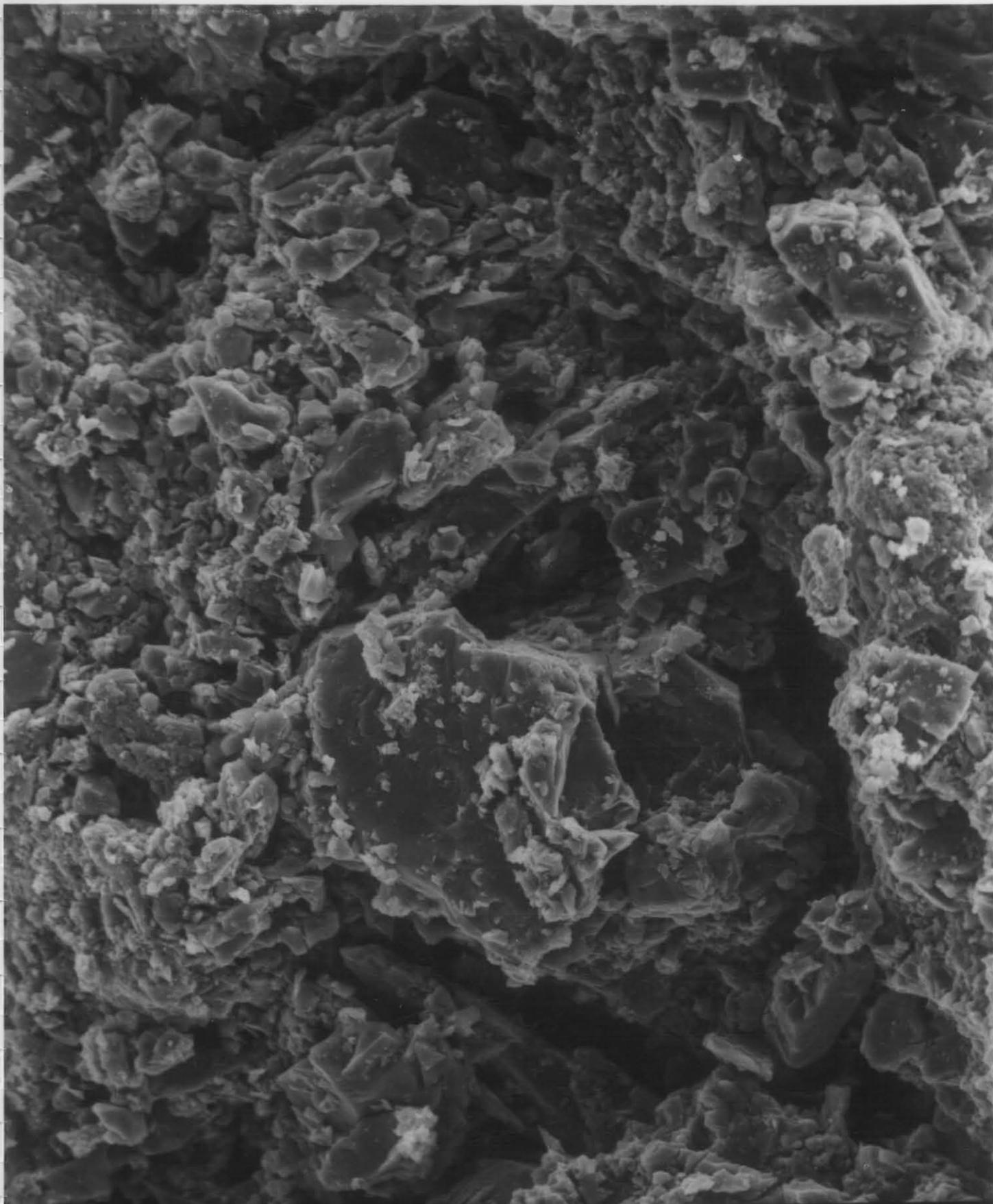


100.0 μ |—|  
04-1 20.0 20 000 022

5 cm

PLATE 42: 3928.5 m  
Some porosity remains at the interstices of the overgrown quartz grains in this otherwise tight sandstone.

453108



01010 u |—|  
04-2 20.0 22 000 023

5 cm

PLATE 43: 3928.5 m

Some small pore spaces have been preserved within the squashed lithic fragments. However, a large proportion of these pores are unlikely to be interconnected. Authigenic clay appears to be absent.

453109