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SEDIMENTOLOGICAL AND PETROGRAPHICAL DESCRIPTION OF CONVENTIONAL CORE WELL: LONGTOM-2 ST1

FINAL REPORT

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Job No.: PRP-04110P/S

April, 2005

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1 SUMMARY

1.1 Core Description and Sedimentology

Overview: Two 18 m conventional cores were described in detail from the interval 2112.39 – 2148.04 m from the Longtom-2 ST1 well. Lithology is mainly sandstone with subordinate claystone.

Sandstone: Most sandstone occurs within two main successions (2142.88 – 2127.00 m, and 2122.86 – 2112.39 m), is mainly fine to medium grained, moderately to moderately well sorted, cross-bedded and locally calcite-cemented. Very fine grained, ripple-laminated, calcite-cemented sandstone occurs near the top of the upper sandstone, and contains thin, drape-like claystone beds. Consolidation is mostly poor, except where calcite-cemented. Grain size profile is slightly erratic, although the upper sandstone succession exhibits broad fining-up profile and clay pebble conglomerate near its base. Cross-bedding is mainly planar with subordinate trough cross-bedding observed. Basal contacts of both sandstones are sharp and erosive.

Claystone: Claystone is mainly laminated and contains thin interbeds of very fine grained sandstone. These beds are generally unbioturbated, although heavy burrowing is seen in a few thin, localised layers. Possible root structures are observed just above the lower sandstone succession along with several mud cracks or fissures. Contorted bedding and water-escape structures are common. A bed of denser claystone with faint rhythmic lamination is observed between the two main sandstone successions.

Depositional Environment: Depositional environment is lacustrine to fluvial. The bulk of the two main sandstone successions are interpreted as low sinuosity, braided river channel deposits, with the uppermost portion of the upper sandstone succession possibly deposited by a more meandering system. Thin-bedded, very fine grained sandstones at the top of the cored interval may represent sheet-splay or crevasse-splay deposits. Laminated claystones near the base of the core are thought to be proximal lake sediments, whereas mud-cracked and root-mottled claystone and siltstone situated above the lower sandstone formed on the lake margin. Dense, faintly laminated claystone that separates the two main sandstone bodies is interpreted to have formed in a deep or distal lake setting.

Reservoir Potential: Most sandstone shows fair to good reservoir potential, although poor consolidation could lead to sand production in the event the zones are productive. The main control on reservoir quality is calcite cementation, with calcite-cemented zones towards the top and bottom of the cored interval showing very poor visible porosity.

Reservoir Geometry: The main sandstone bodies are likely to be elongated, reflecting their deposition by low-sinuosity fluvial channels. However, fluvial activity was probably controlled by local tectonics, thus sandstone geometry may be partly determined by the width and morphology of the flood plain.

SUMMARY (Continued)

1.2 Petrography

Texture and Classification: Most sandstones from the cored interval are feldspathic litharenites or litharenites. Average grain size ranges from very fine to medium, sorting from moderate to moderately good, and fabric from faintly laminated to massive. Grain packing indicates moderate compaction.

Grain Mineralogy: Mainly monocrystalline quartz, with very common volcanic rock fragments, common plagioclase and alkali-feldspar, clay-replaced grains, chert, sandstone rock fragments, minor shale fragments, other lithics, chlorite, biotite and muscovite mica, and localised carbonaceous fragments.

Clays and Matrix: Clays detected by XRD are mainly chlorite, kaolinite and illite/mica. From thin section and SEM observations, these clays can be subdivided into two main classes: structural clay (i.e. clay in grains) and dispersed clay matrix. Structural clay accounts for most of the XRD illite/mica fraction, whereas clay matrix occurs mainly as authigenic pore-lining chlorite and patchily-dispersed authigenic kaolinite. Kaolinite and chlorite are also components of structural clay. Structural clay generally accounts for between 50% and 70% of total clay volume, with authigenic clay making up the remainder.

Cements: Locally abundant, slightly ferroan calcite cement partly to completely infills intergranular porosity in some samples. Minor quartz overgrowths and traces of pyrite are also observed.

Diagenesis: The interpreted sequence of events is: early pyrite, followed by authigenic chlorite, authigenic kaolinite, quartz overgrowth and calcite cementation, and late partial dissolution of feldspar. Compaction is thought to have occurred throughout burial.

Reservoir Quality: Reservoir quality varies from very poor to good, with most of the cored sequence showing fair to good visible porosity. Pores are mainly intergranular with subordinate dissolution porosity in partly leached feldspar grains. The main controls on reservoir quality are compaction, calcite cementation and pore-lining chlorite.

Effects on Wireline Log Response: Vclay estimates of dispersed clay may be overly pessimistic due to common structural clay. High clay volumes (both structural and dispersed) mean that much of the Sw estimated may be immobile. Density porosity may be under-estimated if standard grain density of 2.65 g/cc is used (average core analysis grain density = 2.68 g/cc).

Potential Formation Damage: Formation damage potential is high, and could include possible capillary water-block, ferric hydroxide precipitation, fines migration and sand production.

Comparison with Longtom-1 Petrography: Longtom-1 sandstones show different diagenesis and provenance to those of Longtom-2 ST1. Longtom-1 sandstones are heavily compacted, contain virtually no feldspar and lithics are mainly metamorphic-derived. In contrast, Longtom-2 ST1 sandstones are moderately compacted, contain common feldspar, and lithics are mainly of sedimentary or volcanic/volcaniclastic origins.

Longtom-2 Cuttings Descriptions: Thin sections show that although slightly finer grained, sandstone cuttings from the lower test zone are texturally and mineralogically similar to those of the cored interval. Cuttings from the Volcanic Member indicate a complex sequence, with chert (possibly devitrified volcanic and volcanic clastic material), tuff and other volcanic material, volcaniclastic sandstone, and claystone.

2 INTRODUCTION

2.1 Overview

Approximately 36 metres from two 18 m conventional cores were described in detail from the Longtom-2 ST1 well, drilled in concession VIC/P-54 of the Gippsland Basin, Australia (Figure 3.1). Longtom-2 ST1 is located approximately 0.5 km from the previously drilled Longtom-1 well (Figures 3.1 and 3.2).

Core condition was generally good, although several poorly consolidated sections exhibited horizontal stress-release fractures. Sedimentology is discussed in Section 3 of this report, and is accompanied by selected high definition core scans (Plates 3.1 to 3.15). A 1:50 scale core log is provided at the back of the report (Enclosure 1).

Fourteen samples were chosen from the cored interval for thin section petrographic analysis. Ten of these samples were also examined with Scanning Electron Microscopy (SEM), whereas seven samples were analysed by X-Ray Diffraction (XRD). Petrography is discussed in Section 4 of this report. Thin section and SEM descriptions from the cored interval are accompanied by photomicrographs (Plates 4.1 to 4.24). A further nine cuttings samples from the main borehole of Longtom-2 were also analysed in thin section. Thin section descriptions and photomicrographs are also provided (Plates 4.25 to 4.33).

2.2 Objectives

The main objectives of this report are:

1) Provide a detailed sedimentological description of the cored intervals.
2) Determine lithological facies and ichnofacies profiles.
3) Interpret depositional environments.

4) Establish main sedimentological sequences and boundaries, and estimate their sequence stratigraphic significance.
5) Describe the texture and mineralogy of the sandstone in detail.
6) Establish the sequence of diagenetic events
7) Estimate likely reservoir potential and determine the controls on reservoir quality.
8) Investigate potential formation damage mechanisms and the possible effects of mineralogy on log response.
9) Compare petrographic characteristics of the cored interval in Longtom-2 ST1 with those of sidewall core samples examined from Longtom-1.
10) Describe petrography of cuttings from interval 2188 m – 2410 m in Longtom-2.

2.3 Cored Intervals

The cored intervals recovered are:

Core No.	Depth (metres)
1	2112.39 – 2130.00
2	2130.00 – 2148.04

3 CORE DESCRIPTION & SEDIMENTOLOGY

3.1 Overview

Most of the cored interval consists of sandstone, with subordinate claystone. The sandstone is arranged in two main beds (2142.88 – 2127.00 m and 2122.86 – 2112.39 m), both of which range from very fine to medium grained, are mostly moderately to moderately well sorted and faintly to strongly cross-bedded. Reservoir quality ranges from very poor through fair to good. Good quality intervals are generally poorly consolidated and non-calcareous, whereas poor quality intervals are mostly well consolidated and calcite-cemented.

Most of the claystone is encountered in the lower part of Core 2, although a two-metre thick claystone bed separates the two main sandstone successions (referred to as B1 and B2 respectively – see Figure 3.3), and several thin clay layers are heterolithically interbedded with very fine grained sandstone towards the top of Core 1.

3.2 Lithofacies

Lithofacies encountered in Longtom-2 ST1 are described and interpreted in Table 3.1. The main lithofacies are also summarised below:

3.2.1 Facies Sx

Cross-bedded, fine to medium grained sandstone (Plates 3.4 to 3.7, and 3.11). Cross-bedding appears to be mostly planar, with subordinate trough cross-bedding. This facies is generally non-calcareous to slightly calcareous and mostly poorly consolidated. However, some limited zones of strong calcite-cementation are encountered. Small clay rip-up clasts and carbonaceous laminae are common. Carbonaceous laminae comprise thin layers of finely disseminated carbonaceous debris aligned along cross-bed foresets. Visible porosity is usually fair to good where cementation is minor.

3.2.2 Facies Sm/Sx

Massive to cross-bedded, fine to medium grained sandstone (Plates 3.12, 3.13). Cross-bedding is faint and appears to be mainly planar in character. Thin laminar concentrations of finely disseminated carbonaceous debris are common, and localised calcite cementation is observed. Consolidation varies from good in calcite-cemented zones to poor in uncemented areas. Visible porosity ranges from poor to fair.

3.2.3 Facies Sr

Very fine to fine grained, ripple-laminated, calcite-cemented sandstone (Plate 3.14). Visible porosity is poor to very poor. Ripples appear to be mainly current-formed. This facies occurs mainly at the top of Core 1, above 2115.33 m.

3.2.4 Facies Sl

Minor facies comprising very fine to fine grained, horizontally laminated, calcite-cemented sandstone (Plate 3.10). Carbonaceous laminae are common. Visible porosity is poor.

3.2.5 Facies Gms

Matrix-supported conglomerate of claystone pebbles set within fine grained sandstone matrix (Plate 3.10). This is a rare facies, occurring just above the base of the upper sandstone succession, where it occurs in association with horizontally laminated sandstone.

3.2.6 Facies Hl

Heterolithically interlaminated very fine grained sandstone and claystone (Plate 3.15). Visible porosity is very poor.

3.2.7 Facies Ml

Laminated, slightly silty claystone with thin, intermittent very fine grained sandstone and siltstone laminae (Plates 3.1 to 3.3). This facies occurs mainly towards the base of Core 2, but also occurs locally higher up the cored interval. Dewatering and soft-sediment deformation structures such as contorted bedding and sandstone dykes are locally observed, and mud-filled fissures or cracks are encountered between 2124.50 and 2125.50 m.

3.2.8 Facies Mm

Faintly and rhythmically laminated to massive claystone (Plate 3.9). This facies separates the two main sandstone successions (2122.86 – 2124.35 m).

3.3 Ichnofacies

Bioturbation is very rare throughout the cored interval, although several thin layers exhibit various degrees of burrowing and a few very localised rootlets are also observed. Two layers show heavy burrowing intensity (at 2126.9 m and 2145.5 m) and it is possible that this heavy burrowing may have been associated with brief marine incursions.

Due to the limited nature of the burrowing, it is difficult to classify any of the burrowed zones according to formal ichnofacies types (e.g. Pemberton *et al*, 1992). For this reason, these zones have been labelled after their trace fossil associations. These associations are described briefly below and are summarised in Table 3.2.

3.3.1 Planolites Association

Sparse populations of *Planolites* and possible *Chondrites* occur at several points within the core. Bioturbation intensity is low to very low and the association is found only within claystone. There are no particular environmental implications, as *Planolites* is an extremely wide-ranging trace fossil, and can be found in both marine and non-marine environments.

3.3.2 Palaeophycus Association

A highly localised, thin but intensely bioturbated zone is observed within argillaceous sandstone at 2126.9 m. Burrows appear to consist mainly of *Palaeophycus*, although possible *Thalassinoides*-like structures are also present. As with the *Planolites* Association, these trace fossils are not necessarily diagnostic of either marine or non-marine environments. However, the high bioturbation intensity is unusual for a non-marine setting, and it is thought that a short period of marine flooding may have been responsible for this intense burrowing.

3.3.3 Teichichnus Association

Also highly localised and thin, this association occurs within heterolithic beds at 2145.50 m. Bioturbation intensity is high and burrows appear to consist entirely of *Teichichnus*. The high intensity of burrowing observed and the fact that *Teichichnus* is usually considered as a marine trace fossil imply a brief marine incursion may have occurred at 2145.50 m.

3.3.4 Rootlets

Possible rootlets occur within very fine grained, silty, laminated sandstone at 2125.35 m. These rootlets are accompanied by mud-filled fissures, and are thought to imply a marginal lacustrine environment that was occasionally sub-aerially exposed.

3.4 Palaeo-environmental Setting

The general depositional setting is interpreted to have been a lacustrine basin with the bulk of the sandstone deposited by fluvial bed-load channels in an alluvial plain to deltaic environment (Figure 3.4). Claystone was mainly deposited from suspension in relatively quiet lake environments. Lake margin and possible crevasse or sheet-splay environments are also observed within the cored interval.

3.5 Sandstone Depositional Model

The main sandstone successions are interpreted to represent fluvial channel deposits, as opposed to Gilbert-type delta or lacustrine turbidite deposits. Grain size is considered to be too fine for a Gilbert-type delta, and neither sandstone succession exhibits any features indicative of gravity deposition.

The lower of the two sandstones is thought to have been deposited by a low sinuosity channel system (Figure 3.5), whereas the upper sandstone could have been deposited either by braided channels, by more sinuous, meandering streams (Figure 3.6), or by a combination of both.

The presence of intervening lake sediments can be explained by the autocyclic nature of sedimentation within lacustrine basins, as base level changes frequently act as the basic, underlying control on deposition in such settings (Marriot, 1999).

3.5.1 B2 Sandstone Succession

The lower of the two main sandstone successions (referred to as B2 – see Figure 3.3) is interpreted to have been deposited as a bed-load channel deposit, possibly by a low-sinuosity, braided river (Figure 3.5), as suggested by the following observations:

- Vertical stacking is implied by a combination of factors: the thickness of the succession (15.9 metres), common reactivation surfaces, erratic grain size (Enclosure 1) and erratic gamma ray profile (Figure 3.7).
- Cross-bedding appears to be mostly planar.
- Paucity of claystone layers within the successions suggests dominantly bed-load deposition.

This combination of vertical stacking, planar cross-bedding and bed-load deposition is consistent with a low sinuosity, braided system (Cant, 1982; Galloway, 1985). The fine to medium grained character of the sandstone and the paucity of gravel are thought to suggest a model similar to that of the Platte or South Saskatchewan Rivers (Miall, 1985).

3.5.2 B1 Sandstone Succession

The bulk of the B1 sandstone is also thought to represent a low-sinuosity channel deposit, as suggested by the apparent dominance of planar cross-bedding and paucity of detrital clay. However, there are a number of features of the B1 sandstone, especially towards its top, that are similar to those of the more classical, meandering point-bar model (Figure 3.6, see also Miall, 1985; Galloway, 1985). These features include:

- Less erratic grain size profile than the lower sandstone succession.
- Overall fining-up profile.
- A basal lag of clay rip-up clast conglomerate occurring just above the base of the sandstone.
- Well developed ripple-laminated beds at the top of the succession.
- Thickness (approx 10 metres) that is consistent with that of a point-bar deposit.

The B1 sandstone may represent some form of compound deposit, starting out as braided channel, but changing to meandering channel as accommodation space was used up, or as the rate of base level subsidence slowed. The more heterolithic beds at the very top of the succession could have formed either as the upper portions of a point-bar, or as crevasse-splays or sheet-splays.

3.6 <u>Claystone Depositional Model</u>

The claystone intervals are generally thought to have been deposited within a lacustrine environment. However, there are three distinct claystone facies associations, each of which is interpreted to reflect differing palaeo-water levels. These facies associations are described below:

3.6.1 Laminated Claystones (2143 – 2148 m)

The laminated claystones that occur towards the base of the cored interval are interpreted to have been deposited in a relatively proximal, subaqueous lacustrine environment. Their main characteristics are as follows:

- The claystones are thinly laminated with common millimetre-scale to centimetre-scale silty to very fine grained sandstone layers.
- Bioturbation is very sparse except for several thin, but heavily burrowed, layers.
- Thin, contorted layers are common.

Thin sandy and silty laminae are thought to represent either distal crevasse splays, or weak turbidite lobes. Much of this lamination also appears to be cyclic, suggesting seasonal influences. Contorted beds could have been caused by either periodic earthquakes, by slippage along a sloping lake floor, or both. A brief marine incursion at 2145.5 m is indicated within this interval by the presence of a *Teichichnus* ichnofacies association (see Section 3.3.3).

3.6.2 Interbedded Laminated Claystone and Silty Sandstone (2124.35 – 2126.10 m).

This interval of heterolithically interbedded silty sandstone and claystone exhibits localised rootlets and several fissures or mud cracks, indicative of successive periods of inundation, vegetation, and desiccation (Talbot and Allen, 1996). A lake margin setting is therefore envisaged for these deposits.

3.6.3 Massive to Faintly Laminated Claystone (2122.85 - 2124.35 m)

This short interval of claystone exhibits very faint, rhythmic, millimetre-scale lamination, which is probably seasonal. This facies was almost certainly deposited in a very low energy environment, in either a deep or distal part of the lake.

3.7 Interval by Interval Description

The cored interval can be subdivided into five distinct intervals according to rock type and sedimentary structures. These are described in chronological order below (from bottom to top):

3.7.1 Interval 1: Laminated Claystones (2148.04 – 2142.88 m)

Description: This interval comprises claystone with thin interbeds of very fine grained, often silty sandstone.

The claystones are evenly laminated and generally unbioturbated (Plates 3.1 to 3.3). Sandstone beds in this part of the core are thin and exhibit common carbonaceous laminae, localised amber fragments, and occasional current ripples (Plate 3.2). The sandstones are also mostly unbioturbated, although a few beds exhibit weak bioturbation and one bed (at 2145.5 m) is heavily burrowed (see Section 3.3.3). Thin, contorted sandstone beds are common (Plates 3.1, 3.2) and a water escape pipe is observed towards the top of the interval. Most of the thin sandstone beds are calcareous, whereas claystones are non-calcareous.

Interpretation: These beds are interpreted to have been deposited subaqueously in a proximal lacustrine environment. Sandstone beds are interpreted as either distal crevasse splays, or thin turbidite beds. Contorted layers may have been caused by periodic earthquakes, whereas lamination observed within the claystone is probably seasonal. The heavily bioturbated layer at 2145.5 m may reflect a brief period of marine influence.

Reservoir Potential: Very poor. Sandstone beds are too thin and are of inadequate reservoir quality to provide much economic potential.

3.7.2 Interval 2: B2 Sandstone (2142.88 – 2127.00 m)

Description: This interval comprises a thick succession of fine to medium grained, moderately sorted, cross-bedded arkosic to lithic-rich sandstone. The sandstone rests on top of a very sharp basal contact with underlying claystone (Plate 3.3). Consolidation is mostly poor, except for a few thin, calcite-cemented zones.

The grain size profile across the succession is slightly erratic and reactivation surfaces are common. Cross-bedding appears to be mainly planar, although trough cross-bedding is also observed (Plates 3.4 to 3.7). Carbonaceous debris is common throughout, and is frequently concentrated along cross-bed foresets (Plate 3.4). Detrital clay is very rare, confined to claystone rip-up clasts and a few thin, drape-like laminae. Rip-up clasts are mostly seen towards the base of the succession, where they constitute part of a coarse lag (Plate 3.4).

Interpretation: The thickness of the succession (nearly 16 m), paucity of detrital clay layers, slightly erratic grain size profile and preponderance of planar cross-bedding imply a low-sinuosity, possibly braided bed-load channel (Cant, 1982; Galloway, 1985). The sharp basal contact of the sandstone (Plate 3.3) is interpreted to represent a regressive surface of erosion – probably formed in response to a sudden fall in lake level. Such a surface of erosion could also imply some degree of incision, in which case the sandstones could represent part of an incised valley-fill.

Reservoir Potential: Good. Visible porosity is fair to good in most of the sandstone and is interrupted only locally by thin, tightly calcite-cemented layers.

3.7.3 Interval 3: Thinly Bedded Sandstone and Claystone (2127.00 – 2124.35 m)

Description: The top of the B2 sandstone succession is marked by a thin claystone layer. Above this layer lies a short interval of thin, very fine grained to silty sandstone, interbedded with silty claystone and argillaceous siltstone beds (Plate 3.8). Most of the interval is evenly laminated, and symmetrical ripples are observed in the lower half of the interval. Dewatering pipes and contorted laminae occur throughout the interval (Plate 3.8). Claystone rip-up clasts and carbonaceous fragments are common within sandstone beds, which exhibit upward-decreasing bed thickness. Mud cracks or fissures are observed in the upper part of the interval and several small rootlets are also present (Plate 3.8). A thin, heavily bioturbated layer occurs near the base of the interval, at 2126.9 m. The *Palaeophycus* ichnofacies association (Section 3.3.2) observed in this bioturbated layer implies a brief marine incursion may have occurred at this depth.

Interpretation: This interval is interpreted to be transitional from a fluvial to a lacustrine setting, possibly punctuated by a brief marine incursion. Sandstone beds in the lower half of the interval are thought to represent sheet splay or crevasse splay deposits, whereas thinner, siltier sandstones in the upper part of the interval are believed to represent lake margin sediments. Mud cracks reflect periodic desiccation of the lake margin, possibly as a result of fluctuating lake levels. Dewatering structures and contorted bedding are thought to indicate rapid deposition and burial of fluid-charged sediment.

Reservoir Potential: Poor. The sandstones of this interval exhibit very poor to poor visible porosity as a result of very fine grain size and common argillaceous matrix.

3.7.4 Interval 4: Massive to Faintly Laminated Claystone (2124.35 – 2122.86 m)

Description: This short interval consists entirely of dense, faintly laminated to massive claystone (Plate 3.9). The faint lamination observed is rhythmic.

Interpretation: Deposition is interpreted to have occurred within a very quiet, low energy, deep-water or distal lacustrine setting. The faint, rhythmic lamination is thought to reflect seasonal variations of sediment input.

Reservoir Potential: None. This dense claystone may represent a major baffle or seal.

3.7.5 Interval 5: B1 Sandstone Succession (2122.86 – 2112.39 m)

Description: The B1 sandstone succession comprises a broadly fining-upward sequence dominated by moderately to moderately well sorted, generally fine to medium grained, locally calcite-cemented sandstone (Plates 3.10 to 3.13). Thin drape-like claystone layers are observed towards the base of the succession (Plate 3.11), whereas thicker claystone beds occur in the uppermost 4 metres (Plate 3.14). A thin bed of matrix-supported clay-pebble conglomerate occurs just above the base of the succession (Plate 3.10), which is marked by a sharp and erosive basal contact. This sharp basal contact may represent a regressive surface of erosion, possibly formed in response to a sudden fall in lake level.

The bulk of the sandstone is planar cross-bedded (Plate 3.13), although some trough cross-bedding is observed towards the base of the succession (Plate 3.11) along with several reactivation surfaces. Carbonaceous debris is commonly concentrated along cross-bed foresets. The uppermost 4 metres of the succession is very fine grained, heavily calcite-cemented and wavy laminated, containing common current ripples (Plates 3.14 and 3.15).

Interpretation: The planar cross-bedded sandstone that constitutes the bulk of this interval is interpreted to have been deposited by a low sinuosity, bed-load fluvial channel. Finer grained, more thinly bedded, ripple-laminated sandstone towards the top of the interval is more reminiscent of the upper portions of a meandering river point-bar deposit, although these beds could also represent a series of sheet splays or crevasse splays.

Reservoir Potential: Fair to good in most of the interval. The lower half of this sandstone succession is poorly consolidated and shows fair to good visible porosity. However, much of the upper half of the succession is strongly lithified due to calcite cementation, and shows very poor reservoir potential.

3.8 Sandstone Geometry

Geometry of the two main sandstone bodies is expected to be elongated and relatively linear, reflecting their deposition by a series of vertically stacked, low sinuosity channels. However, the system is likely to have been autocyclic, and therefore reservoir geometry may have been controlled by the width and morphology of the floodplain, which would have been controlled ultimately by local tectonics and local fault architecture.

3.9 Channel Thickness-Depth Ratios

According to data gathered by Fielding and Crane (1987) on a range of river systems, thicknesses of the two channel sandstone successions, at 10.5 metres and 15.9 metres, would suggest average channel depths of around 6 metres and 10 metres, respectively (Figure 3.8). These channel depths in-turn translate to channel belt widths of approximately 400 and 700 metres, respectively. However, these figures are very approximate and are only indicative, as a large number of factors can combine to affect channel geometry and width/depth ratios. Such factors include the following (Marriot, 1999):

- Direction, duration and rate of base level change and resultant fluvial response.
- Climate and its effect on discharge rates.
- Local geology and structure, and the nature of flood-plain alluvium.
- Nature of sediment supply.

3.10 Reservoir Potential

Visible porosity is fair to good over the bulk of the two main sandstone successions, and much of the cored interval is thought to represent potentially viable gas reservoir. Unfortunately, poor consolidation in the best reservoir zones could lead to problems with sand production if the interval does turn out to be productive.

The main control on reservoir quality appears to be calcite cementation. Calcite cement is mostly concentrated towards the base of the lower sandstone succession and towards the top of the upper succession. A few thin, localised bands of calcite also occur at several points within the lower sandstone succession. However, the bulk of the sandstone is free of calcite cement, hence its poor consolidation and fair to good visible porosity.

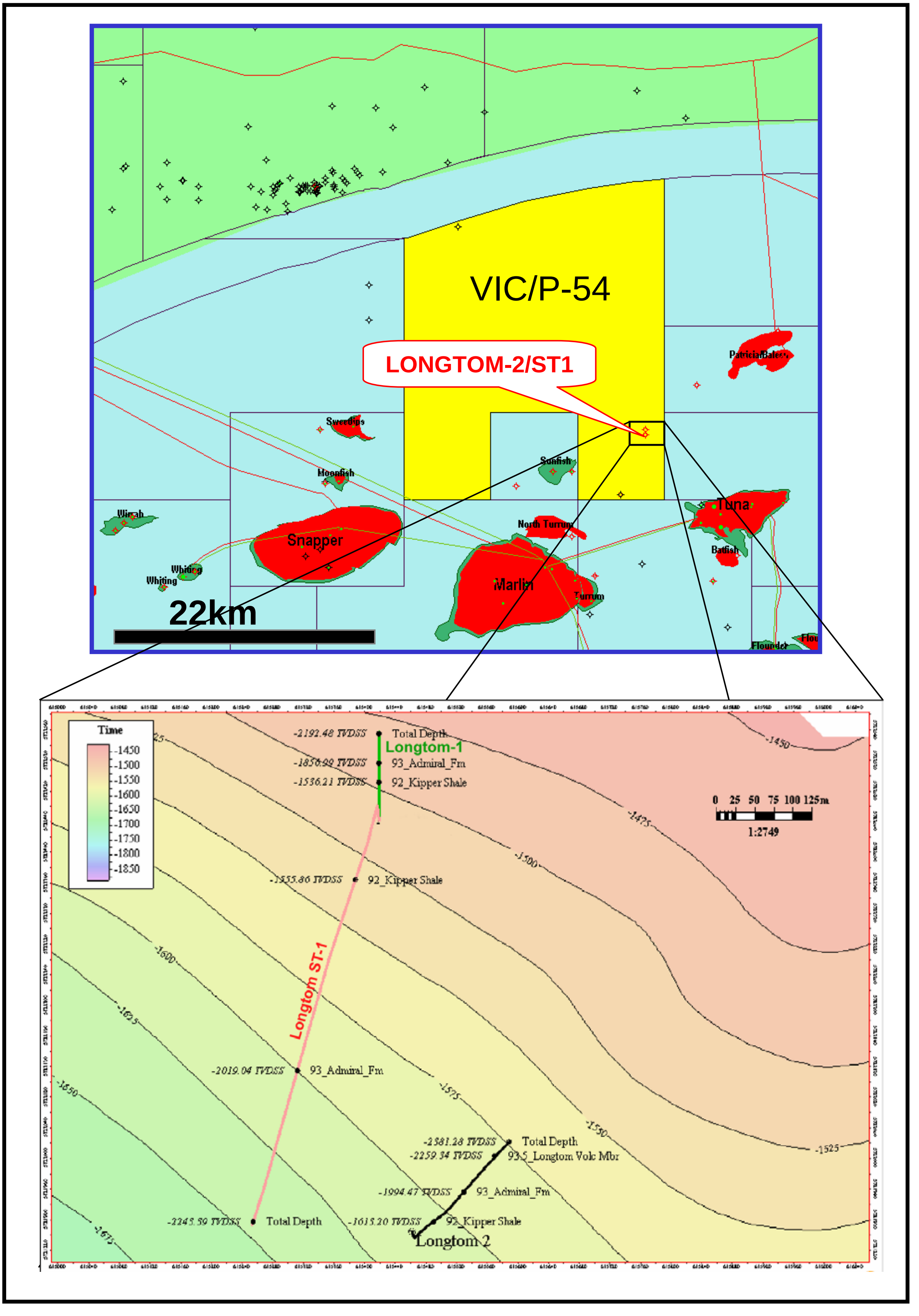


Figure 3.1. Location maps showing position of Longtom-1 relative to Longtom-2 and permit VIC/P-54. Figures provided by Apache Energy Ltd.

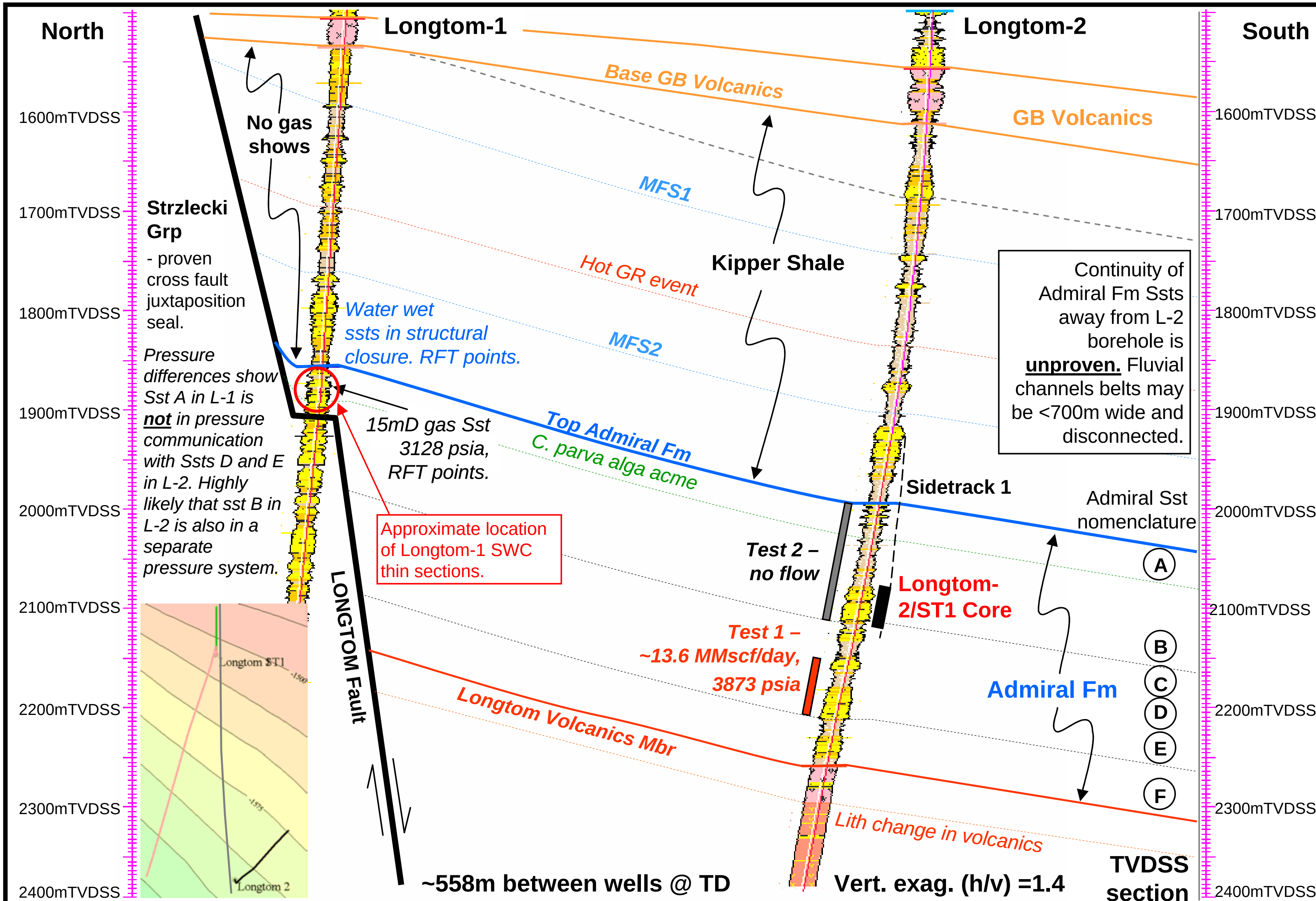


Figure 3.2. Longtom structural cross section, showing approximate location of the Longtom-2/ST1 core relative to the Longtom-1 well. Figure provided by Apache Energy Ltd.

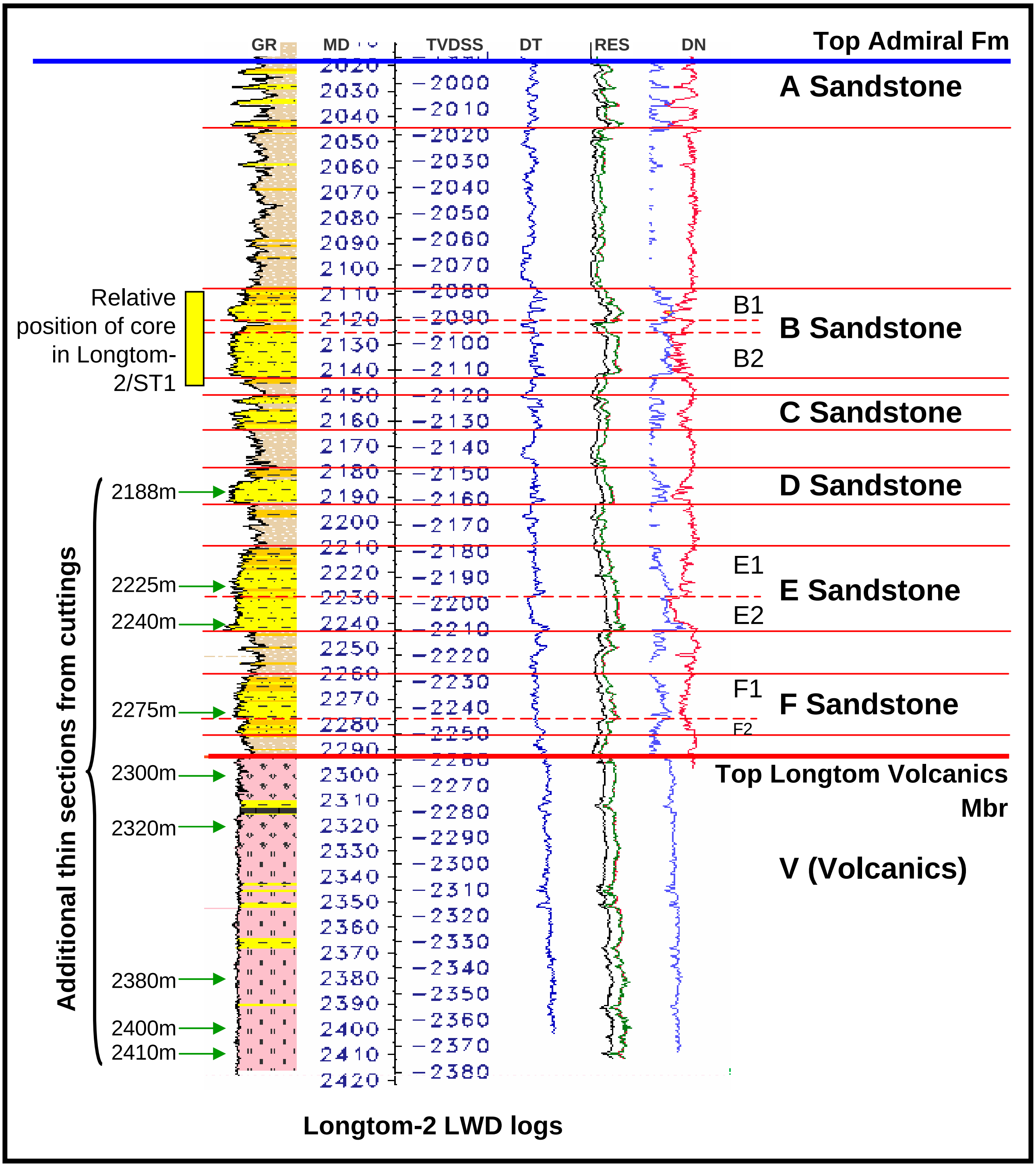


Figure 3.3. Nomenclature for the Admiral Formation sandstone in Longtom-2. Locations of thin sections made from cuttings samples from Longtom 2 are also shown. Figure provided by Apache Energy Limited.

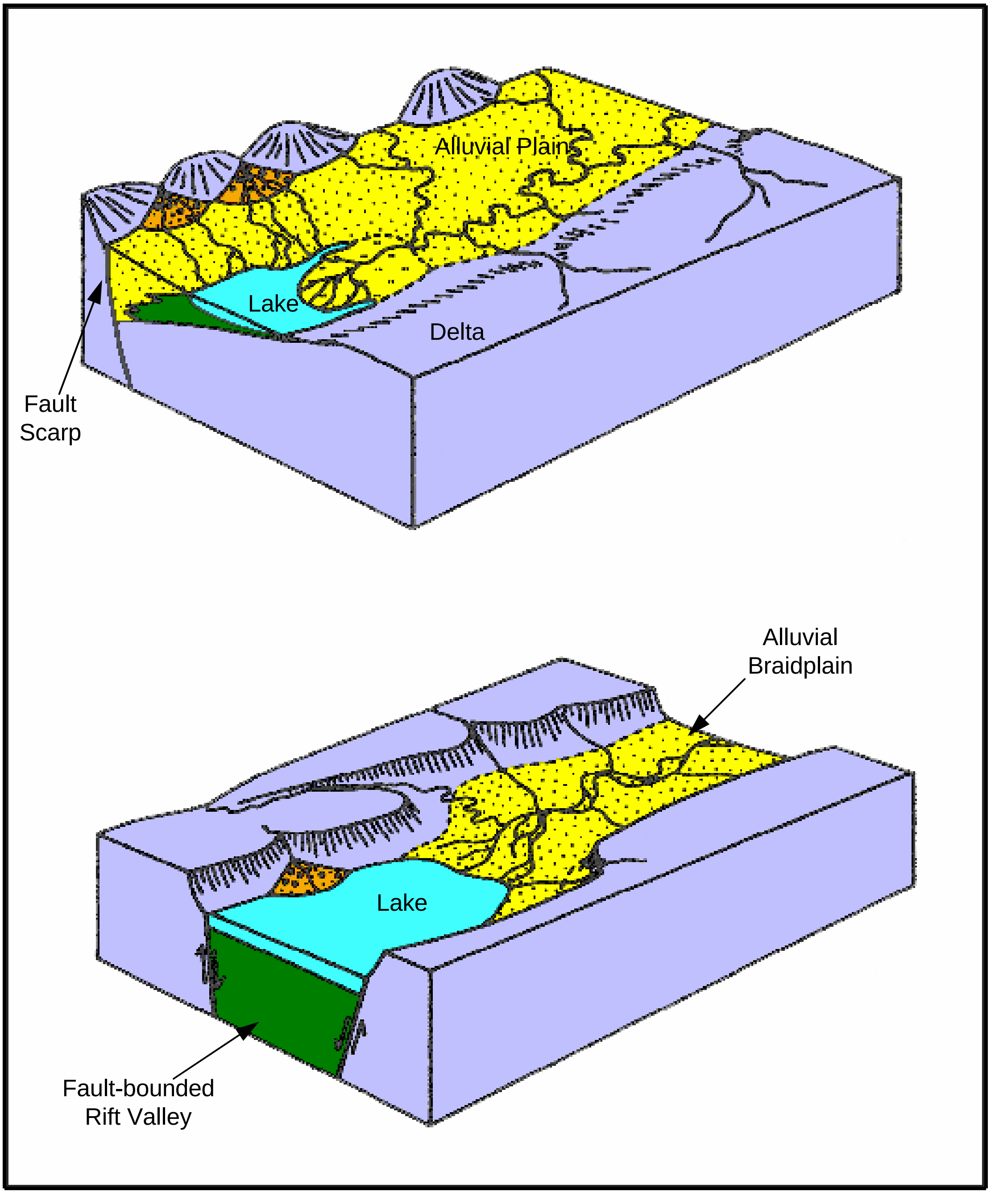


Figure 3.4. Block diagrams showing possible basin fill patterns (after Miall, 1985). Basin fill in the vicinity of Longtom-2 may have had elements of both models.

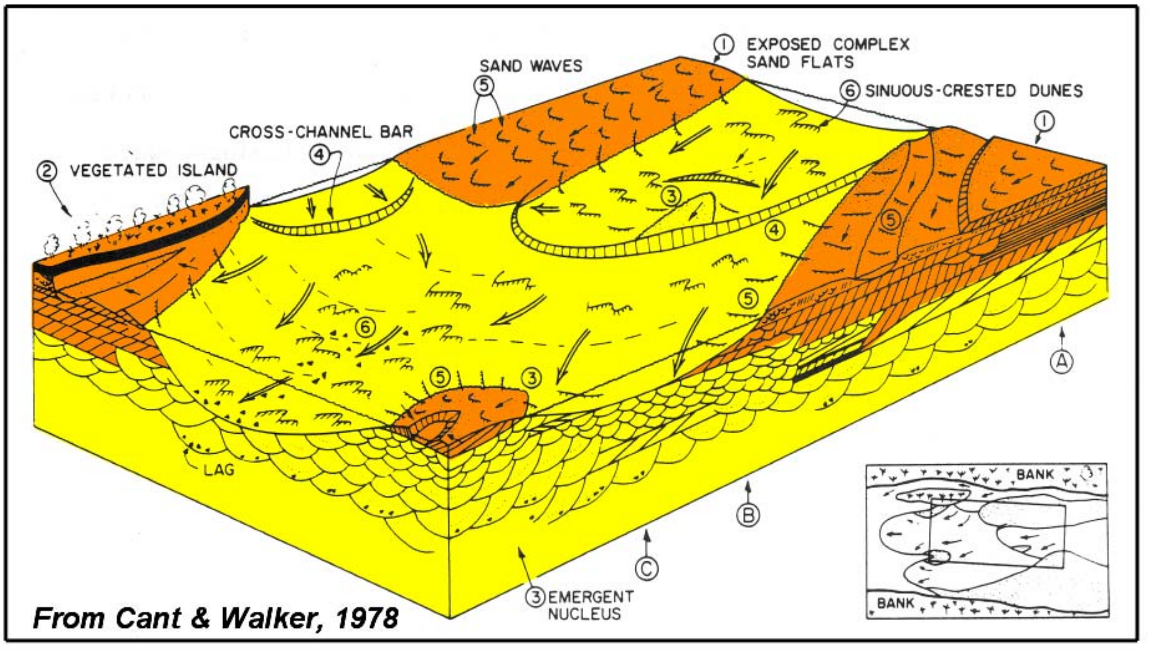


Figure 3.5. Braided stream model. From Cant and Walker, 1978.

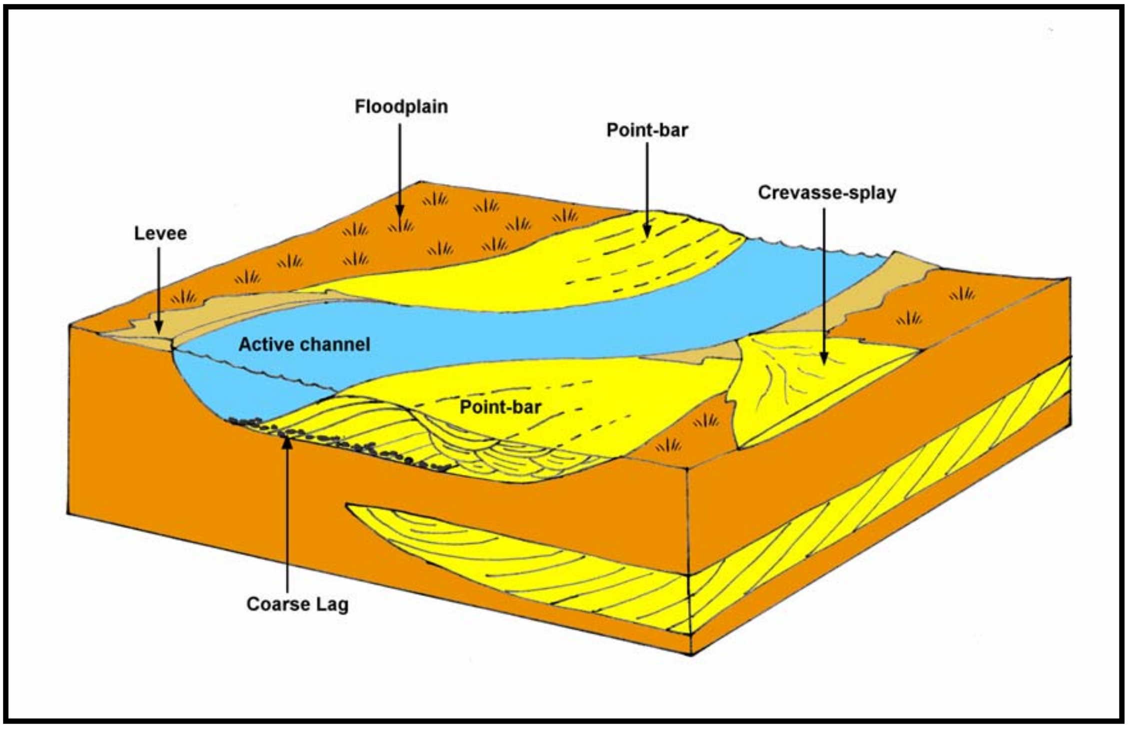


Figure 3.6. Classic meandering stream point-bar model. After Galloway, 1985.

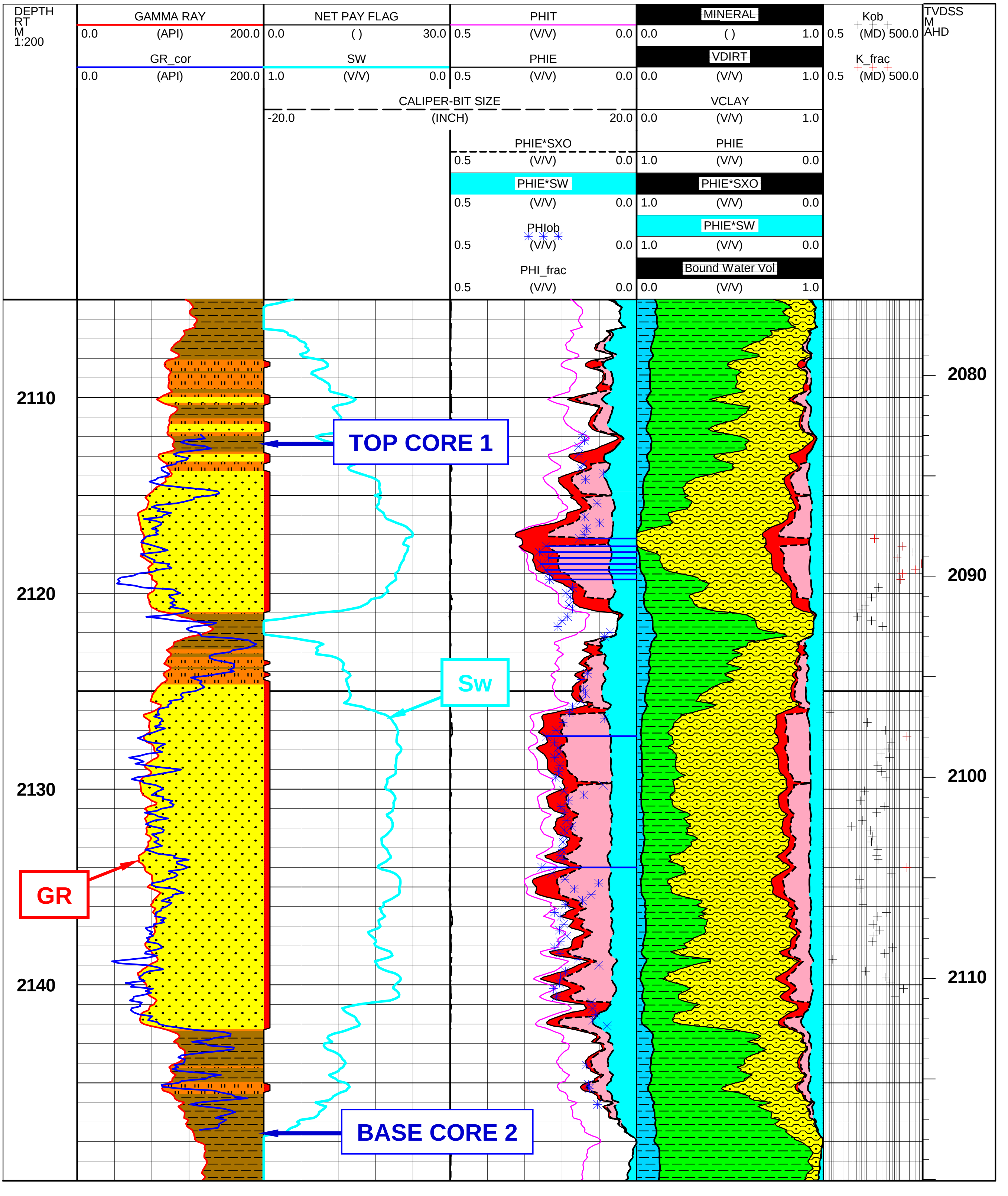
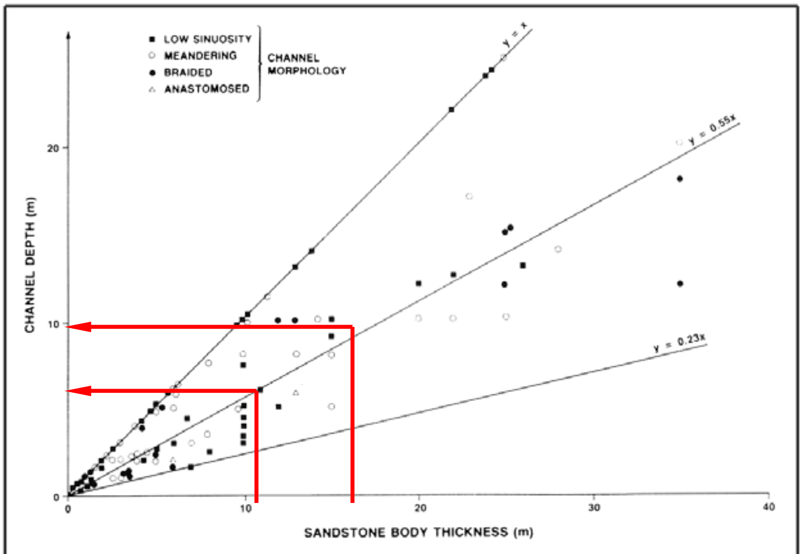
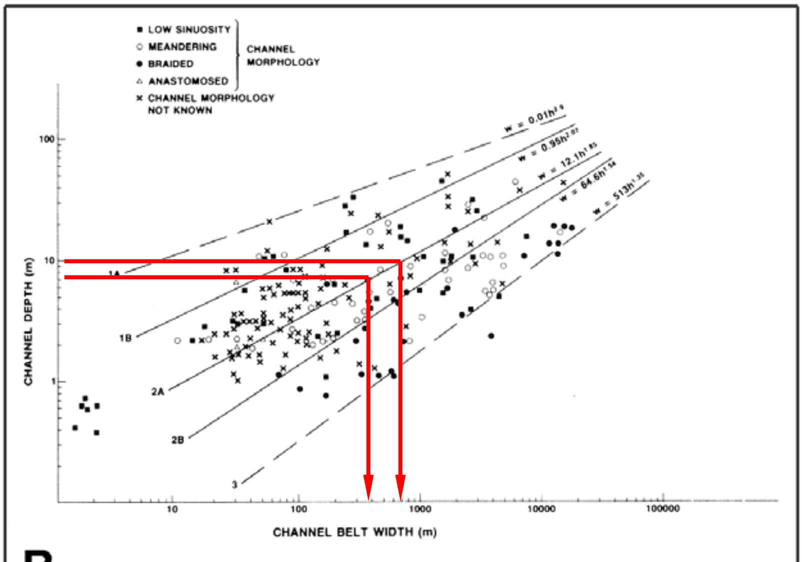


Figure 3.7. Excerpt from Longtom-2 wireline logs corresponding to the Longtom-2 ST1 cored interval. Note the erratic gamma ray profile (GR) across the two main sandstone successions. The lower succession appears to comprise a stacked, multi-storey sequence and the upper succession, although thinner, may also represent a compound sequence. Also note the computed water saturation (Sw), which varies between 20 and 30% across most of the sandstone. Much of this water is expected to be clay-associated immobile water. Figure provided by Apache Energy Ltd.



A —Channel depth vs. sandstone bed thickness relationships for deposits of various fluvial channel types. The two outer lines enclose the limited available data compiled from published studies. A median line (channel depth = 0.55 sandstone bed thickness) is taken as a reasonable representation of the data. Where more reliable data are available on the local relationship between the two parameters in any study, these should be used to generate the required figures in preference to the crossplot.



B —Channel depth vs. channel belt width relationships for various types of modern and ancient fluvial channel deposits (data from 45 published sources).

Figure 3.8. Channel depth vs. sandstone bed thickness, and channel depth vs. channel belt width relationships for various types of modern and ancient fluvial channel deposits. Red arrow overlays show relationships for sandstone beds of around 11 and 16 metres thickness, respectively. Fielding and Crane, 1987.

TABLE 3.1
LITHOFACIES DESCRIPTIONS

FACIES	DESCRIPTION	THICKNESS	DEPOSITIONAL ENVIRONMENT	RESERVOIR POTENTIAL
Sx	Cross-bedded, fine to medium grained sandstone. Cross-bedding is mostly planar, with subordinate trough cross-bedding. Generally non-calcareous to slightly calcareous and poorly consolidated. Limited, localised zones of heavy calcite cementation are encountered. Carbonaceous laminae – most of which comprise thin layers of finely disseminated carbonaceous debris aligned along cross-bed foresets – and small clay rip-up clasts are common. Visible porosity is mostly fair to good, though locally reduced by calcite cement. Associated with facies Sm/Sx.	Individual units 0.2 to approx. 8 m thick.	Fluvial. Stacked, low sinuosity channel sands.	Fair to good. Reduced locally by calcite cementation.
Sm/Sx	Massive to cross-bedded, fine to medium grained sandstone. Cross-bedding is faint and is mainly planar with subordinate trough cross-bedding. Thin laminar concentrations of fine carbonaceous debris are common. Locally calcite cemented. Consolidation varies from good in calcite-cemented zones to poor in uncemented areas. Visible porosity ranges from poor to fair. Associated with facies Sx.	Individual units 0.5 to approx 8 m.	Fluvial. Stacked, low sinuosity channel sands.	Poor to fair, restricted locally by calcite cement.
Sm	Massive, fine grained, calcite-cemented sandstone with very poor visible porosity. Minor facies occurring at the top of the lower sandstone succession. Associated with facies Sx and Sr.	25 cm.	Fluvial. Minor component of crevasse-splay sands.	Very poor due to calcite cementation.
Sr	Very fine to fine grained, ripple-laminated, calcite-cemented sandstone. Ripples appear to be mainly current-formed. Visible porosity is poor to very poor. Occurs mainly at the top of Core 1 where it is interbedded with facies Ml.	Individual units approx. 10 – 50 cm.	Fluvial. Sheet-splay or crevasse-splay sands.	Generally very poor to poor due to calcite cementation.
Sl	Very fine to fine grained, horizontally laminated, calcite-cemented sandstone with common claystone rip-up clasts and carbonaceous laminae. Visible porosity is poor. Minor facies occurring towards the base of each of the two main sandstone successions. Associated with facies Sx	20 – 50 cm.	Fluvial. Component of channel sandstone. Horizontal lamination may represent bottom set beds.	Very poor due to calcite cementation.

TABLE 3.1 (Continued)
LITHOFACIES DESCRIPTIONS

FACIES	DESCRIPTION	THICKNESS	DEPOSITIONAL ENVIRONMENT	RESERVOIR POTENTIAL
Sdef	Deformed and dewatered, very fine to fine grained, moderately sorted sandstone with fair visible porosity. Minor facies occurring at the top of the lower sandstone succession. Associated with facies Sr.	40 cm.	Fluvial. Soft-sediment deformed crevasse-splay sand.	Fair.
SZl	Laminated, silty, very fine grained, moderately well sorted sandstone with small rootlets and mud cracks. Poor visible porosity.	35 cm.	Lacustrine. Lake margin sediment with mud cracks caused by periodic desiccation.	Poor.
Gms	Matrix-supported conglomerate of claystone pebbles. Minor facies occurring just above the base of the upper sandstone succession. Calcareous. Associated with facies Sl.	15 cm.	Fluvial. Basal channel lag.	Poor.
Hl	Heterolithically interbedded very fine grained sandstone and claystone with even, horizontal lamination and very poor visible porosity. Associated with facies Ml and Sr.	Sand/clay laminae 1 – 5 cm, successions up to 30 cm.	Fluvial and lacustrine. Component of sheet-splay/crevasse-splay, proximal lake and lake margin sediments.	Very poor.
Ml	Laminated, slightly silty claystone with thin, very fine grained sandstone and siltstone laminae. Localised contorted bedding and sandstone dykes. Mud cracks at 2124.60 m. Rare, thin bioturbated zones. Associated with facies Sr and Hl.	Up to 55 cm.	Fluvial and lacustrine. Component of sheet-splay sandstones, proximal lake and lake margin deposits. Localised bioturbation may be due to intermittent marine influence.	None to very poor.
Mm	Faintly and rhythmically laminated to massive, dense claystone. Unbioturbated.	1.5 m.	Lacustrine. Proximal or deep lake. Faint lamination may be seasonal.	None. May act as a seal.

TABLE 3.2
ICHNOFACIES DESCRIPTIONS

ICHNOFACIES	DESCRIPTION	DEPOSITIONAL ENVIRONMENT
Planolites Association	Sparse populations of *Planolites* and possible *Chondrites*, occurring locally within laminated claystone. Bioturbation intensity is low to very low.	Lacustrine. *Planolites* has wide environmental range, and is consistent with a lacustrine setting. Marine influence is not necessarily implied by the presence of these burrows.
Palaeophycus Association	Highly localised and intensely bioturbated, occurring within a thin layer of argillaceous sandstone at 2126.9 m. Burrows appear to be mainly *Palaeophycus*, although possible *Thalassinoides*-like structures are also present.	Lacustrine. As with the *Planolites* Association, these trace fossils are not necessarily diagnostic of either marine or non-marine environments. However, their intensity is unusual, and it is possible they could reflect some marine influence.
Teichichnus Association	Thin, highly localised layer of mostly *Teichichnus* burrows occurring within heterolithic beds at 2145.50 m.	Lacustrine with marine influx. *Teichichnus* is usually considered as a marine trace fossil, therefore its presence implies some form of marine influence.
Root Mottled	Sparse rootlets occur within very fine grained, silty, laminated sandstone at 2125.35 m and are accompanied by mud cracks or fissures.	Marginal lacustrine. Periodic inundation followed by desiccation is indicated by the presence of mud cracks.

PLATES 3.1 to 3.15

SELECTED CORE PHOTOGRAPHS

AND DESCRIPTIONS

PLATE 3.1

DEPTH: 2147.70 – 2148.00 m

Facies: Laminated Claystone (Ml)

Laminated silty claystone (CLYST) of an interpreted proximal lacustrine environment is shown in this view from the base of Core 2. The claystone contains thin, very fine grained, silty sandstone laminae (SSTLam), most of which are slightly calcareous. Laminae are frequently contorted (ContLam) due to soft-sediment deformation. This contortion is usually confined to thin bands less than 2 or 3 cm thick, and may have been caused by earthquake activity prior to lithification and burial, or slippage of sediment on a sloping lake floor.

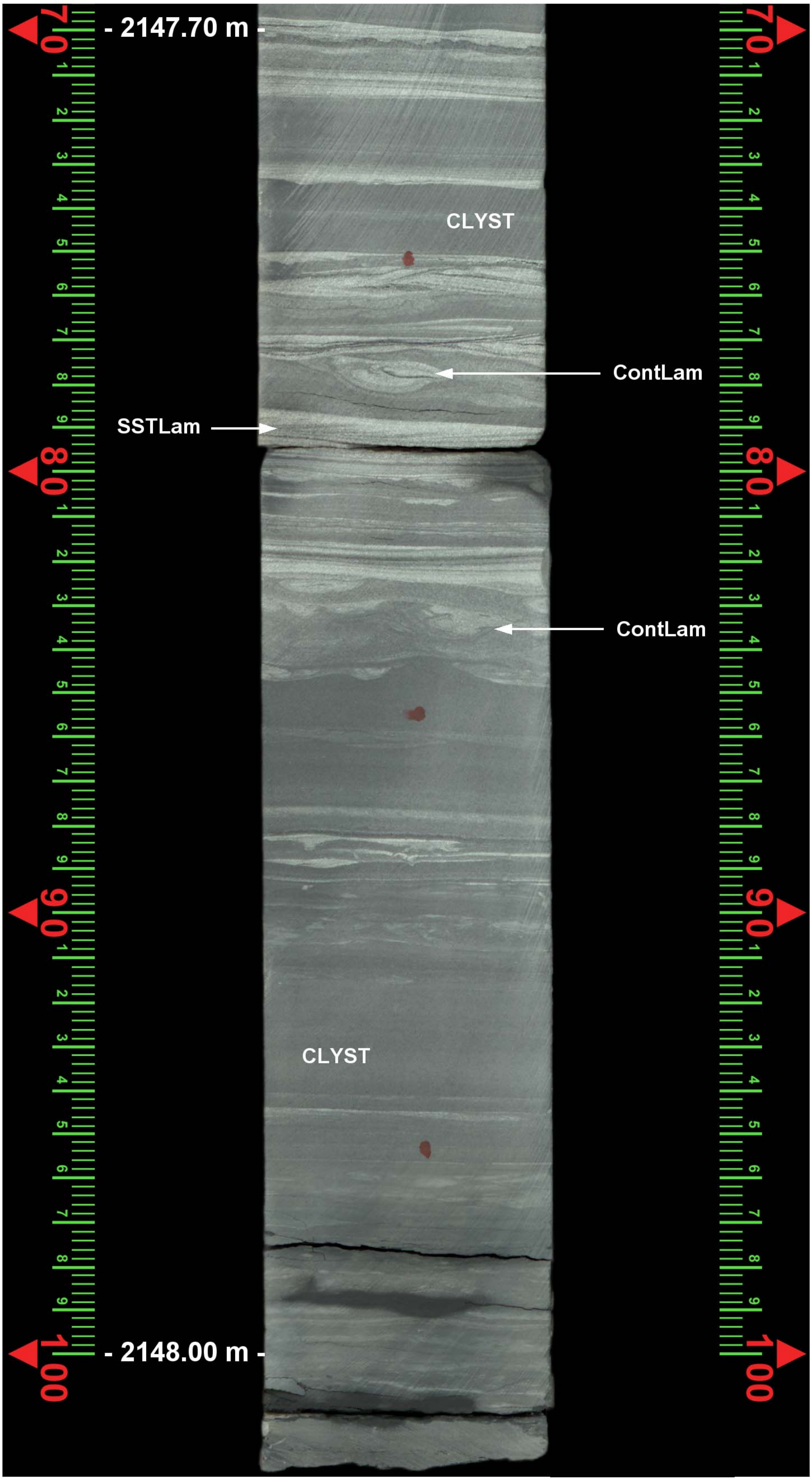


PLATE 3.1

PLATE 3.2

DEPTH: 2145.30 – 2145.60 m

Facies: Heterolithically Interbedded Sandstone and Claystone (Hl) and Laminated Claystone (Ml)

Laminated claystone (CLYST) is locally interbedded heterolithically with thin, laminated, calcareous sandstone beds and laminae (CaSST, CaSSTLam). Occasional deformed sandstone laminae (defLam) and current ripples (defRip) are observed, and a possibly burrowed, silty layer is visible in the claystone (Brwd). Carbonaceous fragments (CarbFrags) and carbonaceous laminae (CarbLam) are common within the sandstone layers. Traces of amber are also noted (Amb). Depositional environment is interpreted as lacustrine.

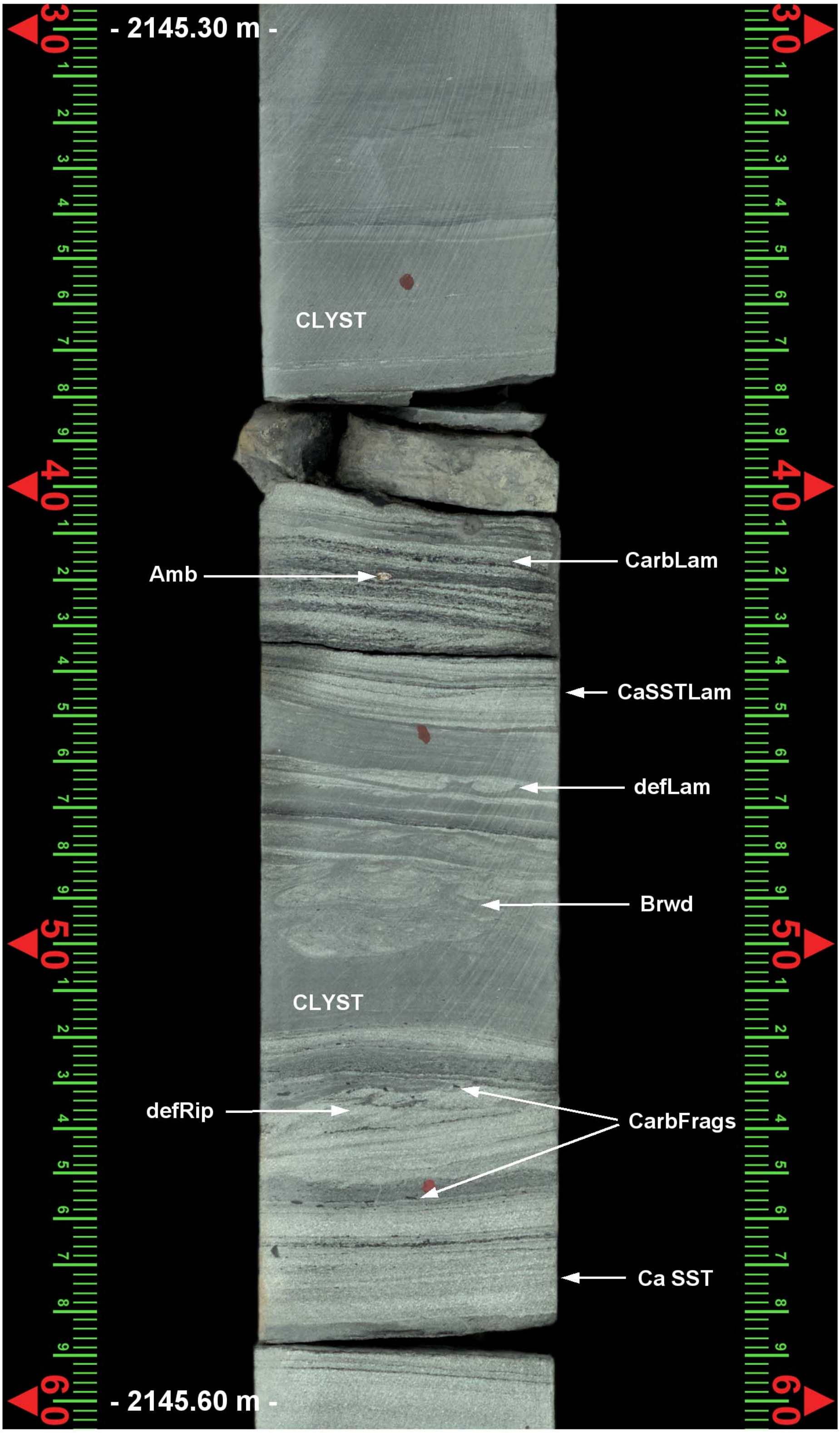

- 2145.30 m -
CLYST
Amb
CarbLam
CaSSTLam
defLam
Brwd
CLYST
defRip
CarbFrags
Ca SST
- 2145.60 m -

PLATE 3.2

PLATE 3.3

DEPTH: 2142.70 – 2143.00 m

Facies: Laminated Sandstone (Sl) Overlying Laminated Claystone (Ml)

The sharp contact (Ctct) between the laminated claystone (LamCLYST) that dominates the lower part of Core 2, and overlying laminated calcareous sandstone (CaLamSST, at the base of the B2 sandstone) are shown in this view. Laminae within the claystone are generally silty, whereas laminae in the sandstone contain finely disseminated carbonaceous debris. The claystone is interpreted to have been deposited in proximal lacustrine environment, whereas the sandstone is thought to represent a fluvial channel deposit. Note the scoured surface within the claystone (Scour). View shows the base of the B2 sandstone.

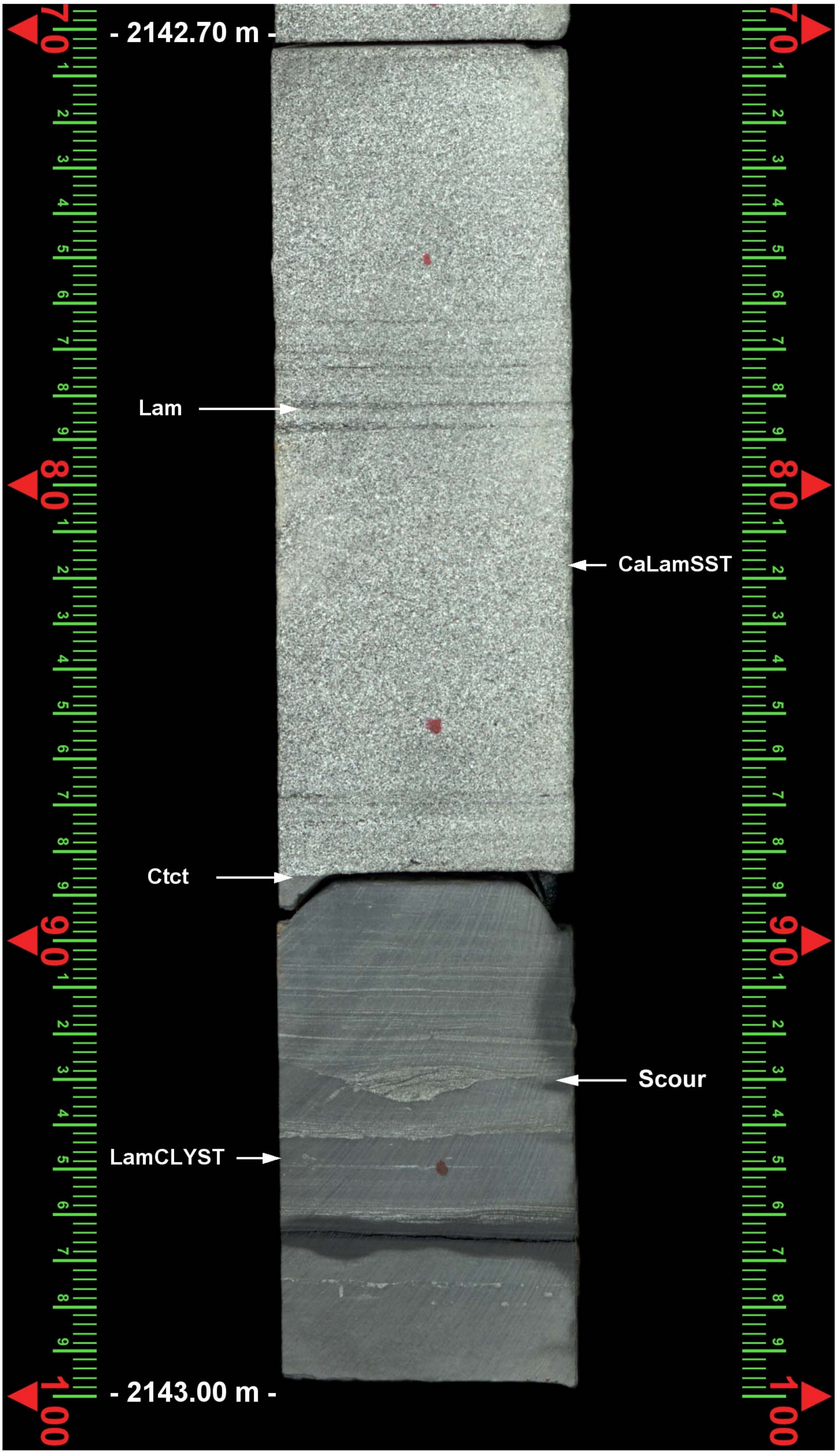


PLATE 3.3

PLATE 3.4

DEPTH: 2142.00 – 2142.30 m

Facies: Cross-Bedded Sandstone (Sx)

Faintly cross-bedded, medium grained calcite-cemented sandstone (CaSST) is shown in this view. Cross-bedding laminae are mostly faint, but are locally marked by thin layers of carbonaceous debris (CarbLam). Most of the cross-bedding appears to be trough-like in this view. Also visible are a number of carbonaceous fragments (CarbFrags) and pebble-sized clay clasts (ClyClst). This sandstone is located close to the base of the lower sandstone succession and may represent part of a fluvial channel lag. B2 Sandstone.

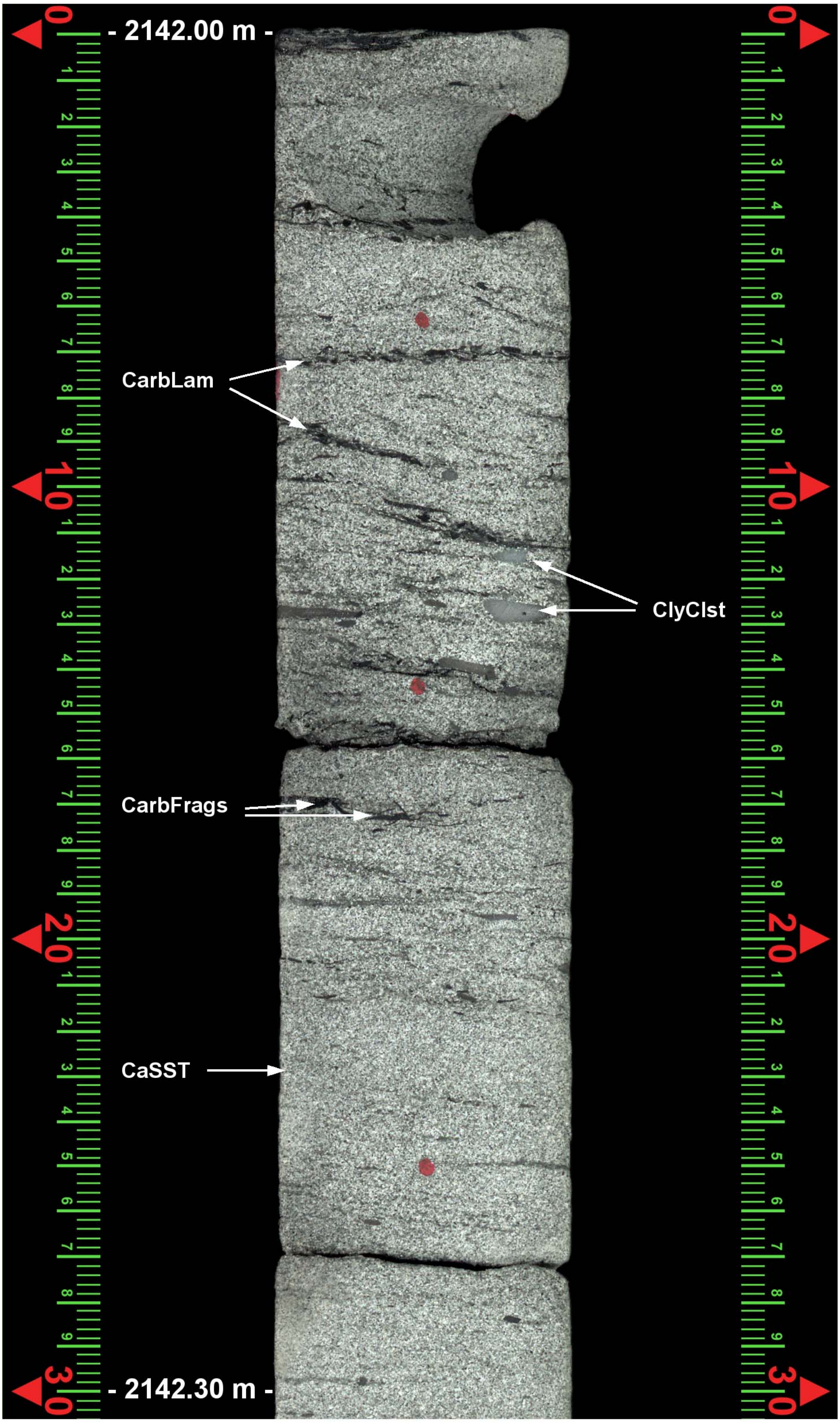


PLATE 3.4

PLATE 3.5

DEPTH: 2135.20 – 2135.50 m

Facies: Cross-bedded Sandstone (Sx)

Faintly cross-bedded, calcareous sandstone (CaSST) is shown here overlain by non-calcareous sandstone (NonCaSST). Cross-bedding appears to be mainly of the planar variety in this part of the core (PXBdg). Depositional environment is interpreted as a possibly braided fluvial channel. B2 sandstone.

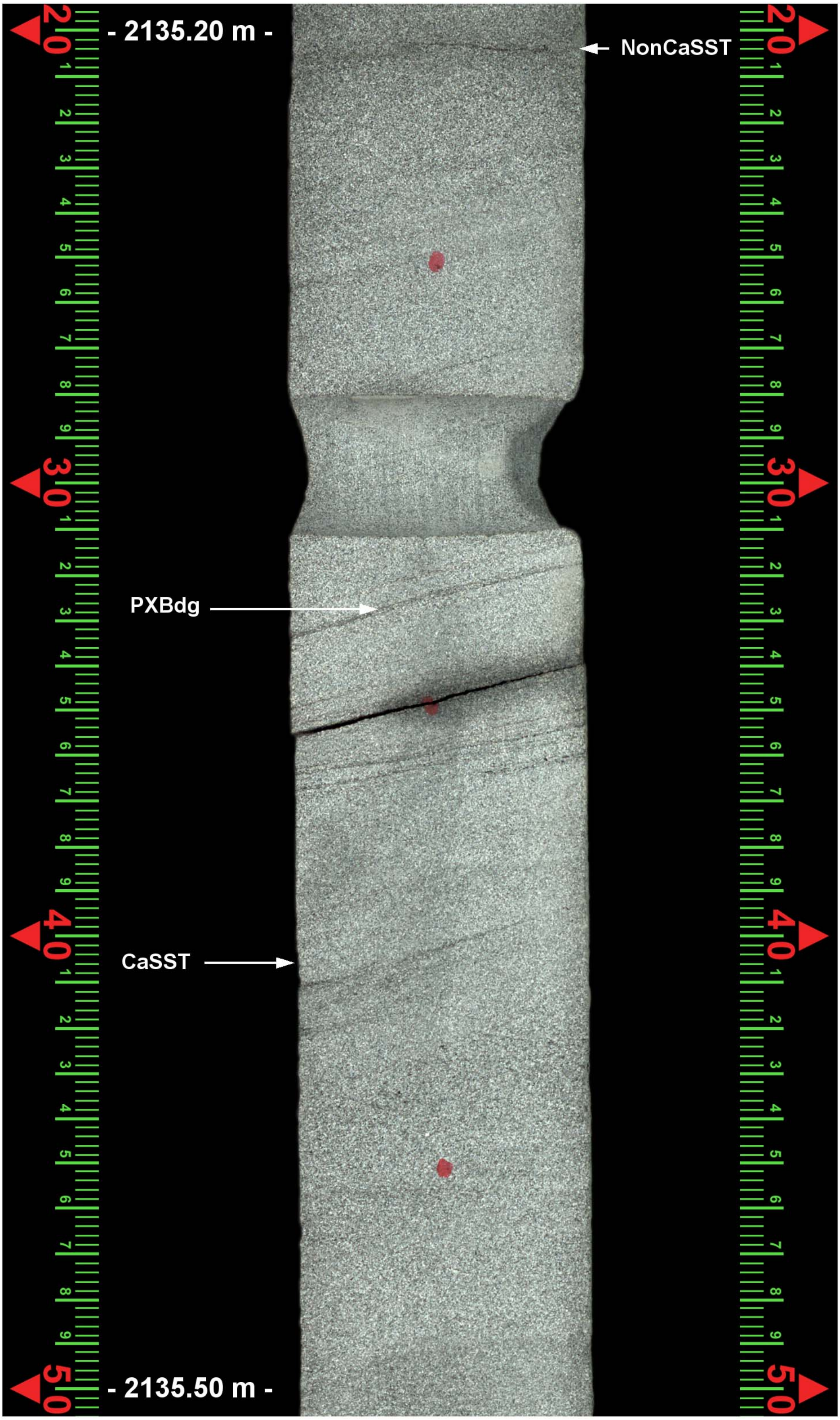


PLATE 3.5

PLATE 3.6

DEPTH: 2133.30 – 2133.60 m

Facies: Cross-bedded Sandstone (Sx)

Fine to medium grained, non-calcareous, cross-bedded sandstone (SST) of an interpreted, possibly braided fluvial channel environment is illustrated in this view. Cross-bedding lamination appears to be mainly planar (PXBdg). B2 sandstone.

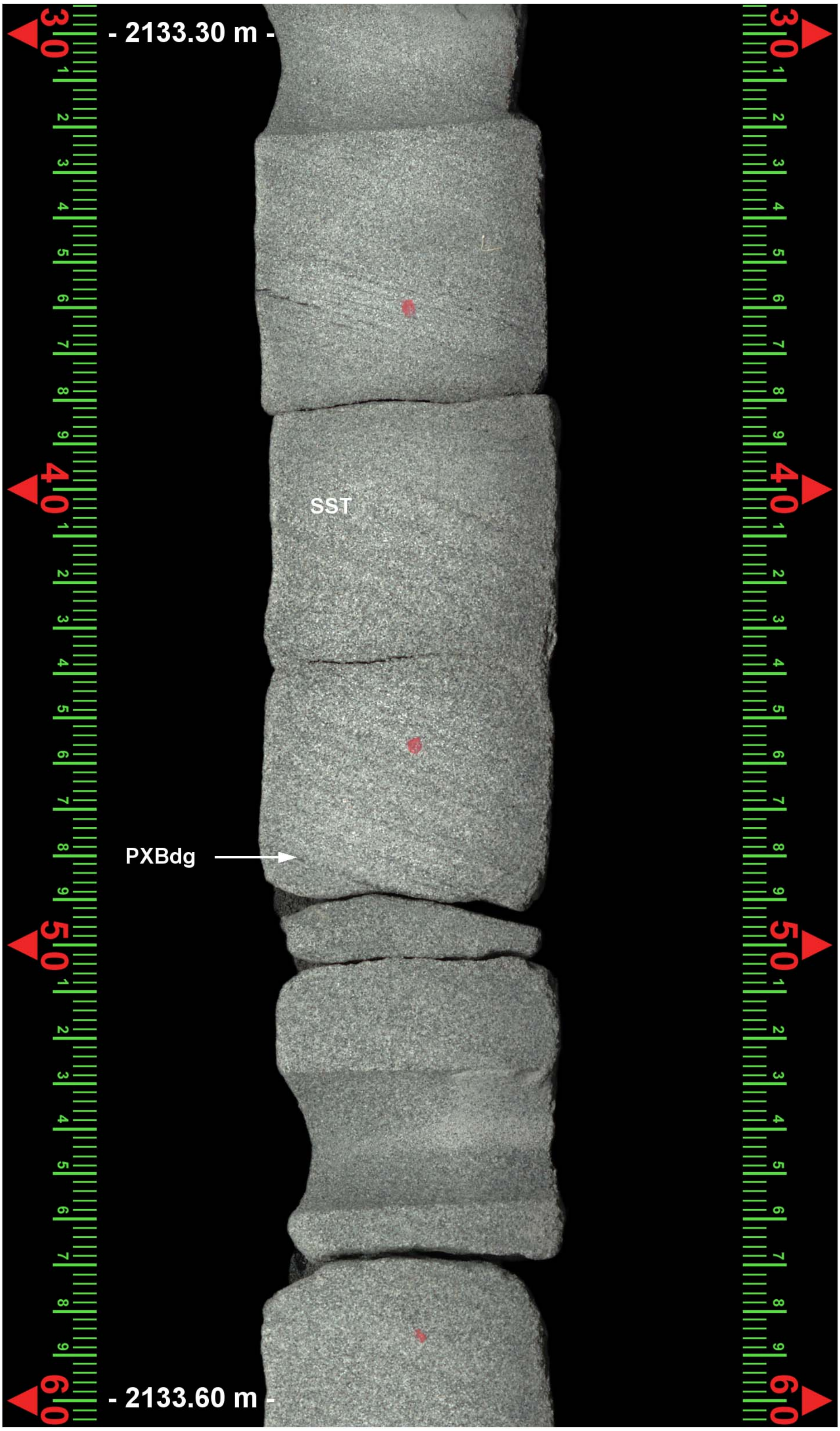


PLATE 3.6

PLATE 3.7

DEPTH: 2130.60 – 2130.90 m

Facies: Cross-bedded Sandstone (Sx)

Cross-bedding lamination in the fine to medium grained sandstone illustrated in this view appears to be trough-like (TXBdg), and is locally marked by the presence of thin layers of very fine carbonaceous debris (CarbLam). Note the reactivation surface (RSurf), which appears to have been overlain by a thin layer of bottom-set beds, followed by a series of down-lapping foresets. Depositional environment is interpreted as fluvial channel. B2 sandstone.

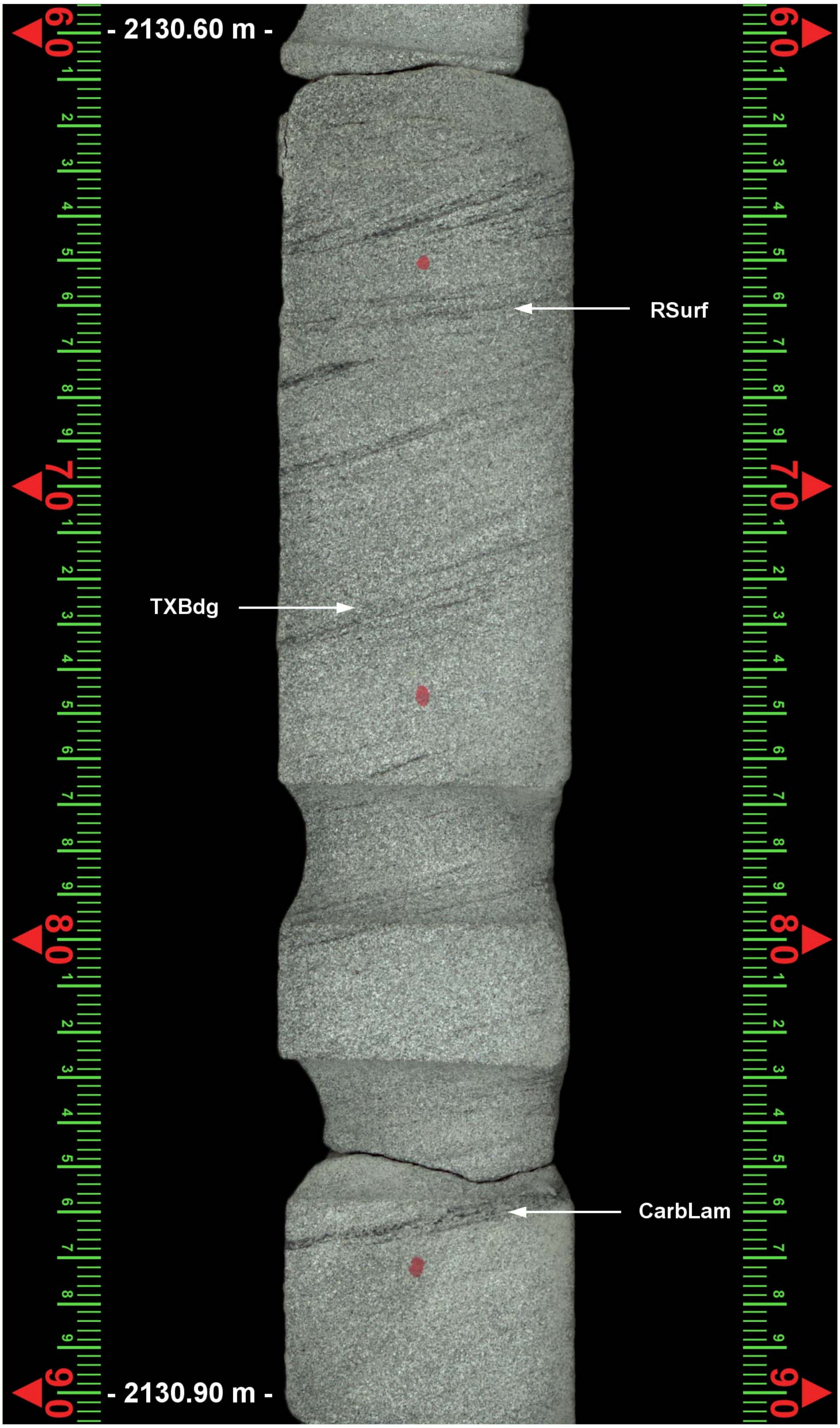


PLATE 3.7

PLATE 3.8

DEPTH: 2125.20 – 2125.50 m

Facies: Silty Laminated Sandstone (SZl) Overlain by Laminated Claystone (Ml)

Faintly laminated, silty sandstone (SltySST), that lies just above the lower of the two main sandstone bodies, is interpreted to represent a lake margin deposit. It is cut by fissure fills (FissFill) and sandstone dykes (or possibly water-escape pipes; Dyke/Esc). The fissure fills are interpreted to have formed in response to desiccation of the sediment (possibly due to a fall in lake level), whereas the dykes or water-escape pipes imply rapid burial of fluid-charged sediment. The top of the silty sandstone is marked by a sharp, undulating surface (Ctct), and is overlain by silty claystone (SltyCLYST) that appears to contain a number of small rootlets (Rt).

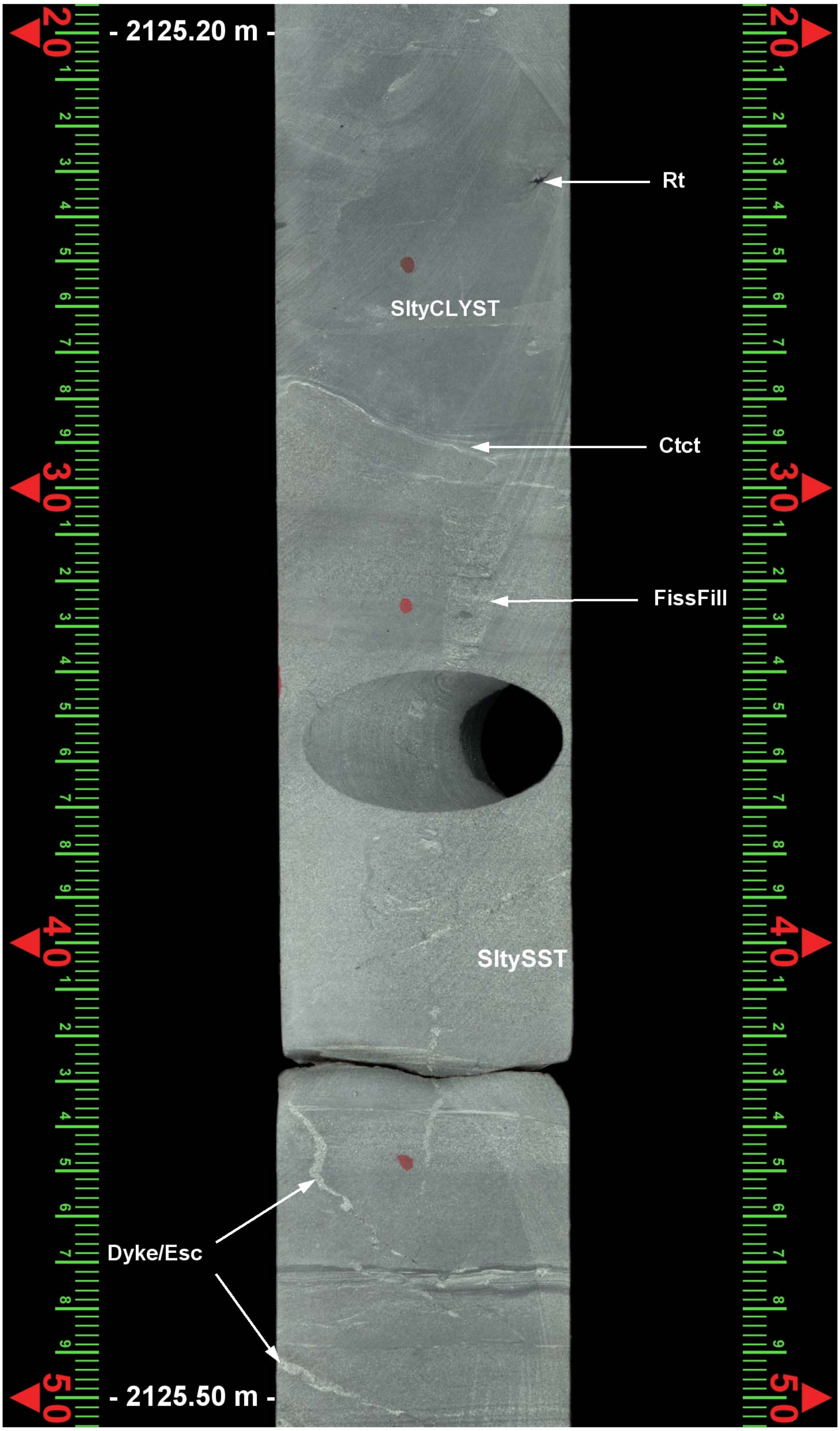

- 2125.20 m -
Rt
SltyCLYST
Ctct
FissFill
SltySST
Dyke/Esc
- 2125.50 m -

PLATE 3.8

PLATE 3.9

DEPTH: 2123.50 – 2123.80 m

Facies: Massive to Faintly Laminated Claystone (Mm)

Massive to faintly laminated claystone is illustrated in this view (CLYST). Bioturbation appears to be absent, and apart from very faint, even lamination and artificial desiccation cracks, the rock is virtually featureless. Depositional environment is interpreted as very low energy, possibly distal lacustrine.

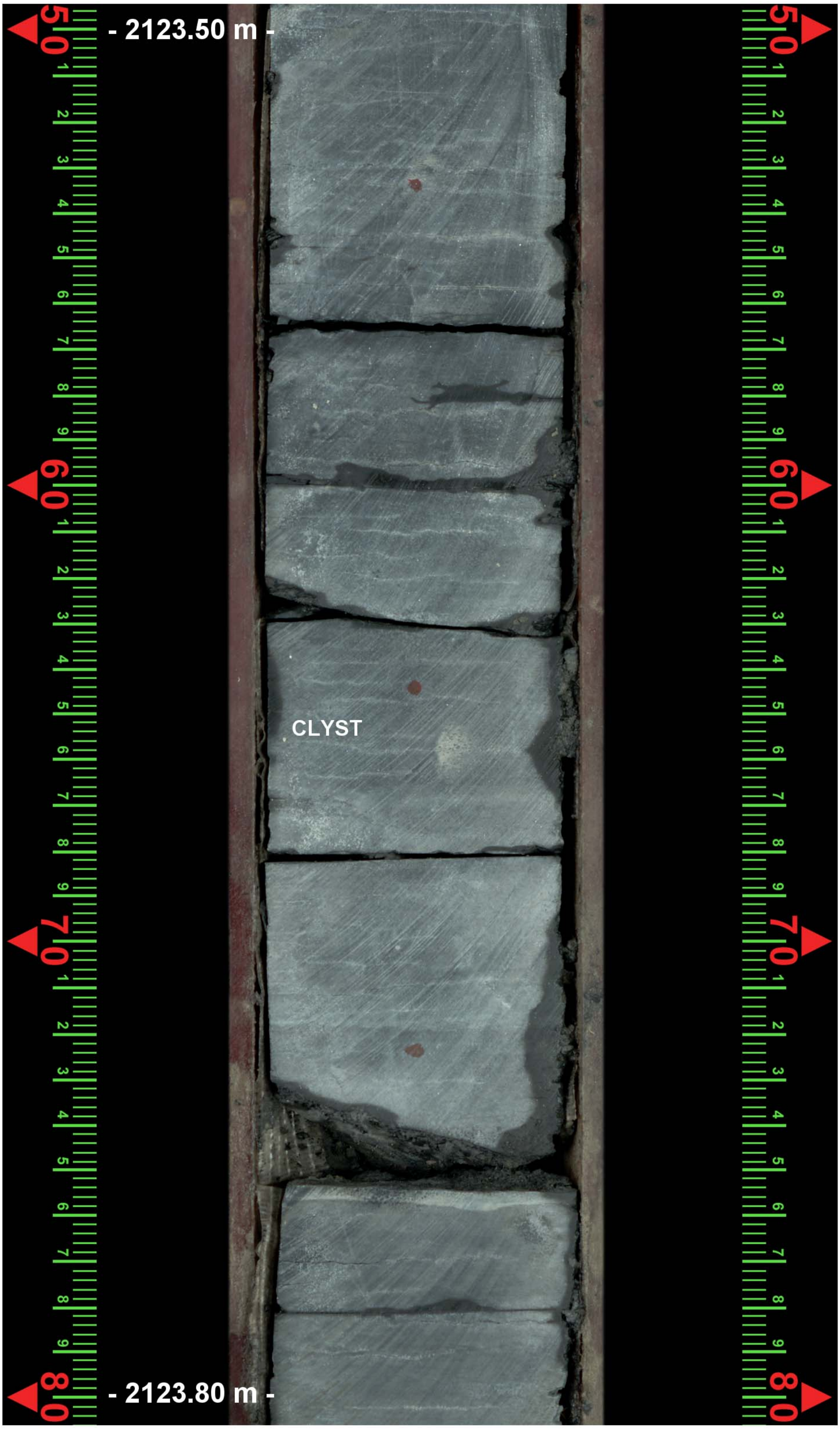


PLATE 3.9

PLATE 3.10

DEPTH: 2122.40 – 2122.70 m

Facies: Matrix-supported Conglomerate (Gms) Overlain and Underlain by Laminated Sandstone (Sl)

This matrix-supported conglomerate (CGLM) occurs as a thin layer of locally-derived pebble to cobble-sized claystone clasts (ClyPbs) within an otherwise calcareous, fine to medium grained, laminated sandstone sequence (CaSST, LamCaSST). The conglomerate is thought to represent some form of fluvial channel lag deposit, as it lies just above the base of the upper sandstone succession. However, it could alternatively have formed by channel bank collapse, or could represent some form of debris flow deposit. B1 sandstone.

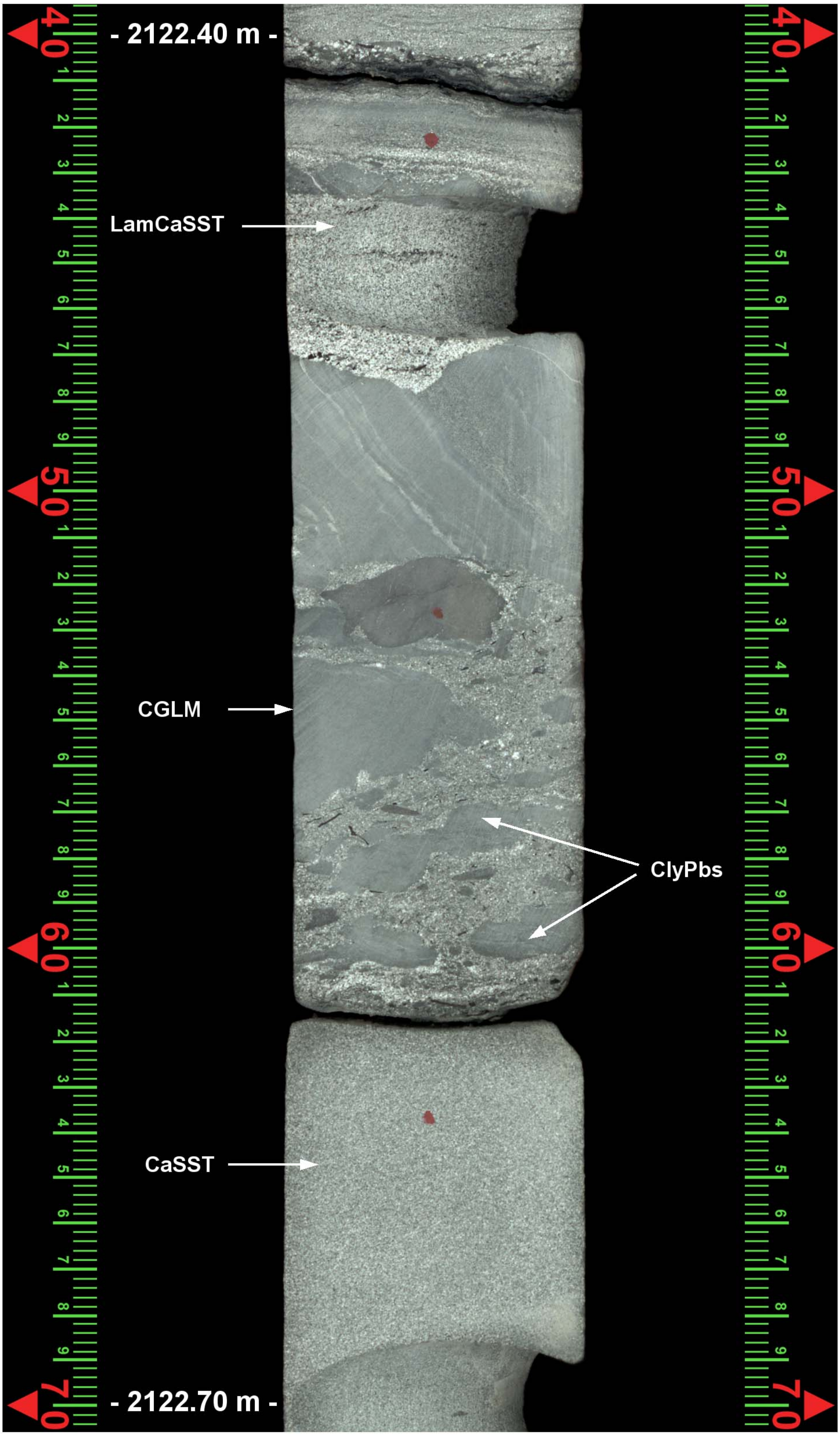


PLATE 3.10

PLATE 3.11

DEPTH: 2121.40 – 2121.70 m

Facies: Cross-bedded Sandstone (Sx)

Fine to medium grained cross-bedded sandstone (SST) of an interpreted fluvial channel environment is illustrated in this view. Note the trough like cross-beds (TXBdg), and the thin, drape-like claystone layer towards the top of the view (ClyDrp). This clay layer is interpreted to have formed during a period of slack water, and is expected to drape over the surface of the channel bedform. B1 sandstone.

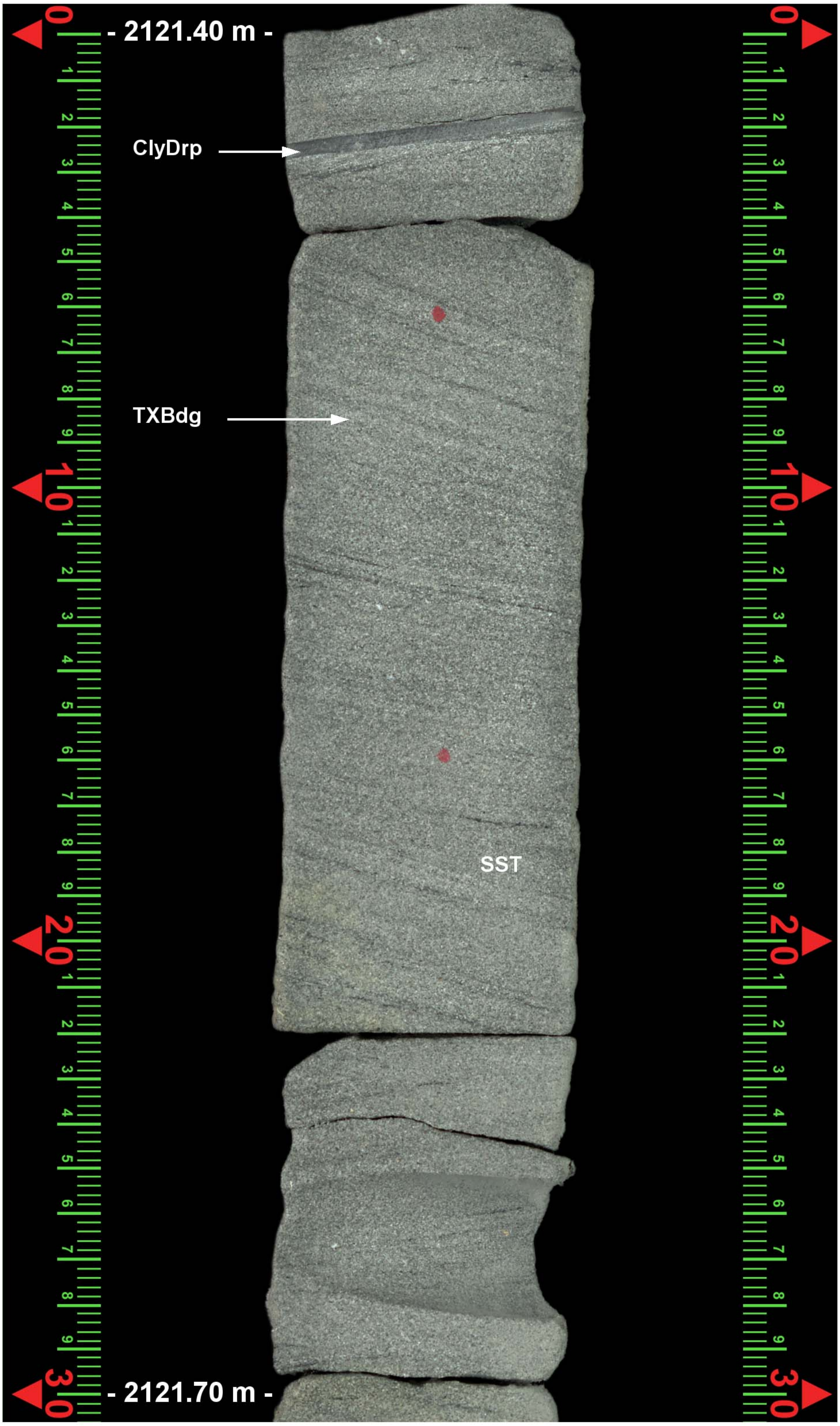


PLATE 3.11

PLATE 3.12

DEPTH: 2118.50 – 2118.80 m

Facies: Massive to Faintly Cross-bedded Sandstone (Sm/Sx)

Poorly consolidated, non-calcareous, generally massive to locally faintly cross-bedded sandstone is illustrated in this view. Note the localised carbonaceous laminae (CarbLam) and artificial stress-release fractures (srFrac). Depositional environment is interpreted as fluvial channel. B1 sandstone.

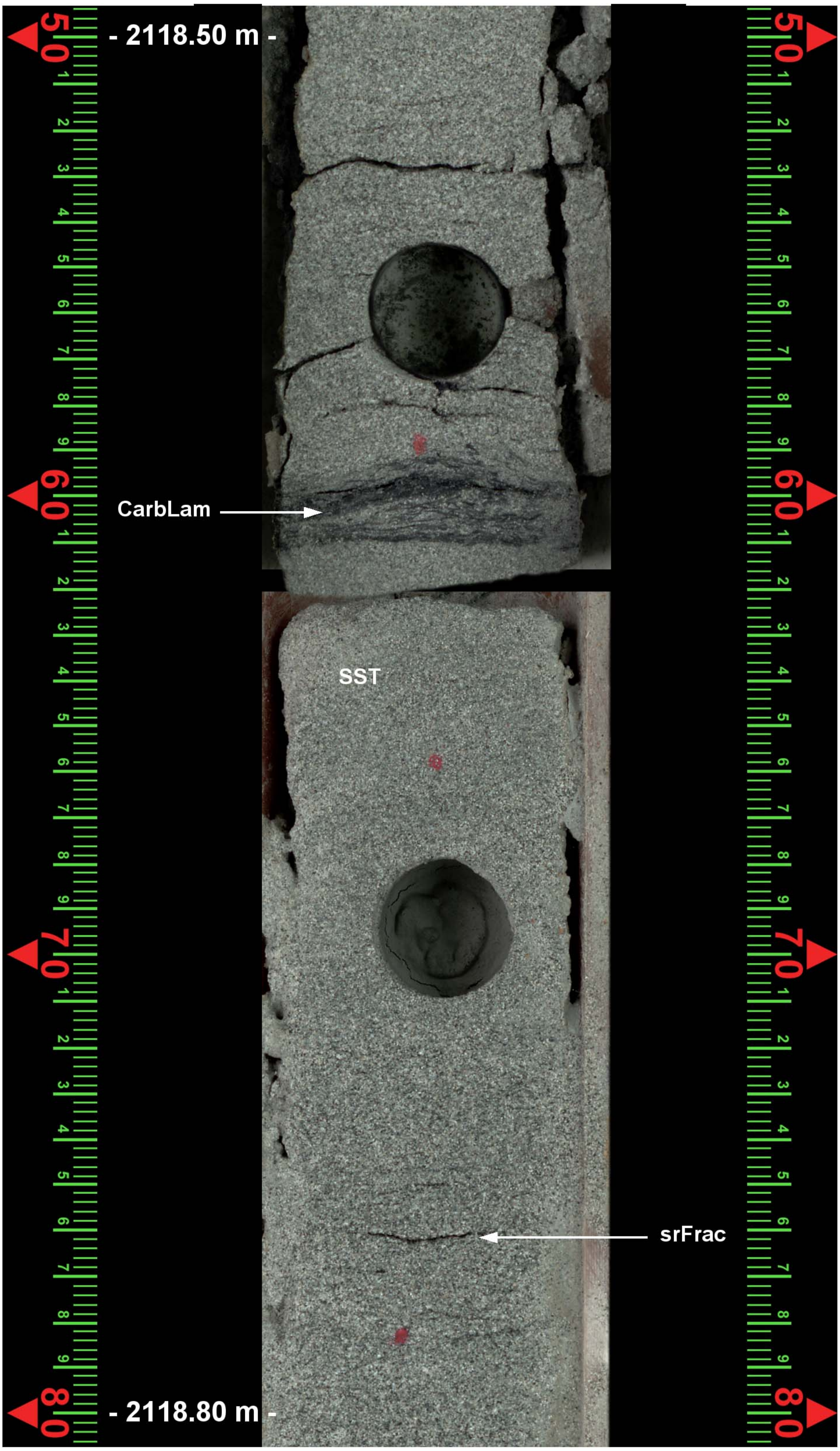


PLATE 3.12

PLATE 3.13

DEPTH: 2116.50 – 2116.80 m

Facies: Massive to Cross-bedded Sandstone (Sm/Sx)

Faintly cross-bedded to massive, fine grained, calcite-cemented sandstone (SST) is illustrated in this view. Most of the cross-bedding (XBdg) appears to be planar, although the reversal in bedding direction seen in the upper part of the view could alternatively be interpreted as a feature of large-scale trough cross-bedding. Depositional environment is interpreted as fluvial channel. B1 sandstone.

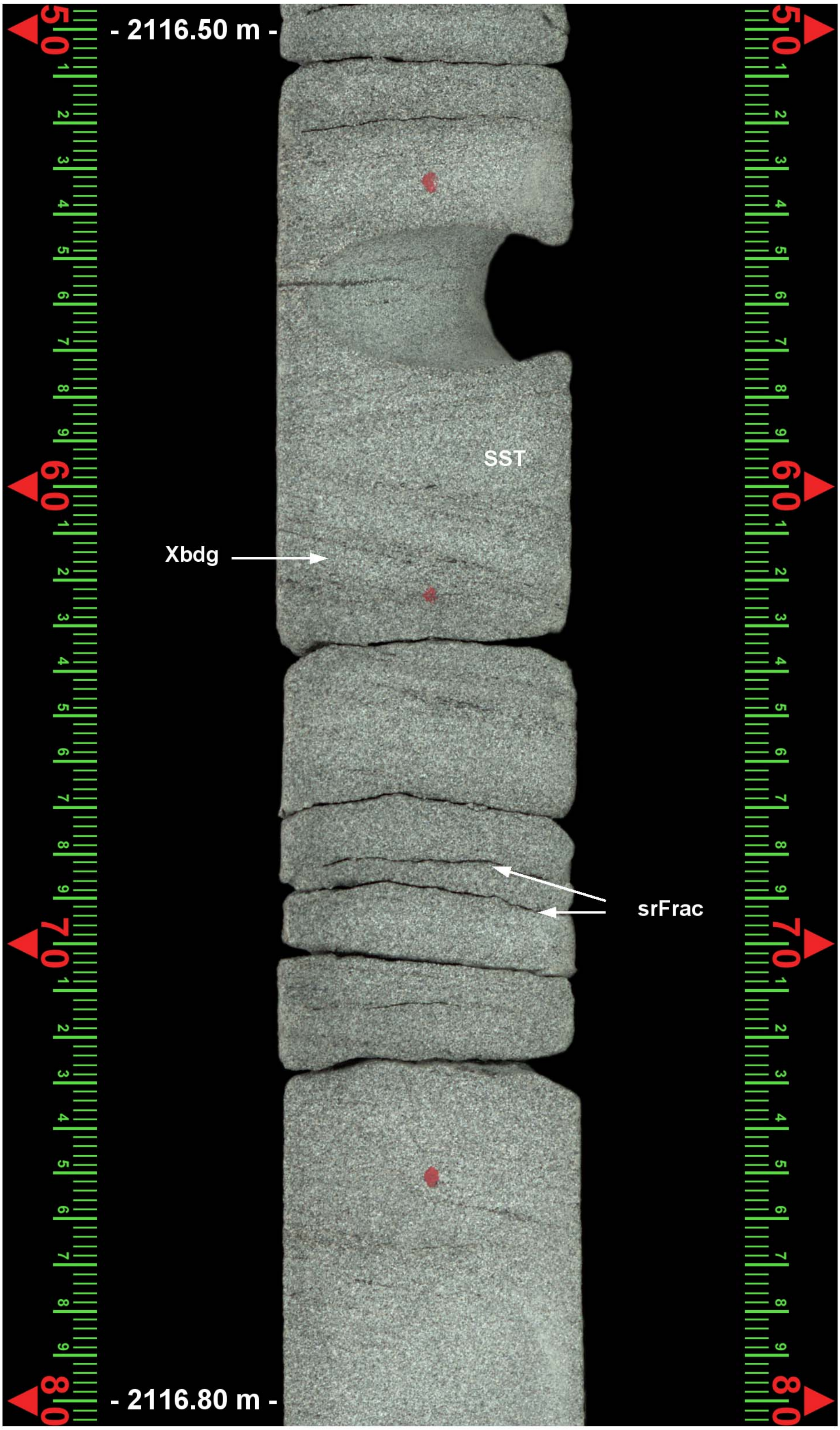


PLATE 3.13

PLATE 3.14

DEPTH: 2115.10 – 2115.40 m

Facies: Laminated Claystone (Ml) Overlain by Ripple-Laminated Sandstone (Sr)

Laminated claystone (LamCLYST) is shown here overlain by very fine to fine grained, ripple-laminated sandstone (RipSST). Most of the ripples within the sandstone appear to be current-formed (CRip). Note the isolated *Planolites* burrow (Pl) in the claystone. Deposition is interpreted to have occurred in a crevasse or sheet-splay, or possibly at the top of a point-bar deposit.

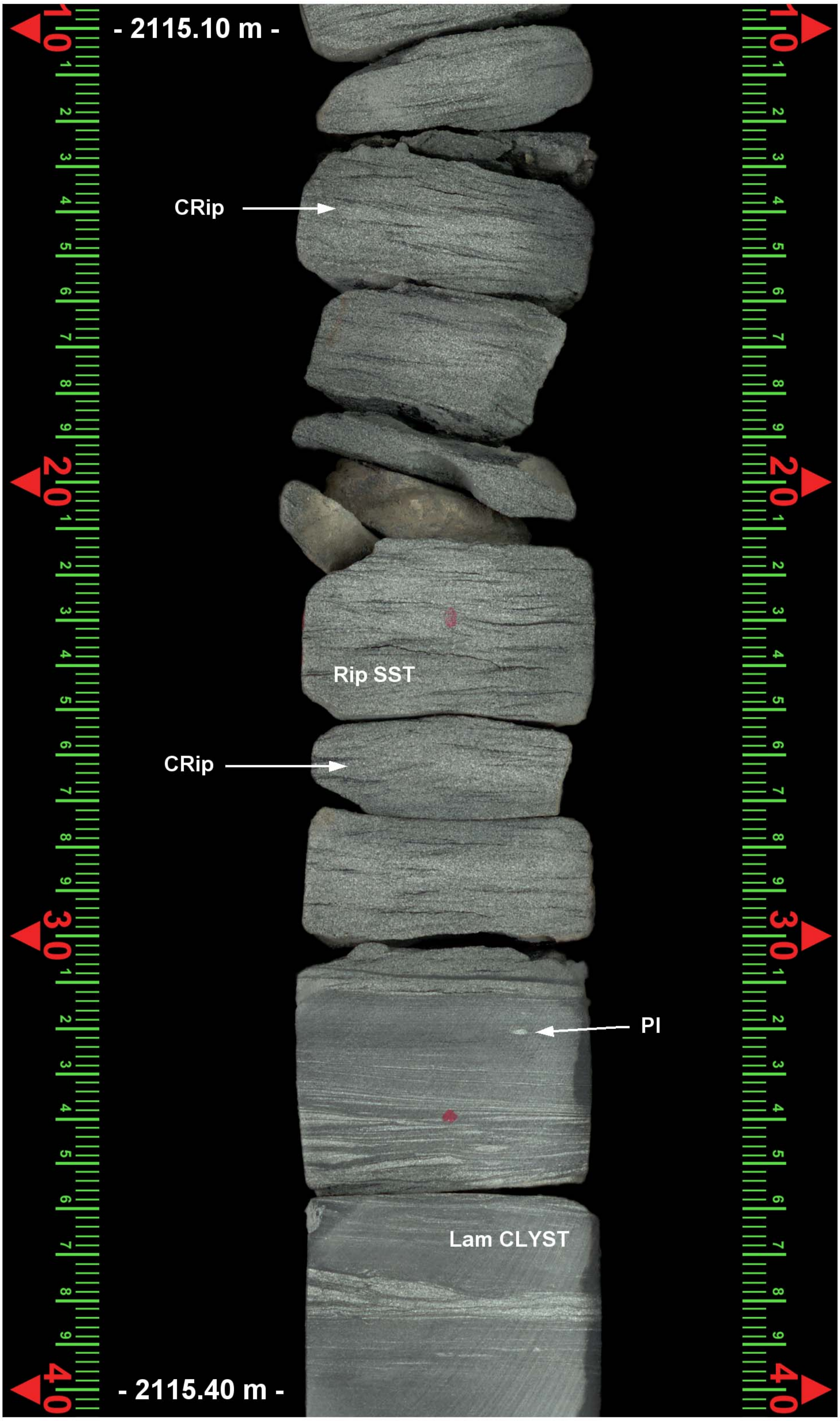


PLATE 3.14

PLATE 3.15

DEPTH: 2112.70 – 2113.00 m

Facies: Heterolithically Interbedded Claystone and Sandstone (Hl)

This view illustrates heterolithically interbedded silty claystone (SltyCLYST) and very fine grained, calcareous sandstone (vfSST). Note the wavy lamination (WLam) and current ripples (CRip) that are a common feature of the very fine to fine grained sandstones located towards the top of the upper sandstone succession in Core 1. Localised soft-sediment deformation and contortion is also observed, mainly in the claystone (CnLam). Depositional environment is interpreted to have been crevasse-splay to proximal lacustrine.

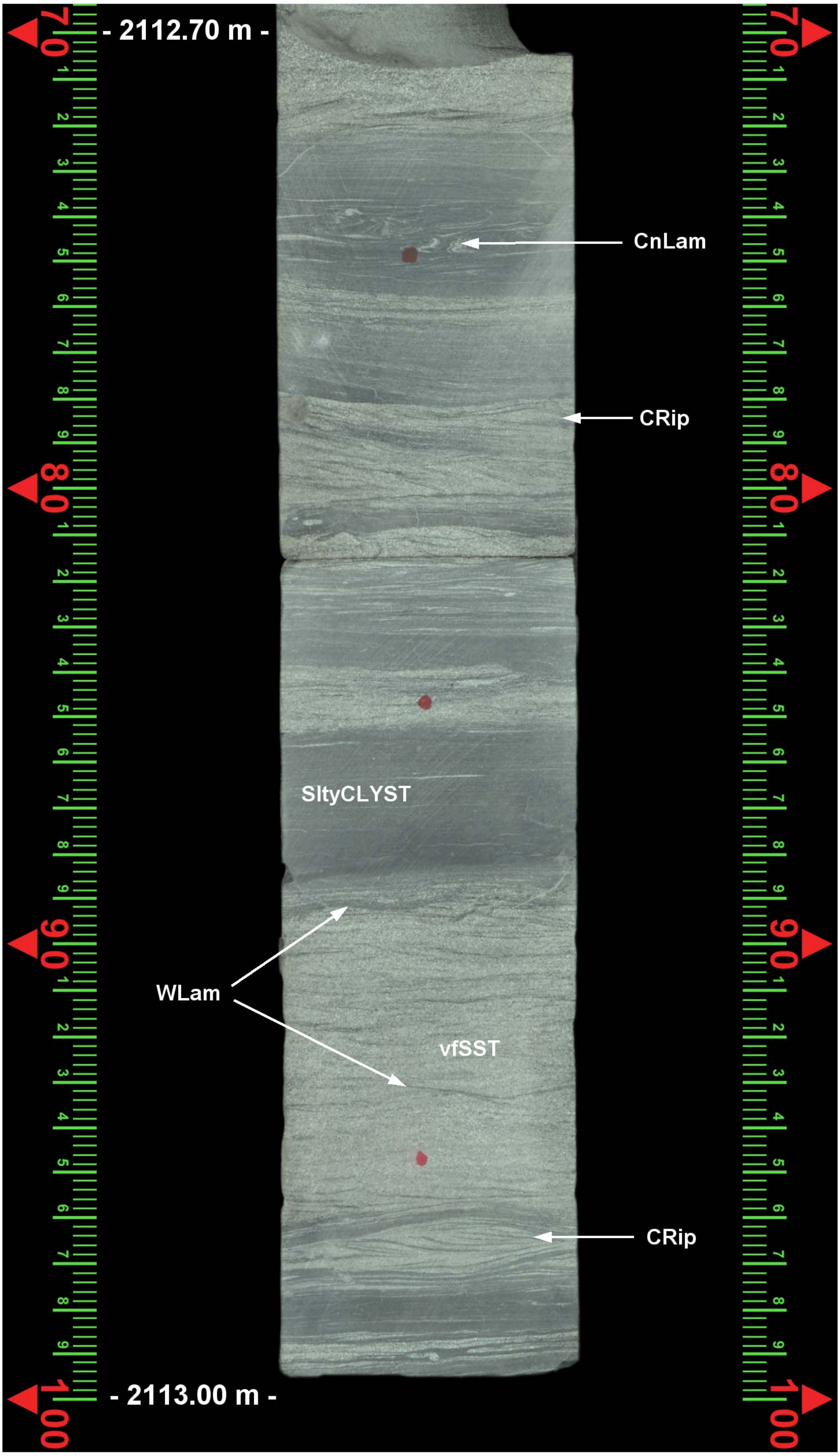


PLATE 3.15

4 PETROGRAPHY

4.1 Overview

Core samples were examined by a combination of thin section, scanning electron microscopy, and X-ray diffraction analyses (see Table 4.1 for a list of sample depths and analyses). Samples taken from the cored interval (B1 and B2 sandstones, Figure 3.3) comprise mainly feldspathic litharenite to litharenite sandstone, and are locally calcite-cemented (see Table 4.2 for a summary of petrographic characteristics over the cored interval, Table 4.3 for modal point-count data, and Table 4.4 for X-ray diffraction data). Grain sizes range from very fine to medium, sorting from moderate to moderately good, and texture from massive to locally faintly laminated. Visible porosity varies from very poor to good.

The cuttings samples that were examined from Longtom-2 borehole were taken from below the cored interval. The stratigraphic position of these samples in the borehole is shown in Figure 3.3. Cuttings lithologies range from claystones and sandstones to volcanic, volcaniclastic and tuffaceous rocks (the petrography of cuttings samples is summarised in Table 4.5).

Most of the following discussion concentrates on the cored interval of Longtom-2 ST1. Cuttings samples from Longtom-2 are discussed separately (see Section 4.16).

4.2 Texture

Most of the sandstones analysed from the cored interval are massive at thin section scale, although a number show very faint lamination, and one sample (2114.72 m; Plate 4.2A) exhibits ripple lamination. Grain shapes are mostly equant to subelongate.

Grain size ranges from very fine grained to medium grained. Sorting is generally moderately good, locally moderate.

4.3 Grain Packing and Compaction

Compactional deformation is considered to be moderate. Grain packing is moderate throughout, with planar (long) grain contacts slightly more common or roughly equal in abundance to point contacts (Table 4.2). Concavo-convex contacts are also observed, although these are nearly always associated with ductile grains such as shale fragments, degraded glassy volcanic rock fragments, or clay-replaced grains. Some ductile grains have been compactionally deformed into minor pseudomatrix (Plate 4.2B).

4.4 Sandstone Classification

Most of the sandstone samples examined in thin section are classified as feldspathic litharenite to litharenite (Figure 4.1). One sample was described as a lithic arkose (at 2112.70 m; Plate 4.1A). Sandstone classifications are according to Folk (1974).

4.5 Grain Mineralogy

Grains are mainly monocrystalline quartz, with common to very common volcanic rock fragments, common feldspar, clay-replaced grains, polycrystalline quartz, chert, minor to common sandstone rock fragments, minor shale fragments, mica (mainly chlorite with subordinate biotite and muscovite), rare plutonic rock fragments, metamorphic rock fragments, occasional carbonaceous fragments, and rare to trace heavy minerals (mainly tourmaline and zircon).

Quartz shows straight to moderately undulose extinction and is locally rutilated (Plate 4.10B). A few grains exhibit embayment (Plate 4.3B), indicating that some quartz may be volcanically-derived.

Feldspar grains are generally degraded, either through alteration and partial replacement by clay minerals, or by partial leaching (Plates 4.5B, 4.10B). In thin section, most feldspars are untwinned, with only a few exhibiting multiple plagioclase twinning. However, XRD analyses indicate that plagioclase is either subequal or slightly more abundant than alkali feldspar (Table 4.4). Much of the plagioclase in these samples may therefore be untwinned.

Lithic grains are dominated by very common volcanic rock fragments. These fragments range from microlitic to porphyritic in texture (Plates 4.3B, 4.6B), but also include common, degraded volcanic glass (Plates 4.2B, 4.8B). Some of this volcanic glass appears to have been partly replaced by chloritic clay. Other lithic grains include common chert (many of which are thought to represent devitrified volcanic rock fragments; Plates 4.6B, 4.11B), sandstone rock fragments (Plate 4.3B), minor shale fragments (Plate 4.5B, 4.7B), phyllitic metamorphic rock fragments (Plate 4.2B), and rare plutonic rock fragments.

Accessory grains mostly comprise clay-replaced grains (Plate 4.2B). These are grains that have been so extensively altered to clay minerals that their original mineralogy can no longer be reliably determined. Clay-replaced grains are thought to include altered feldspars, lithics and possibly mica. Other accessory grains include chlorite mica (Plate 4.11B), biotite (Plate 4.12B) and muscovite. Some of the chlorite mica may represent chloritised grains.

4.6 Provenance

Provenance for the sandstones in Longtom-2 ST1 is thought to have involved a mixture of volcanic, clastic sedimentary and possibly plutonic sources. Volcanic provenance is clearly demonstrated by the presence of very common volcanic rock fragments and untwinned plagioclase feldspar, whereas clastic sedimentary provenance is indicated by sandstone rock fragments and shale fragments. Evidence for plutonic input is provided by rare plutonic rock fragments, moderately undulose quartz extinction and by the presence of rutile inclusions in much of the quartz. However, it should be noted that these undulose and rutilated grains could simply represent plutonic quartz that has been recycled from older sediments.

4.7 Clay Minerals and Clay Matrix

XRD analyses show that clay minerals are very common to abundant throughout the cored sequence, ranging from 15 to 60 wt % in the samples analysed (Table 4.4 – note that these figures include two shale samples). The clay assemblage in most sandstone samples is dominated by chlorite and kaolinite, with common illite/mica and rare mixed-layer illite smectite. The two shale samples analysed show a broadly similar clay mineral assemblage.

Thin section point-counts indicate that roughly 50% to 70% of the total clay content of the sandstones consists of structural clay, mainly in the form of clay-replaced grains. Structural clay is thought to account for most of the illite/mica portion of the clay mineral assemblage detected by XRD, and much of the illite/mica seen by XRD is likely to include biotite and muscovite mica grains. However, some kaolinite and chlorite are also expected to be included with structural clay, as evidenced by the presence of minor kaolinite-replaced grains (Plate 4.9B) and detrital chlorite (Plates 4.1B, 4.3B, 4.7B, 4.11B). Although much of this detrital chlorite occurs as mica flakes (Plates 4.1B, 4.11B), some of it is thought to represent chloritised grains (Plates 4.3B, 4.7B).

Clay matrix in the sandstones appears to be almost entirely authigenic, consisting mainly of pore-lining chlorite (Plates 4.1B, 4.9B, 4.15B, 4.16D, 4.17B, 4.22B) and pore-filling kaolinite (Plates 4.2B, 4.7B, 4.10B, 4.11B, 4.16B, 4.20B, 4.24B). Some pseudomatrix caused by compaction of ductile grains is also observed (Plate 4.2B).

Pore-lining authigenic chlorite is encountered throughout the cored sequence, and is frequently common, reaching up to 8.4% by point-count (see Table 4.3). SEM images show how the clay has formed extensive, well-crystalline coats on grains, and lines virtually the entire pore network of the reservoir (Plates 4.15B, 4.16D, 4.17B, 4.22B). Only the later-formed quartz overgrowth cements and authigenic kaolinite appear to be free of this authigenic chlorite (Plates 4.16A, 4.17B, 4.24B).

Pore-filling authigenic kaolinite is also observed throughout the cored sequence, often occurring in similar quantities to chlorite (Table 4.3). The kaolinite generally occurs in small patches, often spanning less than one or two pore diameters (Plates 4.2B, 4.7B, 4.10B, 4.11B). SEM images show the clay to be well crystalline and extremely fine (diameters of kaolinite plates are generally around 5 microns; Plates 4.16B, 4.20B, 4.24B). Although the main habit of the clay is pore-filling, some grain-replacing kaolinite is also encountered (Plate 4.9B).

Interestingly, XRD analyses of two claystone samples (at 2123.87 m and 2144.10 m) show that the detrital clay assemblage is similar to the authigenic clay assemblage. Detrital clay mineralogy comprises subequal chlorite, kaolinite and illite/mica, with rare mixed-layer illite/smectite (Table 4.4).

4.8 <u>Cements</u>

In addition to authigenic chlorite and kaolinite, cements include locally common to abundant ferroan calcite, trace to minor quartz overgrowths and trace to rare pyrite.

4.8.1 Calcite

Calcite cement occurs in nine of the fourteen sandstone core samples analysed in thin section, and ranges from around 2% to 20% by point-count (Table 4.3). The calcite is generally medium to coarsely crystalline, and is locally poikilotopic. Composition appears to be very slightly ferroan, as indicated by its faint purplish to pink stain after Alizarin Red/potassium ferricyanide staining (Plates 4.6B, 4.13B). At its most abundant, calcite almost totally fills the intergranular pore network (Plates 4.6B, 4.9B, 4.13B).

In sandstones where calcite is less common, it occurs as scattered crystals that fill or partly fill single pores, or small groups of pores (Plates 4.2B, 4.5B). There is no evidence to suggest any etching of the calcite has occurred, with calcite showing pristine crystal faces in SEM (Plate 4.24A).

4.8.2 Quartz Overgrowths

Quartz overgrowths are seen throughout the cored interval, but are never common, and in most cases are poorly to moderately developed (Plates 4.2B, 4.10B, 4.12B). Quartz overgrowths appear to have been hampered in their development by earlier-formed chlorite clay coats, and in SEM images they are easily recognised by their pristine appearance and lack of chlorite coating (Plates 4.16A, 4.17B, 4.19B).

4.8.3 Pyrite

Pyrite is rare, occurring as small, scattered replacive framboids within matrix and grains.

4.9 Diagenesis

4.9.1 Overview

The main controls on reservoir quality in the cored section of Longtom-2 ST1 are diagenetic: calcite cementation, compaction, and authigenic clay precipitation. The interpreted sequence of diagenetic events is summarised below in approximate chronological order (see also Figure 4.2):

4.9.2 Pyrite

Pyrite is thought to have formed in the sulphate reduction zone during very early burial.

4.9.3 Pore-lining Chlorite

Pore-lining and grain-coating chlorite is interpreted to have formed relatively early. The provenance of the chlorite is unknown, although one possibility is it may have formed as a replacement of former detrital clay that had infiltrated the sand shortly after deposition.

4.9.4 Authigenic Kaolinite

Pore-filling authigenic kaolinite is pristine, well crystalline and free of any authigenic chlorite (Plates 4.16B, 4.20B, 4.24B), indicating it formed after chlorite precipitation. Kaolinite also appears to have been partly enveloped by quartz overgrowths (Plate 4.17B), indicating it formed before the bulk of quartz cementation. Some of the kaolinite is thought to represent grain-replacive material.

4.9.5 Quartz Overgrowths

Quartz overgrowths almost certainly formed after chlorite authigenesis, and possibly after kaolinite precipitation, whereas the presence of quartz overgrowths underneath calcite indicates that at least some quartz preceded calcite cementation. However, point-count analyses show that quartz overgrowths are more common in samples where calcite cement is either absent or minor (Table 4.3), implying that quartz cementation continued after calcite cementation had ceased.

4.9.6 Calcite Cementation

Slightly ferroan calcite is interpreted to have precipitated during relatively late burial, after the onset of quartz overgrowth cementation. This interpretation is indicated by the presence of quartz overgrowths underneath the calcite (Plates 4.5B, 4.6B 4.13B), and is given further support by grain packing densities, which are moderate throughout the sequence, regardless of whether or not the sandstone is calcite-cemented. Calcite cement crystals have pristine appearance under SEM (Plates 4.19B, 4.24A), and show no apparent signs of etching or corrosion, even though some leaching of grains is interpreted to have occurred after calcite precipitation.

Calcite mainly occurs towards the top of the upper sandstone succession, and towards the base of the lower sandstone succession (see core description log in Enclosure 1). Coupled with the pristine state of the calcite and its relatively late timing, this may indicate that the calcite was sourced from overlying and underlying claystone. Calcite cement may therefore have formed from pore fluids expelled into the sandstone as a result of dewatering of the claystones during burial.

4.9.7 Dissolution of Grains

Most dissolution porosity is interpreted to have formed after calcite cementation. Dissolution pores mainly occur in partly leached feldspar grains (Plates 4.5B, 4.7B, 4.10B, 4.16C), but in some cases whole grains have been dissolved (Plates 4.2B, 4.10B). Although a few relatively early-formed dissolution pores have been filled with calcite in calcite-cemented samples, most dissolution pores are considered to have formed later than calcite, as they remain free of calcite, even when calcite cement is immediately adjacent to these grains (Plate 4.10B).

4.10 Reservoir Quality

Reservoir quality ranges from very poor to fair, and is locally good. The best quality occurs in uncemented, poorly consolidated sandstone, whereas heavily calcite-cemented sandstone exhibits the lowest quality. Helium injection porosity values at net overburden pressure vary from 7.1% to 26.1%, and Klinkenberg permeability values at net overburden pressure vary from 0.002 md to 460 md.

Prior to core slabbing, a number of stress-release fractures were observed in the core. These stress-release fractures generally occur within the most poorly consolidated sandstone, and tend to correspond with zones where measured porosity and permeability are highest. Unfortunately, it was impossible to avoid these stress-fractured zones when taking core plug samples, and it is possible that some of the higher porosity and permeability values observed could have been exaggerated by this fracturing. However, thin section analyses show that these sandstones tend to have well-developed, relatively open intergranular pore networks (Plates 4.3A, 4.7A, 4.8A, 4.16A), which in themselves would lead to higher porosity and permeability. Another possibility is therefore that the physical properties of these sandstones could have led to their being preferentially fractured, and that the higher permeability seen in these samples could be natural, rather than artefact.

Another feature to note is that porosity and permeability values from most of these higher quality sandstones roughly follow the same trend line as defined by slightly lower quality samples thought to be unaffected by stress-release fracturing (Figure 4.3). Samples with artificial fracture permeability would normally be expected to plot separately, above this main trend line, as indeed appears to be the case with several lower porosity samples.

4.11 Visible Porosity

Visible porosity in thin sections varies from very poor to good (0.4% to 19.0%; see Table 4.3), and is mainly intergranular (Plates 4.5B, 4.7B, 4.12B) with minor dissolution pores. Dissolution porosity mainly occurs in partly leached feldspars (Plates 4.5B, 4.7B, 4.16C). In the best quality sandstones, intergranular pore sizes are relatively large, although a combination of compaction and the presence of pore-lining chlorite clay have combined to reduce permeability by restricting pore throats.

4.12 Porosity and Permeability Controls

The main controls on reservoir quality are listed below in approximate order of importance:

4.12.1 Calcite Cement

Calcite is locally abundant, almost completely closing off the pore network in several parts of the cored interval, and occurring as localised pore-filling crystals elsewhere (Plates 4.5B, 4. 6B, 4.9B, and 4.13B).

4.12.2 Compaction

Moderate compaction has occurred throughout, reducing pore and pore throat sizes as a result of grain rotation, and creating localised patches of pseudomatrix by deforming ductile grains (Plate 4.2B).

4.12.3 Grain Size

When unimpeded by calcite, coarser grained samples generally exhibit the best permeability on account of their larger pore sizes (Plates 4.3B, 4.8B).

4.12.4 Authigenic Clays

Both pore-filling kaolinite and pore-lining/grain-coating chlorite have reduced porosity and permeability by partly obstructing the intergranular pore network and by obstructing pore throats (Plates 4.2B, 4.10B, 4.11B, 4.16B, 4.20B, 4.24B). Chlorite is thought to have had a much greater impact on permeability compared to porosity on account of its pore-lining and grain-coating habit.

4.12.5 Quartz Overgrowth Cements

Quartz overgrowths have reduced permeability by narrowing some pore throats (Plates 4.19A, 4.24A). However, quartz overgrowths are generally small and tend to be only locally developed, thus their effect on permeability is thought to be minor.

4.12.6 Grain Dissolution

Partial leaching of feldspar grains has enhanced porosity, although permeability is unlikely to have been significantly increased.

4.13 <u>Effects on Wireline Log Response</u>

A number of features may affect wireline log responses, or the way in which wireline logs are interpreted. These are summarised in Table 4.6, and are listed below:

4.13.1 Vclay Estimates

Roughly half the total clay content across the cored interval consists of structural clay (i.e. clay in grains), and therefore does not impede the pore network (except when compacted into pseudomatrix). Since structural clay cannot be distinguished from dispersed clay matrix using wireline logs, Vclay estimates may be over-pessimistic if all the clay estimated from logs is assumed to be dispersed.

4.13.2 Clay-Associated Bound Water

Appreciable quantities of immobile water may be associated with common structural clay, pore-lining chlorite and pore-filling kaolinite. Since resistivity log-derived estimates of water saturation will include this bound water, the formation may therefore produce with less water than anticipated.

The presence of well crystalline, dispersed chlorite clay may also influence resistivity measurements. Although chlorite is generally considered to have low cation exchange capacity, or CEC (Eslinger and Pevear, 1988), its dispersed, pore-lining habit and high surface area could combine to cause at least some suppression of resistivity values.

4.13.3 Elevated Grain Density

Density porosity estimates risk being overly pessimistic if a standard sandstone matrix density of 2.65 g/cc is used, since average grain density across the cored interval is 2.68 g/cc.

4.14 <u>Potential Formation Damage</u>

The potential for formation damage as a result of adverse fluid-rock interaction is considered to be high. The main hazards are summarised in Table 4.7, and are discussed briefly below:

4.14.1 Capillary Water Block

Water lost to the formation during drilling may be difficult to remove due to capillary retention. Capillary retention in these sandstones is likely to be exacerbated by the high surface area presented by extensive, well crystalline chlorite clay linings.

4.14.2 Acid Sensitivity

The potential for damage as a result of acid stimulation is considered to be very high. Hydrochloric (HCl) pre-flushes would be required ahead of any hydrofluoric acid (HF) treatment in order to remove calcite cement and avoid insoluble calcium fluoride precipitation. However, contact between HCl and iron-bearing chlorite could itself lead to precipitation of ferric hydroxide, which is also insoluble. To avoid damage to the reservoir, the effectiveness of any proposed acid stimulation work should first be tested in the laboratory using core samples.

4.14.3 Fines Migration

Migration of authigenic kaolinite fines is also a potential hazard. Authigenic kaolinite, which is common in much of the cored interval, is loosely attached to its substrate and can easily become detached during production, causing it to block pore throats already narrowed by chlorite. The problem is often exacerbated when the wetting phase moves (e.g. during aquifer encroachment).

4.14.4 Sand Production

Sand production is considered to be a potential hazard due to the poor consolidation shown by much of the sandstone. Laboratory tests can be employed to determine optimum production rates, thereby minimising the risk of lost production.

4.15 Comparisons with Longtom-1 Petrography

Thin sections from Longtom-1 (taken from percussion sidewall cores between 1892.5 m and 1928.5 m) were compared to thin sections from the cored interval of Longtom-2 ST1, and thin sections prepared from cuttings from the main borehole of Longtom-2. These comparisons show that grain mineralogy (and therefore provenance), diagenesis, and porosity development differ between Longtom-1 and Longtom-2/Longtom-2 ST1. Sandstones from the two wells therefore appear to be unrelated, even though they are both from the Admiral Formation, and may have been deposited in similar fluvio-lacustrine environments.

The Admiral Formation in Longtom-1 correlates with the A sandstone unit in Longtom-2 (Figures 3.2 and 3.3). The equivalents of the B1, B2 and older sandstone units in Longtom-2 were not intersected in Longtom-1. No petrography has been conducted on cuttings from the thin sandstone beds of the A sandstone unit in Longtom-2.

Most of the Longtom-1 samples have suffered heavy percussion damage (only one sample, at 1928.5 m, is considered to be relatively undamaged). As a result, textural relationships and visible porosity are difficult to assess precisely. However, sandstones from the two wells can be distinguished by the following features:

- Almost no feldspars were recognised in thin section in Longtom-1 (Wilson and Van Noord, 1995), whereas feldspars are common in Longtom-2 ST1. On the Folk classification plot, the Longtom-1 samples plot along the right-hand margin of the litharenite field (Figure 4.4), whereas most samples from Longtom-2 ST1 are classified as feldspathic litharenites (Figure 4.1). However, some degree of caution is advised here, as mineralogy in Longtom-1 was determined by visual estimate, whereas the Longtom-2 ST1 samples were point-counted.
- Lithic grains in Longtom-1 are described as being of mainly phyllitic and mica-schist origins, thereby indicating a strong metamorphic bias to

sediment provenance. Lithic grains in Longtom-2 ST1 are of mostly volcanic and clastic sedimentary origins.

- Advanced compaction in Longtom-1 has led to extensive deformation of ductile grains into pseudomatrix, resulting in "over-compacted" fabric. Although it is conceivable that this "over-compacted" fabric could be due to sidewall coring damage, it is more likely to be natural, as it is prevalent in the relatively undamaged sample at 1928.5 m. The Longtom-1 section is also very close to the Longtom Fault (Figure 3.2), and could have experienced greater stress – and hence more advanced compaction – as a result. In contrast, pseudomatrix of ductile grains is minor in Longtom-2 ST1.
- Although accurate assessment of porosity is difficult due to percussion sidewall coring damage in the Longtom-1 samples, it appears that the intergranular pore network has been heavily reduced by compaction. In contrast, intergranular porosity is moderately well preserved in most of the Longtom-2 ST1 cored interval.

4.16 Petrography of Longtom-2 Cuttings Samples

Nine cuttings samples were described in thin section. Descriptions and photomicrographs are provided at the back of the report (Plates 4.25 to 4.33). Cuttings petrographic data are summarised in Table 4.5, and are discussed briefly below:

4.16.1 Interval 2188 – 2300 m

Over most of this interval, which corresponds roughly with the sandstone of the lower test zone, the cuttings mainly comprise silty claystone, argillaceous siltstone and with sandstone (Plates 4.25 to 4.29). The stratigraphic position of the cuttings sampled is shown in Figure 3.3; samples were taken from the D, E1, E2 and F1 sandstones.

The sandstone in this interval is generally similar in texture and mineralogy to the sandstone encountered in the cored interval of Longtom-2 ST1, although grain size appears to be generally slightly finer in the cuttings than in the core (however note that the cuttings may not be truly representative of the sandstone units they come from). Grain size of these sandstone cuttings is mainly very fine to fine, locally lower medium, and sorting is moderate to moderately good. Most sandstone cuttings exhibit lithic arkose to feldspathic litharenite composition, with grains including monocrystalline and common polycrystalline quartz, degraded feldspar, clay-altered grains, volcanic rock fragments (both glassy and microlitic), shale fragments, chert and minor detrital chlorite mica.

4.16.2 Interval 2320 – 2410 m

This interval corresponds to the Longtom Volcanics Member of the Admiral Formation. Although the cuttings from the uppermost sample are dominated by claystone (at 2320 m, Plate 4.30), they also contain common fragments of chert, confirming that a change of lithology occurs at the top of the interval. The remaining samples, from 2380 m down to 2410 m (Plates 4.31 to 4.33), are dominated by chert, with subordinate loose quartz, subarkosic very fine to very coarse grained sandstone, microlitic and porphyritic volcanic material, tuff and tuffaceous sandstone, claystone (some of which contains planktonic forams), and loose feldspar.

The origins of chert are often difficult to determine (Pettijohn, Potter and Siever, 1987), and the chert cuttings observed in these samples are no exception to this rule. However, much of the chert is suspected to comprise either devitrified tuff and tuffite, or devitrified tuffaceous and volcaniclastic sandstone. This interpretation is based on the localised presence of relict tuff-like structures within the chert, and the inclusion of occasional pristine, euhedral feldspar grains.

The mixture of different rock types observed in the cuttings – porphyritic, glassy and microlitic volcanic material, tuffaceous/volcaniclastic sandstone and subarkosic sandstone – implies a complex, possibly interbedded sequence of clastic, volcaniclastic and volcanic rocks for this part of the well.

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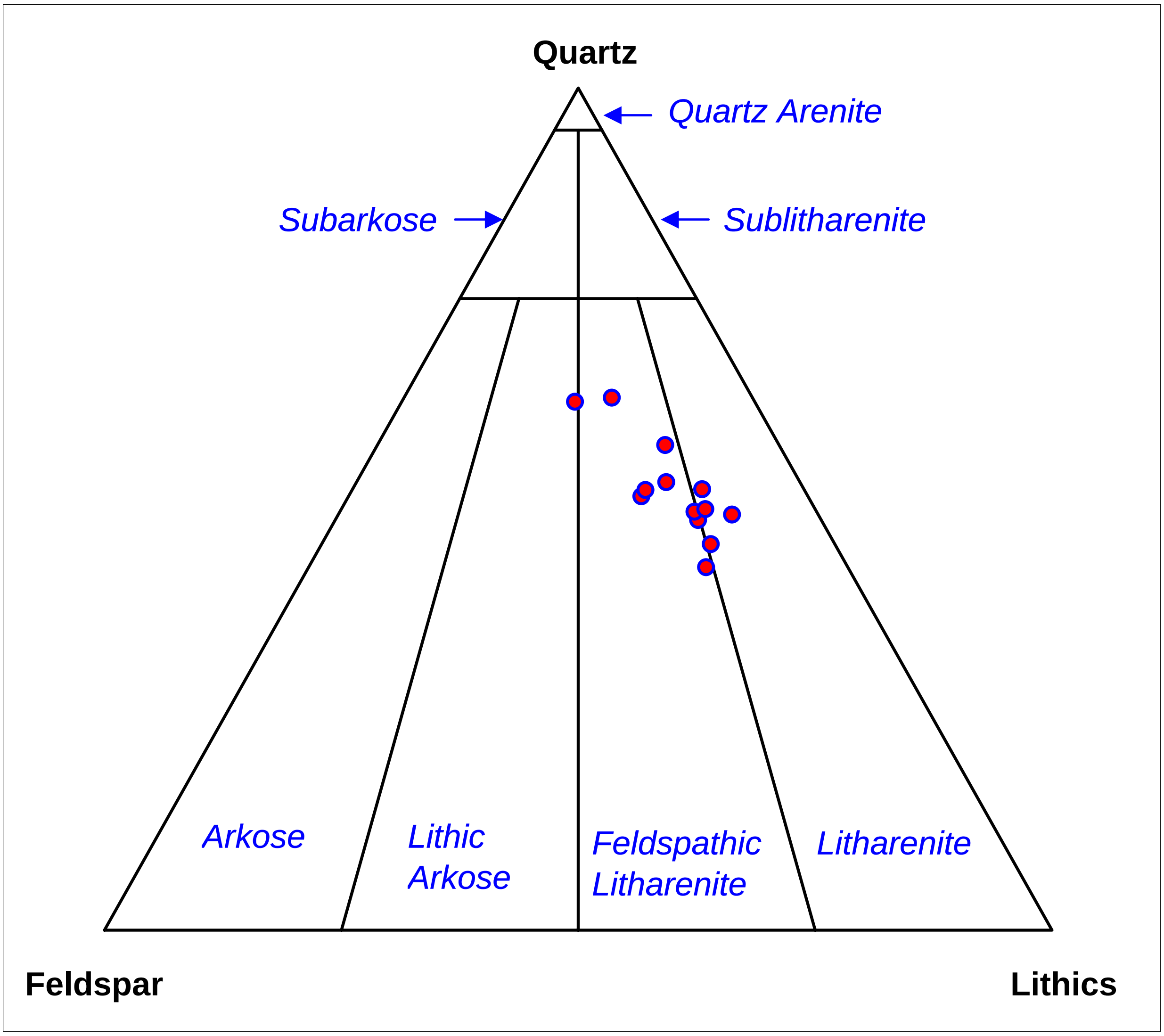


FIG. 4.1: SANDSTONE CLASSIFICATION
Longtom-2 ST1 Cored Interval
(After Folk, 1974)

Note: Chert counted as a lithic

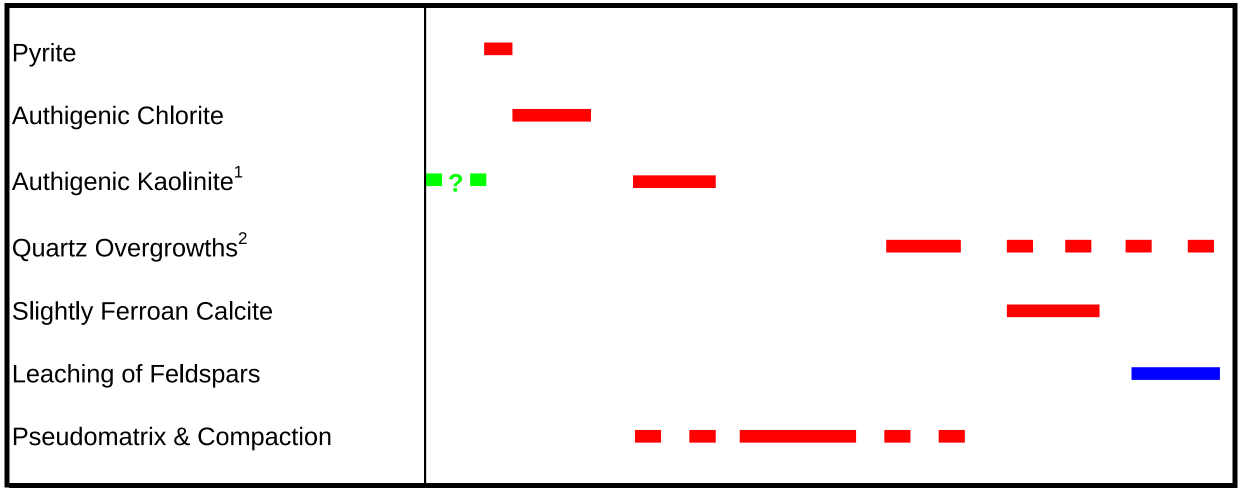


FIGURE 4.2. INTERPRETED SEQUENCE OF MAIN DIAGENETIC EVENTS LONGTOM-2 ST1 CORE SAMPLES

KEY:
- Green = Inherited From Time Before Deposition
- Blue = Porosity Enhancement
- Red = Porosity Reduction

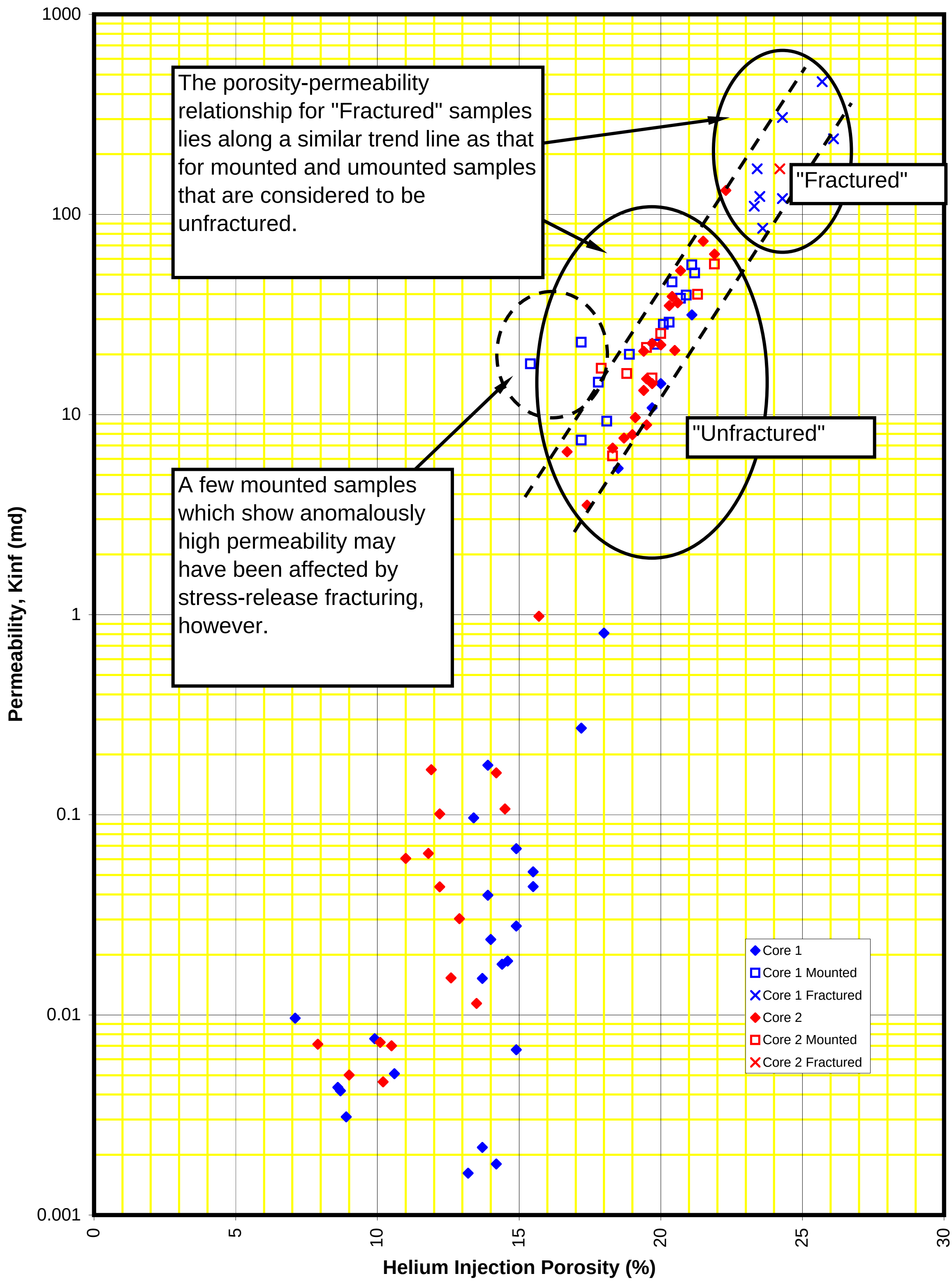
Interpretation based on textural relationships observed in thin section and SEM.

NOTES

[1] Some grains may have been partly kaolinitised by weathering prior to deposition.

[2] Quartz overgrowth formation is interpreted to have continued after calcite cementation.

Figure 4.3
Longtom-2 ST1 Permeability vs Porosity
NOBP 1800psi



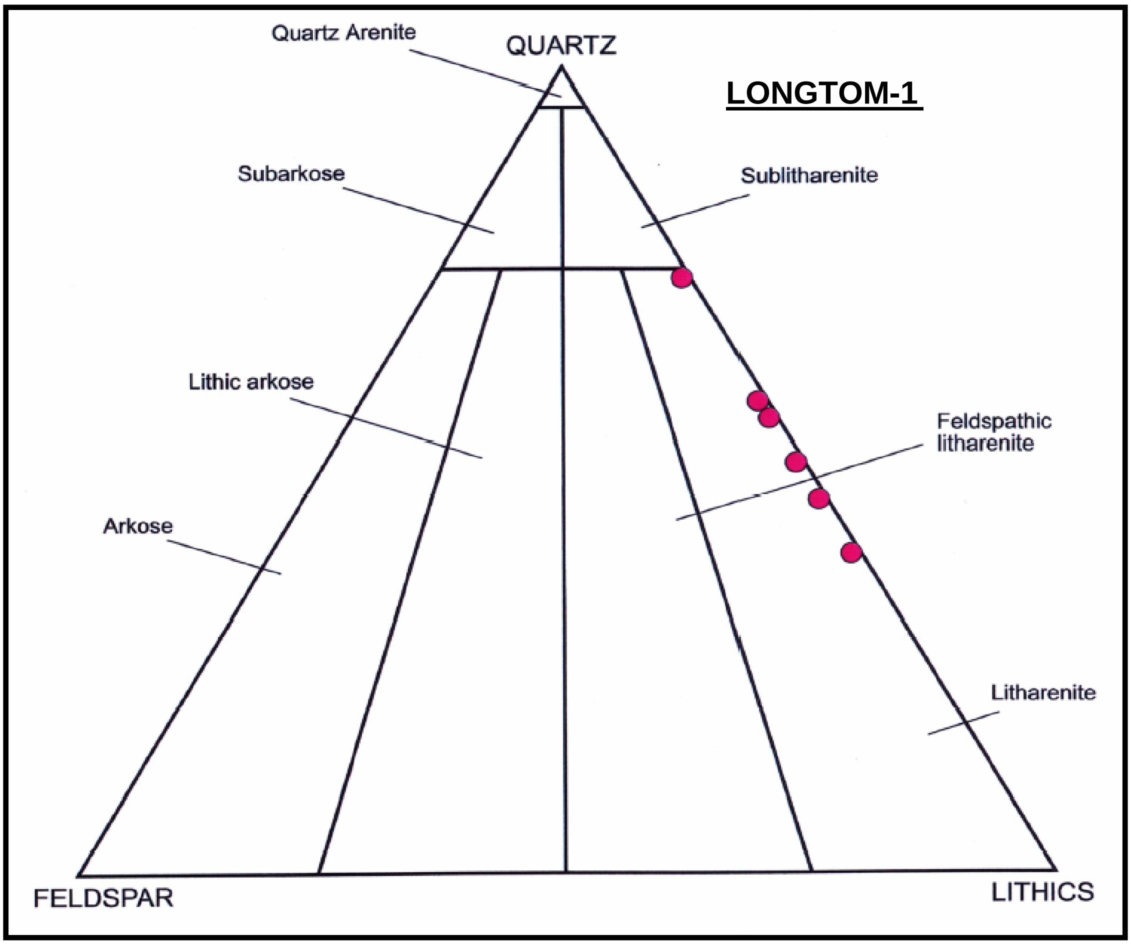


Figure 4.4. Folk sandstone classification for Longtom-1 sidewall core samples. Note that the mineralogical data from Longtom-1 were obtained by visual estimation. Figure reproduced from Wilson and Van Noord, 1995.

TABLE 4.1
SAMPLE DEPTHS & ANALYSES

SAMPLE ID	DEPTH (M)	THIN SECTION	POINT COUNT	BULK XRD	CLAY XRD	SEM
LONGTOM-2 ST1						
PLUG #2	2112.70	X	X	-	-	-
PLUG #8	2114.72	X	X	X	X	X
CHIP/PLUG #18	2118.35	X	X	X	X	X
CHIP/PLUG #23	2119.82	X	X	-	-	X
PLUG #29	2121.65	X	X	X	X	X
PLUG #33	2122.74	X	X	-	-	X
CORE CHIP	2123.87	-	-	X	X	-
PLUG #43	2127.48	X	X	X	X	X
PLUG #51	2129.86	X	X	-	-	X
PLUG #52	2130.26	X	X	-	-	-
PLUG #53	2133.55	X	X	X	X	X
PLUG #74	2136.82	X	X	-	-	X
PLUG #82	2139.18	X	X	-	-	-
PLUG #92	2142.34	X	X	X	X	X
CORE CHIP	2144.10	-	-	-	-	-
PLUG #94	2144.61	X	X	-	-	-
LONGTOM-2						
CUTTINGS	2188	X	-	-	-	-
CUTTINGS	2225	X	-	-	-	-
CUTTINGS	2240	X	-	-	-	-
CUTTINGS	2275	X	-	-	-	-
CUTTINGS	2300	X	-	-	-	-
CUTTINGS	2320	X	-	-	-	-
CUTTINGS	2380	X	-	-	-	-
CUTTINGS	2400	X	-	-	-	-
CUTTINGS	2410	X	-	-	-	-
TOTALS:		**23**	**14**	**7**	**7**	**10**

TABLE 4.2: THIN SECTION PETROGRAPHIC SUMMARY
LONGTOM-2 ST1 CORE SAMPLES

SAMPLE ID	MEASURED DEPTH (m)	Lithology	Folk Classification	Grain Size	Average Grain Size (mm)	Sorting	Texture/Fabric	Modifier	Angularity	Sphericity	Grain Contacts	Porosity Types	Porosity Controls	Visible Porosity (%)
PLUG #2	2112.70 m	Sst	Lith Ark	lvf-uf	0.15	MW	Fnt Lam	Calc	Ang-Sbrd	Eq-Sbel	Pl=Pt>CC	Inter>Diss	Authigenic clays, calcite cement, compaction.	4.0
PLUG #8	2114.72 m	Sst	Feld Lith	uvf-lm	0.20	MW	Rip Lam	Calc	Ang-Sbrd	Eq-Sbel	Pl>Pt>CC	Inter>Diss	Authigenic clays, calcite cement, compaction.	4.4
CHIP/PLUG #18	2118.35 m	Sst	Litharen	uf-lc	0.35	MW	Mass		Ang-Sbrd	Eq-Sbel	Pl=Pt>CC	Inter>Diss	Compaction, authigenic clay matrix.	19.2
CHIP/PLUG #23	2119.82 m	Sst	Feld Lith	lf-lc	0.32	M	Mass-Loc Lam		Ang-Sbrd	Eq-Sbel	Pl>Pt>CC	Inter>Diss	Compaction, authigenic clay matrix.	11.2
PLUG #29	2121.65 m	Sst	Feld Lith	lf-lc	0.28	M-MW	Mass	sli Calc	Ang-Sbrd	Eq-Sbel	Pl>Pt>CC	Inter>Diss	Authigenic clays, compaction, calcite cement.	10.8
PLUG #33	2122.74 m	Sst	Feld Lith	uvf-lm	0.23	M	Mass	v Calc	Ang-Sbrd	Eq-Sbel	Pl=Pt>CC	Diss	Calcite cement, authigenic clays.	1.6
PLUG #43	2127.48 m	Sst	Feld Lith	lf-um	0.30	MW	Mass		Ang-Sbrd	Eq-Sbel	Pl=Pt>CC	Inter>Diss	Compaction, authigenic clay.	14.0
PLUG #51	2129.86 m	Sst	Feld Lith	lf-um	0.27	MW	Mass		Ang-Sbrd	Eq-Sbel	Pl=Pt>CC	Inter>Diss	Authigenic clays, compaction.	16.0
PLUG #52	2130.26 m	Sst	Litharen	uf-um	0.30	MW	Mass-Fnt Lam	v Calc	Ang-Sbrd	Eq-Sbel	Pl=Pt>CC	Diss	Calcite cement.	0.4
PLUG #53	2133.55 m	Sst	Litharen	lf-um	0.27	MW	Mass	sli Calc	Ang-Sbrd	Eq-Sbel	Pl>Pt>CC	Inter>Diss	Authigenic clays, compaction, calcite and quartz cement.	10.0
PLUG #74	2136.82 m	Sst	Feld Lith	lf-um	0.27	M-MW	Mass		Ang-Sbrd	Eq-Sbel	Pl=Pt>CC	Inter>Diss	Authigenic clay, compaction.	16.0
PLUG #82	2139.18 m	Sst	Feld Lith	lf-um	0.30	MW	Mass	sli Calc	Ang-Sbrd	Eq-Sbel	Pl>Pt>CC	Inter>Diss	Authigenic clay, compaction, calcite cement.	6.8
PLUG #92	2142.34 m	Sst	Litharen	lf-lc	0.35	M	Mass	v Calc	Ang-Sbrd	Eq-Sbel	Pl=Pt>CC	Inter=Diss	Calcite cement, authigenic clays.	3.6
PLUG #94	2144.61 m	Sst	Feld Lith	lvf-uf	0.15	MW	Fnt Lam	Calc	Ang-Sbrd	Eq-Sbel	Pl>Pt>CC	Inter>Diss	Authigenic clay matrix, calcite cement, compaction.	4.8

Abbreviations

Sst = Sandstone	u = upper	M = moderate	Sid = sideritic	Sbang = Subangular	Eq = equant	Inter = Intergranular
Clyst = Claystone	l = lower	Pr = poor	Calc = calcareous	Sbrd = subrounded	El = elongate	Intra = Intraparticle
Arg = Argillaceous	v = very	W = well	Dol = dolomitic	Rnd = Rounded	Sbel = subelongate	Diss = Dissolution
Qtz Aren = Quartz arenite	f = fine	Fnt = faintly	Bitum = bituminous	Ang = Angular	Pt = Point	
Sublith = Subarkose	m = medium	Lam = laminated	Tuffac = tuffaceous		Pl = Planar	
Lith = Litharenite	c = coarse	Biot = bioturbated	Bim = bimodal		Flt = Floating	
Ark = Arkose	sli = slightly	Mass = massive			CC = Concavo-convex	
Feld = Feldspathic		Xbdg = cross bedding			St = Sutured	
N/A = Not applicable		Loc = locally				
		Rip - Ripple				

COMPANY: APACHE ENERGY LTD

WELL: LONGTOM-2 ST1

TABLE 4.3: THIN SECTION POINT COUNT DATA (based on 250 points)
LONGTOM-2 ST1 CORE SAMPLES

		QUARTZ			FELDSPAR				LITHICS								ACCESSORIES					
SAMPLE ID	MEASURED DEPTH (m)	TOTAL QUARTZ	Monocrystalline Quartz	Polycrystalline Quartz	TOTAL FELDSPAR	Untwinned Feldspar	Plagioclase	Microcline	TOTAL LITHICS	Volcanic Rock Fragments	Metamorphic Rock Fragments	Plutonic Rock Fragments	Chert	Sandstone Rock Fragments	Shale Fragments	Undifferentiated Lithics	TOTAL ACCESSORIES	Bioclasts	Organic Laminae + Grains	Carbonate-Replaced Grains	Heavy Minerals	Phosphatic Grains
PLUG #2	2112.70 m	38.4	34.0	4.4	11.6	8.0	3.6		11.2	4.4	0.4	Tr	3.6	0.8	2.0		2.0		2.0			
PLUG #8	2114.72 m	42.8	39.6	3.2	8.8	8.0	0.8		10.4	4.4	0.4	Tr	2.0	2.0	1.2	0.4	0.8		0.8		Tr	
CHIP/PLUG #18	2118.35 m	31.2	24.0	7.2	6.4	5.2	1.2		22.0	3.6	1.2	0.8	6.4	4.0	6.0				Tr			
CHIP/PLUG #23	2119.82 m	36.4	28.0	8.4	7.6	5.6	2.0		19.2	4.8	0.4	Tr	5.2	3.2	5.6		2.8		2.8			
PLUG #29	2121.65 m	33.2	28.4	4.8	8.8	7.6	1.2		20.4	6.4	0.4	0.4	6.0	3.2	4.0		0.8		0.4		0.4	
PLUG #33	2122.74 m	39.2	36.4	2.8	9.2	7.2	2.0		13.6	4.8	0.4	Tr	5.2	0.8	2.4		0.4				0.4	
PLUG #43	2127.48 m	30.0	24.4	5.6	8.0	7.6	0.4		23.6	10.8	0.4	1.2	4.4	4.8	2.0		0.8		0.8			
PLUG #51	2129.86 m	32.4	25.2	7.2	8.4	7.6	0.8		24.4	5.6	0.8	0.8	6.0	5.6	5.6				Tr		Tr	
PLUG #52	2130.26 m	30.4	25.2	5.2	5.6	5.2	0.4		25.6	13.6	0.8	Tr	4.8	2.4	4.0					Tr		
PLUG #53	2133.55 m	30.8	26.0	4.8	8.8	6.8	2.0		27.6	10.8	1.6	1.2	5.6	5.2	3.2						Tr	
PLUG #74	2136.82 m	34.0	28.4	5.6	11.6	8.8	2.8		20.4	11.2	Tr	0.8	1.2	4.4	2.8				Tr		Tr	
PLUG #82	2139.18 m	30.0	23.6	6.4	10.4	6.8	3.6		29.2	12.8	2.0	Tr	8.0	4.4	2.0							
PLUG #92	2142.34 m	32.8	30.0	2.8	7.6	5.6	2.0		25.2	11.2	0.4	1.2	4.8	5.2	2.4							
PLUG #94	2144.61 m	32.4	30.0	2.4	10.4	8.0	2.4		19.2	9.6	0.8	0.8	4.8	1.6	1.6		0.8		0.8			

			STRUCTURAL CLAY						CLAY MATRIX						CEMENTS					POROSITY		
SAMPLE ID	MEASURED DEPTH (m)	TOTAL CLAY	TOTAL STRUCTURAL CLAY*	Clay-Replaced Grains	Glauconite	Biotite	Muscovite	Chlorite	TOTAL CLAY MATRIX	Undifferentiated	Authigenic Kaolinite	Authigenic Pore-Lining	Pseudomatrix	LAMINAR CLAYS	TOTAL CEMENTS	Silica	Ferroan Calcite	Siderite	Pyrite	TOTAL POROSITY	Intergranular	Dissolution
PLUG #2	2112.70 m	27.6	13.6	7.6		0.8	1.2	2.0	14.0	1.2	4.8	6.4	1.6		7.2	0.4	6.8		Tr	4.0	3.2	0.8
PLUG #8	2114.72 m	26.8	12.8	9.2		Tr	0.8	1.6	14.0	1.6	2.4	8.4	1.6		7.2	0.4	6.4		0.4	4.4	3.6	0.8
CHIP/PLUG #18	2118.35 m	25.6	15.6	6.4		Tr	Tr	3.2	10.0	0.4	5.6	4.0	Tr		1.6	1.6			Tr	19.2	18.0	1.2
CHIP/PLUG #23	2119.82 m	26.8	15.6	5.6		Tr		4.4	11.2	0.8	5.2	4.4	0.8		1.6	1.6			Tr	11.2	10.4	0.8
PLUG #29	2121.65 m	26.8	15.6	6.0		1.2	0.4	4.0	11.2	0.4	4.4	4.4	2.0		3.2	1.2	2.0		Tr	10.8	9.2	1.6
PLUG #33	2122.74 m	22.4	10.8	7.2		Tr	Tr	1.2	11.6	0.8	2.0	6.8	2.0		16.0	Tr	15.6		0.4	1.6	Tr	1.6
PLUG #43	2127.48 m	23.2	15.6	8.4		1.6		3.6	7.6	Tr	3.2	4.4	Tr		2.4	2.4			Tr	14.0	12.8	1.2
PLUG #51	2129.86 m	23.6	16.0	6.8		0.4	Tr	3.2	7.6	0.4	4.4	2.0	0.8		0.8	0.8			Tr	16.0	13.6	2.4
PLUG #52	2130.26 m	21.6	15.2	5.6		0.8	0.4	4.4	6.4	Tr	0.8	1.2	4.4		20.4	Tr	20.4		Tr	0.4	Tr	0.4
PLUG #53	2133.55 m	22.0	10.8	5.6		Tr	Tr	2.0	11.2	0.4	4.4	4.4	2.0		4.0	2.0	2.0		Tr	10.0	8.4	1.6
PLUG #74	2136.82 m	20.0	12.8	5.6			0.8	3.6	7.2	Tr	4.0	3.2	Tr		0.8	0.8			Tr	16.0	15.2	0.8
PLUG #82	2139.18 m	21.6	12.8	8.0		0.4	Tr	2.4	8.8	Tr	2.0	4.0	2.8		4.0	0.8	3.2		Tr	6.8	5.6	1.2
PLUG #92	2142.34 m	14.8	9.2	4.8			Tr	2.0	5.6	0.4	2.0	3.2	Tr		18.4	0.4	18.0		Tr	3.6	2.0	1.6
PLUG #94	2144.61 m	28.4	12.4	7.6			0.8	2.4	16.0	5.2	2.4	6.0	2.4		5.6	Tr	5.6		Tr	4.8	3.2	1.6

Note : * Shale fragments have been counted both as a lithic grain, and as a component of structural clay (and are therefore included in total clay).

Company: Apache Energy Ltd **Well: Longtom-2 ST1**

TABLE 4.4
BULK AND CLAY X-RAY DIFFRACTION DATA

		CALCULATED WHOLE ROCK COMPOSITION (Weight %)									RELATIVE CLAY ABUNDANCE Normalized to 100%			
Sample ID	Depth (m)	Quartz	Plagioclase	K-Feldspar	Calcite	Dolomite / Fe-Dolomite	Siderite	Pyrite	Anhydrite	Total Clay	Illite & Mica	Kaolinite	Chlorite	Mixed-Layer Illite/Smectite *
8	2114.72	55	8	7	9	0	0	0	0	21	15	41	41	3
18	2118.35	70	10	4	0	0	0	0	0	16	16	45	35	4
29	2121.65	63	6	7	1	0	0	0	0	23	14	40	44	2
-	2123.87	34	4	2	0	0	0	0	0	60	33	25	31	11
43	2127.48	69	6	4	0	0	0	0	0	21	15	34	49	2
53	2133.55	65	8	7	2	0	0	0	0	18	18	40	40	2
92	2142.34	59	5	4	17	0	0	0	0	15	17	27	53	3
-	2144.10	47	7	3	0	0	0	0	0	43	19	30	42	9

Note: Average proportion of expandable smectite interlayers in mixed-layer clays is 15 - 20%

TABLE 4.5: THIN SECTION PETROGRAPHIC SUMMARY
LONGTOM-2 CUTTINGS SAMPLES

DEPTH	MAIN LITHOLOGY (1)	MAIN LITHOLOGY (2)	MAIN LITHOLOGY (3)	OTHERS
2188 m	**Arg SLTST (50%)** Med slt, mass.	**CLYST (40%)** Mass, sli slty.	**SST (10%)** F, w srtd, ang-sbrd, mass.	Tr lse qtz.
2225 m	**CLYST (50%)** Mass, sli slty.	**SST (30%)** Vf-f, mw srtd, ang-sbrd, mass.	**Arg SLTST (20%)** Med-crse slt, mass.	Tr lse qtz, volcs.
2240 m	**CLYST (50%)** Mass, sli slty.	**SST (40%)** Vf-f, loc med, m-mw srtd, ang-sbrd, mass.	**Arg SLTST (10%)** Med-crse slt, mass.	Tr volcs, SST.
2275 m	**Arg SLTST (40%)** Med-crse slt, mass.	**SST (40%)** Vf-f, m-mw srtd, ang-sbrd, mass.	**CLYST (20%)** Mass, sli slty.	Tr foss.
2300 m	**SST (40%)** Vf-f, loc crse, pr-mw srtd, ang-sbrd, mass.	**CLYST (30%)** Mass, sli slty.	**Arg SLTST (20%)** Med-crse slt, mass.	10% tf CLYST
2320 m	**CLYST (90%)** Mass, loc slty.	**CHT (10%)** Poss devitfd tuff or tuffite.	**SST (Tr)** Vf, m srtd, ang-sbang, mass.	Tr foss.
2380 m	**CHT (50%)** Poss devitfd tuff or tuffite.	**LSE QTZ (30%)** Slt-f, m-pr srtd.	**SST (15%)** Vf-f, m-pr srtd, ang-sbang, mass.	5% volcs, tr lse calc cmt, plag, tr plnkt forams.
2400 m	**CHT (50%)** Poss devitfd tuff or tuffite, loc silicfd SST.	**LSE QTZ (40%)** Slt-f, m-pr srtd.	**SST (10%)** Vf-crse, m-pr srtd, ang-sbang, mass.	Tr volcs, CLYST, lse plag, plnkt forams.
2410 m	**CHT (50%)** Poss devitfd tuff or tuffite, loc silicfd SST.	**SST (20%)** Vf-v crse, m-pr srtd, ang-sbang, mass.	**CLYST (15%)** Slty, mass-fnt lam.	10% volcs, 5% lse qtz, tr plag.

Abbreviations

ang = angular	fnt lam = faintly laminated	poss = possible	srtd = sorted
arg = argillaceous	foss = fossils	pr = poor	SST = Sandstone
calc = calcite	loc = localised	qtz = quartz	tf = tuffaceous
CHT = Chert	lse = loose	sbang = subangular	tr = trace
CLYST = Claystone	m = moderate	sbrd = subrounded	v = very
cmt = cement	mass = massive	silicfd = silicified	volcs = volcanics
crse = coarse	med = medium	sli = slightly	w = well
devitfd = devitrified	plag = plagioclase	slt/slty = silt/silty	
f = fine	plnkt = planktonic	SLTST = Siltstone	

TABLE 4.6
MINERALOGICAL/LITHOLOGICAL EFFECTS ON WIRELINE LOG RESPONSES

Cause	Affected Logs	Effects
Structural Clay	Vclay estimates	Common structural clay is indistinguishable from dispersed clay in log-derived Vclay estimates. This could lead to over-pessimistic estimates of clay volume if all clay is assumed to be dispersed matrix.
Common Clay Minerals	Resistivity-derived Sw estimates	High clay-bound water saturation should be expected due to the abundance of clay minerals (including structural clay). Since this water is immobile, water-free production may be possible where water production is otherwise anticipated.
Elevated Grain Density	Density porosity, neutron-density porosity.	Since average grain density is 2.68 g/cc, density-derived porosity estimates may be overly pessimistic if a standard grain density of 2.65 g/cc is assumed for the porosity calculation.

TABLE 4.7
POTENTIAL FORMATION DAMAGE MECHANISMS

Problem	Magnitude of Problem	Sensitive Mineral(s)/ Source	Avoid Using	Use	Treatment to Eliminate Problem
Capillary Water Block	Possibly high.	Extensive pore-lining chlorite.	-	-	Simulate in laboratory before deciding course of action.
Acid Sensitivity	High.	Pore-lining chlorite, calcite cement.	Untested acids.	HCl pre-flushes, iron-sequestering agents.	Test acid jobs in laboratory using core samples. Pickle drill pipe.
Mobile Fines	Moderate.	Authigenic kaolinite. Pores restricted by chlorite.	High flow rates. High transient Pressures.	Lower flow rates, low transient pressures.	Acidise only if skin damage is high.
Sand Production	High.	Poorly consolidated sandstone.	Excessive flow rates.	Controlled flow rates, gravel packs, screens, etc.	Determine optimum flow rate using laboratory tests.

PLATES 4.1 to 4.14

THIN SECTION DESCRIPTIONS,

POINT-COUNT DATA

AND PHOTOMICROGRAPHS

CORE SAMPLES

LONGTOM-2 ST1
PLUG #2
2112.70 m

LITHOLOGY:	Sandstone. Lower very fine to upper fine, moderately well sorted, faintly laminated, calcite cemented.		
Consolidation:	Good	Sorting:	Moderately good
Folk Classification:	Lithic arkose	Angularity:	Angular-Subround
Ave Grain Size (mm):	0.15 (lower fine)	Sphericity:	Equant-Subelongate
Max Grain Size (mm):	0.35 (lower medium)	Visible Porosity (%):	4.0
Grain Contacts:	Planar = Point > Concavo-convex	Hel Inj Porosity (%):	14.0
Porosity Types:	Intergranular > Dissolution	Klink Perm (md):	0.024
Porosity Controls:	Authigenic clays, calcite cement, compaction.		

WHOLE ROCK CONSTITUENTS (Vol. %)

GRAINS	63.2	ACCESSORIES	2.0	***CEMENT***	7.2
TOTAL QUARTZ	38.4	Bioclasts		Silica	0.4
Monocrystalline Quartz	34.0	Organic Laminae + Grains	2.0	Non-Ferroan Calcite	
Polycrystalline Quartz	4.4	Carbonate-Replaced Grains		Ferroan Calcite	6.8
TOTAL FELDSPAR	11.6	Heavy Minerals		Non-Ferroan Dolomite	
Untwinned Feldspar	8.0	Phosphatic Grains		Ferroan Dolomite	
Plagioclase	3.6	***STRUCTURAL CLAYS***	11.6	Siderite	
Microcline		Clay-Replaced Grains	7.6	Pyrite	Tr
		Glauconite		Zeolite	
TOTAL ROCK FRAGMENTS	11.2	Biotite	0.8	Barytes	
Volcanic Rock Fragments	4.4	Muscovite	1.2	Bitumen/Dead Oil	
Metamorphic Rock Fragments	0.4	Chlorite	2.0		
Plutonic Rock Fragments	Tr	Clay Rip-Up Clasts			
Chert	3.6	Others			
Sandstone Rock Fragments	0.8	***DISPERSED MATRIX***	14.0	***VISIBLE POROSITY***	4.0
Shale Fragments	2.0	Undifferentiated	1.2	Intergranular	3.2
Limestone Rock Fragments		Authigenic Kaolinite	4.8	Dissolution	0.8
Dolostone Rock Fragments		Authigenic Chlorite	6.4	Intraparticle	
Others		Pseudomatrix	1.6	Fracture	
		Rock Flour			
		LAMINAR CLAYS		***TOTAL***	100.0

PLATE 4.1A

Low magnification overview of a lower very fine to upper fine grained, moderately well sorted, faintly laminated, calcite-cemented, lithic arkose sandstone. Grains are mainly monocrystalline quartz (MQ) with common degraded untwinned feldspar (UFspr), polycrystalline quartz (PQ), glassy volcanic rock fragments (VRFg), clay-replaced grains (CRG), multiple-twinned plagioclase, chert (Cht), mica (mainly detrital chlorite, DetChl; degraded biotite, Bi; and muscovite), shale fragments and other lithics. Clay matrix comprises common pore-lining authigenic chlorite, pore-filling authigenic kaolinite (K) and minor pseudomatrix created by ductile compaction of argillaceous grains. Cements include common slightly ferroan calcite (Ca), rare quartz overgrowths and traces of pyrite. Visible porosity is poor, mostly comprising poorly interconnected intergranular pores (IP).

(28X, Plane-polarised Light)

PLATE 4.1B

High magnification view of the area shown at the centre of Plate 4.1A above, showing several pores lined with authigenic chlorite (plChl). Also visible are small patches of authigenic kaolinite (K) and scattered calcite-cemented pores (Ca). The faint purplish hue to the calcite's stain indicates slightly ferroan composition. Note the moderately tight grain packing, which in addition to authigenic clays and calcite cement has helped to reduce intergranular pore space (IP). Grains include monocrystalline (MQ) and polycrystalline quartz (PQ), porphyritic (VRFp) and glassy volcanic rock fragments (VRFg), detrital chlorite (DetChl; possibly a chloritised grain), and a partly leached feldspar (lFspr).

(130X, Plane-polarised Light)

LONGTOM-2 ST1
CORE PLUG #2
2112.70 m

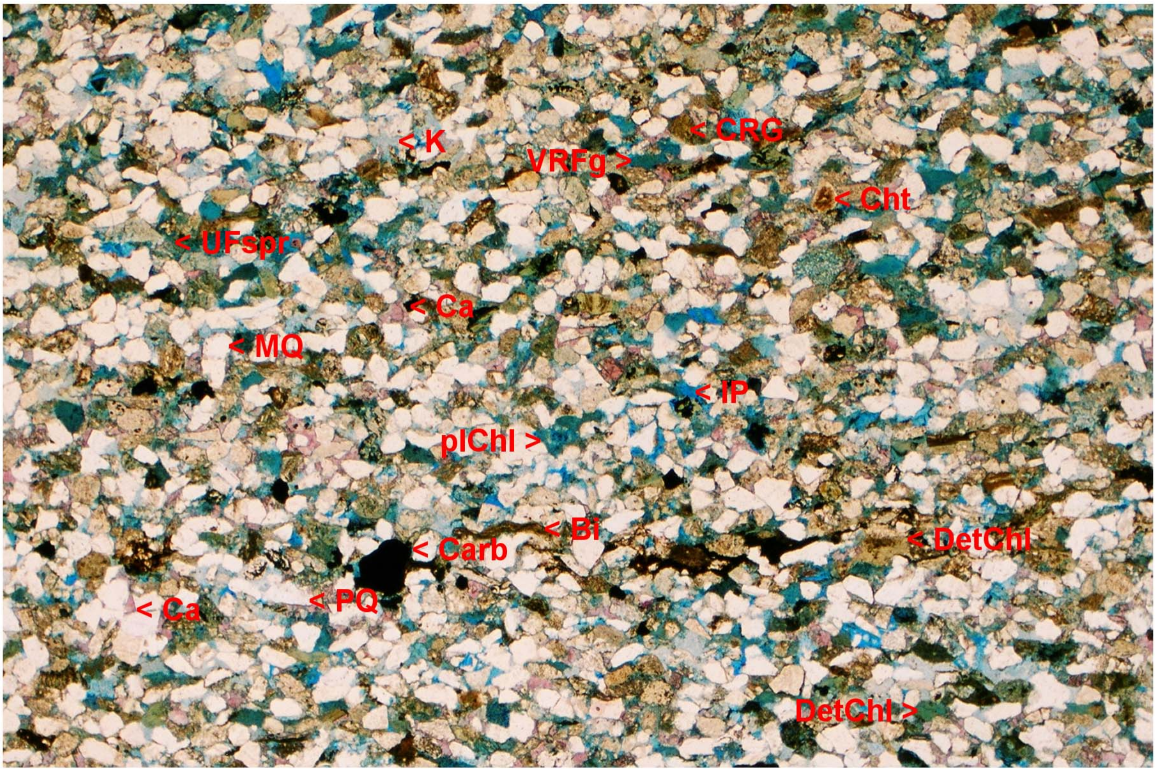


PLATE 4.1A

0 mm 0.5 1

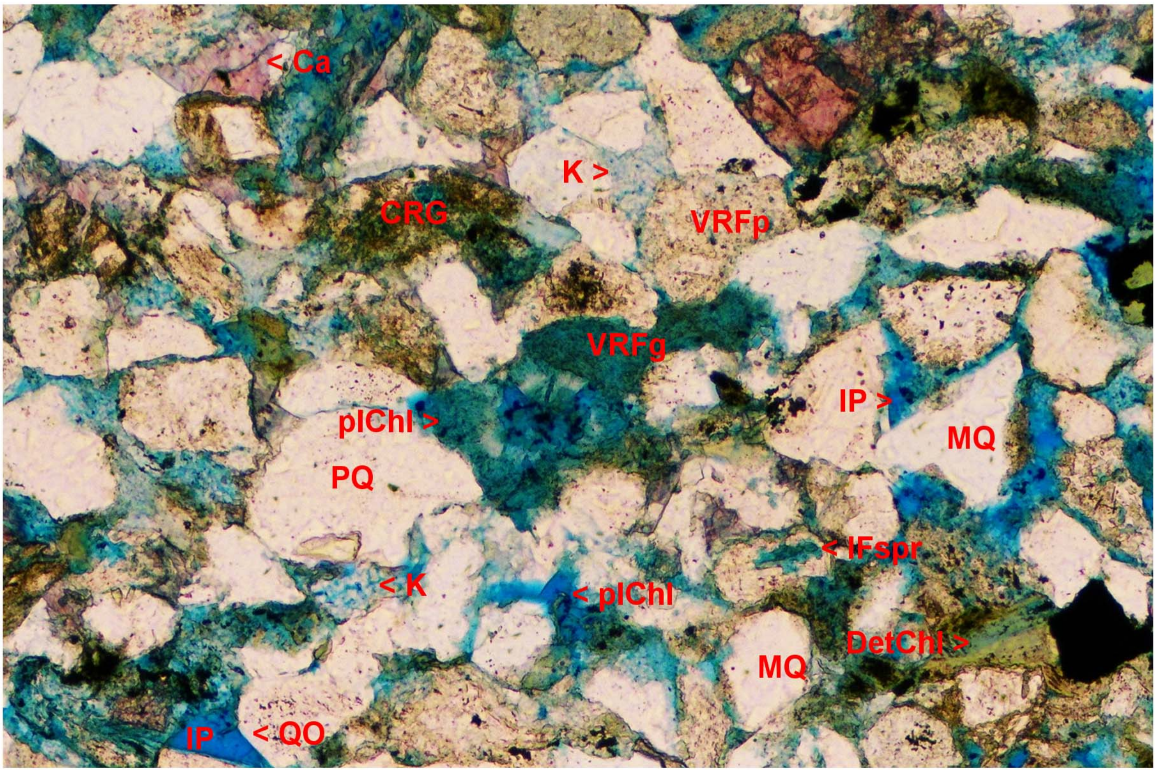


PLATE 4.1B

0 mm 0.125 0.25

LONGTOM-2 ST1
PLUG #8
2114.72 m

LITHOLOGY:	Sandstone. Upper very fine to lower medium grained, moderately well sorted, ripple-laminated, calcite-cemented.		
Consolidation:	Good	Sorting:	Moderately good
Folk Classification:	Feldspathic litharenite	Angularity:	Angular-Subround
Ave Grain Size (mm):	0.20 (lower very coarse)	Sphericity:	Equant-Subelongate
Max Grain Size (mm):	0.45 (upper medium)	Visible Porosity (%):	4.4
Grain Contacts:	Planar > Point > Concavo-convex	Hel Inj Porosity (%):	13.7
Porosity Types:	Intergranular > Dissolution	Klink Perm (md):	0.015
Porosity Controls:	Authigenic clays, calcite cement, compaction.		

WHOLE ROCK CONSTITUENTS (Vol. %)

GRAINS	62.8	ACCESSORIES	0.8	***CEMENT***	7.2
TOTAL QUARTZ	42.8	Bioclasts		Silica	0.4
Monocrystalline Quartz	39.6	Organic Laminae + Grains	0.8	Non-Ferroan Calcite	
Polycrystalline Quartz	3.2	Carbonate-Replaced Grains		Ferroan Calcite	6.4
TOTAL FELDSPAR	8.8	Heavy Minerals	Tr	Non-Ferroan Dolomite	
Untwinned Feldspar	8.0	Phosphatic Grains		Ferroan Dolomite	
Plagioclase	0.8	***STRUCTURAL CLAYS***	11.6	Siderite	
Microcline		Clay-Replaced Grains	9.2	Pyrite	0.4
		Glauconite		Zeolite	
TOTAL ROCK FRAGMENTS	10.4	Biotite	Tr	Barytes	
Volcanic Rock Fragments	4.4	Muscovite	0.8	Bitumen/Dead Oil	
Metamorphic Rock Fragments	0.4	Chlorite	1.6		
Plutonic Rock Fragments	Tr	Clay Rip-Up Clasts			
Chert	2.0	Others			
Sandstone Rock Fragments	2.0	***DISPERSED MATRIX***	14.0	***VISIBLE POROSITY***	4.4
Shale Fragments	1.2	Undifferentiated	1.6	Intergranular	3.6
Limestone Rock Fragments		Authigenic Kaolinite	2.4	Dissolution	0.8
Dolostone Rock Fragments		Authigenic Chlorite	8.4	Intraparticle	
Others	0.4	Pseudomatrix	1.6	Fracture	
		Rock Flour			
		LAMINAR CLAYS		***TOTAL***	100.0

PLATE 4.2A

Low magnification overview of an upper very fine to lower medium grained, moderately well sorted, ripple-laminated, feldspathic litharenite sandstone. Grains are mainly monocrystalline quartz (MQ), with common feldspar (Fspr), clay-replaced grains (CRG), heavily altered, glassy volcanic rock fragments (VRFg), minor polycrystalline quartz (PQ), shale fragments (ShFr), sandstone rock fragments, chert (probably devitrified volcanic fragments), mica (including biotite; Bi) and localised carbonaceous fragments (Carb). Matrix comprises mainly authigenic kaolinite (K) and pore-lining/grain-coating chlorite. Some pseudomatrix from compacted argillaceous grains is also observed. The main cementing agent is slightly ferroan calcite (Ca), which although unevenly distributed through the pore network, is the main porosity and permeability-reducing agent. Visible porosity is poor, confined to restricted intergranular pores (IP) and localised dissolution pores in leached grains.

(28X, Plane-polarised Light)

PLATE 4.2B

High magnification view of the centre of Plate 4.2A above. Grains include monocrystalline quartz (MQ), degraded glassy volcanic rock fragments (VRFg), chert (Cht), metamorphic rock fragments (MRF) and degraded plagioclase feldspar (dFspr; possibly part of a heavily degraded volcanic rock fragment). Much of the apparent matrix in this sample consists of compacted grain material (note pseudomatrix formed by compaction and merging of several degraded volcanic grains, Pmtx). Otherwise, matrix is mainly authigenic, comprising pore-filling kaolinite (K) and pore-lining chlorite (Chl). Cements include patchily distributed, slightly ferroan calcite (Ca) and poorly developed quartz overgrowths (QO). Quartz overgrowths preceded calcite cement. Note the dissolution pore caused by leaching of a grain (DP).

(130X, Plane-polarised Light)

LONGTOM-2 ST1
CORE PLUG #8
2114.72 m

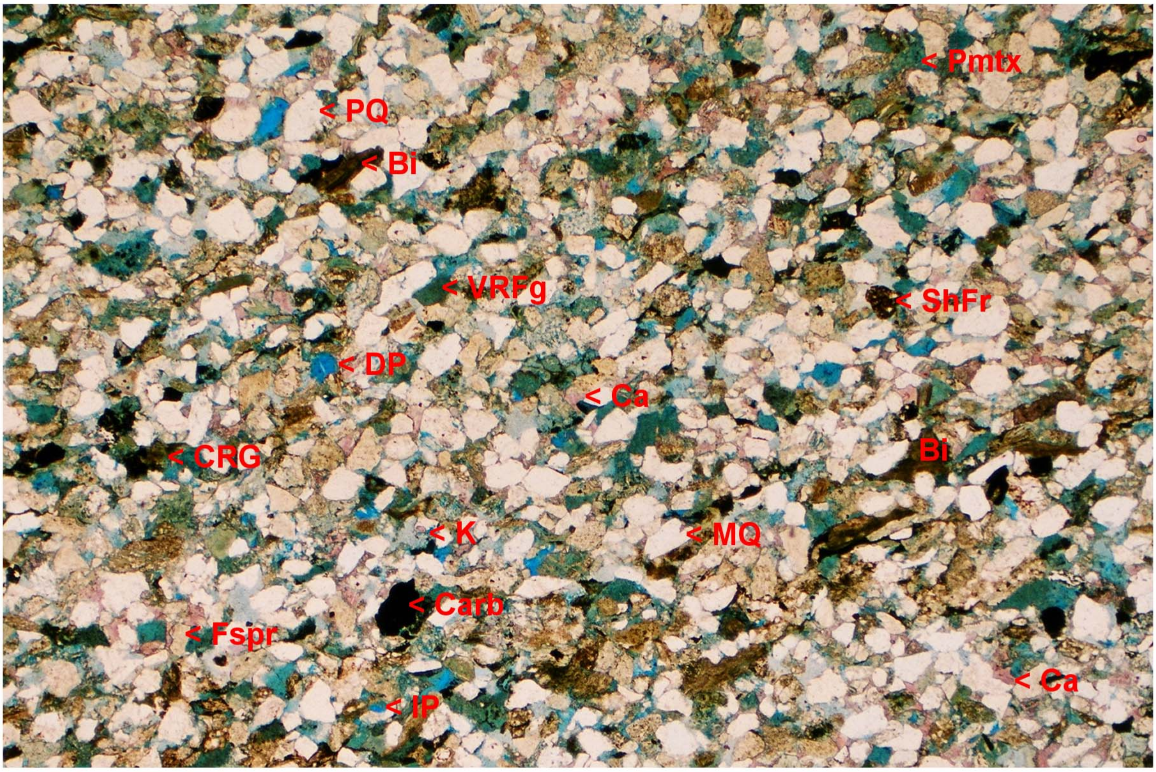
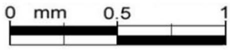


PLATE 4.2A



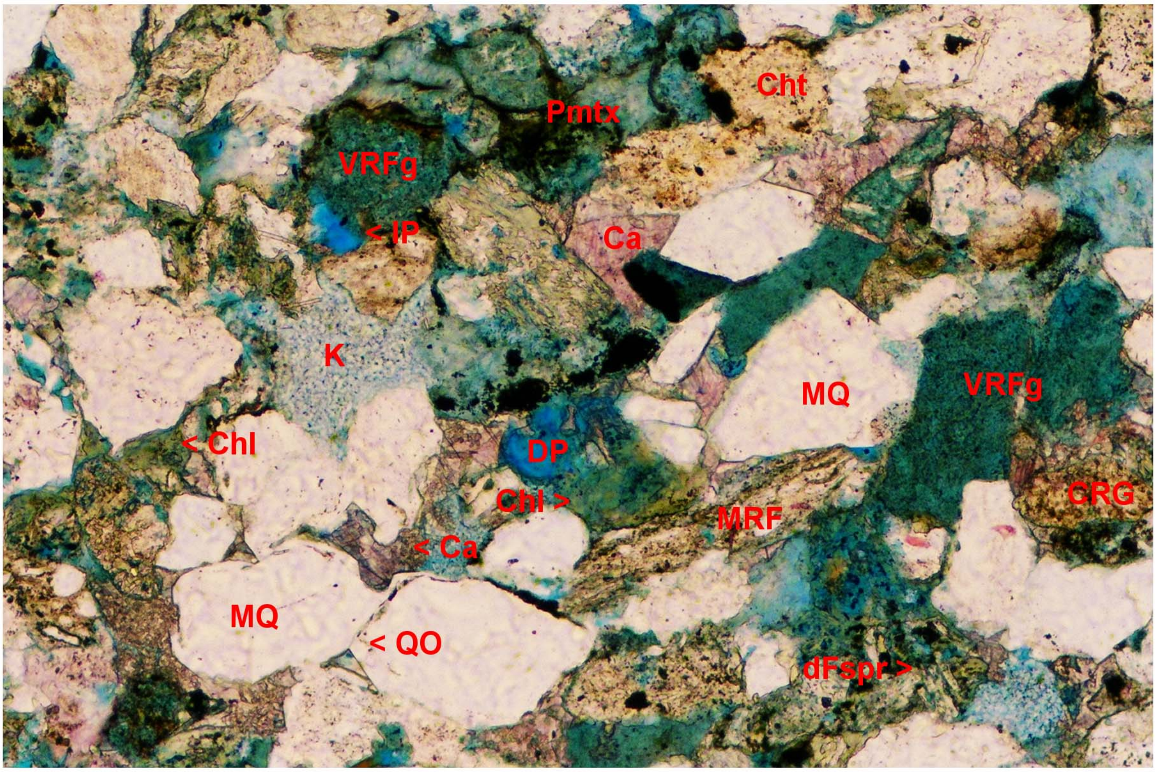
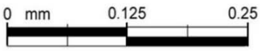


PLATE 4.2B



LONGTOM-2 ST1
CHIP ADJACENT TO PLUG #18
2118.35 m

LITHOLOGY:	Sandstone. Upper fine to lower coarse, moderately well sorted, massive.			
Consolidation:	Poor		Sorting:	Moderately good
Folk Classification:	Litharenite		Angularity:	Angular-Subround
Ave Grain Size (mm):	0.35	(upper medium)	Sphericity:	Equant-Subelongate
Max Grain Size (mm):	0.55	(lower coarse)	Visible Porosity (%):	19.2
Grain Contacts:	Planar = Point > Concavo-convex		Hel Inj Porosity (%):	26.1
Porosity Types:	Intergranular > Dissolution		Klink Perm (md):	239
Porosity Controls:	Compaction, authigenic clay matrix.			

WHOLE ROCK CONSTITUENTS (Vol. %)

GRAINS	59.6	ACCESSORIES		***CEMENT***	1.6
TOTAL QUARTZ	31.2	Bioclasts		Silica	1.6
Monocrystalline Quartz	24.0	Organic Laminae + Grains	Tr	Non-Ferroan Calcite	
Polycrystalline Quartz	7.2	Carbonate-Replaced Grains		Ferroan Calcite	
TOTAL FELDSPAR	6.4	Heavy Minerals		Non-Ferroan Dolomite	
Untwinned Feldspar	5.2	Phosphatic Grains		Ferroan Dolomite	
Plagioclase	1.2	***STRUCTURAL CLAYS***	9.6	Siderite	
Microcline		Clay-Replaced Grains	6.4	Pyrite	Tr
		Glauconite		Zeolite	
TOTAL ROCK FRAGMENTS	22.0	Biotite	Tr	Barytes	
Volcanic Rock Fragments	3.6	Muscovite	Tr	Bitumen/Dead Oil	
Metamorphic Rock Fragments	1.2	Chlorite	3.2		
Plutonic Rock Fragments	0.8	Clay Rip-Up Clasts			
Chert	6.4	Others			
Sandstone Rock Fragments	4.0	***DISPERSED MATRIX***	10.0	***VISIBLE POROSITY***	19.2
Shale Fragments	6.0	Undifferentiated	0.4	Intergranular	18.0
Limestone Rock Fragments		Authigenic Kaolinite	5.6	Dissolution	1.2
Dolostone Rock Fragments		Authigenic Chlorite	4.0	Intraparticle	
Others		Pseudomatrix	Tr	Fracture	
		Rock Flour			
		LAMINAR CLAYS		***TOTAL***	100.0

PLATE 4.3A

Low magnification overview of upper fine to lower coarse grained, moderately well sorted, massive litharenite sandstone. Grains are mainly monocrystalline quartz (MQ) with common polycrystalline quartz (PQ), chert (Cht), feldspar (mainly degraded; dFspr), clay-replaced grains, shale fragments (ShFr), sandstone rock fragments, glassy and porphyritic volcanic rock fragments (VRFg, VRFp), minor metamorphic and plutonic rock fragments, mica (mainly chlorite), and traces of carbonaceous material (Carb). Clay matrix is common, mainly comprising patchily distributed pore-filling authigenic kaolinite (K) and pore-lining and grain-coating chlorite. Cements are rare, confined to a few locally developed quartz overgrowths (QO). Visible porosity is good, mainly consisting of moderately well interconnected, relatively large intergranular pores (IP).

(28X, Plane-polarised Light)

PLATE 4.3B

High magnification view of the area shown at the centre of Plate 4.3A above. Note the large, mostly open intergranular pores (IP), with pore throats locally restricted by quartz overgrowth cement (QO) and pore-lining chlorite (plChl). Grains comprise monocrystalline quartz (MQ; note localised embayment, Emb), argillaceous sandstone rock fragments (ArgSRF), feldspar (Fspr), chert (Cht), a chloritised grain (ChlGrn) and a microlitic volcanic rock fragment (VRFml).

(130X, Plane-polarised Light)

LONGTOM-2 ST1
CHIP/PLUG #18
2118.35 m

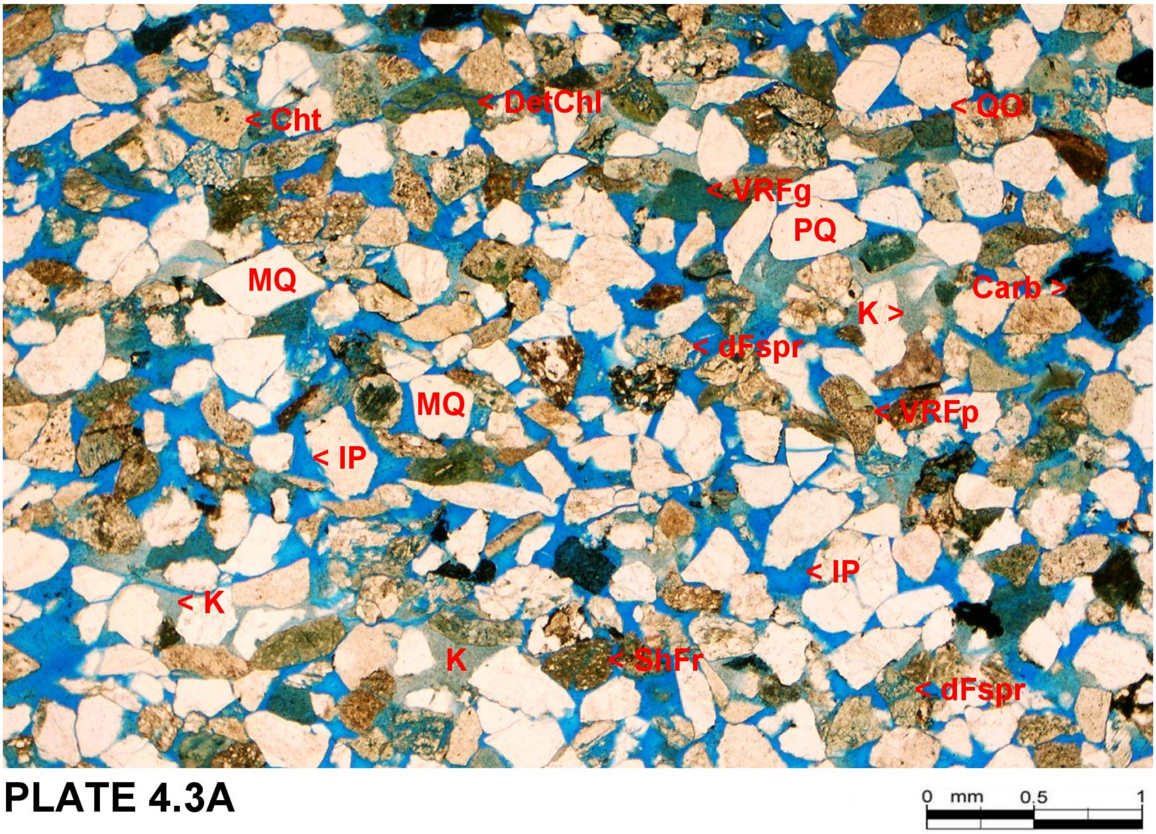


PLATE 4.3A

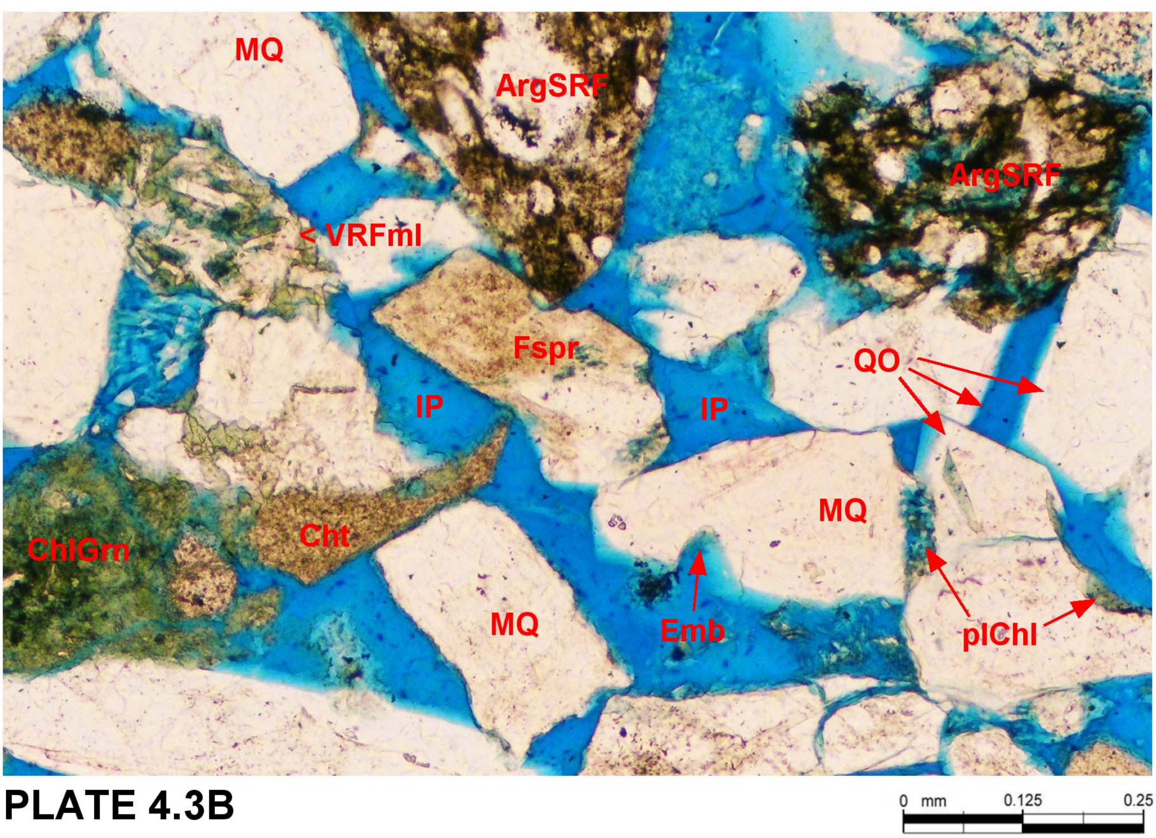


PLATE 4.3B

LONGTOM-2 ST1
CHIP ADJACENT TO PLUG #23
2119.82 m

LITHOLOGY:	Sandstone. Lower fine to lower coarse grained, moderately sorted, massive to locally laminated.		
Consolidation:	Poor	Sorting:	Moderate
Folk Classification:	Feldspathic Litharenite	Angularity:	Angular-Subround
Ave Grain Size (mm):	0.32 (lower medium)	Sphericity:	Equant-Subelongate
Max Grain Size (mm):	0.80 (upper coarse)	Visible Porosity (%):	11.2
Grain Contacts:	Planar > Point > Concavo-convex	Hel Inj Porosity (%):	23.3
Porosity Types:	Intergranular > Dissolution	Klink Perm (md):	110
Porosity Controls:	Compaction, authigenic clay matrix.		

WHOLE ROCK CONSTITUENTS (Vol. %)

GRAINS	66.0	ACCESSORIES	2.8	***CEMENT***	1.6
TOTAL QUARTZ	36.4	Bioclasts		Silica	1.6
Monocrystalline Quartz	28.0	Organic Laminae + Grains	2.8	Non-Ferroan Calcite	
Polycrystalline Quartz	8.4	Carbonate-Replaced Grains		Ferroan Calcite	
TOTAL FELDSPAR	7.6	Heavy Minerals		Non-Ferroan Dolomite	
Untwinned Feldspar	5.6	Phosphatic Grains		Ferroan Dolomite	
Plagioclase	2.0	***STRUCTURAL CLAYS***	10.0	Siderite	
Microcline		Clay-Replaced Grains	5.6	Pyrite	Tr
		Glauconite		Zeolite	
TOTAL ROCK FRAGMENTS	19.2	Biotite	Tr	Barytes	
Volcanic Rock Fragments	4.8	Muscovite		Bitumen/Dead Oil	
Metamorphic Rock Fragments	0.4	Chlorite	4.4		
Plutonic Rock Fragments	Tr	Clay Rip-Up Clasts			
Chert	5.2	Others			
Sandstone Rock Fragments	3.2	***DISPERSED MATRIX***	11.2	***VISIBLE POROSITY***	11.2
Shale Fragments	5.6	Undifferentiated	0.8	Intergranular	10.4
Limestone Rock Fragments		Authigenic Kaolinite	5.2	Dissolution	0.8
Dolostone Rock Fragments		Authigenic Pore-Lining	4.4	Intraparticle	
Others		Pseudomatrix	0.8	Fracture	
		Rock Flour			
		LAMINAR CLAYS		***TOTAL***	100.0

PLATE 4.4A

Low magnification view of lower fine to lower coarse grained, moderately sorted, massive to locally laminated feldspathic litharenite sandstone. Grains are mainly monocrystalline quartz (MQ) with common polycrystalline quartz (PQ), feldspars (mainly untwinned; UFspr), shale fragments (ShFr), clay-replaced grains (CRG), chert (Cht), glassy and porphyritic volcanic rock fragments (VRFp), chlorite mica (DetChl), sandstone rock fragments (SRF), minor carbonaceous laminae (CarbLam) and carbonaceous grains. Clay matrix is common and almost entirely authigenic, comprising pore-filling kaolinite (K), and pore-lining and grain-coating chlorite. Cements are rare, confined to localised quartz overgrowths and traces of pyrite. Visible porosity is fair, mainly intergranular (IP), with minor dissolution porosity in some leached feldspars (DP).

(28X, Plane-polarised Light)

PLATE 4.4B

High magnification view of the centre of Plate 4.4A above, illustrating an area with pore-filling kaolinite (K), which has locally enveloped earlier-formed pore-lining chlorite (plChl). Also visible are occasional small quartz overgrowths (QO). Porosity is mainly intergranular (IP), although breakage incurred during thin section sample preparation has resulted in some minor induced fracturing (IndFrac). Grains include monocrystalline (MQ) and polycrystalline quartz (PQ), untwinned feldspar (UFspr), a compactionally-deformed clay-replaced grain (CRG), a shale fragment (ShFr) and a porphyritic volcanic rock fragment (VRFp).

(130X, Plane-polarised Light)

LONGTOM-2 ST1

CHIP/PLUG #23

2119.82 m

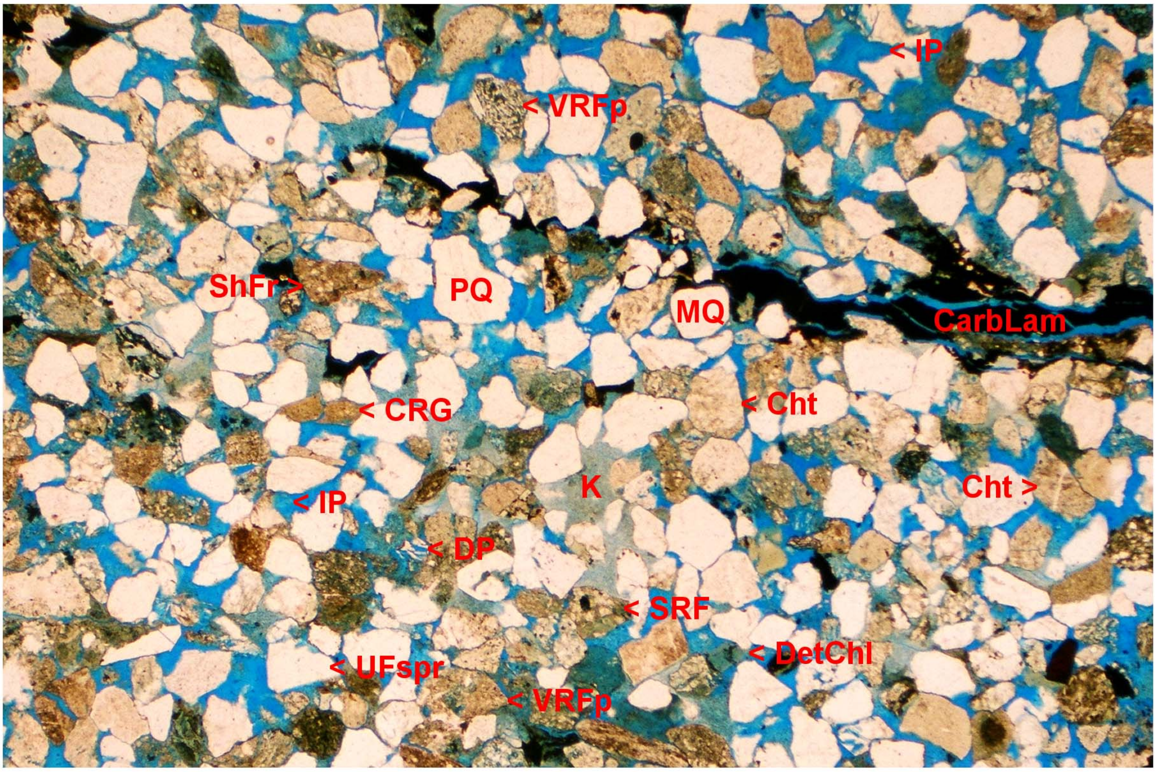
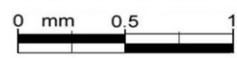


PLATE 4.4A



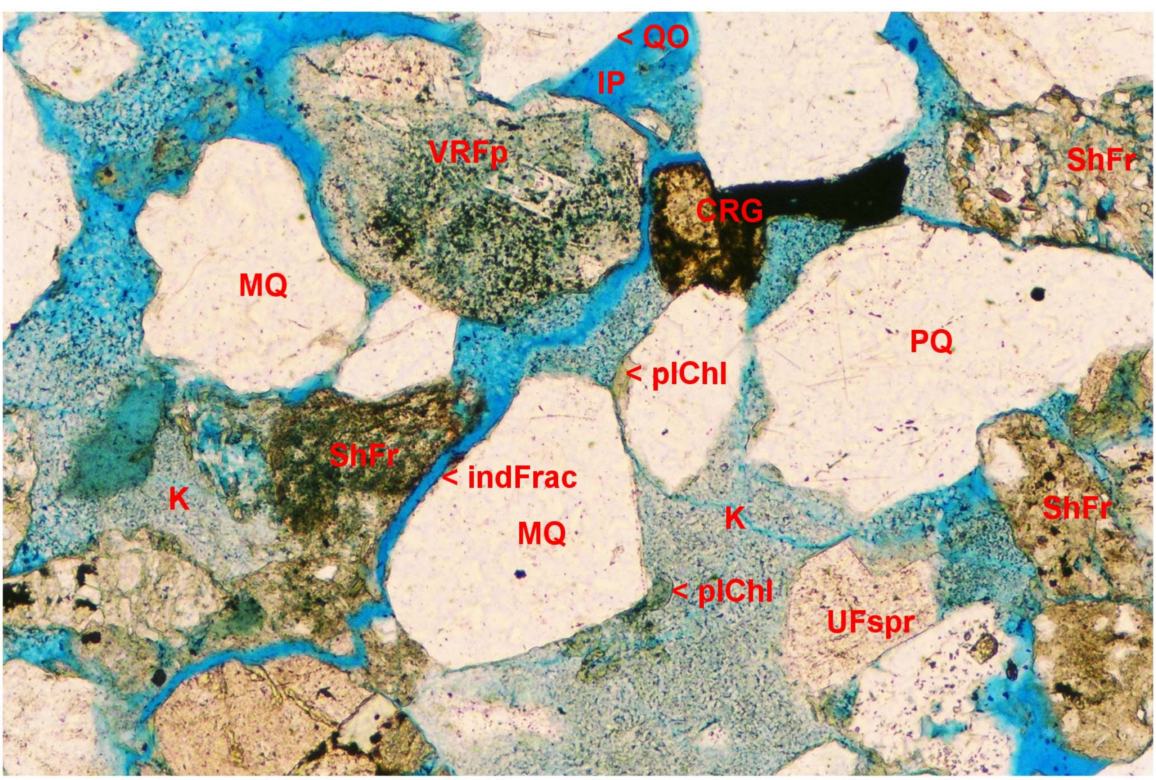
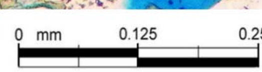


PLATE 4.4B



LONGTOM-2 ST1
PLUG #29
2121.65 m

LITHOLOGY:	Sandstone. Lower fine to lower coarse, moderately to moderately well sorted, massive.		
Consolidation:	Poor to moderate	Sorting:	Moderate to mod good
Folk Classification:	Feldspathic litharenite	Angularity:	Angular-Subround
Ave Grain Size (mm):	0.28 (lower medium)	Sphericity:	Equant-Subelongate
Max Grain Size (mm):	0.65 (lower coarse)	Visible Porosity (%):	10.8
Grain Contacts:	Planar > Point > Concavo-convex	Hel Inj Porosity (%):	18.5
Porosity Types:	Intergranular > Dissolution	Klink Perm (md):	5.38
Porosity Controls:	Authigenic clays, compaction, calcite cement.		

WHOLE ROCK CONSTITUENTS (Vol. %)

GRAINS	63.2	ACCESSORIES	0.8	***CEMENT***	3.2
TOTAL QUARTZ	33.2	Bioclasts		Silica	1.2
Monocrystalline Quartz	28.4	Organic Laminae + Grains	0.4	Non-Ferroan Calcite	
Polycrystalline Quartz	4.8	Carbonate-Replaced Grains		Ferroan Calcite	2.0
TOTAL FELDSPAR	8.8	Heavy Minerals	0.4	Non-Ferroan Dolomite	
Untwinned Feldspar	7.6	Phosphatic Grains		Ferroan Dolomite	
Plagioclase	1.2	***STRUCTURAL CLAYS***	11.6	Siderite	
Microcline		Clay-Replaced Grains	6.0	Pyrite	Tr
		Glauconite		Zeolite	
TOTAL ROCK FRAGMENTS	20.4	Biotite	1.2	Barytes	
Volcanic Rock Fragments	6.4	Muscovite	0.4	Bitumen/Dead Oil	
Metamorphic Rock Fragments	0.4	Chlorite	4.0		
Plutonic Rock Fragments	0.4	Clay Rip-Up Clasts			
Chert	6.0	Others			
Sandstone Rock Fragments	3.2	***DISPERSED MATRIX***	11.2	***VISIBLE POROSITY***	10.8
Shale Fragments	4.0	Undifferentiated	0.4	Intergranular	9.2
Limestone Rock Fragments		Authigenic Kaolinite	4.4	Dissolution	1.6
Dolostone Rock Fragments		Authigenic Chlorite	4.4	Intraparticle	
Others		Pseudomatrix	2.0	Fracture	
		Rock Flour			
		LAMINAR CLAYS		***TOTAL***	100.0

PLATE 4.5A

Low magnification overview of a lower fine to lower coarse grained, moderately to moderately well sorted, massive, feldspathic litharenite sandstone. Grains are mainly monocrystalline quartz (MQ), with common feldspar (Fspr), clay-replaced grains (CRG), heavily altered volcanic rock fragments, minor shale fragments (ShFr), sandstone rock fragments, chert (devitrified volcanic fragments) and mica (including detrital chlorite fragments; DetChl). Matrix is mainly authigenic, with patchily distributed kaolinite (K) and pore-lining/grain-coating chlorite. Localised pseudomatrix from compacted argillaceous grains is also present. Cements are rare, comprising occasional isolated crystals of slightly ferroan calcite (Ca) and poorly developed quartz overgrowths. Visible porosity is fair, mainly intergranular (IP), with localised dissolution pores (DP) caused by partial to complete leaching of grains.

(28X, Plane-polarised Light)

PLATE 4.5B

High magnification view of the centre of Plate 4.5A above. The pore network is moderately well preserved, with common, moderately well interconnected intergranular (IP) and dissolution pores (DP). Localised reduction of porosity and permeability has been caused by compaction (note common planar grain contacts), pore-filling authigenic kaolinite (K), minor pore-lining chlorite and isolated crystals of calcite (Ca). Quartz overgrowths are also present (QO), but are poorly developed and have little effect on permeability. Most grains in this view are either monocrystalline quartz (MQ) or polycrystalline quartz (PQ). A degraded untwinned feldspar (UFspr), a partly chloritised volcanic rock fragment (VRFchl), a microlitic volcanic grain (VRFml), and a shale fragment (ShFr) are also visible.

(130X, Plane-polarised Light)

LONGTOM-2 ST1
CORE PLUG #29
2121.65 m

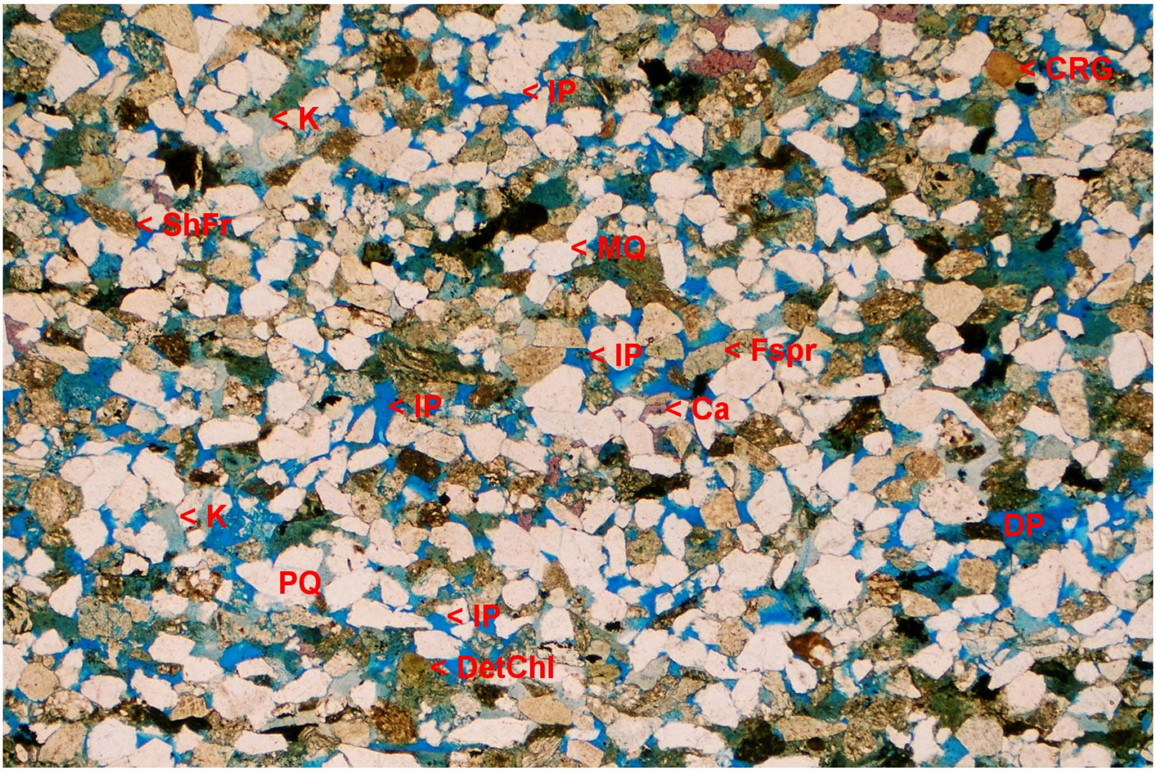
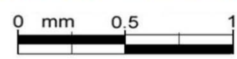


PLATE 4.5A



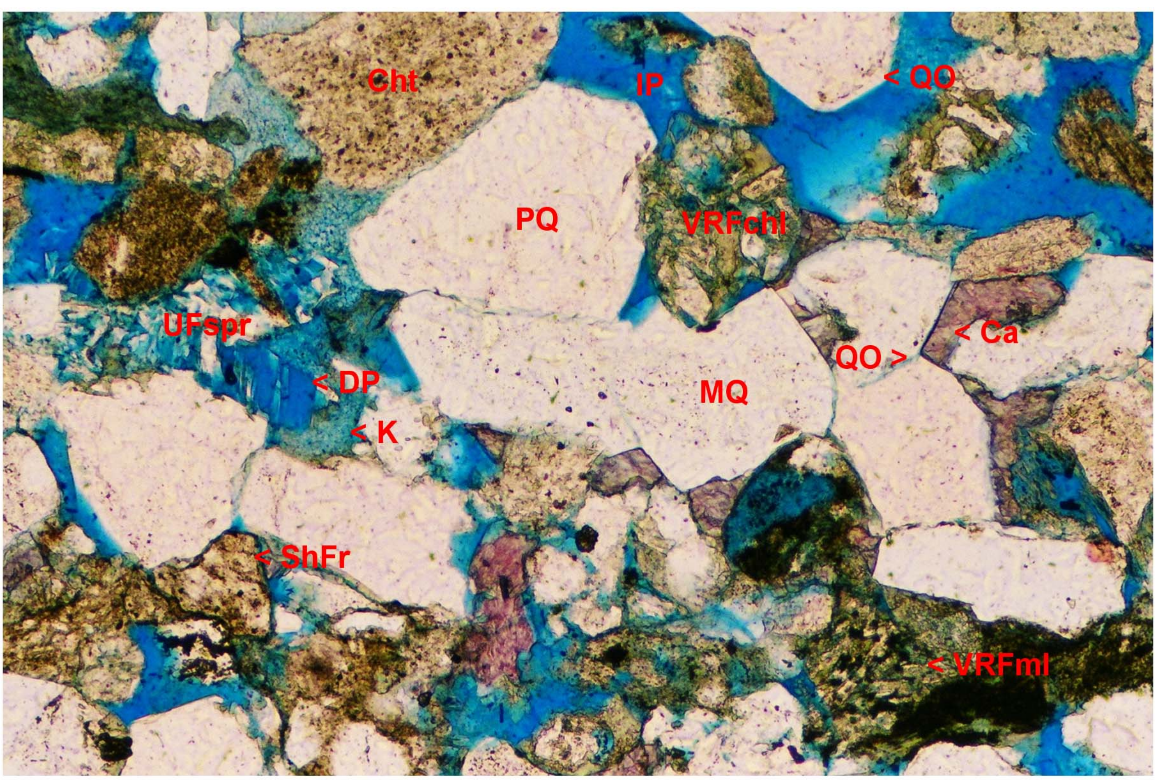
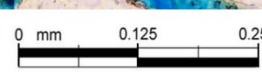


PLATE 4.5B



LONGTOM-2 ST1
PLUG #33
2122.74 m

LITHOLOGY:	Sandstone. Upper very fine to lower medium grained, moderately sorted, massive, calcite cemented.		
Consolidation:	Good	Sorting:	Moderate
Folk Classification:	Feldspathic Litharenite	Angularity:	Angular-Subrounded
Ave Grain Size (mm):	0.23 (upper fine)	Sphericity:	Equant-Subelongate
Max Grain Size (mm):	0.50 (lower coarse)	Visible Porosity (%):	1.6
Grain Contacts:	Planar = Point > Concavo-convex	Hel Inj Porosity (%):	8.6
Porosity Types:	Dissolution	Klink Perm (md):	0.004
Porosity Controls:	Calcite cement, authigenic clays.		

WHOLE ROCK CONSTITUENTS (Vol. %)

GRAINS	62.4	ACCESSORIES	0.4	***CEMENT***	16.0
TOTAL QUARTZ	39.2	Bioclasts		Silica	Tr
Monocrystalline Quartz	36.4	Organic Laminae + Grains		Non-Ferroan Calcite	
Polycrystalline Quartz	2.8	Carbonate-Replaced Grains		Ferroan Calcite	15.6
TOTAL FELDSPAR	9.2	Heavy Minerals	0.4	Non-Ferroan Dolomite	
Untwinned Feldspar	7.2	Phosphatic Grains		Ferroan Dolomite	
Plagioclase	2.0	***STRUCTURAL CLAYS***	8.4	Siderite	
Microcline		Clay-Replaced Grains	7.2	Pyrite	0.4
		Glauconite		Zeolite	
TOTAL ROCK FRAGMENTS	13.6	Biotite	Tr	Barytes	
Volcanic Rock Fragments	4.8	Muscovite	Tr	Bitumen/Dead Oil	
Metamorphic Rock Fragments	0.4	Chlorite	1.2		
Plutonic Rock Fragments	Tr	Clay Rip-Up Clasts			
Chert	5.2	Others			
Sandstone Rock Fragments	0.8	***DISPERSED MATRIX***	11.6	***VISIBLE POROSITY***	1.6
Shale Fragments	2.4	Undifferentiated	0.8	Intergranular	Tr
Limestone Rock Fragments		Authigenic Kaolinite	2.0	Dissolution	1.6
Dolostone Rock Fragments		Authigenic Pore-Lining	6.8	Intraparticle	
Others		Pseudomatrix	2.0	Fracture	
		Rock Flour			
		LAMINAR CLAYS		***TOTAL***	100.0

PLATE 4.6A

Low magnification overview of an upper very fine to lower medium grained, moderately sorted, massive, calcite-cemented feldspathic litharenite sandstone. Grains are mainly quartz (mainly monocrystalline, MQ; with minor polycrystalline, PQ), common untwinned feldspar (UFspr) and multiple-twinned plagioclase feldspar, clay-replaced grains (CRG), volcanic rock fragments (glassy, VRFg; and microlitic, VRFml), chert, shale fragments (ShFr), other lithics and mica. Clay matrix includes common pore-lining authigenic chlorite, minor authigenic kaolinite (K) and pseudomatrix from compacted argillaceous grains. Cements are dominated by medium to coarsely crystalline, slightly ferroan calcite (Ca), which is locally poikilotopic and fills most intergranular pores. Visible porosity is consequently very poor.

(28X, Plane-polarised Light)

PLATE 4.6B

High magnification view of the area at the centre of Plate 4.6A above, illustrating grains comprising a microlitic volcanic rock fragment (VRFml), monocrystalline quartz (MQ), polycrystalline quartz (PQ), chert (Cht) and degraded feldspar (dFspr), which have been tightly cemented by slightly ferroan calcite (Ca).

(130X, Plane-polarised Light)

LONGTOM-2 ST1
CORE PLUG #33
2122.74 m

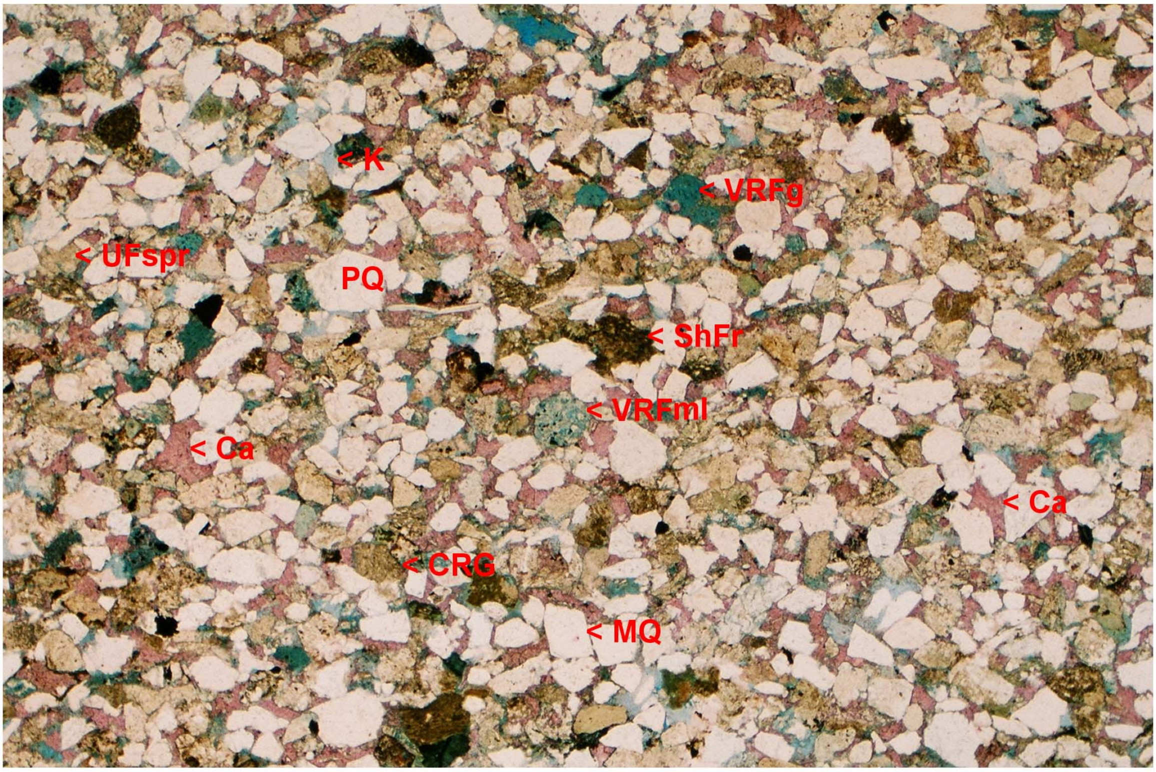
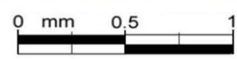


PLATE 4.6A



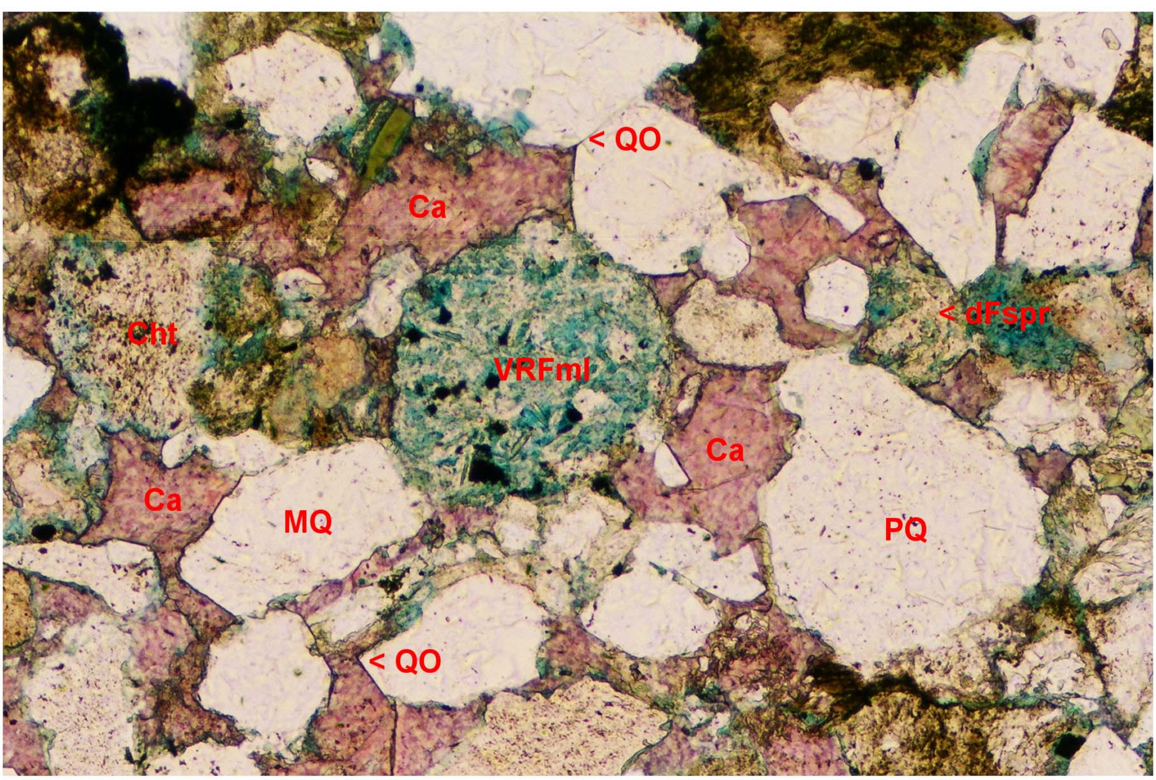


PLATE 4.6B

LONGTOM-2 ST1
PLUG #43
2127.48 m

LITHOLOGY:	Sandstone. Lower fine to upper medium, moderately well sorted, massive.		
Consolidation:	Poor	Sorting:	Moderately good
Folk Classification:	Feldspathic Litharenite	Angularity:	Angular-Subround
Ave Grain Size (mm):	0.30 (lower medium)	Sphericity:	Equant-Subelongate
Max Grain Size (mm):	0.60 (lower coarse)	Visible Porosity (%):	14.0
Grain Contacts:	Planar = Point > Concavo-convex	Hel Inj Porosity (%):	20.7
Porosity Types:	Intergranular > Dissolution	Klink Perm (md):	38.1
Porosity Controls:	Compaction, authigenic clay.		

WHOLE ROCK CONSTITUENTS (Vol. %)

GRAINS	62.4	ACCESSORIES	0.8	***CEMENT***	2.4
TOTAL QUARTZ	30.0	Bioclasts		Silica	2.4
Monocrystalline Quartz	24.4	Organic Laminae + Grains	0.8	Non-Ferroan Calcite	
Polycrystalline Quartz	5.6	Carbonate-Replaced Grains		Ferroan Calcite	
TOTAL FELDSPAR	8.0	Heavy Minerals		Non-Ferroan Dolomite	
Untwinned Feldspar	7.6	Phosphatic Grains		Ferroan Dolomite	
Plagioclase	0.4	***STRUCTURAL CLAYS***	13.6	Siderite	
Microcline		Clay-Replaced Grains	8.4	Pyrite	Tr
		Glauconite		Zeolite	
TOTAL ROCK FRAGMENTS	23.6	Biotite	1.6	Barytes	
Volcanic Rock Fragments	10.8	Muscovite		Bitumen/Dead Oil	
Metamorphic Rock Fragments	0.4	Chlorite	3.6		
Plutonic Rock Fragments	1.2	Clay Rip-Up Clasts			
Chert	4.4	Others			
Sandstone Rock Fragments	4.8	***DISPERSED MATRIX***	7.6	***VISIBLE POROSITY***	14.0
Shale Fragments	2.0	Undifferentiated	Tr	Intergranular	12.8
Limestone Rock Fragments		Authigenic Kaolinite	3.2	Dissolution	1.2
Dolostone Rock Fragments		Authigenic Pore-Lining	4.4	Intraparticle	
Others		Pseudomatrix	Tr	Fracture	
		Rock Flour			
		LAMINAR CLAYS		***TOTAL***	100.0

PLATE 4.7A

Low magnification view of lower fine to upper medium grained, moderately well sorted, massive, feldspathic litharenite sandstone. Grains are mainly monocrystalline quartz (MQ) with common volcanic rock fragments (glassy, VRFg; and microlitic, VRFml), feldspar (mostly untwinned, but also including multiple-twinned plagioclase, Plag), clay-replaced grains, sandstone rock fragments (SRF), chert, shale fragments (ShFr), mica)Mic)and other lithics. Clay matrix consists mainly of pore-lining authigenic chlorite and pore-filling kaolinite (K). Cements are minor, comprising mainly scattered poorly to moderately developed quartz overgrowths (QO). Calcite cement is absent. Visible porosity is good, mainly intergranular (IP) with minor oversized dissolution pores (DP) and dissolution porosity in partly leached feldspar grains (lFspr).

(28X, Plane-polarised Light)

PLATE 4.7B

High magnification view of the area depicted at the centre of Plate 4.7A above. Grains are mainly quartz (monocrystalline, MQ; and polycrystalline, PQ), volcanic rock fragments (VRF; some of which are degraded, dVRF), shale fragments (ShFr), feldspar (Fspr) and detrital chlorite mica (possibly chloritised grains, DetChl). The pore network comprises mainly intergranular pores (IP), augmented by localised dissolution pores (DP), which frequently occur within partly leached feldspar grains. Note the presence of authigenic kaolinite (K)and pore-lining authigenic chlorite clays (plChl) which, along with compaction, have reduced porosity and permeability. At least some of the kaolinite is suspected to represent altered grains.

(130X, Plane-polarised Light)

LONGTOM-2 ST1
CORE PLUG #43
2127.48 m

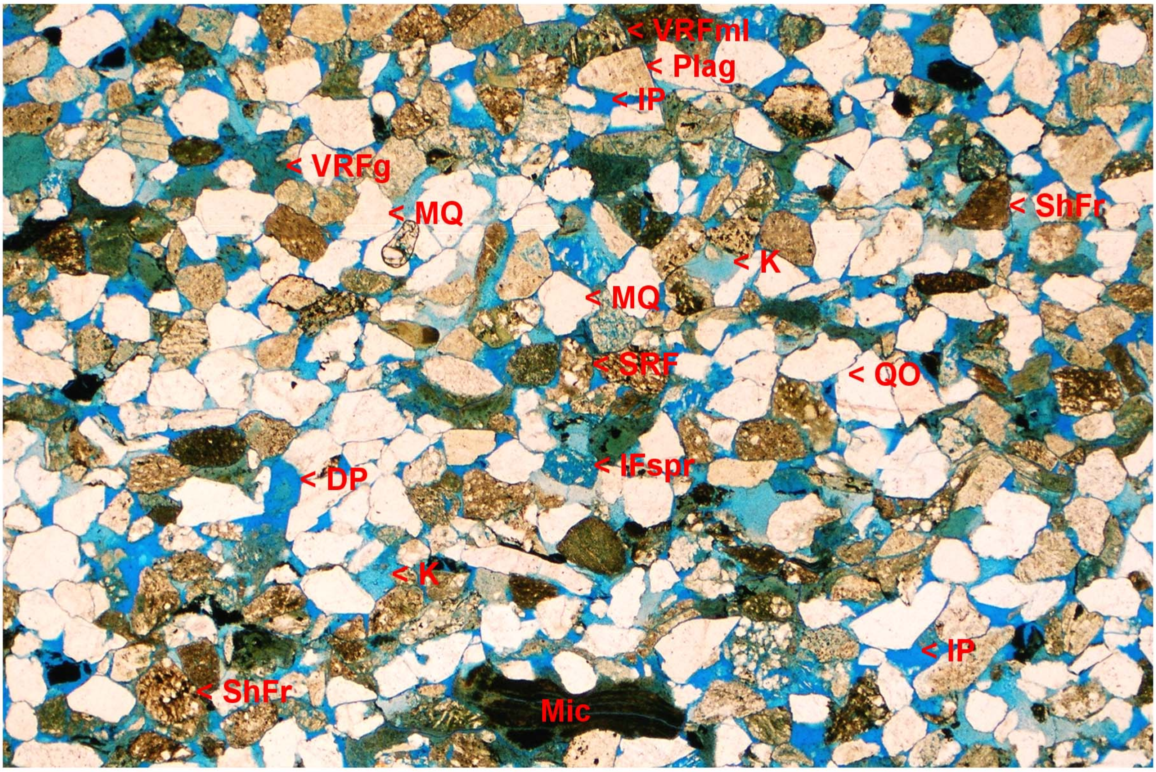
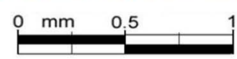


PLATE 4.7A



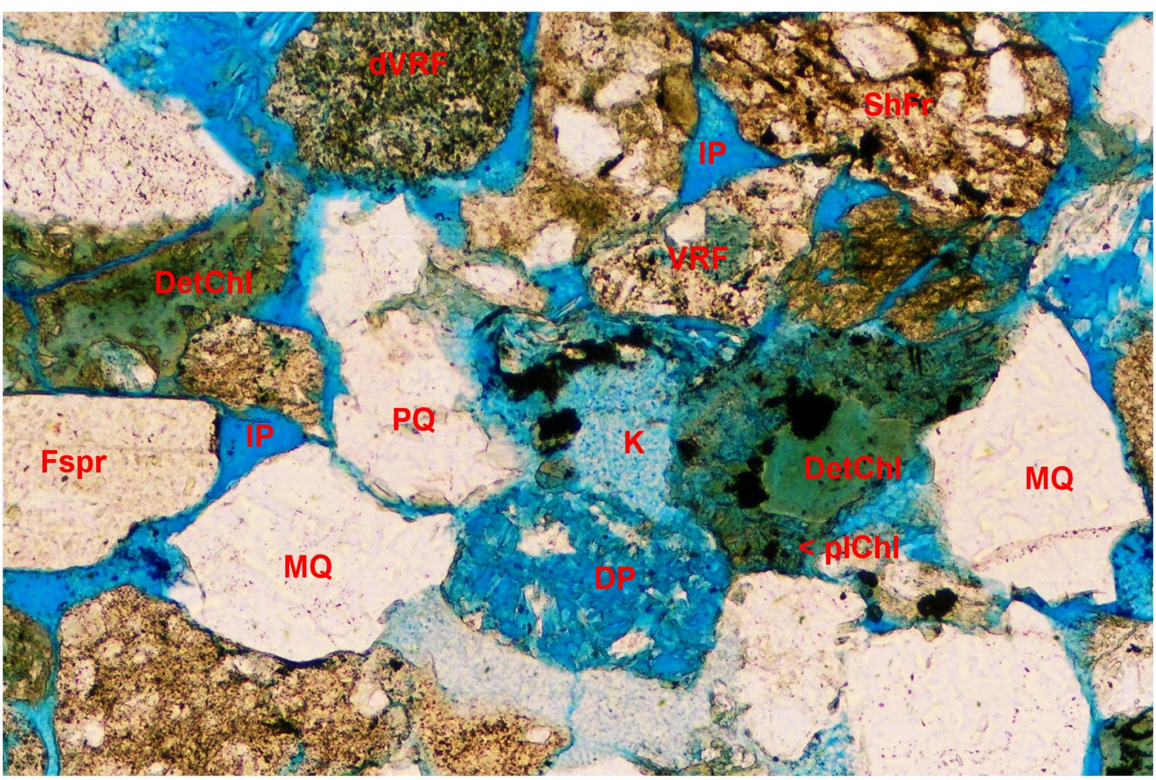
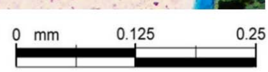


PLATE 4.7B



LONGTOM-2 ST1
PLUG #51
2129.86 m

LITHOLOGY:	Sandstone. Lower fine to upper medium, moderately well sorted, massive.		
Consolidation:	Poor	Sorting:	Moderately good
Folk Classification:	Feldspathic Litharenite	Angularity:	Angular-Subround
Ave Grain Size (mm):	0.27 (lower medium)	Sphericity:	Equant-Subelongate
Max Grain Size (mm):	0.60 (lower coarse)	Visible Porosity (%):	16.0
Grain Contacts:	Planar = Point > Concavo-convex	Hel Inj Porosity (%):	20.9
Porosity Types:	Intergranular > Dissolution	Klink Perm (md):	39.5
Porosity Controls:	Authigenic clays, compaction.		

WHOLE ROCK CONSTITUENTS (Vol. %)

GRAINS	65.2	ACCESSORIES		***CEMENT***	0.8
TOTAL QUARTZ	32.4	Bioclasts		Silica	0.8
Monocrystalline Quartz	25.2	Organic Laminae + Grains	Tr	Non-Ferroan Calcite	
Polycrystalline Quartz	7.2	Carbonate-Replaced Grains		Ferroan Calcite	
TOTAL FELDSPAR	8.4	Heavy Minerals	Tr	Non-Ferroan Dolomite	
Untwinned Feldspar	7.6	Phosphatic Grains		Ferroan Dolomite	
Plagioclase	0.8	***STRUCTURAL CLAYS***	10.4	Siderite	
Microcline		Clay-Replaced Grains	6.8	Pyrite	Tr
		Glauconite		Zeolite	
TOTAL ROCK FRAGMENTS	24.4	Biotite	0.4	Barytes	
Volcanic Rock Fragments	5.6	Muscovite	Tr	Bitumen/Dead Oil	
Metamorphic Rock Fragments	0.8	Chlorite	3.2		
Plutonic Rock Fragments	0.8	Clay Rip-Up Clasts			
Chert	6.0	Others			
Sandstone Rock Fragments	5.6	***DISPERSED MATRIX***	7.6	***VISIBLE POROSITY***	16.0
Shale Fragments	5.6	Undifferentiated	0.4	Intergranular	13.6
Limestone Rock Fragments		Authigenic Kaolinite	4.4	Dissolution	2.4
Dolostone Rock Fragments		Authigenic Pore-Lining	2.0	Intraparticle	
Others		Pseudomatrix	0.8	Fracture	
		Rock Flour			
		LAMINAR CLAYS		***TOTAL***	100.0

PLATE 4.8A

Low magnification overview of a lower fine to upper medium grained, moderately well sorted, massive, feldspathic litharenite sandstone. Grains are mainly monocrystalline quartz (most white grains), with common feldspar (Fspr), clay-replaced grains, heavily altered glassy volcanic rock fragments (VRFg), minor shale fragments, sandstone rock fragments, chert (devitrified volcanic fragments) and mica (including biotite fragments; Bi). Matrix comprises mainly patchily distributed authigenic kaolinite (K), pore-lining/grain-coating chlorite and localised pseudomatrix from compacted argillaceous grains. The only secondary cement observed in this sample is silica, in the form of poorly developed quartz overgrowths (Qo). Calcite is absent. Visible porosity is good due to a well interconnected, relatively unimpeded network of intergranular pores (IP).

(28X, Plane-polarised Light)

PLATE 4.8B

High magnification view of the centre of Plate 4.8A above, showing the well developed intergranular pore network (IP) augmented by localised dissolution pores (DP). Note the small patches of authigenic kaolinite (K) and pore-lining chlorite (plChl), which cause some localised reduction of pores and pore throats. Quartz overgrowths (QO) are too poorly developed to have had much effect as a permeability reducing agent. Grains include monocrystalline quartz (MQ), degraded and partly leached plagioclase (Plag), partly clay-altered untwinned feldspar (UFspr), glassy volcanic rock fragments (VRFg) and detrital chlorite (DetChl). Note the possible stress-release fracture that runs from left to right across the lower part of the view (srFrac). Stress-release fracturing may have caused some localised exaggeration of permeability results.

(130X, Plane-polarised Light)

LONGTOM-2 ST1
CORE PLUG #51
2129.86 m

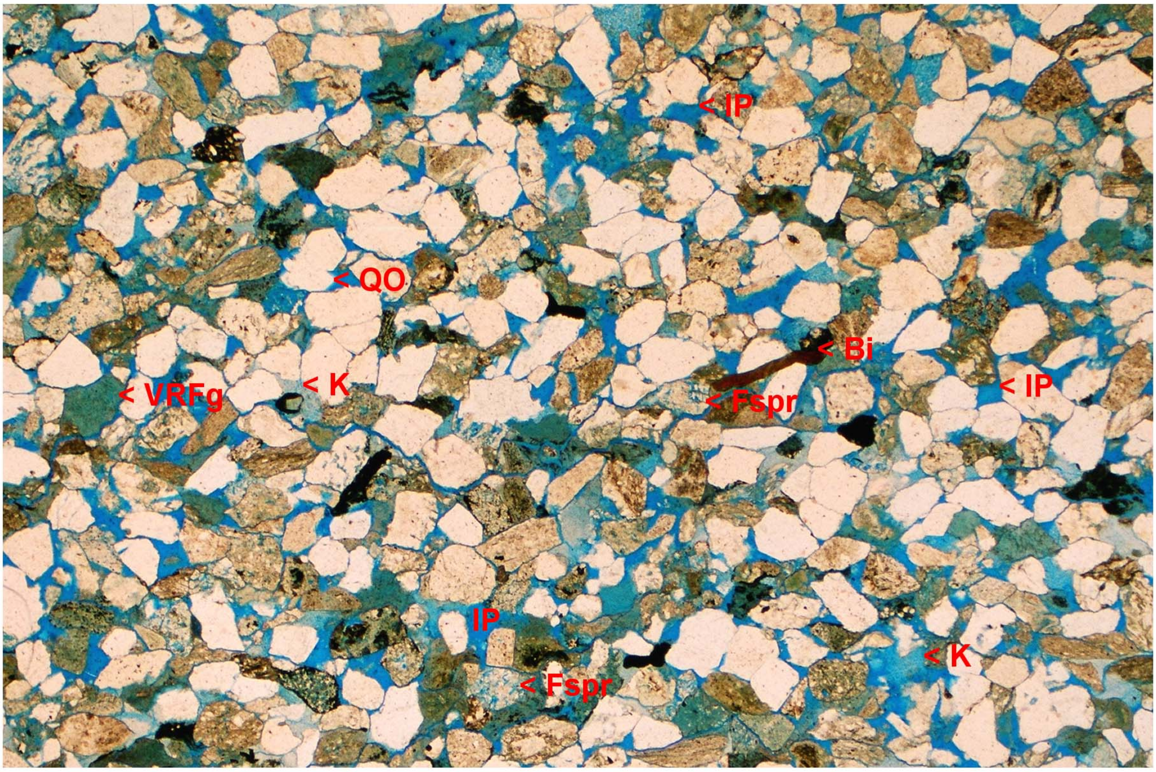


PLATE 4.8A

0 mm 0.5 1

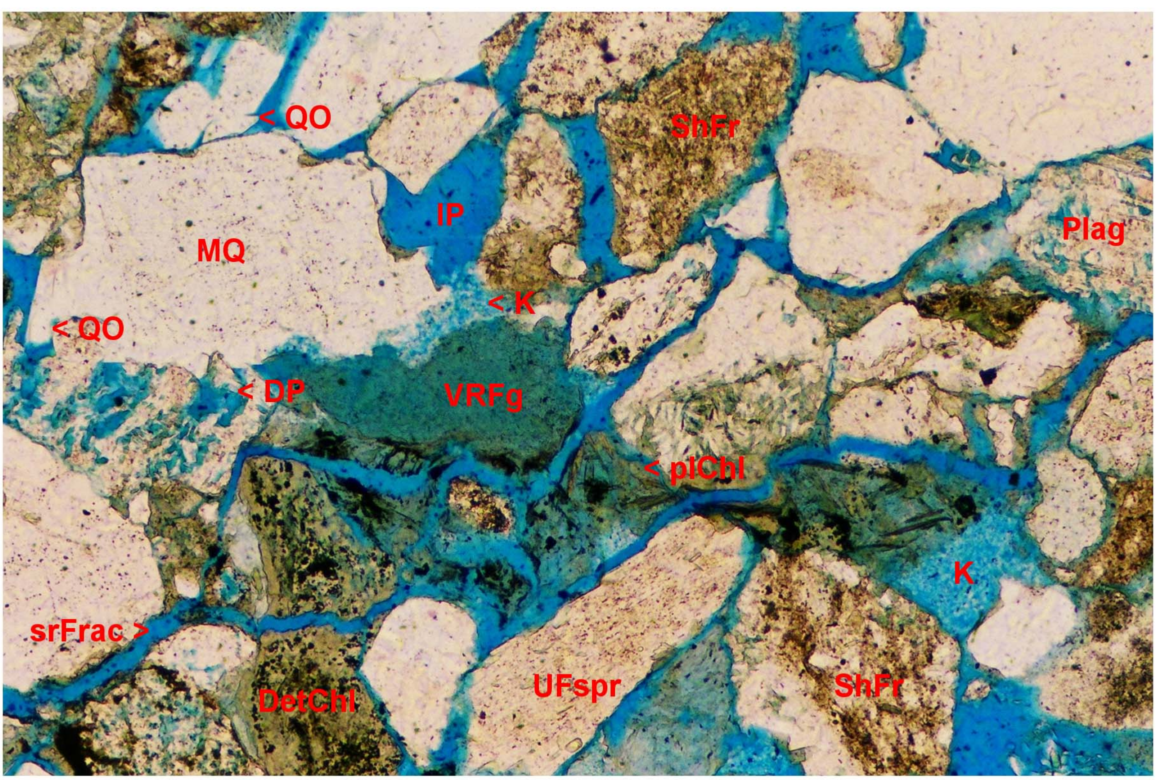


PLATE 4.8B

0 mm 0.125 0.25

LONGTOM-2 ST1
PLUG #52
2130.26 m

LITHOLOGY:	Sandstone. Upper fine to upper medium, moderately well sorted, massive to faintly laminated, calcite cemented.		
Consolidation:	Very good	Sorting:	Moderately good
Folk Classification:	Litharenite	Angularity:	Angular-subround
Ave Grain Size (mm):	0.30 (lower medium)	Sphericity:	Equant-Subelongate
Max Grain Size (mm):	0.85 (upper coarse)	Visible Porosity (%):	0.4
Grain Contacts:	Planar = Point > Concavo-convex	Hel Inj Porosity (%):	9.0
Porosity Types:	Dissolution	Klink Perm (md):	0.005
Porosity Controls:	Calcite cement.		

WHOLE ROCK CONSTITUENTS (Vol. %)

GRAINS	61.6	ACCESSORIES		***CEMENT***	20.4
TOTAL QUARTZ	30.4	Bioclasts		Silica	Tr
Monocrystalline Quartz	25.2	Organic Laminae + Grains		Non-Ferroan Calcite	
Polycrystalline Quartz	5.2	Carbonate-Replaced Grains	Tr	Ferroan Calcite	20.4
TOTAL FELDSPAR	5.6	Heavy Minerals		Non-Ferroan Dolomite	
Untwinned Feldspar	5.2	Phosphatic Grains		Ferroan Dolomite	
Plagioclase	0.4	***STRUCTURAL CLAYS***	11.2	Siderite	
Microcline		Clay-Replaced Grains	5.6	Pyrite	Tr
		Glauconite		Zeolite	
TOTAL ROCK FRAGMENTS	25.6	Biotite	0.8	Barytes	
Volcanic Rock Fragments	13.6	Muscovite	0.4	Bitumen/Dead Oil	
Metamorphic Rock Fragments	0.8	Chlorite	4.4		
Plutonic Rock Fragments	Tr	Clay Rip-Up Clasts			
Chert	4.8	Others			
Sandstone Rock Fragments	2.4	***DISPERSED MATRIX***	6.4	***VISIBLE POROSITY***	0.4
Shale Fragments	4.0	Undifferentiated	Tr	Intergranular	Tr
Limestone Rock Fragments		Authigenic Kaolinite	0.8	Dissolution	0.4
Dolostone Rock Fragments		Authigenic Pore-Lining	1.2	Intraparticle	
Others		Pseudomatrix	4.4	Fracture	
		Rock Flour			
		LAMINAR CLAYS		***TOTAL***	100.0

PLATE 4.9A

Low magnification view of upper fine to upper medium grained, moderately well sorted, massive to faintly laminated, calcite-cemented litharenite sandstone. Grains are mainly monocrystalline quartz (MQ), with common volcanic rock fragments (VRF), feldspar (mainly untwinned, UFspr; but also including multiple-twinned plagioclase, Plag), clay-replaced grains (CRG; also note the kaolinite-replaced grain, Kgr), chert (Cht), shale fragments (ShFr), sandstone rock fragments (SRF), mica (mainly chlorite) and traces of calcite-replaced grains (CaRG). Clay matrix includes common pseudomatrix from compacted grains, minor pore-lining chlorite and pore-filling kaolinite. Medium to coarsely crystalline, locally poikilotopic calcite cement is abundant. Visible porosity is therefore very poor, confined to a few isolated dissolution pores and cement-restricted intergranular pores.

(28X, Plane-polarised Light)

PLATE 4.9B

High magnification view of the area shown at the centre of Plate 4.9A above. Grains visible are mainly quartz (monocrystalline, MQ and polycrystalline, PQ), with volcanic rock fragments (VRF), a shale fragment (ShFr), locally veined and degraded chert (Cht), a kaolinite-replaced grain (Kgr), an altered grain (possibly volcanic; AltGr) and microgranite (MiGr). Very slightly ferroan calcite cement (Ca) fills virtually all available porosity and appears to have post-dated pore-lining chlorite (plChl), which lies underneath the calcite.

(130X, Plane-polarised Light)

LONGTOM-2 ST1
CORE PLUG #52
2130.26 m

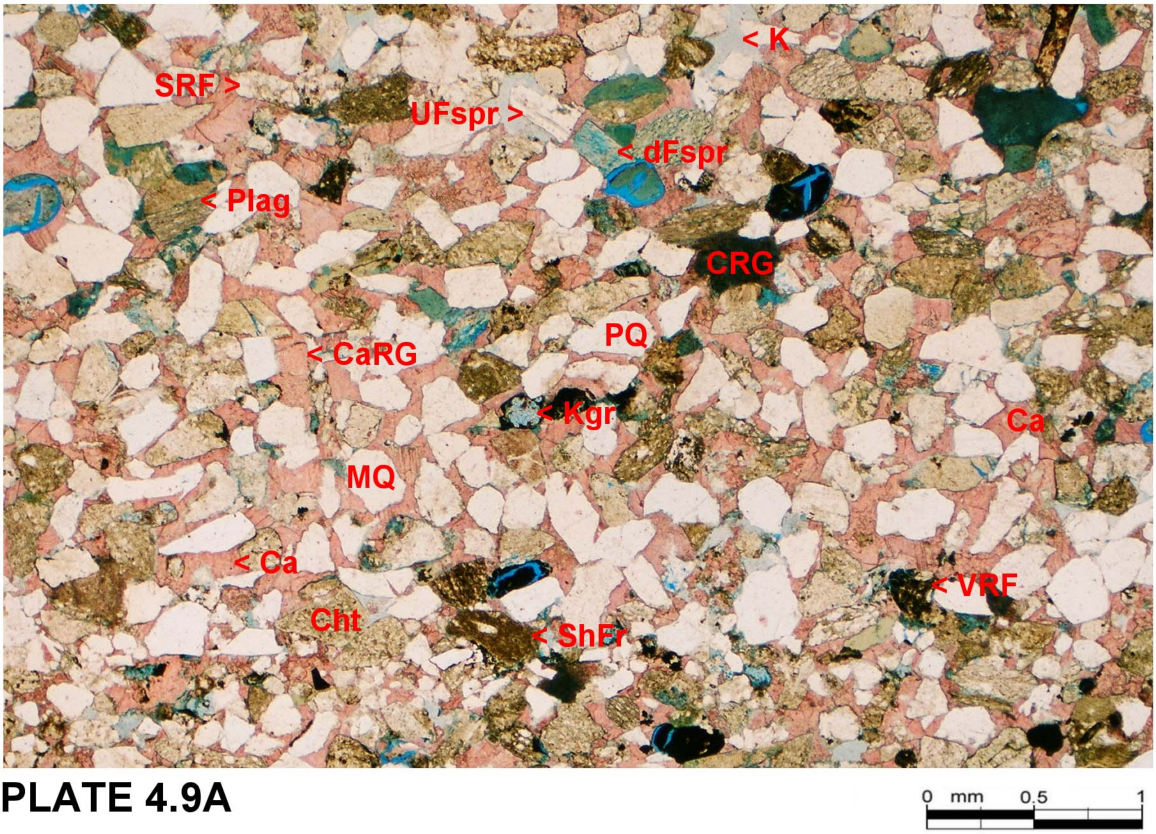


PLATE 4.9A

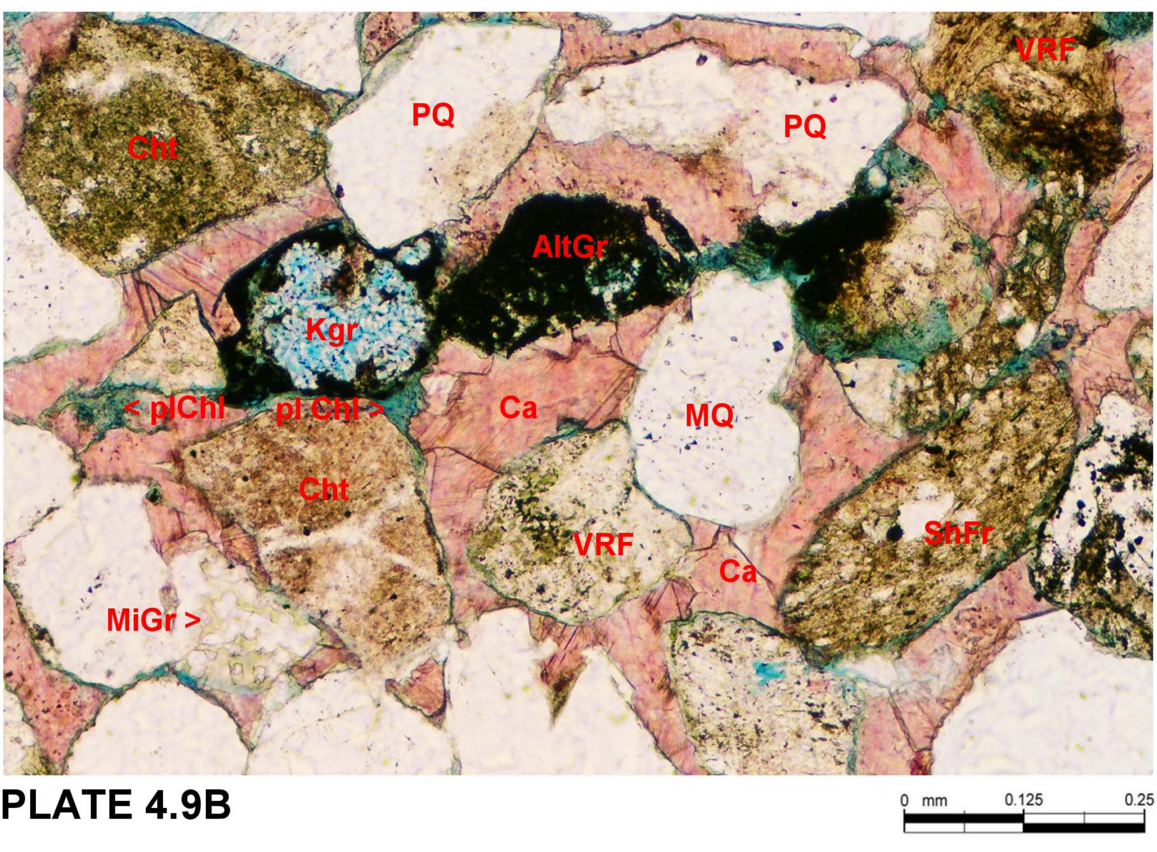


PLATE 4.9B

LONGTOM-2 ST1
PLUG #53
2133.55 m

LITHOLOGY:	Sandstone. Lower fine to upper medium grained, moderately well sorted, massive.		
Consolidation:	Poor to moderate.	Sorting:	Moderately good
Folk Classification:	Litharenite	Angularity:	Angular-Subround
Ave Grain Size (mm):	0.27 (lower medium)	Sphericity:	Equant-Subelongate
Max Grain Size (mm):	0.50 (lower coarse)	Visible Porosity (%):	10.0
Grain Contacts:	Planar > Point > Concavo-convex	Hel Inj Porosity (%):	20
Porosity Types:	Intergranular > Dissolution	Klink Perm (md):	22.3
Porosity Controls:	Authigenic clays, compaction, calcite and quartz cement.		

WHOLE ROCK CONSTITUENTS (Vol. %)

GRAINS	67.2	ACCESSORIES		***CEMENT***	4.0
TOTAL QUARTZ	30.8	Bioclasts		Silica	2.0
Monocrystalline Quartz	26.0	Organic Laminae + Grains		Non-Ferroan Calcite	
Polycrystalline Quartz	4.8	Carbonate-Replaced Grains		Ferroan Calcite	2.0
TOTAL FELDSPAR	8.8	Heavy Minerals	Tr	Non-Ferroan Dolomite	
Untwinned Feldspar	6.8	Phosphatic Grains		Ferroan Dolomite	
Plagioclase	2.0	***STRUCTURAL CLAYS***	7.6	Siderite	
Microcline		Clay-Replaced Grains	5.6	Pyrite	Tr
		Glauconite		Zeolite	
TOTAL ROCK FRAGMENTS	27.6	Biotite	Tr	Barytes	
Volcanic Rock Fragments	10.8	Muscovite	Tr	Bitumen/Dead Oil	
Metamorphic Rock Fragments	1.6	Chlorite	2.0		
Plutonic Rock Fragments	1.2	Clay Rip-Up Clasts			
Chert	5.6	Others			
Sandstone Rock Fragments	5.2	***DISPERSED MATRIX***	11.2	***VISIBLE POROSITY***	10.0
Shale Fragments	3.2	Undifferentiated	0.4	Intergranular	8.4
Limestone Rock Fragments		Authigenic Kaolinite	4.4	Dissolution	1.6
Dolostone Rock Fragments		Authigenic Pore-Lining	4.4	Intraparticle	
Others		Pseudomatrix	2.0	Fracture	
		Rock Flour			
		LAMINAR CLAYS		***TOTAL***	100.0

PLATE 4.10A

Low magnification overview of lower fine to upper medium grained, moderately well sorted, massive, slightly calcareous litharenite sandstone. Grains are mainly monocrystalline quartz (MQ), with common volcanic rock fragments (glassy, VRFg; and microlitic, VRFml), polycrystalline quartz (PQ), feldspar (much of which is degraded or partly leached, lFspr), chert (Cht), sandstone rock fragments (SRF), shale fragments (ShFr), mica (Mic), and other lithics. Matrix comprises authigenic pore-lining chlorite, pore-filling kaolinite and pseudomatrix from compacted argillaceous grains. Minor, scattered calcite cement crystals (Ca) and localised quartz overgrowths (QO) are the main cementing agents. Visible porosity is fair, mainly intergranular (IP) with minor dissolution porosity in partly leached feldspars.

(28X, Plane-polarised Light)

PLATE 4.10B

High magnification view of the area at the centre of Plate 4.10A above, showing moderately well interconnected intergranular pores (IP) that have been locally reduced by authigenic kaolinite (K), calcite cement (Ca) and quartz overgrowths (QO). Note the dissolution porosity created by complete dissolution of a grain (DP) and partial leaching of a feldspar grain (lFspr) adjacent to calcite cement (Ca). The absence of calcite within this dissolution porosity indicates dissolution probably occurred after calcite cementation. Most of the other grains in this view comprise monocrystalline quartz (MQ) and polycrystalline quartz (PQ). Some of the quartz carries rutile inclusions (ri).

(130X, Plane-polarised Light)

LONGTOM-2 ST1
CORE PLUG #53
2133.55 m

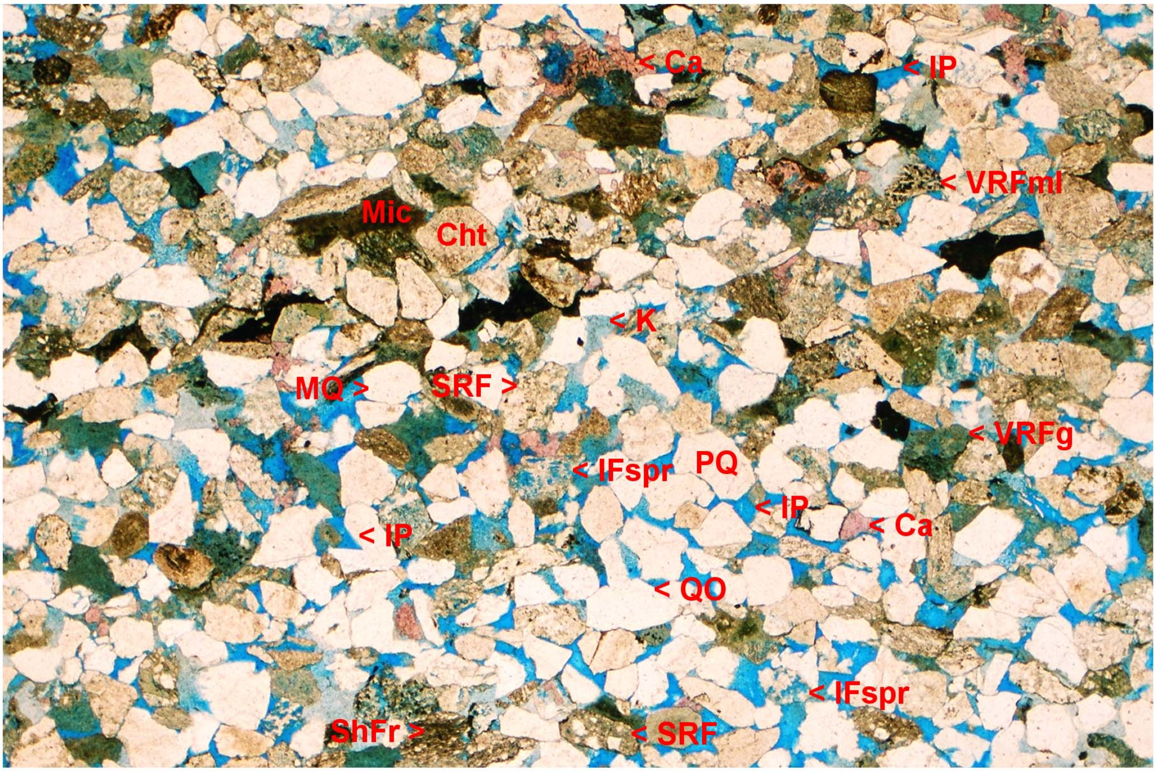
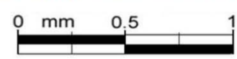


PLATE 4.10A



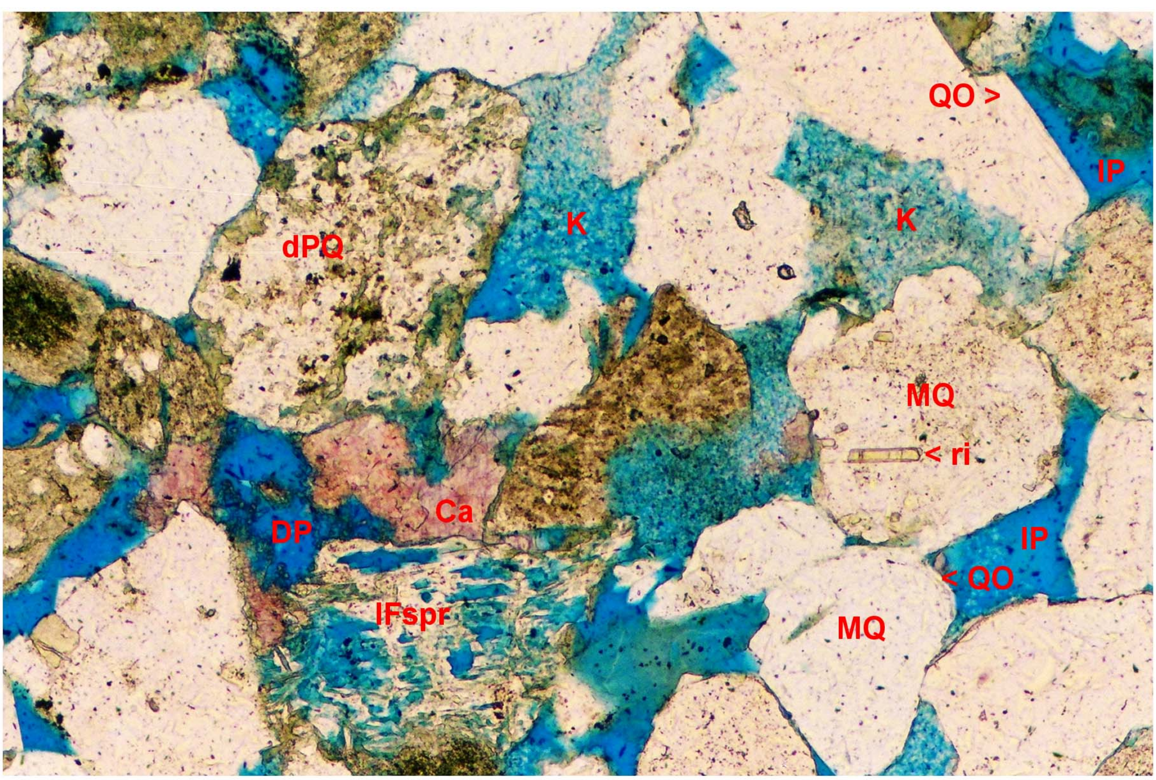
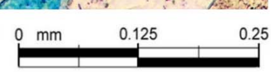


PLATE 4.10B



LONGTOM-2 ST1
PLUG #74
2136.82 m

LITHOLOGY:	Sandstone. Lower fine to upper medium, moderately to moderately well sorted, massive.		
Consolidation:	Poor	Sorting:	Moderate to Mod good
Folk Classification:	Feldspathic Litharenite	Angularity:	Angular-Subround
Ave Grain Size (mm):	0.27 (lower medium)	Sphericity:	Equant-Subelongate
Max Grain Size (mm):	0.53 (lower granule)	Visible Porosity (%):	16.0
Grain Contacts:	Planar = Point > Concavo-convex	Hel Inj Porosity (%):	21.3
Porosity Types:	Intergranular > Dissolution	Klink Perm (md):	39.9
Porosity Controls:	Authigenic clay, compaction.		

WHOLE ROCK CONSTITUENTS (Vol. %)

GRAINS	66.0	ACCESSORIES		***CEMENT***	0.8
TOTAL QUARTZ	34.0	Bioclasts		Silica	0.8
Monocrystalline Quartz	28.4	Organic Laminae + Grains	Tr	Non-Ferroan Calcite	
Polycrystalline Quartz	5.6	Carbonate-Replaced Grains		Ferroan Calcite	
TOTAL FELDSPAR	11.6	Heavy Minerals	Tr	Non-Ferroan Dolomite	
Untwinned Feldspar	8.8	Phosphatic Grains		Ferroan Dolomite	
Plagioclase	2.8	***STRUCTURAL CLAYS***	10.0	Siderite	
Microcline		Clay-Replaced Grains	5.6	Pyrite	Tr
		Glauconite		Zeolite	
TOTAL ROCK FRAGMENTS	20.4	Biotite		Barytes	
Volcanic Rock Fragments	11.2	Muscovite	0.8	Bitumen/Dead Oil	
Metamorphic Rock Fragments	Tr	Chlorite	3.6		
Plutonic Rock Fragments	0.8	Clay Rip-Up Clasts			
Chert	1.2	Others			
Sandstone Rock Fragments	4.4	***DISPERSED MATRIX***	7.2	***VISIBLE POROSITY***	16.0
Shale Fragments	2.8	Undifferentiated	Tr	Intergranular	15.2
Limestone Rock Fragments		Authigenic Kaolinite	4.0	Dissolution	0.8
Dolostone Rock Fragments		Authigenic Pore-Lining	3.2	Intraparticle	
Others		Pseudomatrix	Tr	Fracture	
		Rock Flour			
		LAMINAR CLAYS		***TOTAL***	100.0

PLATE 4.11A

Low magnification overview of a lower fine to upper medium grained, moderately to moderately well sorted, massive, feldspathic litharenite sandstone. Grains are mainly monocrystalline quartz (MQ), with very common volcanic rock fragments (mainly degraded and glassy; VRFg), common feldspar, clay-replaced grains (CRG), polycrystalline quartz (PQ), minor sandstone rock fragments, shale fragments (ShFr), chert (devitrified volcanic fragments; Cht) and mica. Matrix comprises mainly patchily distributed authigenic kaolinite (K) and pore-lining/grain-coating chlorite, with occasional pseudomatrix occurring from compacted argillaceous grains. Calcite cement is absent, and only small quantities of poorly developed quartz overgrowth cement are present. Visible porosity is good, due to the moderately well interconnected, relatively unimpeded network of intergranular pores (IP), which is augmented by dissolution pores (DP), many of which are due to partial dissolution of feldspar grains (DPf).

(28X, Plane-polarised Light)

PLATE 4.11B

High magnification view of the centre of Plate 4.11A above, illustrating a patch of authigenic kaolinite (K) that spans across several pores. Grains are mostly monocrystalline quartz (MQ), but also include polycrystalline quartz (PQ), partly degraded chert (Cht), an almost opaque shale or tuff fragment (Sh/TfFr?), detrital chlorite mica (detChl), plagioclase (Plag) and partly leached untwinned feldspar (UFspr). Apart from the areas obscured by kaolinite, intergranular pores (IP) are generally free of clays, although some pore throats have been restricted by pore-lining authigenic chlorite (plChlor).

(130X, Plane-polarised Light)

LONGTOM-2 ST1
CORE PLUG #74
2136.82 m

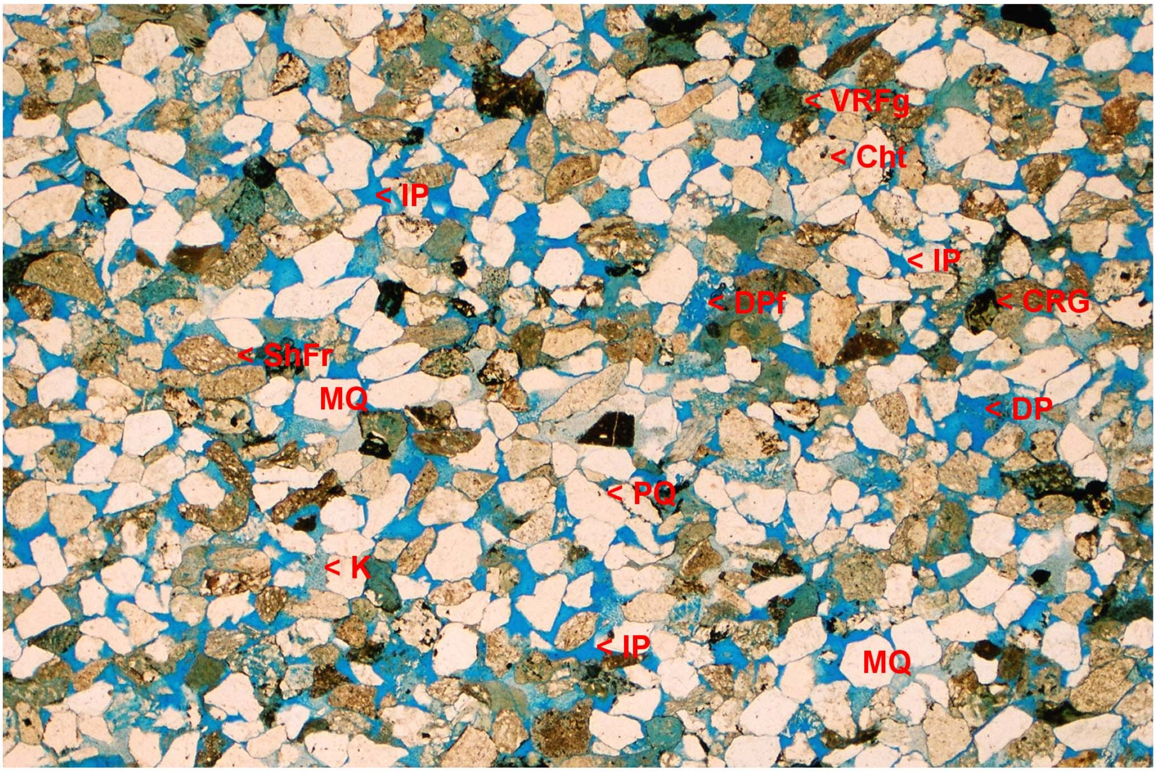


PLATE 4.11A

0 mm 0.5 1

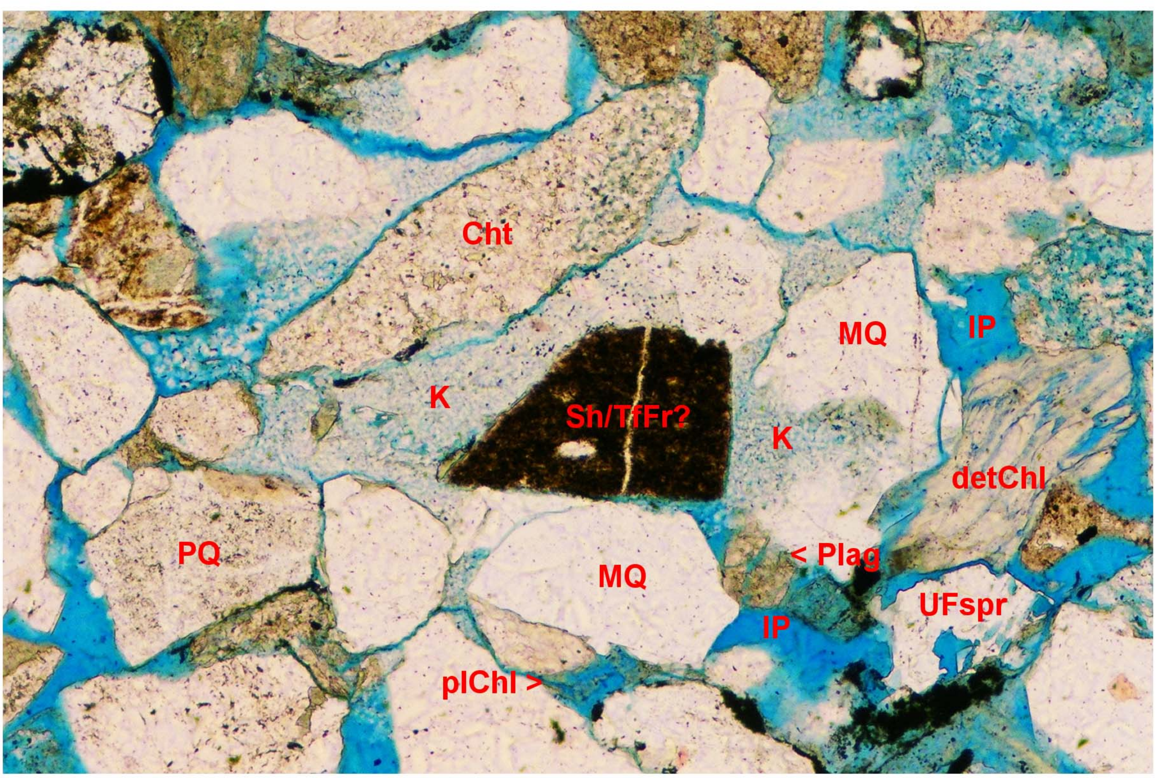


PLATE 4.11B

0 mm 0.125 0.25

LONGTOM-2 ST1
PLUG #82
2139.18 m

LITHOLOGY:	Sandstone. Lower fine to upper medium, moderately well sorted, massive, partly calcite cemented.		
Consolidation:	Poor to moderate	Sorting:	Moderately good
Folk Classification:	Feldspathic Litharenite	Angularity:	Angular-Subround
Ave Grain Size (mm):	0.30 (lower medium)	Sphericity:	Equant-Subelongate
Max Grain Size (mm):	0.50 (lower granule)	Visible Porosity (%):	6.8
Grain Contacts:	Planar > Point > Concavo-convex	Hel Inj Porosity (%):	15.7
Porosity Types:	Intergranular > Dissolution	Klink Perm (md):	0.981
Porosity Controls:	Authigenic clay, compaction, calcite cement.		

WHOLE ROCK CONSTITUENTS (Vol. %)

GRAINS	69.6	ACCESSORIES		***CEMENT***	4.0
TOTAL QUARTZ	30.0	Bioclasts		Silica	0.8
Monocrystalline Quartz	23.6	Organic Laminae + Grains		Non-Ferroan Calcite	
Polycrystalline Quartz	6.4	Carbonate-Replaced Grains		Ferroan Calcite	3.2
TOTAL FELDSPAR	10.4	Heavy Minerals		Non-Ferroan Dolomite	
Untwinned Feldspar	6.8	Phosphatic Grains		Ferroan Dolomite	
Plagioclase	3.6	***STRUCTURAL CLAYS***	10.8	Siderite	
Microcline		Clay-Replaced Grains	8.0	Pyrite	Tr
		Glauconite		Zeolite	
TOTAL ROCK FRAGMENTS	29.2	Biotite	0.4	Barytes	
Volcanic Rock Fragments	12.8	Muscovite	Tr	Bitumen/Dead Oil	
Metamorphic Rock Fragments	2.0	Chlorite	2.4		
Plutonic Rock Fragments	Tr	Clay Rip-Up Clasts			
Chert	8.0	Others			
Sandstone Rock Fragments	4.4	***DISPERSED MATRIX***	8.8	***VISIBLE POROSITY***	6.8
Shale Fragments	2.0	Undifferentiated	Tr	Intergranular	5.6
Limestone Rock Fragments		Authigenic Kaolinite	2.0	Dissolution	1.2
Dolostone Rock Fragments		Authigenic Pore-Lining	4.0	Intraparticle	
Others		Pseudomatrix	2.8	Fracture	
		Rock Flour			
		LAMINAR CLAYS		***TOTAL***	100.0

PLATE 4.12A

Low magnification view of lower fine to upper medium grained, moderately well sorted, massive, partly calcite-cemented feldspathic litharenite sandstone. Grains are mainly quartz (monocrystalline, MQ; and lesser polycrystalline), with common volcanic rock fragments (mainly glassy, VRFg; and microlitic), untwinned feldspar (UFspr), multiple-twinned plagioclase (Plag), sandstone rock fragments, shale fragments (ShFr), mica (mainly detrital chlorite and biotite, Bi), and other lithic grains. Matrix is mainly authigenic, comprising pore-lining chlorite and pore-filling kaolinite (K), and localised pseudomatrix from ductile compaction of argillaceous grains. Cements are generally minor, mainly consisting of scattered crystals of slightly ferroan calcite (Ca) and rare quartz overgrowths (QO). Visible porosity is poor to fair, mainly intergranular (IP) with minor dissolution pores (DP). Porosity and permeability have been reduced by a combination of compaction, calcite cementation and authigenic clay.

(28X, Plane-polarised Light)

PLATE 4.12B

High magnification view of the area shown at the centre of Plate 4.12A above. Grains include monocrystalline quartz (MQ), degraded polycrystalline quartz (dPQ), detrital chlorite mica (DetChl), glassy volcanic rock fragments (VRFg) and biotite (Bi). Note how intergranular porosity (IP) has been restricted by pore-lining chlorite (plChl) and pore-filling kaolinite (K) clays, and by the compactional deformation of ductile grains, such as the two altered glassy volcanic rock fragments and the biotite shown in the upper and right-hand parts of the photomicrograph. Quartz overgrowths (QO) also project into pore space, though they are thought to be generally too small and too localised to have had much effect on porosity or permeability reduction.

(130X, Plane-polarised Light)

LONGTOM-2 ST1

CORE PLUG #82

2139.18 m

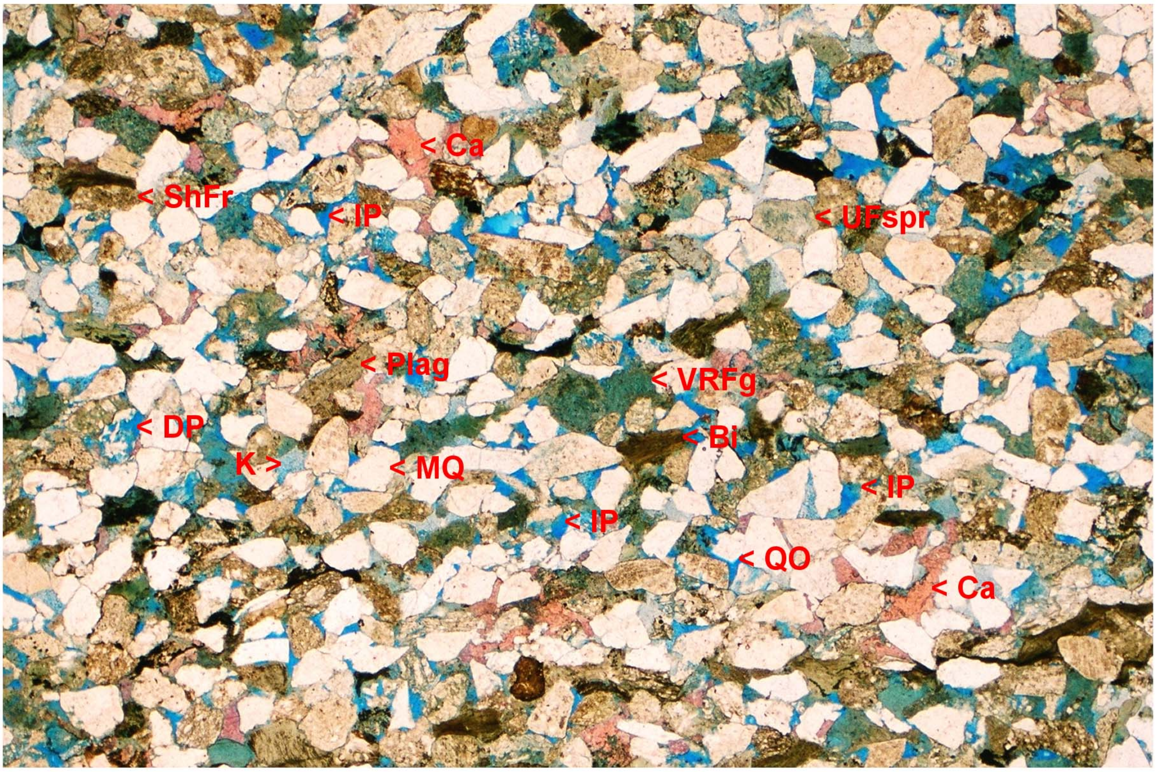


PLATE 4.12A

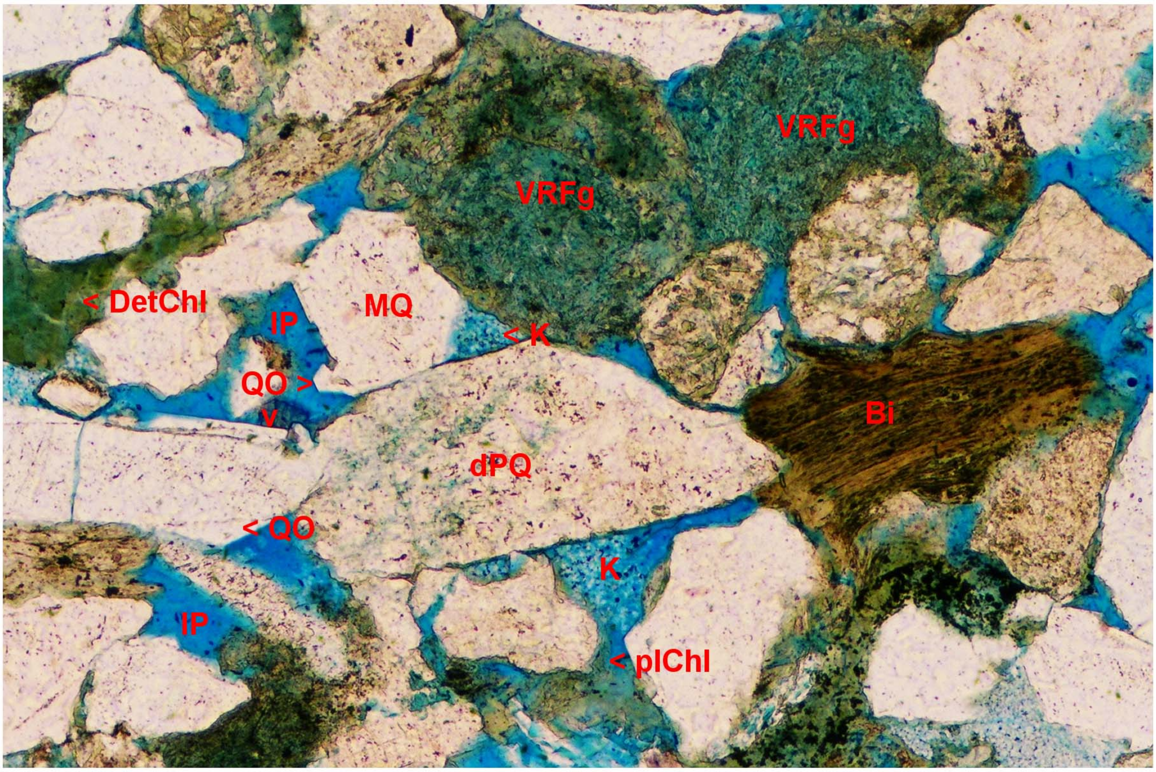


PLATE 4.12B

LONGTOM-2 ST1
PLUG #92
2142.34 m

LITHOLOGY:	Sandstone. Lower fine to lower coarse grained, moderately sorted, massive, calcite-cemented.		
Consolidation:	Very good	Sorting:	Moderate
Folk Classification:	Litharenite	Angularity:	Angular-Subround
Ave Grain Size (mm):	0.35 (lower medium)	Sphericity:	Equant-Subelongate
Max Grain Size (mm):	1.05 (lower very coarse)	Visible Porosity (%):	3.6
Grain Contacts:	Planar = Point > Concavo-convex	Hel Inj Porosity (%):	11.8
Porosity Types:	Intergranular = Dissolution	Klink Perm (md):	0.064
Porosity Controls:	Calcite cement, authigenic clays.		

WHOLE ROCK CONSTITUENTS (Vol. %)

GRAINS	65.6	ACCESSORIES		***CEMENT***	18.4
TOTAL QUARTZ	32.8	Bioclasts		Silica	0.4
Monocrystalline Quartz	30.0	Organic Laminae + Grains		Non-Ferroan Calcite	
Polycrystalline Quartz	2.8	Carbonate-Replaced Grains		Ferroan Calcite	18.0
TOTAL FELDSPAR	7.6	Heavy Minerals		Non-Ferroan Dolomite	
Untwinned Feldspar	5.6	Phosphatic Grains		Ferroan Dolomite	
Plagioclase	2.0	***STRUCTURAL CLAYS***	6.8	Siderite	
Microcline		Clay-Replaced Grains	4.8	Pyrite	Tr
		Glauconite		Zeolite	
TOTAL ROCK FRAGMENTS	25.2	Biotite		Barytes	
Volcanic Rock Fragments	11.2	Muscovite	Tr	Bitumen/Dead Oil	
Metamorphic Rock Fragments	0.4	Chlorite	2.0		
Plutonic Rock Fragments	1.2	Clay Rip-Up Clasts			
Chert	4.8	Others			
Sandstone Rock Fragments	5.2	***DISPERSED MATRIX***	5.6	***VISIBLE POROSITY***	3.6
Shale Fragments	2.4	Undifferentiated	0.4	Intergranular	2.0
Limestone Rock Fragments		Authigenic Kaolinite	2.0	Dissolution	1.6
Dolostone Rock Fragments		Authigenic Pore-Lining	3.2	Intraparticle	
Others		Pseudomatrix	Tr	Fracture	
		Rock Flour			
		LAMINAR CLAYS		***TOTAL***	100.0

PLATE 4.13A

Low magnification view of a lower fine to lower coarse grained, moderately sorted, massive, calcite-cemented litharenite sandstone. Grains are mainly quartz (mostly monocrystalline, MQ; with minor polycrystalline, PQ), volcanic rock fragments (VRF), untwinned (UFspr) and plagioclase (Plag) feldspar, sandstone rock fragments, clay-replaced grains (CRG), chert, shale fragments (ShFr), chlorite mica and other lithic grains. Matrix is almost entirely authigenic, comprising pore-lining/grain-coating chlorite rims and isolated patches of pore-filling kaolinite (K). Slightly ferroan, medium to coarsely crystalline, locally poikilotopic calcite cement is very common (Ca), filling most available porosity. Visible porosity is consequently very poor to poor, confined to isolated dissolution (DP) and intergranular pores (IP).

(28X, Plane-polarised Light)

PLATE 4.13B

High magnification view of the area at the centre of Plate 4.13A above. Grains are mainly monocrystalline quartz (MQ), but also include a glassy volcanic rock fragment (VRFg) and degraded, veined chert (Cht). Calcite cement (Ca) fills most available interstices, and appears to have post-dated quartz overgrowth cement (QO) and authigenic chlorite (aChl).

(130X, Plane-polarised Light)

LONGTOM-2 ST1
CORE PLUG #92
2142.34 m

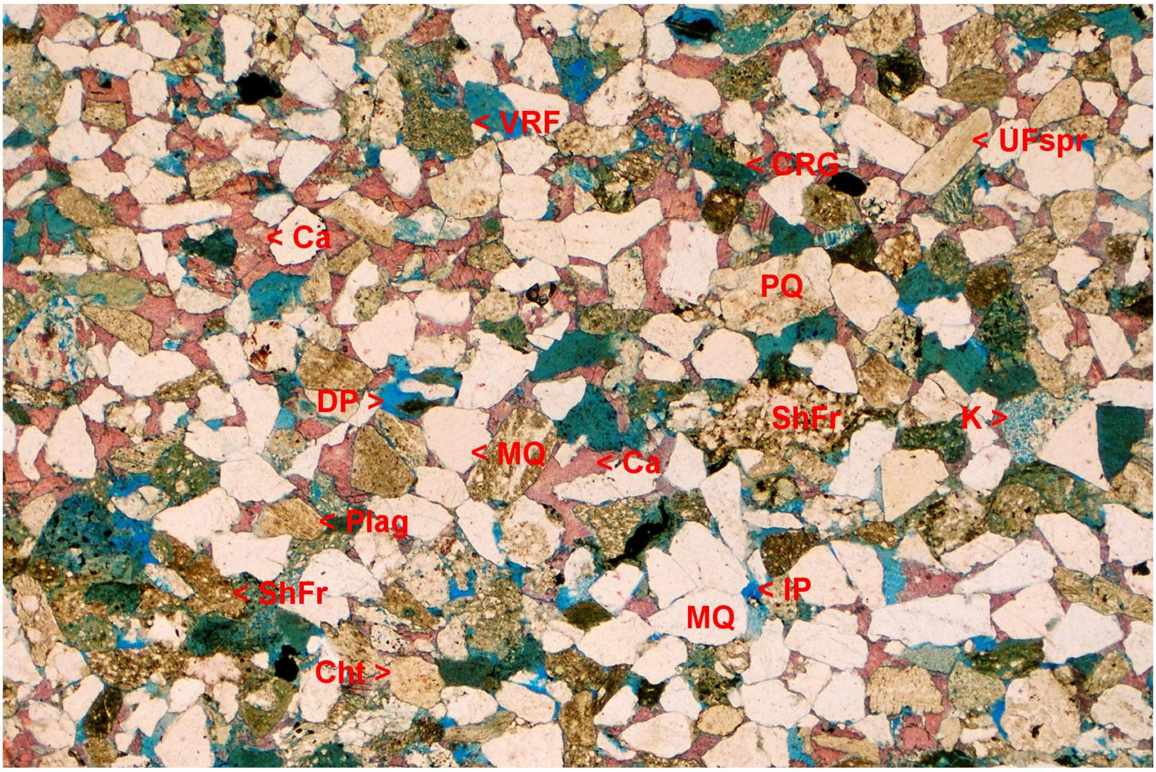


PLATE 4.13A

0 mm 0.5 1

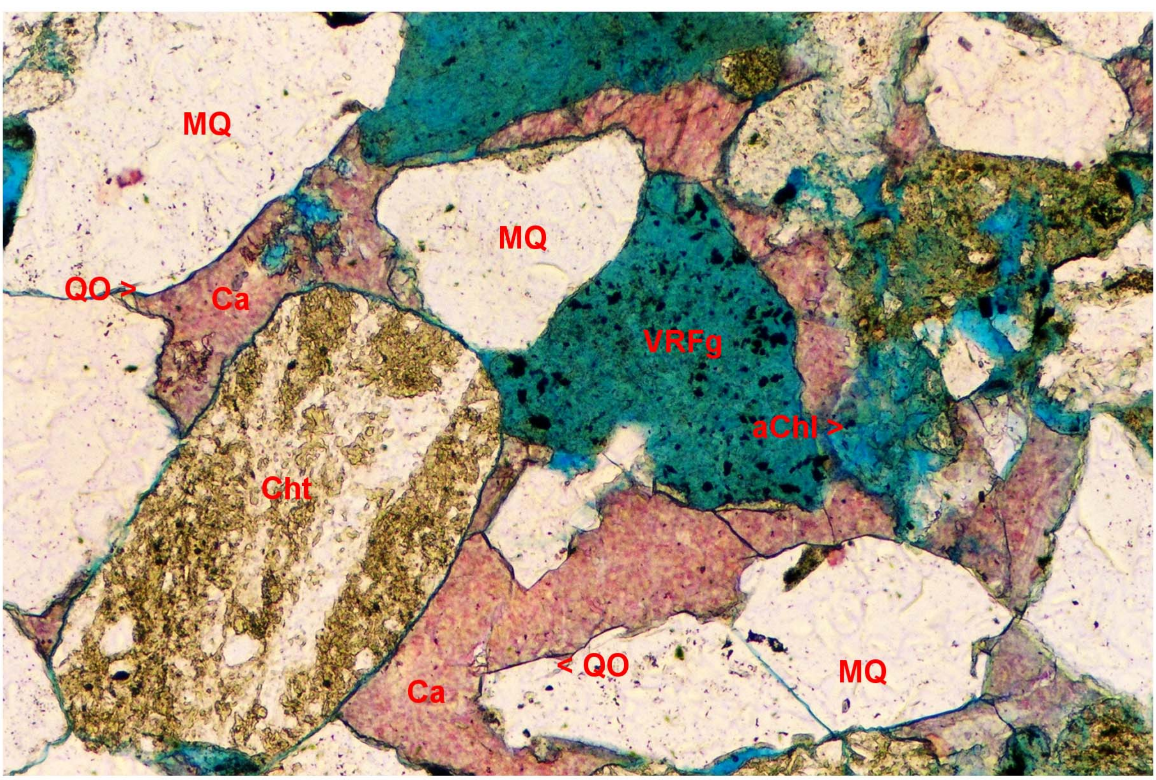


PLATE 4.13B

0 mm 0.125 0.25

LONGTOM-2 ST1
PLUG #94
2144.61 m

LITHOLOGY:	Sandstone. Lower very fine to upper fine, moderately well sorted, faintly laminated, calcite-cemented.		
Consolidation:	Good	Sorting:	Moderately good
Folk Classification:	Feldspathic litharenite	Angularity:	Angular-Subround
Ave Grain Size (mm):	0.15 (lower fine)	Sphericity:	Equant -Subelongate
Max Grain Size (mm):	0.27 (lower medium)	Visible Porosity (%):	4.8
Grain Contacts:	Planar > Point > Concavo-convex	Hel Inj Porosity (%):	13.5
Porosity Types:	Intergranular > Dissolution	Klink Perm (md):	0.011
Porosity Controls:	Authigenic clay matrix, calcite cement, compaction.		

WHOLE ROCK CONSTITUENTS (Vol. %)

GRAINS	62.8	ACCESSORIES	0.8	***CEMENT***	5.6
TOTAL QUARTZ	32.4	Bioclasts		Silica	Tr
Monocrystalline Quartz	30.0	Organic Laminae + Grains	0.8	Non-Ferroan Calcite	
Polycrystalline Quartz	2.4	Carbonate-Replaced Grains		Ferroan Calcite	5.6
TOTAL FELDSPAR	10.4	Heavy Minerals		Non-Ferroan Dolomite	
Untwinned Feldspar	8.0	Phosphatic Grains		Ferroan Dolomite	
Plagioclase	2.4	***STRUCTURAL CLAYS***	10.8	Siderite	
Microcline		Clay-Replaced Grains	7.6	Pyrite	Tr
		Glauconite		Zeolite	
TOTAL ROCK FRAGMENTS	19.2	Biotite		Barytes	
Volcanic Rock Fragments	9.6	Muscovite	0.8	Bitumen/Dead Oil	
Metamorphic Rock Fragments	0.8	Chlorite	2.4		
Plutonic Rock Fragments	0.8	Clay Rip-Up Clasts			
Chert	4.8	Others			
Sandstone Rock Fragments	1.6	***DISPERSED MATRIX***	16.0	***VISIBLE POROSITY***	4.8
Shale Fragments	1.6	Undifferentiated	5.2	Intergranular	3.2
Limestone Rock Fragments		Authigenic Kaolinite	2.4	Dissolution	1.6
Dolostone Rock Fragments		Authigenic Pore-Lining	6.0	Intraparticle	
Others		Pseudomatrix	2.4	Fracture	
		Rock Flour			
		LAMINAR CLAYS		***TOTAL***	100.0

PLATE 4.14A

Low magnification view of a lower very fine to upper fine grained, moderately well sorted, faintly laminated, calcite-cemented feldspathic litharenite sandstone. Grains are mainly monocrystalline quartz (MQ), with common volcanic rock fragments, untwinned feldspar (UFspr), clay-replaced grains, chert (Cht), minor mica (mainly chlorite, DetChl; and biotite, Bi), carbonaceous grains (Carb; note locally well preserved cellular structure), shale fragments (ShFr), sandstone rock fragments and other lithic grains. Matrix comprises common pore-lining authigenic chlorite, undifferentiated dispersed clay, authigenic kaolinite and pseudomatrix from compacted ductile grains. Slightly ferroan, medium crystalline calcite cement is locally common. Visible porosity is poor, mainly comprising intergranular pores (IP) reduced by a combination of compaction, authigenic clays and calcite cement.

(28X, Plane-polarised Light)

PLATE 4.14B

High magnification view of the area at the centre of Plate 4.14A above, showing the restricted nature of the pore network. Intergranular pores (IP) are generally small and poorly interconnected, reduced in size by compaction (note pseudomatrix from compacted ductile grains; Pmtx), pore-lining authigenic chlorite (plChl), authigenic kaolinite (K), and scattered calcite cement crystals (Ca). Grains in this view include monocrystalline quartz (MQ), carbonaceous fragments (Carb), biotite (Bi), untwinned feldspar (UFspr), partly leached feldspar (lFspr), chert (Cht), shale fragments (ShFr), a microlitic volcanic rock fragment (VRFml) and detrital chlorite mica (DetChl).

(130X, Plane-polarised Light)

LONGTOM-2 ST1
CORE PLUG #94
2144.61 m

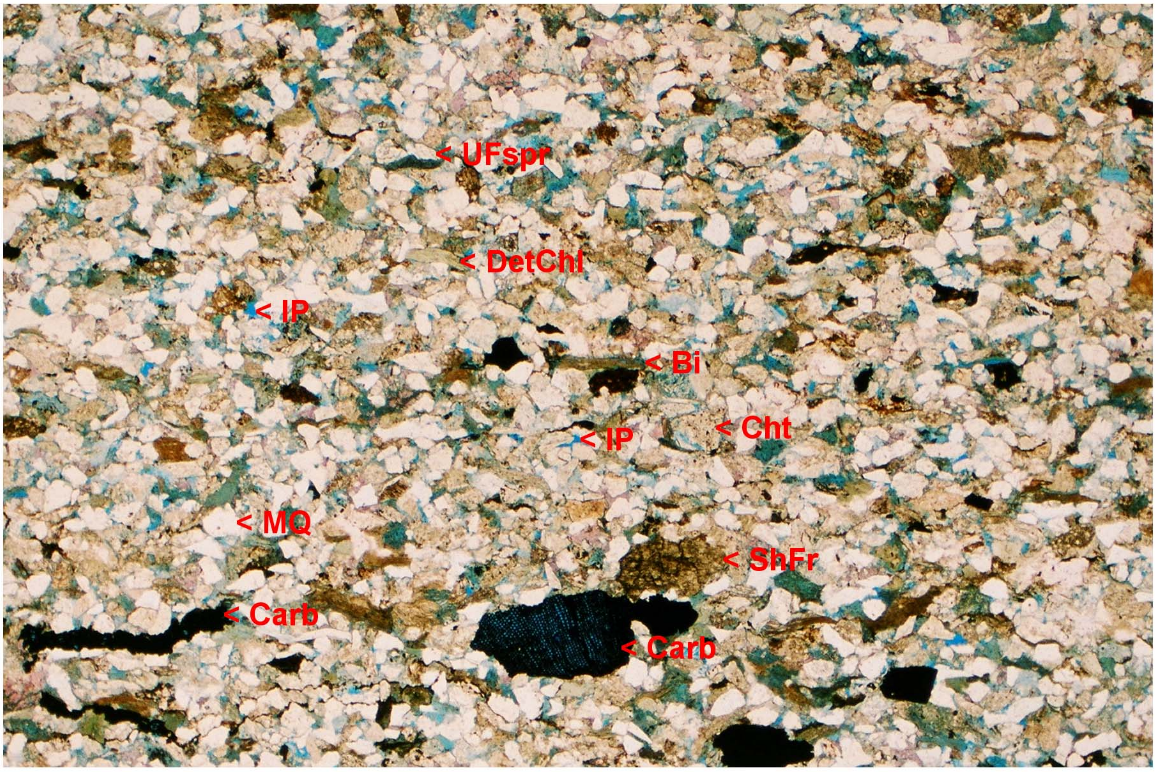


PLATE 4.14A

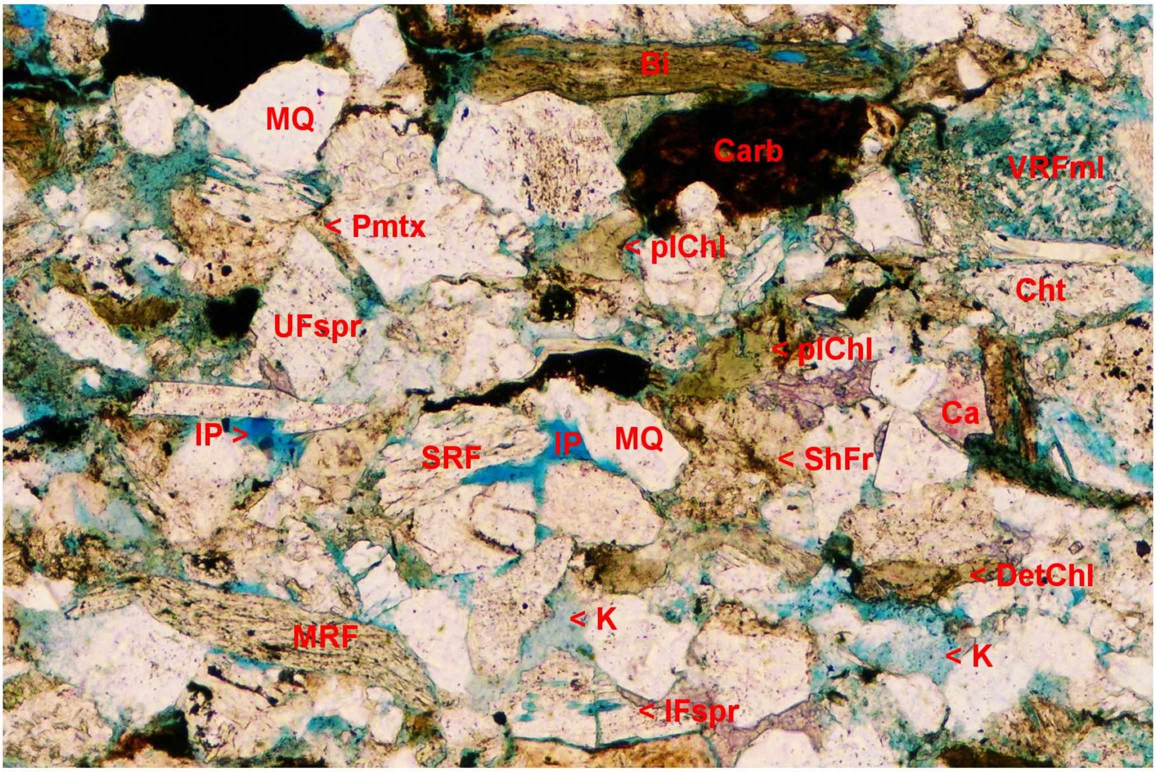


PLATE 4.14B

PLATES 4.15 to 4.24

SCANNING ELECTRON MICROGRAPHS

AND DESCRIPTIONS

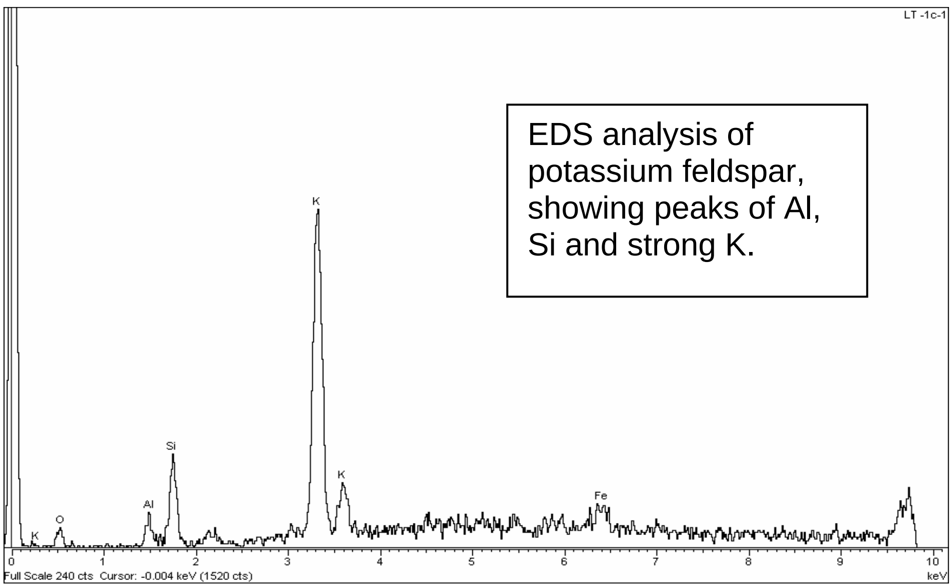
SCANNING ELECTRON MICROSCOPY
2114.72 m
Plug #8

PLATE 4.15A

Moderately low magnification backscatter overview of an upper very fine to fine, moderately sorted, moderately indurated, variably calcite-cemented sandstone. Framework grains are predominantly quartz with accessory feldspars (e.g. F-K), rock fragments and a trace of mica (M). Quartz framework grains are for the most part coated with chlorite (QcCL) and there is minor development of silica overgrowth cement (QO). Pores are intergranular (IP) but some of this pore space is occluded by patchily developed calcite (Ca) cement. The boxed area is shown in more detail in Plate 4.15B below.
Magnification: 200x

PLATE 4.15B

Close-up view of an intergranular pore framed by chlorite-coated quartz grains (QcCL), mica (M) and a broken feldspar (F-K). This feldspar grain is potassium dominated according to EDS analysis in the boxed area indicated (see spectrum below). The chlorite is, for the most part, a flattened grain-coat between framework grains. However, within open pore space, recrystallised chlorite (CL) shows uninhibited growth and takes on typical rosette-like form as illustrated by the higher magnification inset. Minor quartz cement (QO) also is present in this void.
Magnification: 800x



LONGTOM-2 ST1
Core Plug # 8
2114.72 m

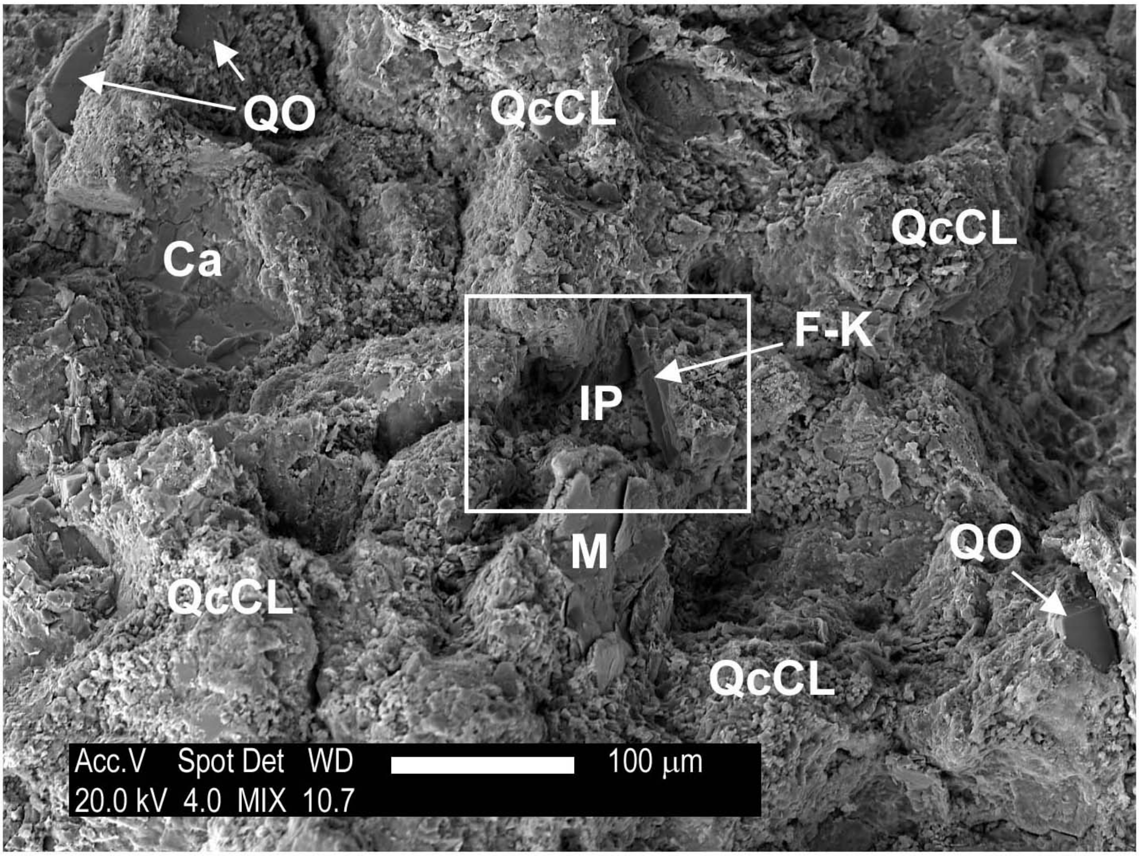


PLATE 4.15A

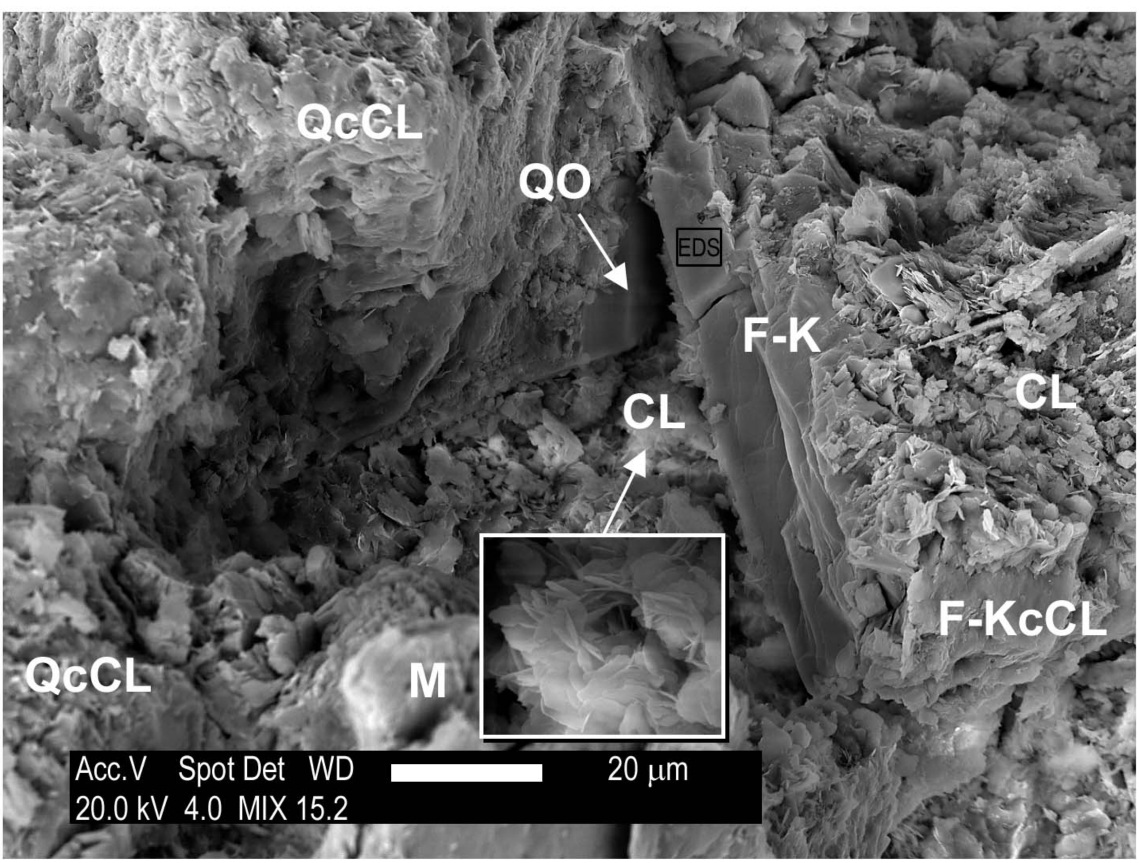


PLATE 4.15B

SCANNING ELECTRON MICROSCOPY
2118.35 m
Plug #18

PLATE 4.16A

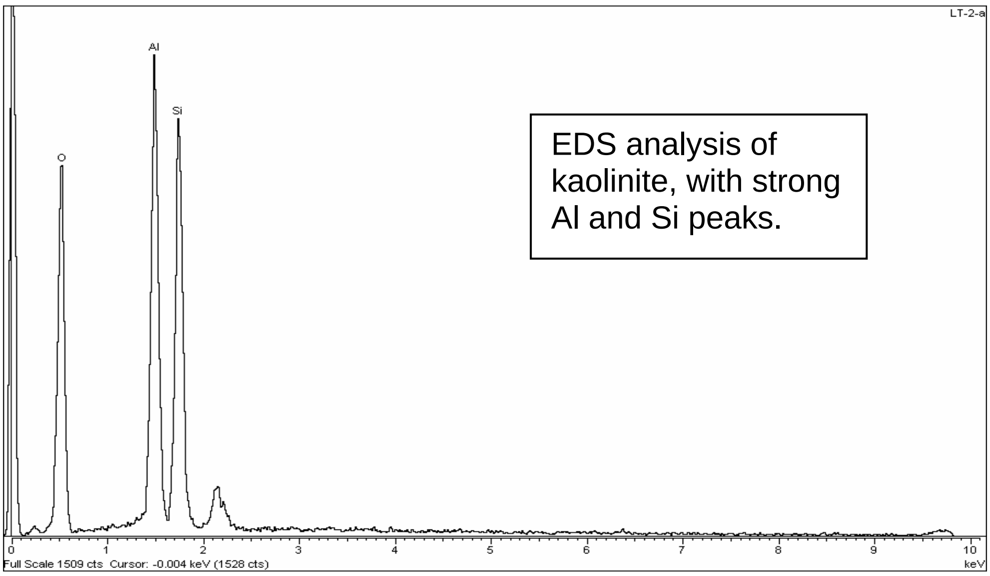
Low magnification backscatter overview of a lower medium to lower coarse, predominantly medium, moderately sorted, poorly indurated, massive sandstone. The mainly quartz framework grains (e.g. Q) show incipient development of quartz overgrowth cement (QO). The fabric shows significant preservation of intergranular pores (IP), but in places pore throats are reduced in size by this authigenic silica (rPT). Some pores are partially occluded by the presence of kaolinite (K), a feature that is shown in more detail in the boxed area of Plate 4.16B below. Several feldspar grains are noted (e.g. F-K). According to EDS analysis, both grains indicated are potassium dominated. The feldspar in the boxed area is partially dissolved and is shown under higher magnification in Plate 2C. Ubiquitous chlorite grain-coats are not visible in this view due to the low magnification of the image. However, grain coats are highlighted in the following close-up images.

Magnification: 100x

PLATE 4.16B

This high magnification view shows detail of a mass of kaolinite (K) within an intergranular pore. The EDS trace, typical of kaolinite (see spectrum below), was collected from the boxed area indicated. A quartz grain bounding the pore is partially coated with recrystallised chlorite (QcCL). EDS analysis on this material reveals Si, Al, Mg and Fe elemental composition, typical of chlorite.

Magnification: 1600x



LONGTOM-2 ST1
Core Plug # 18
2118.35 m

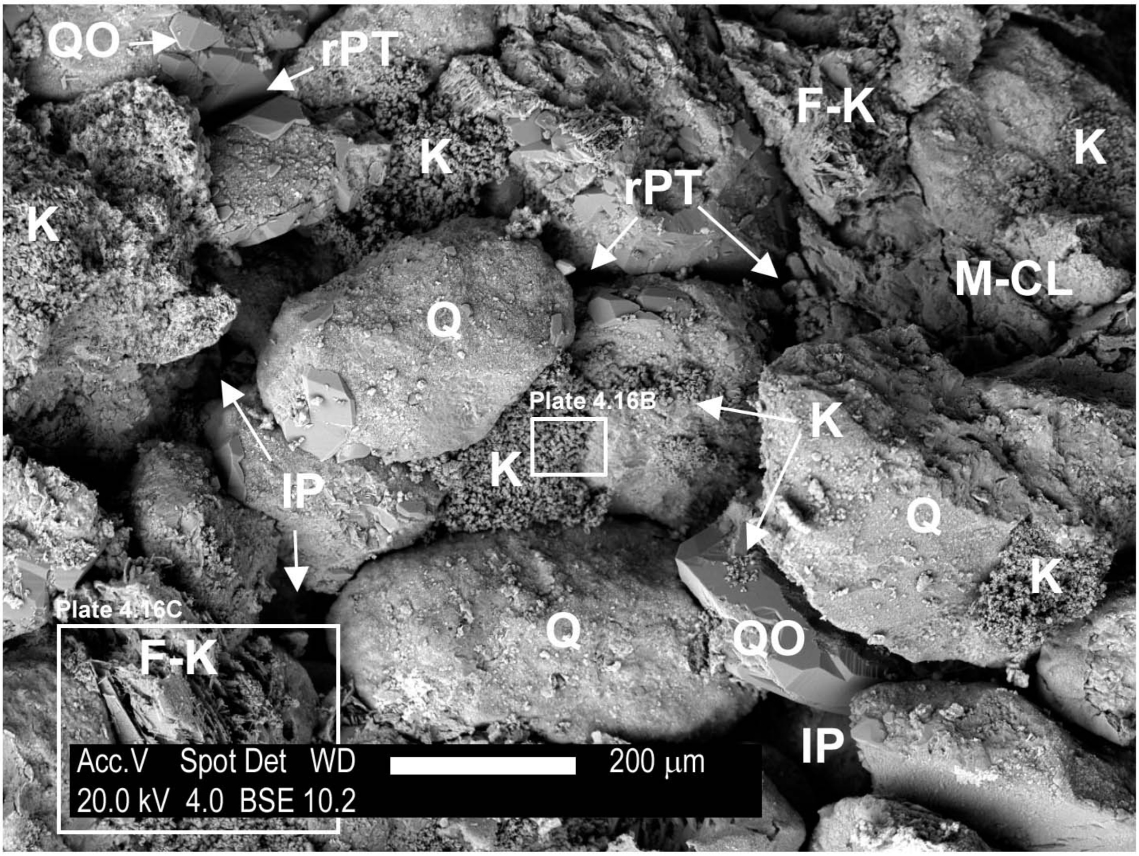


PLATE 4.16A

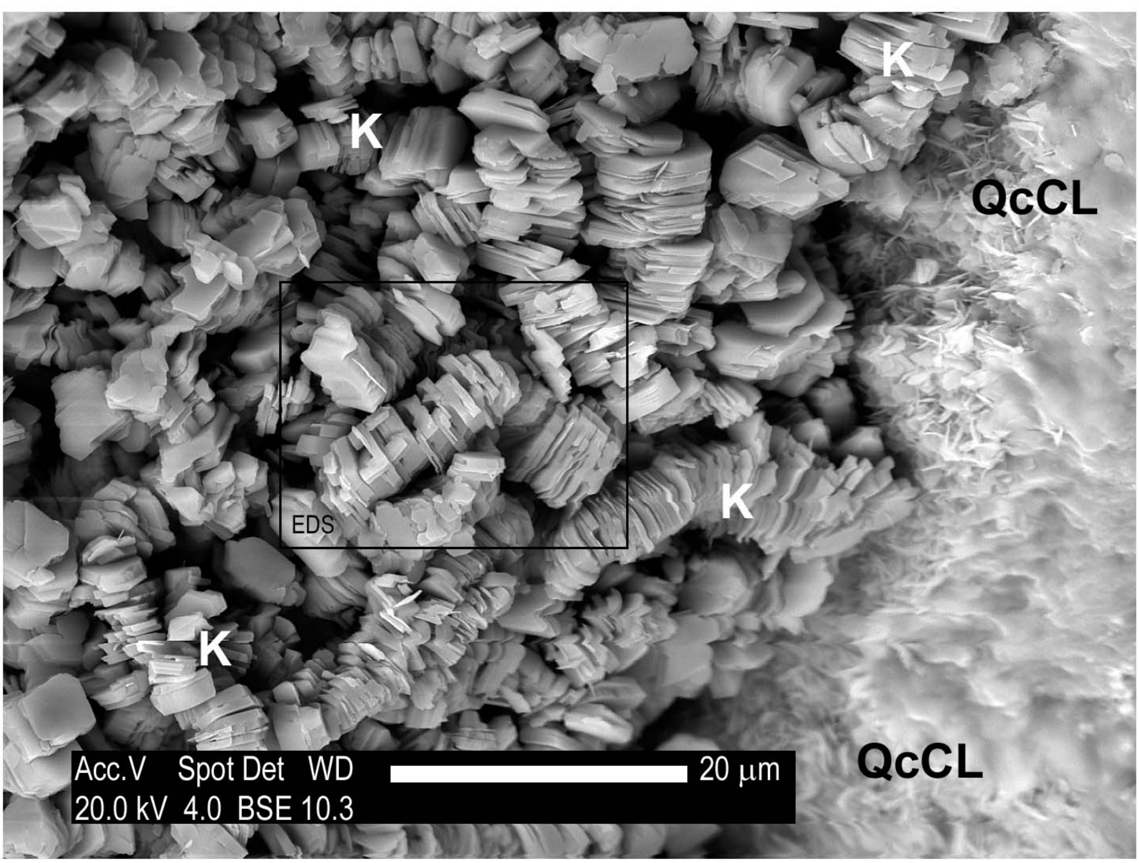


PLATE 4.16B

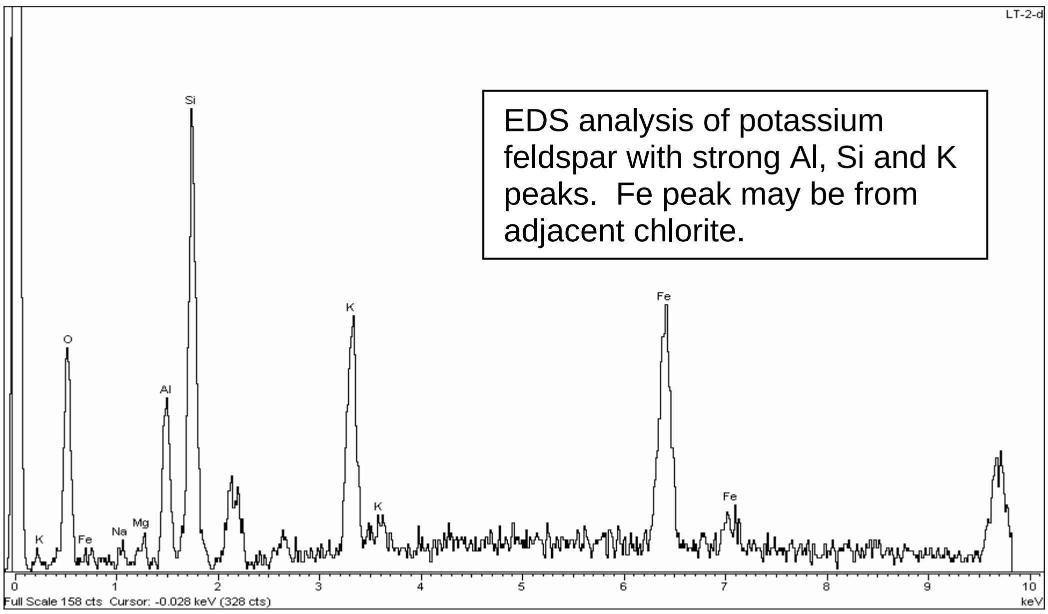
SCANNING ELECTRON MICROSCOPY
2118.35 m (Continued)
Plug #18

PLATE 4.16C

Close-up view showing a feldspar framework grain (F-K). The grain is partially dissolved and displays a relict fabric. The trace from EDS analysis of the boxed area indicated shows the feldspar to be potassium dominated (see spectrum below). In places, the grain retains a coating of chlorite (FcCL) – see also Plate 4.16D below. Other framework grains in the field are quartz (Q) and these too show authigenic chlorite grain-coats (Q-cCL). A patch of silica overgrowth cement is also indicated (QO). Also present are several patches of kaolinite (K).
Magnification: 400x

PLATE 4.16D

High magnification image showing well crystalline chlorite (FcCL) partially coating the surface of the relict feldspar grain (F-K) of Plate 4.16C above. Note the high surface area associated with this authigenic chlorite.
Magnification: 5000x



LONGTOM-2 ST1
Core Plug # 18
2118.35 m

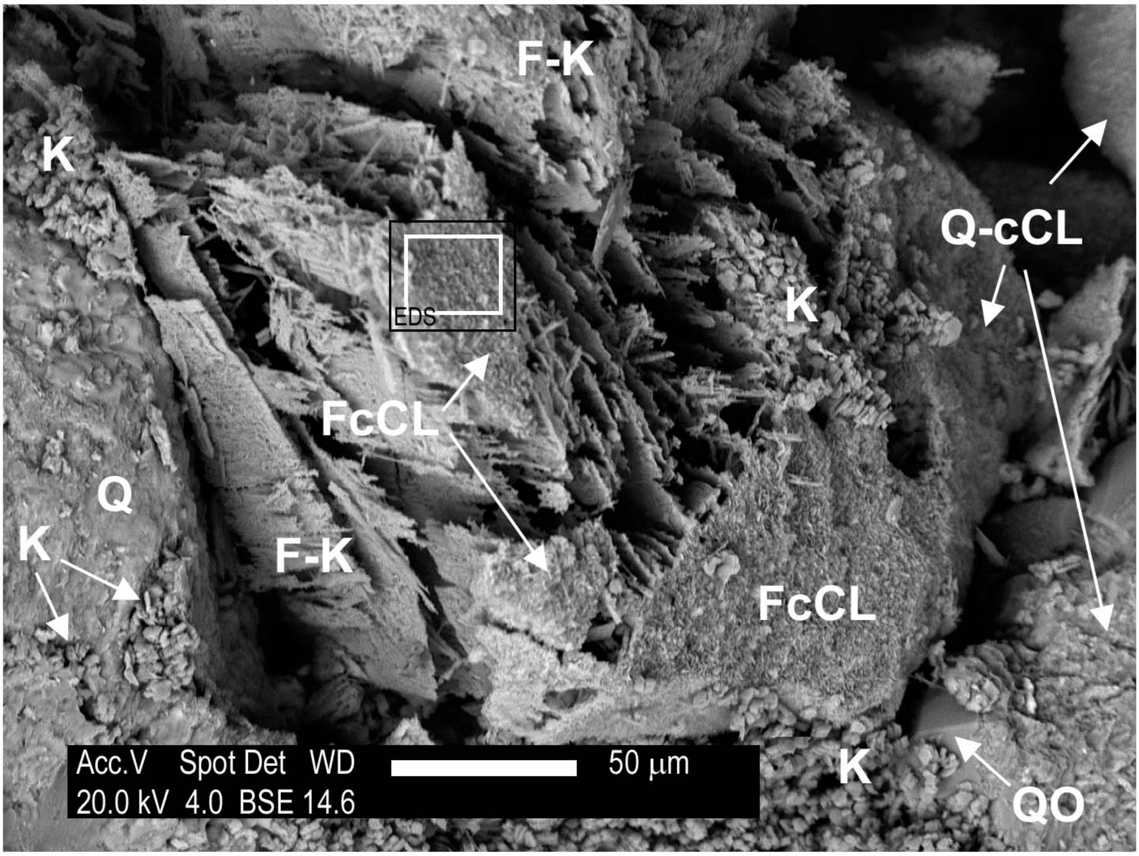


PLATE 4.16C

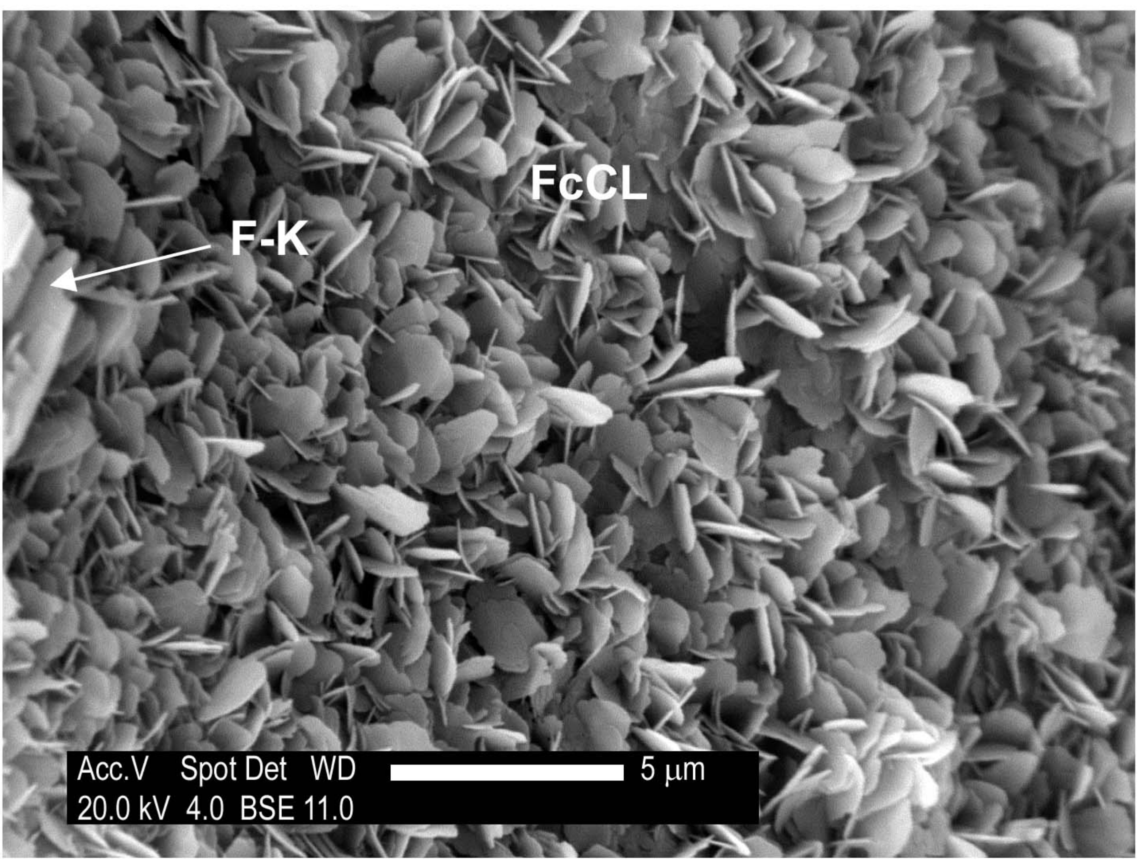


PLATE 4.16D

SCANNING ELECTRON MICROSCOPY
2119.82 m
Plug #23

PLATE 4.17A

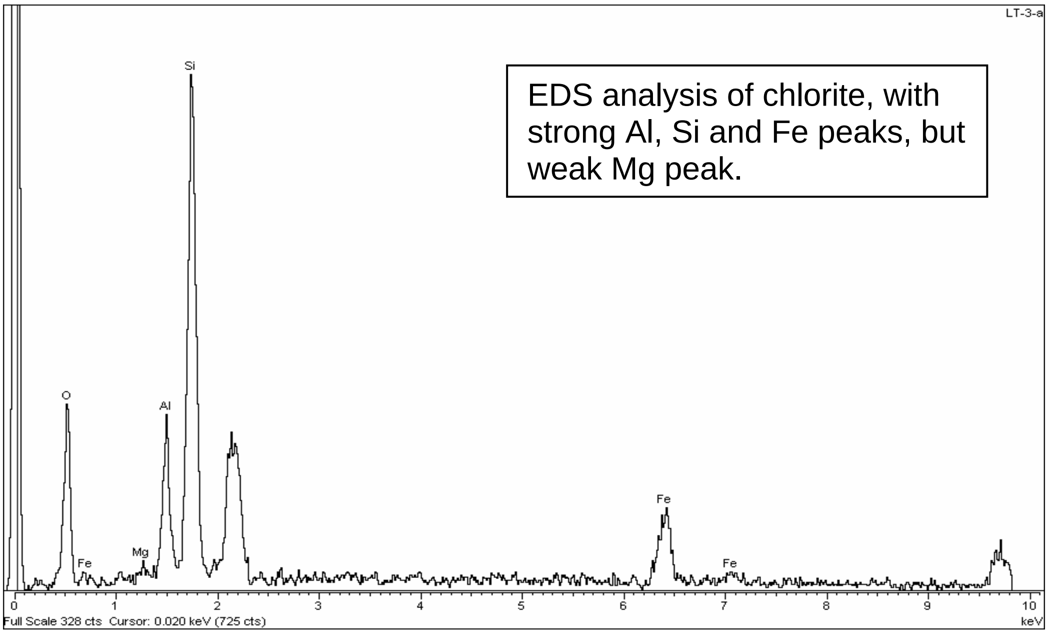
Low magnification backscatter overview of a lower medium to lower coarse, predominantly medium, moderately sorted, poorly indurated massive sandstone. Framework grains are mainly chlorite-coated quartz (e.g. QcCL), with rare feldspar and undifferentiated micaceous clay grains (M-CL). Quartz overgrowth cement (QO) is developed in places and kaolinite (K) fills some pores. Pores are predominantly intergranular, although some fracture-like porosity has been created around grains in this very poorly consolidated sample as a result of breakage during sampling and handling. The boxed area is detailed in Plate 4.17B below.

Magnification: 100x

PLATE 4.17B

Close-up view of a quartz framework grain (Q) featuring grain-coating recrystallised chlorite (QcCL). The trace generated from EDS analysis of the boxed area is typical of chlorite (see spectrum below). The other clay phase present is authigenic kaolinite (K). A patch of quartz overgrowth cement (QO) is prominent on the quartz grain. Note that in places quartz overgrowths have engulfed both kaolinite (QOeK) and chlorite (QOeCL), indicating later quartz cementation.

Magnification: 1600x



LONGTOM-2 ST1
Core Plug # 23
2119.82 m

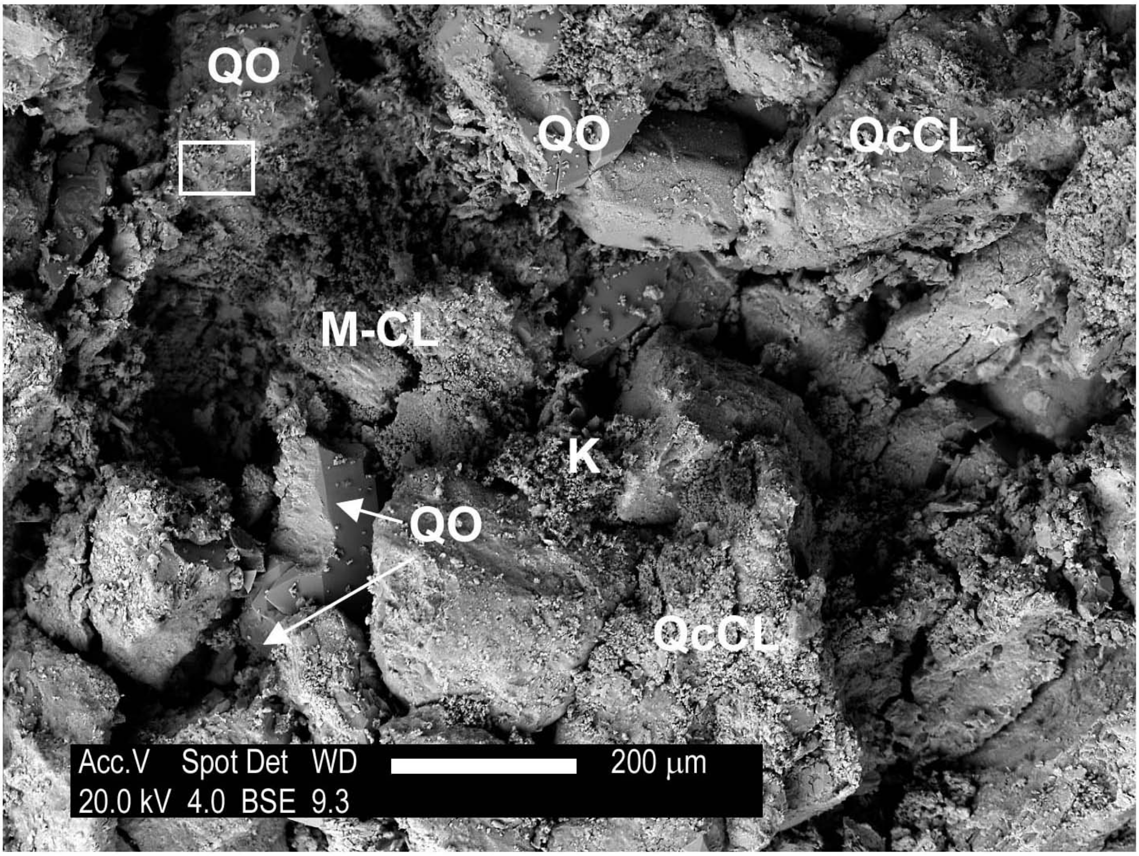


PLATE 4.17A

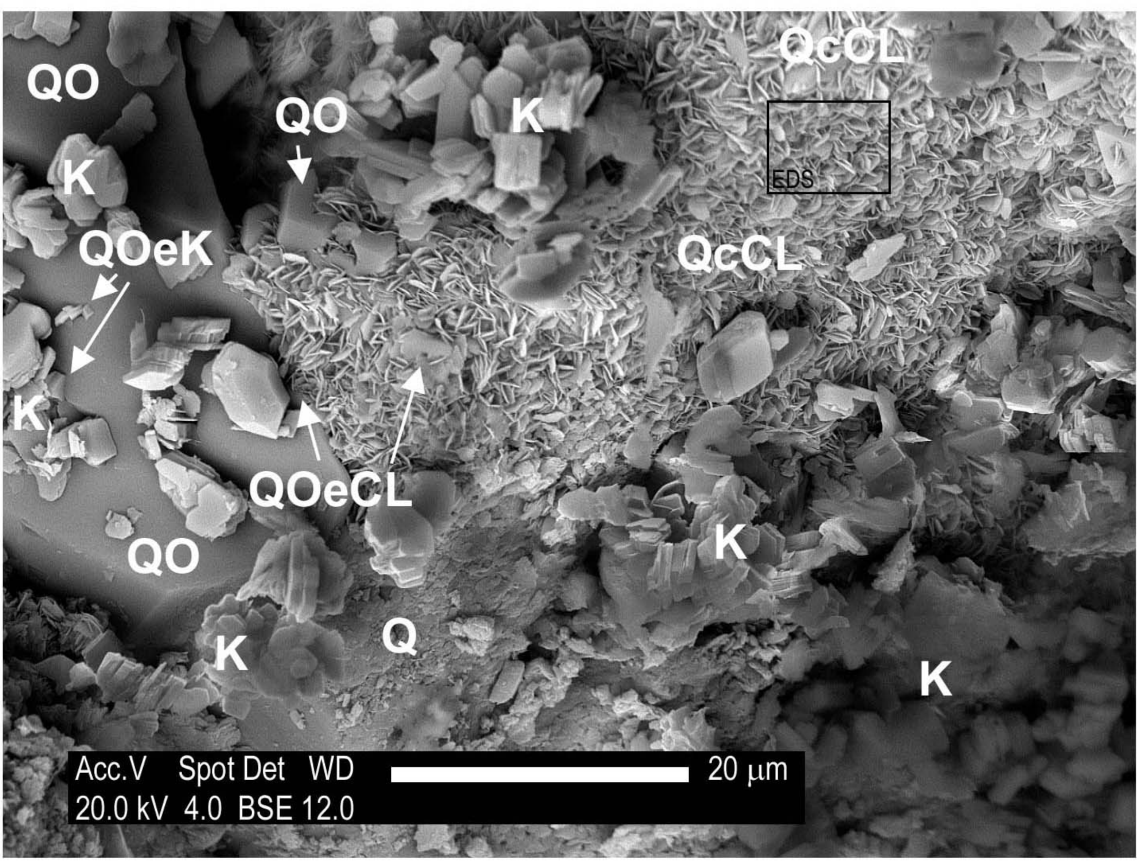


PLATE 4.17B

SCANNING ELECTRON MICROSCOPY
2121.65 m
Plug #29

PLATE 4.18A

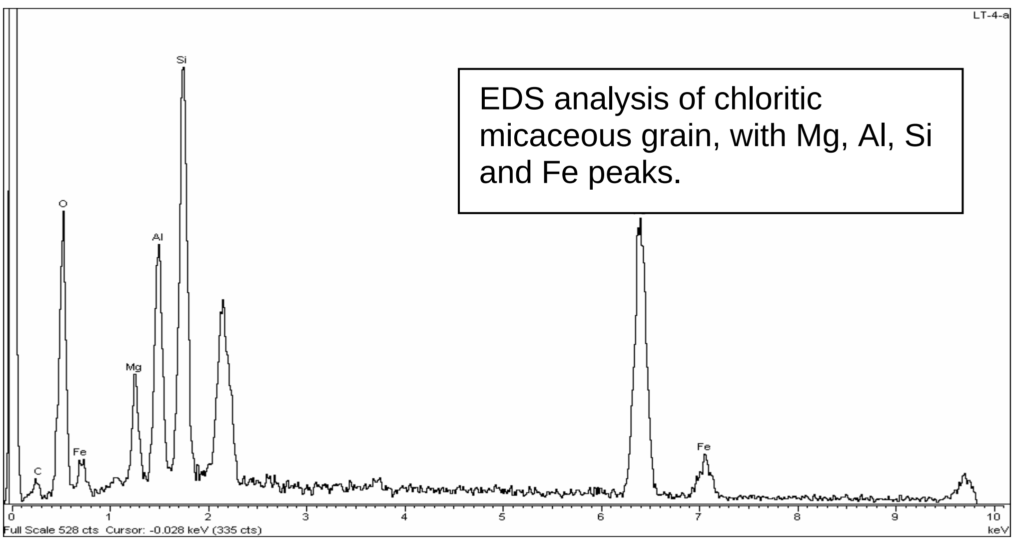
Low magnification backscatter overview of a fine, moderately sorted, poorly indurated massive sandstone. Framework grains are predominantly quartz with accessory feldspars, and traces of micaceous rock fragments and argillaceous grains. In places, quartz overgrowth cement is apparent (e.g. QO) and pore throats (PT) may be somewhat restricted by the presence of this phase (e.g. rPT). Pore space is intergranular and in places contains significant masses of authigenic kaolinite (K). Also present is pore-lining/grain-coating chlorite, which occurs as slight speckling on framework grains in this low magnification view. Chlorite is more apparent at high magnification in Plate 4.18B below. The presence of a few shattered quartz grains (sQ) indicates some minor sampling damage.

Magnification: 100x

PLATE 4.18B

This close-up view shows a well preserved intergranular pore (PT). The surrounding quartz grains (Q) exhibit small quartz overgrowth cements (QO), but for the most part they are coated with chloritic clay (QcCL). Note the absence of chlorite clay on the quartz overgrowths, implying earlier chlorite precipitation. The inset shows well crystallised chlorite (CL) at higher magnification. EDS analysis of the boxed area reveals micaceous grains (M-CL) have a chloritic signature (see below). Authigenic kaolinite (K) is mostly loose, although closer examination reveals it has been locally engulfed by later-formed authigenic silica.

Magnification: 400x



LONGTOM-2 ST1
Core Plug # 29
2121.65 m

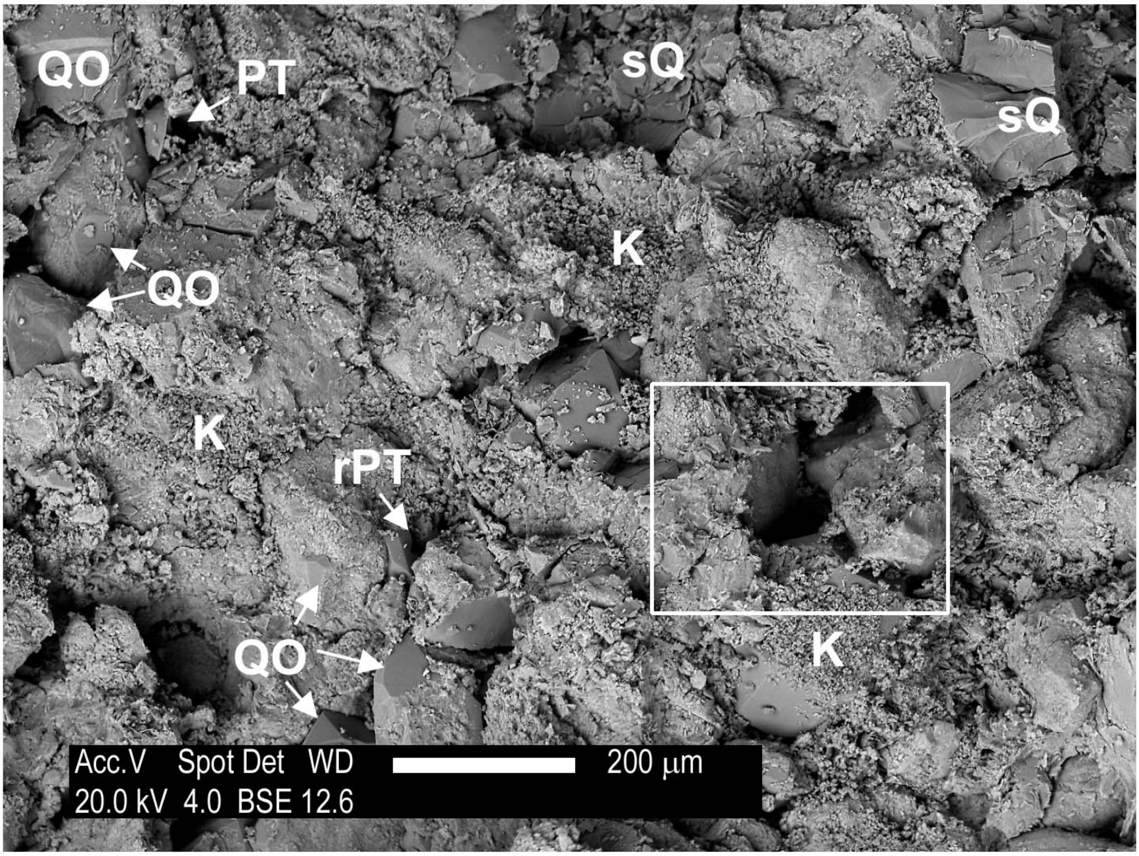


PLATE 4.18A

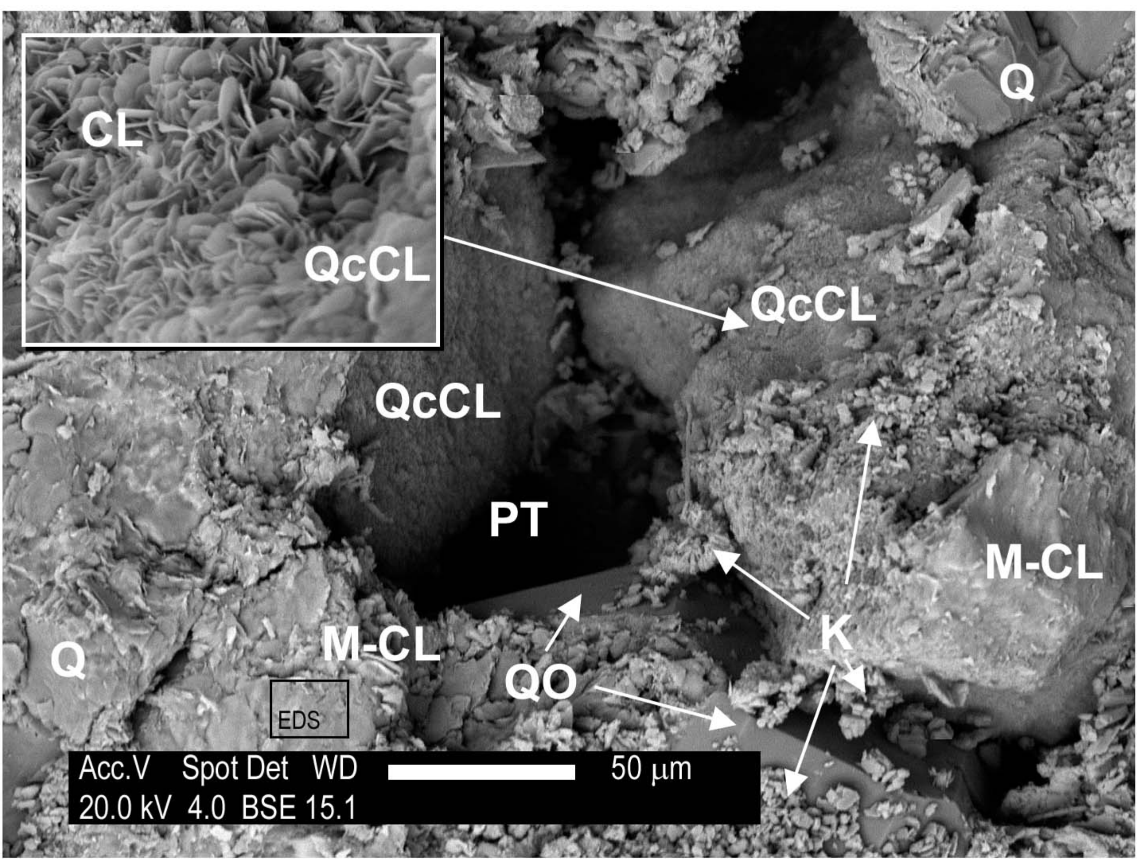


PLATE 4.18B

SCANNING ELECTRON MICROSCOPY
2122.74 m
Plug #33

PLATE 4.19A

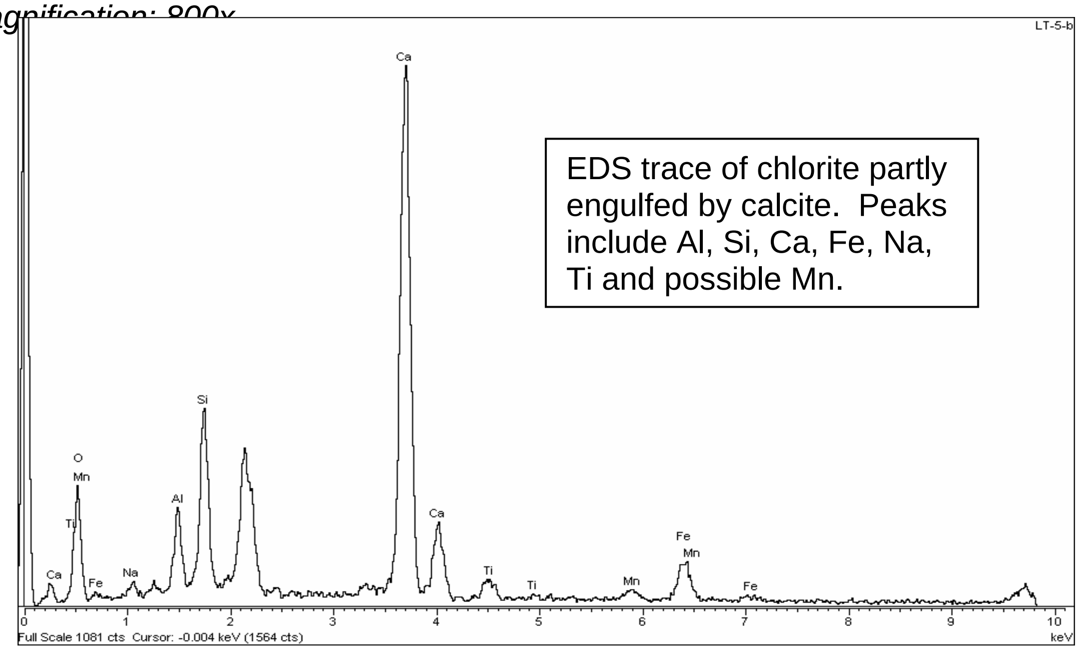
Moderately low magnification backscatter overview of a fine to medium, moderately sorted, moderately well indurated, massive calcite-cemented sandstone. Framework grains are predominantly quartz with accessory feldspars (e.g. F-K) and a trace of undifferentiated micaceous-chloritic grains (e.g. M-CL). Calcite cement (Ca) is abundant and, together with minor quartz cement (QO), occludes pore space. Slight speckling in the field is attributable to the presence of authigenic clays - mainly ubiquitous chlorite and localised kaolinite. Authigenic chlorite is often observed coating quartz grains (QcCL). The boxed area illustrates these clays in more detail in Plate 4.19B below.

Magnification: 200x

PLATE 4.19B

This high magnification view features massive calcite (Ca) almost completely filling pore space. Framework grains include potassium feldspar (F-K) and quartz. Quartz grains are extensively chlorite-coated (e.g. QcCL) and are partly covered by authigenic silica (QO). Undifferentiated detrital chloritic micas (M-CL) show similar EDS response to the pore-lining and grain-coating chlorite. Authigenic chlorite locally exhibits rosette-like forms. Calcite locally engulfs the chlorite (CacCL) and this is the cause of the mixed chlorite-calcite EDS trace from the area indicated at lower right (see spectrum below).

Magnification: 800x



EDS trace of chlorite partly engulfed by calcite. Peaks include Al, Si, Ca, Fe, Na, Ti and possible Mn.

LONGTOM-2 ST1
Core Plug # 33
2122.74 m

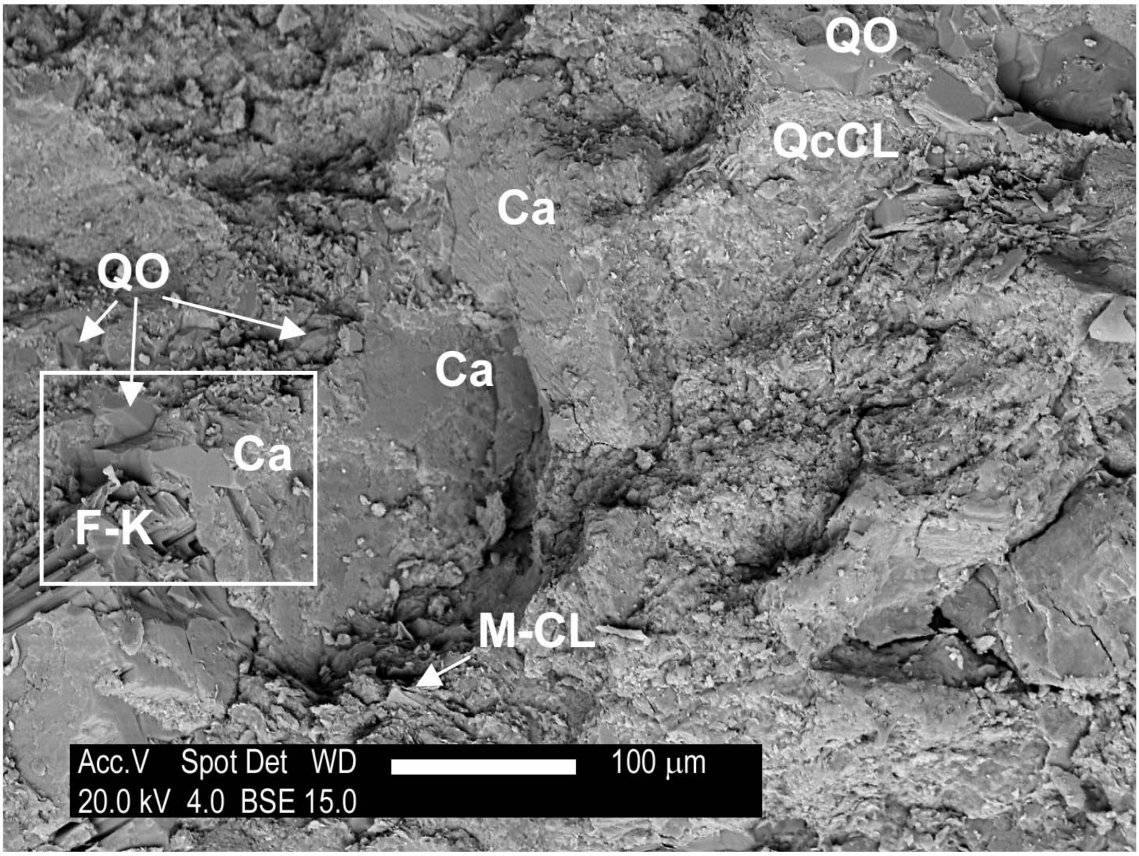


PLATE 4.19A

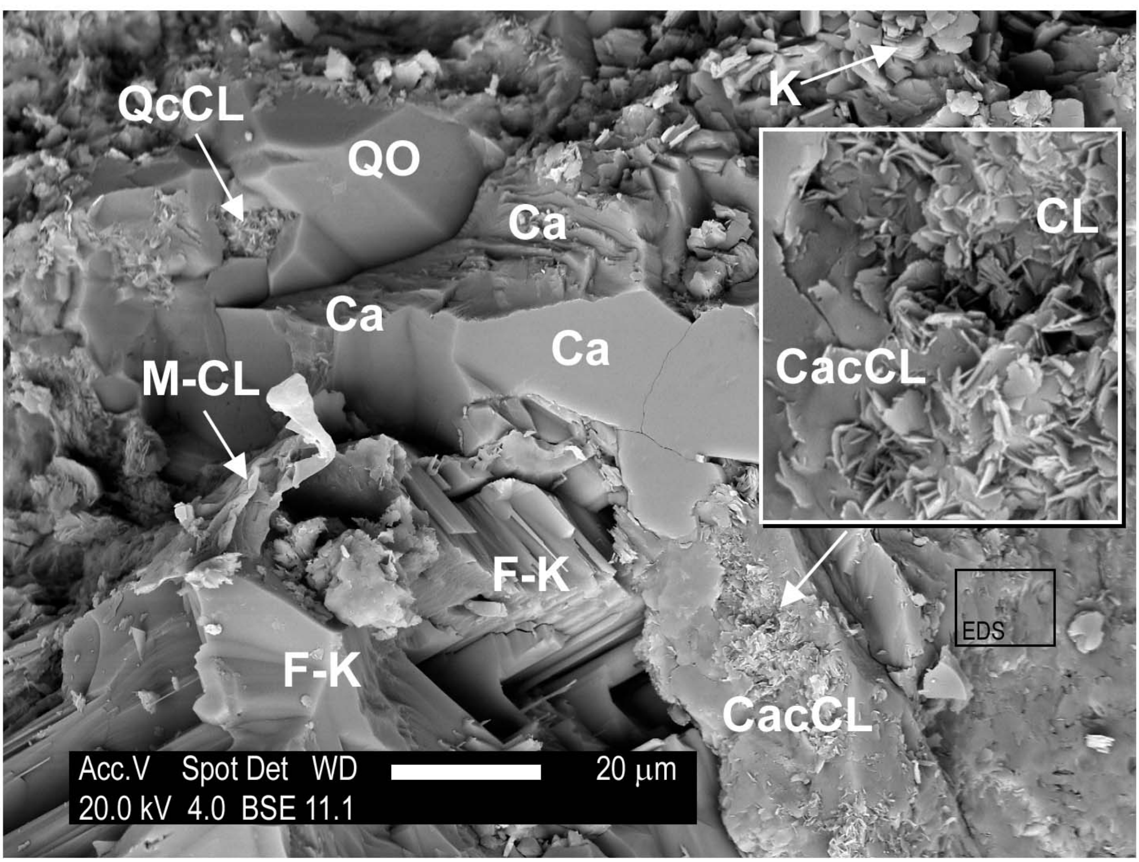


PLATE 4.19B

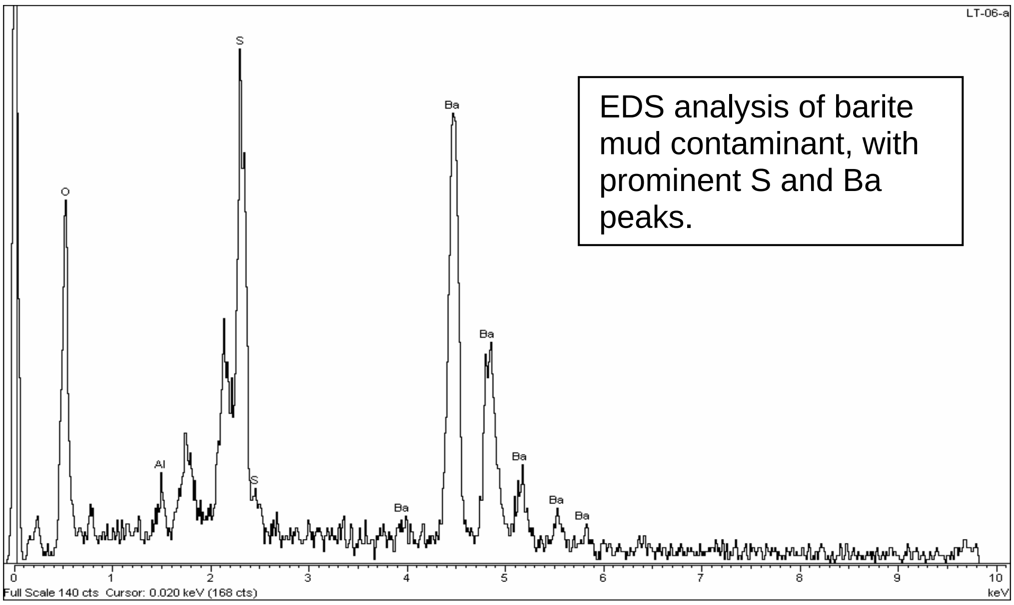
SCANNING ELECTRON MICROSCOPY
2127.48 m
Plug #43

PLATE 4.20A

Moderately low magnification backscatter overview of a fine, moderately sorted, poorly indurated sandstone. Framework grains are predominantly quartz (e.g. Q) with accessory feldspars and a trace of undifferentiated chloritic mica (e.g. M-CL). The sample appears to have suffered some damage due to mud filtrate invasion, and is contaminated by barite-bearing mud solid debris (Ba). However, some intergranular pores (IP) are preserved. The boxed area at upper left exhibits remnants of pore-filling kaolinite (K), which are shown in more detail in Plate 4.20B below.
Magnification: 200x

PLATE 4.20B

This close-up view shows remnants of well crystalline, pore-filling authigenic kaolinite (K), which is loosely attached to underlying quartz (Q) and chloritic mica (M-CL) grains. The sample has been contaminated by barite (Ba) and barite-bearing mud solid debris (Ba-MS) as a result of mud filtrate invasion (EDS obtained from the boxed area indicates mainly Barium and Sulfur; see spectrum below). Barite is usually easy to identify in backscatter images due to its characteristic bright appearance.
Magnification 1600x



LONGTOM-2 ST1
Core Plug # 43
2127.48 m

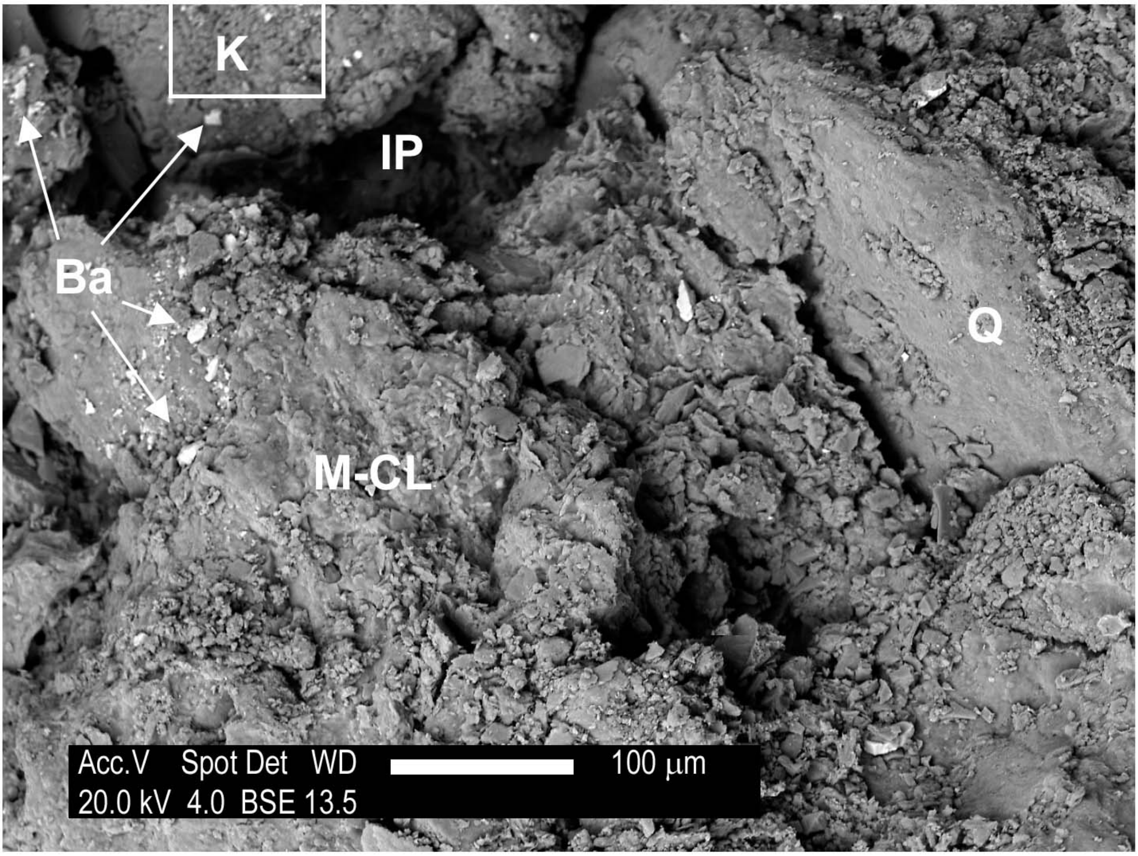


PLATE 4.20A

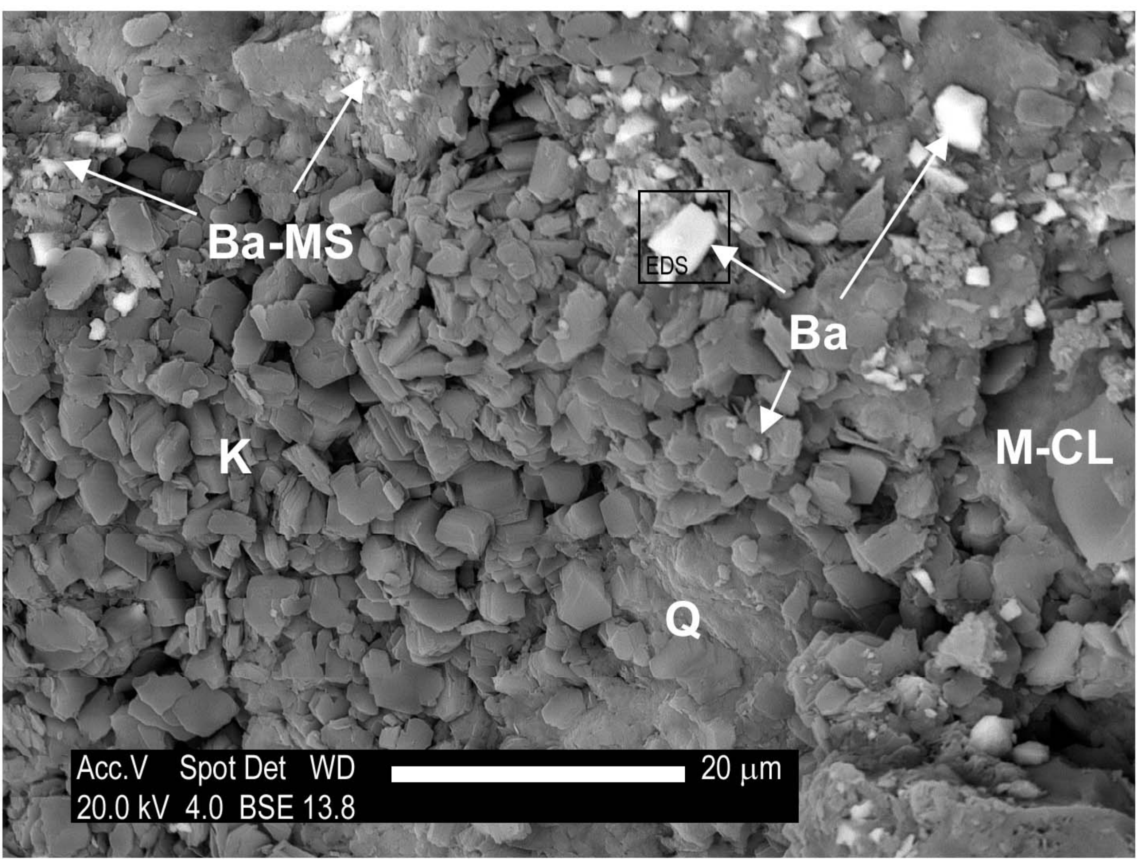


PLATE 4.20B

SCANNING ELECTRON MICROSCOPY
2129.86 m
Plug #51

PLATE 4.21A

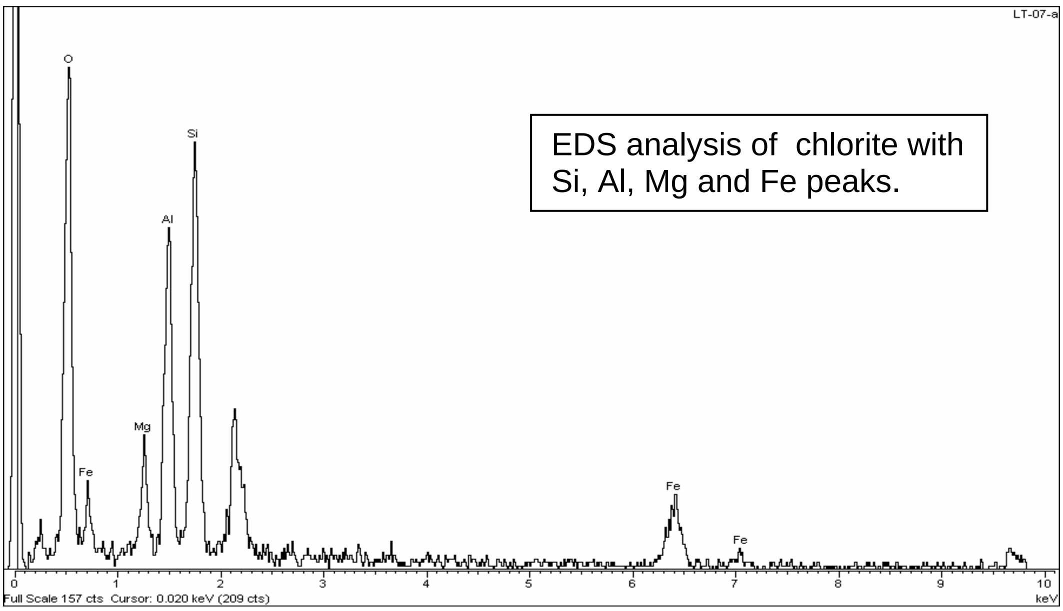
This high magnification view shows well crystalline chlorite (CL), some of which coats a quartz framework grain (QcCL). Also visible are authigenic kaolinite (K) and quartz overgrowth cement (QO), which probably formed within open pore space. This sample is very poorly indurated and has become partly disaggregated. Grains are predominantly quartz with accessory feldspar, rock fragments and mica. The EDS trace from the boxed area displays typical Si, Al, Mg and Fe elemental composition of chlorite (see spectrum below).

Magnification: 800x

PLATE 4.21B

Higher magnification view from another quartz grain surface. Some of the grain-coating chlorite (QcCL) has been flattened by compaction at points of grain contact, whereas chlorite that lines open pore space is well crystalline and locally exhibits incipient rosette-like form (CL). Authigenic microquartz crystals (MQ) are occasionally observed between chlorite crystals. Note how some of the chlorite has been partly engulfed by this microquartz, implying quartz cementation occurred after chlorite authigenesis.

Magnification: 4000x



LONGTOM-2 ST1
Core Plug # 51
2129.86 m

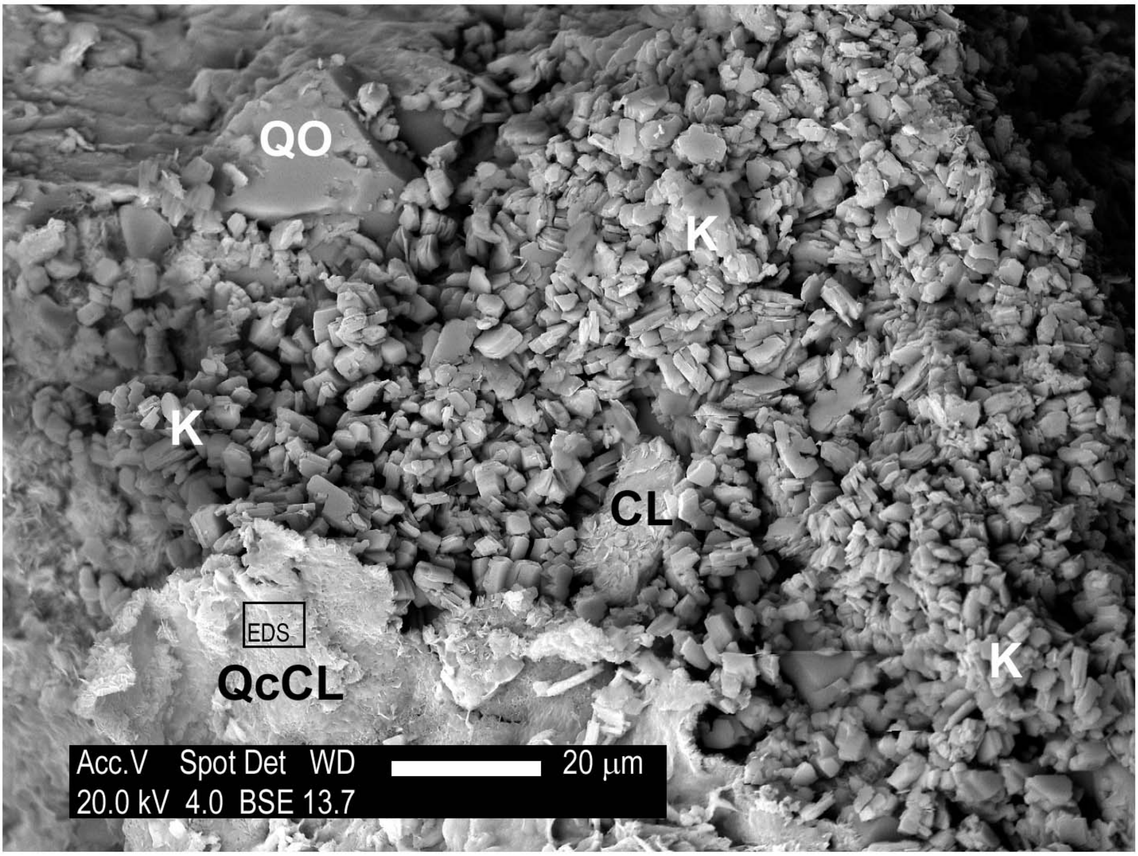


PLATE 4.21A

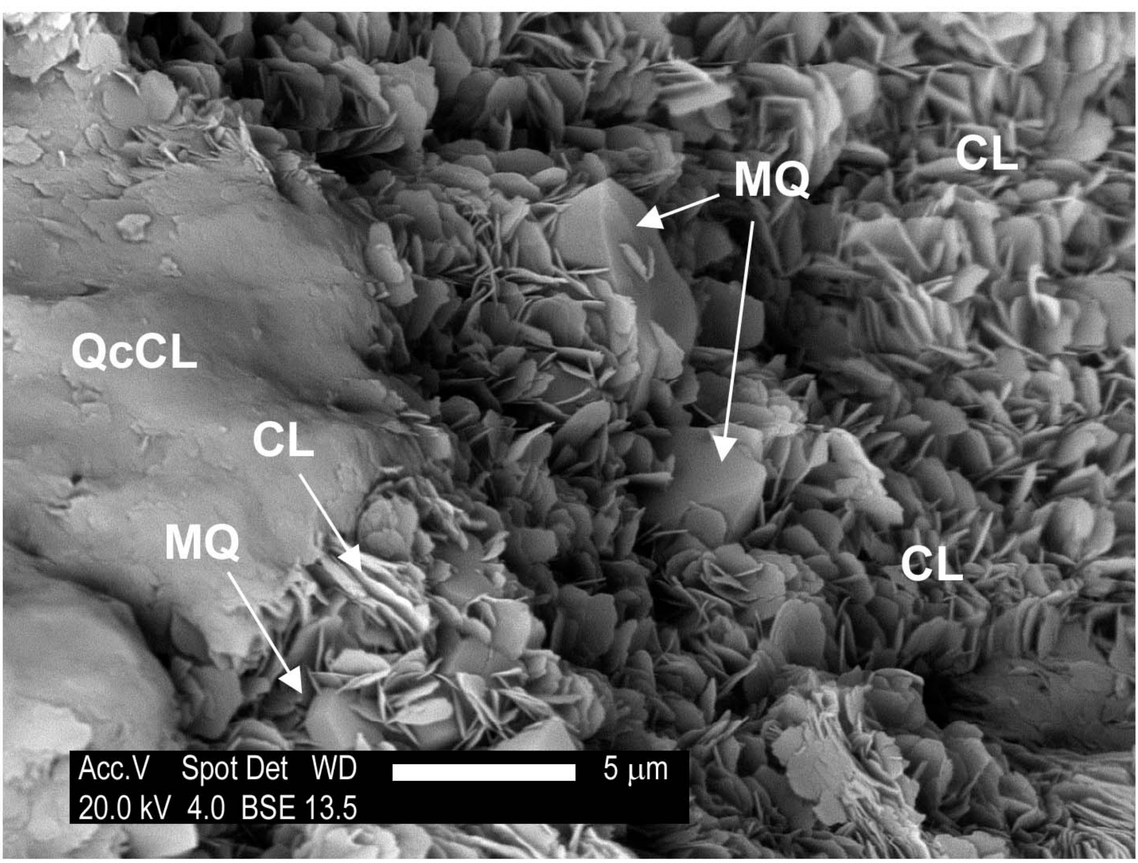


PLATE 4.21B

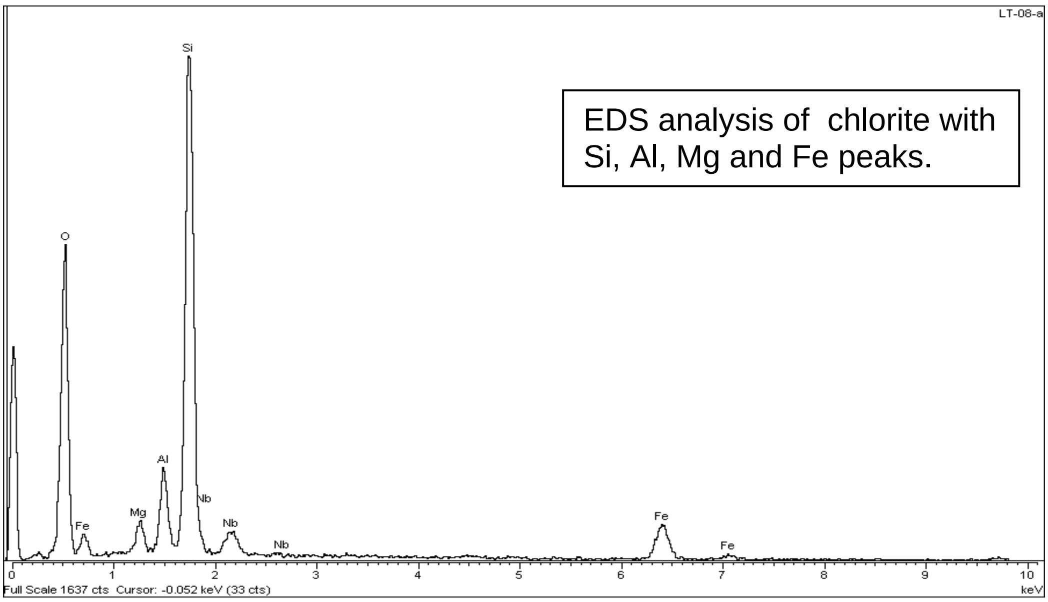
SCANNING ELECTRON MICROSCOPY
2133.55 m
Plug #53

PLATE 4.22A

Moderately low magnification backscatter overview of an upper fine to lower medium, moderately sorted, poorly indurated sandstone. Framework grains are predominantly quartz with accessory feldspars, rock fragments and traces of mica. Quartz grains show minor development of silica cement (QO) but are more commonly coated with chlorite (QcCL) – see also Plate 4.22B below for a higher magnification view of the boxed area. Intergranular pores are generally well preserved, although some pores have been restricted by patches of authigenic kaolinite (K). Quartz overgrowths partially occlude some pore throats (e.g. PT), although their effect on permeability reduction is probably minor. Contamination from mud filtrate invasion has partly disturbed the sample fabric (bright particles are barite-bearing mud solids).
Magnification: 200x

PLATE 4.22B

High magnification view showing the well crystalline, grain-coating and pore-lining morphology of chlorite (CL) on top of a quartz grain. The EDS trace from the boxed area indicated shows typical Si, Al, Mg and Fe elemental composition of chlorite (see below). A loose kaolinite crystal (K) lies on top of the chlorite.
Magnification: 4000x



LONGTOM-2 ST1
Core Plug # 53
2133.55 m

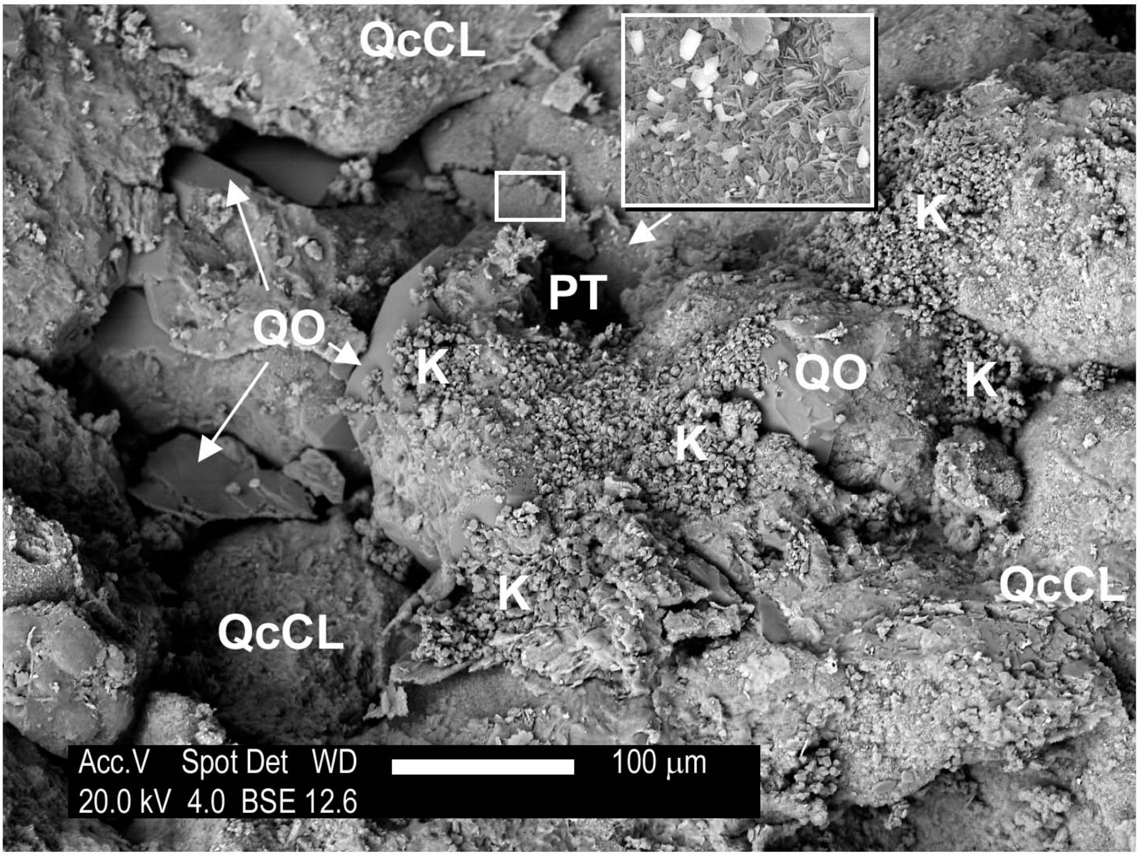


PLATE 4.22A

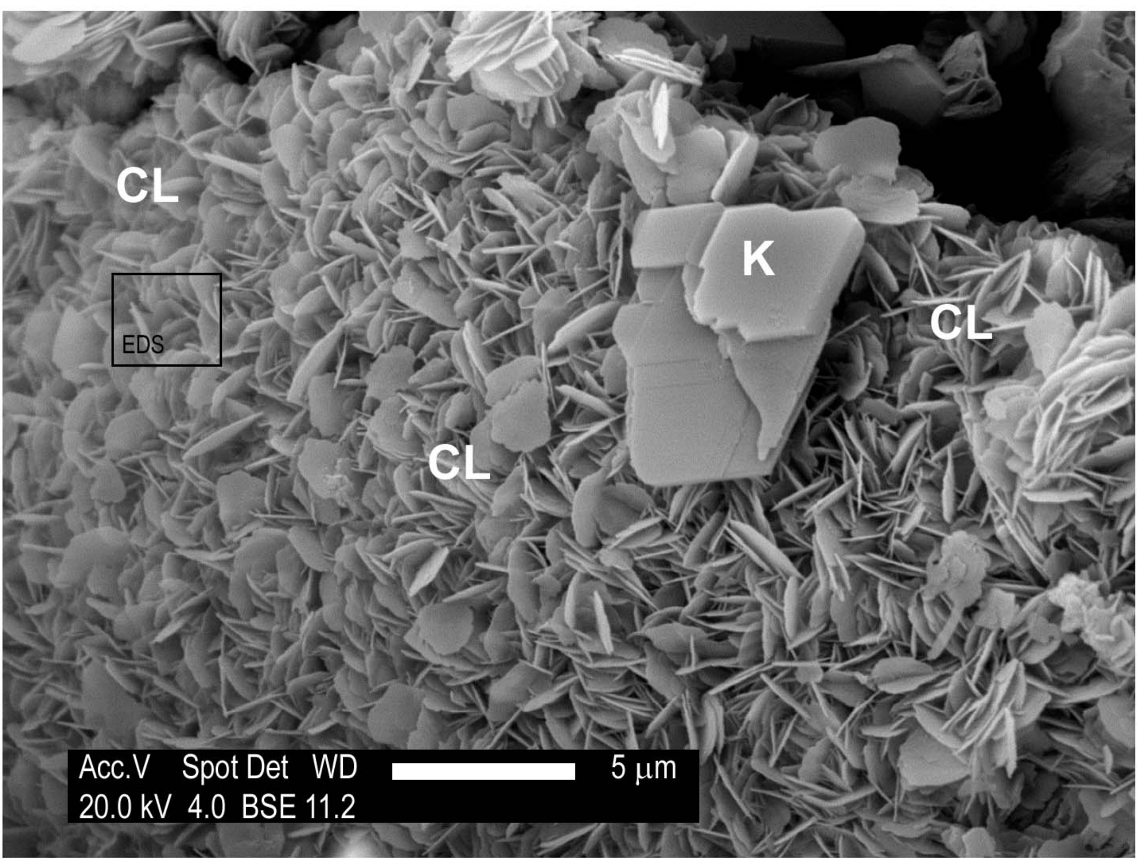


PLATE 4.22B

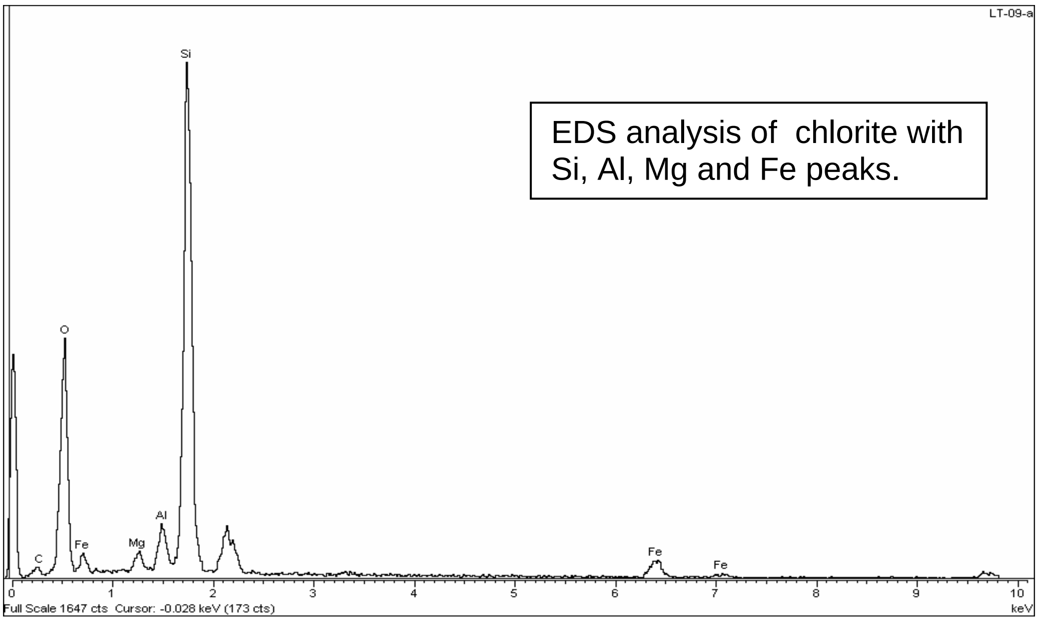
SCANNING ELECTRON MICROSCOPY
2136.82 m
Plug #74

PLATE 4.23A

Moderately low magnification backscatter overview of an upper fine to upper medium, moderately sorted, poorly indurated sandstone. Framework grains are predominantly quartz with accessory feldspars, rock fragments and minor mica. The field shows a large expanse of pore-filling authigenic kaolinite (K), from which a number of quartz framework grains protrude (some of these grains appear to have been broken during sampling; sQ). Small, localised quartz overgrowths (QO) are observed on some of these grains (see inset at upper left). The boxed area at lower left is shown in more detail in Plate 4.23B below.
Magnification: 150x

PLATE 4.23B

High magnification view of the surface of a quartz grain partly coated with chlorite (QcCL). Note the incipient development of quartz overgrowths (QO) where the chlorite coating appears to be thin or incomplete. Authigenic kaolinite crystals and booklets (K) are scattered over the grain surface, and partly fill intergranular pore spaces to the right and lower left. The EDS trace from the boxed area indicated shows typical Si, Al, Mg and Fe elemental composition of chlorite (see spectrum below).
Magnification: 2300x



LONGTOM-2 ST1
Core Plug # 74
2136.82 m

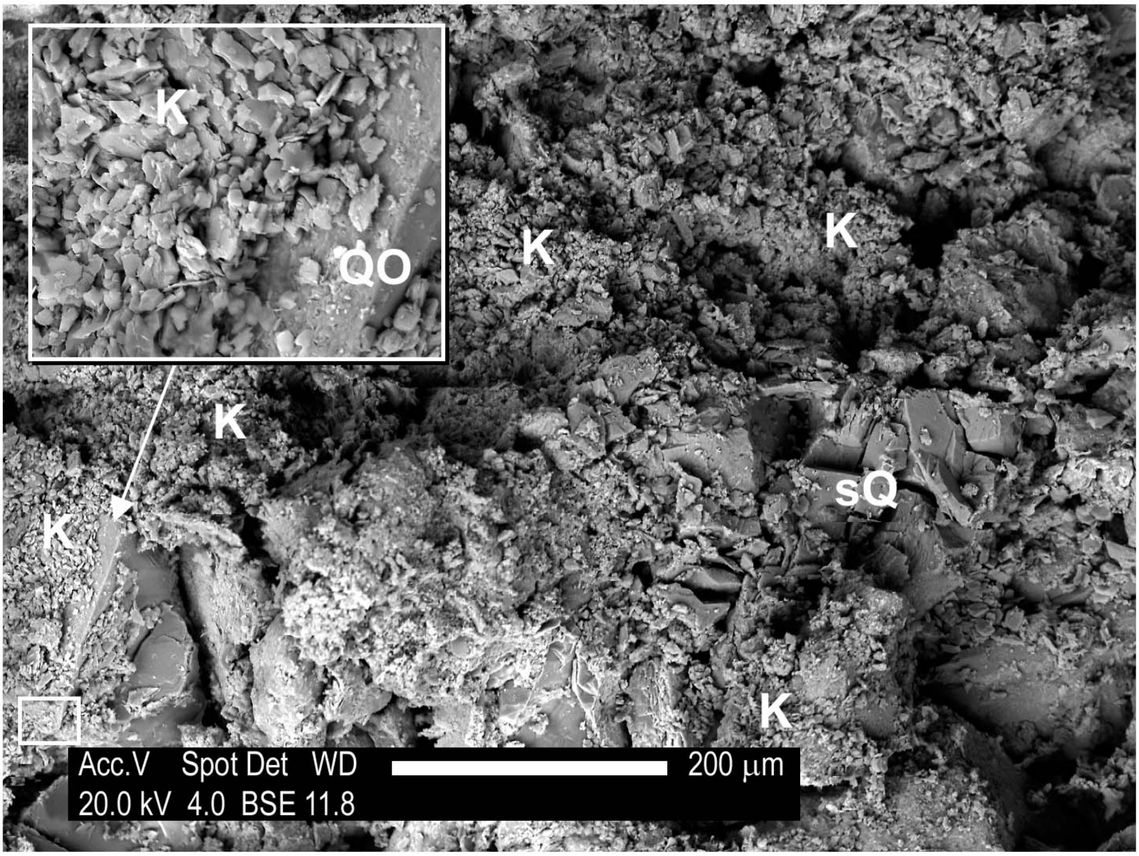


PLATE 4.23A

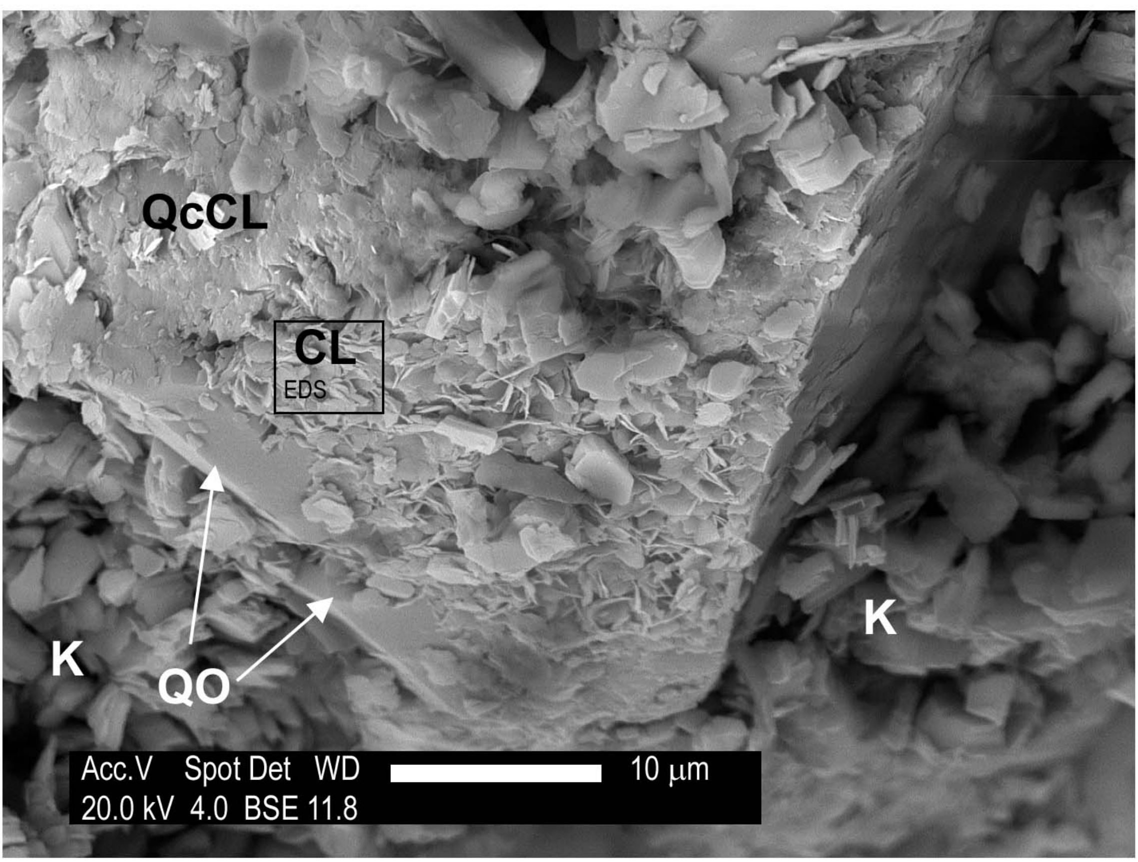


PLATE 4.23B

SCANNING ELECTRON MICROSCOPY
2142.34 m
Plug #92

PLATE 4.24A

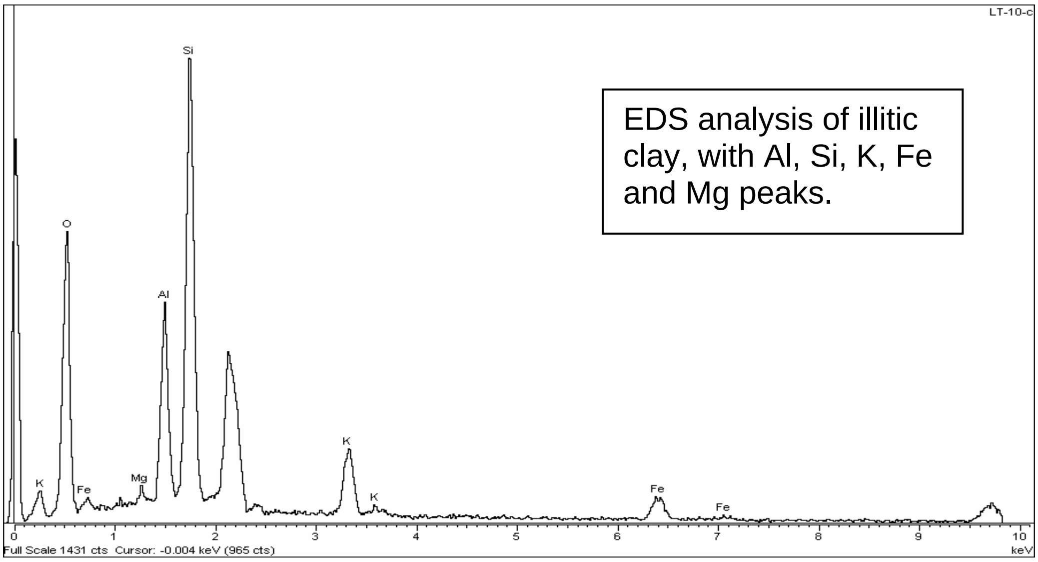
Moderately low magnification backscatter overview of an upper fine to upper medium, moderately sorted, well indurated calcite-cemented sandstone. Framework grains are predominantly quartz with accessory feldspars (e.g. F-K), rock fragments and minor mica. Quartz framework grains are mainly coated with a fine layer of chlorite (QcCL) and locally exhibit quartz overgrowth cement (QO). Calcite (Ca) occludes much of the pore space in this sample, although intergranular pores and pore throats (rPT) are preserved. These pores and pore throats have been partly restricted by quartz overgrowths (QO) and authigenic kaolinite (K). The boxed area is detailed in Plate 4.24B below.

Magnification: 150x

PLATE 4.24B

Close-up view of an intergranular pore partly filled by authigenic chlorite (CL) and authigenic kaolinite (K). Grain-coating chlorite (QcCL) is generally well crystalline, exhibiting incipient rosette-like form. However, some chlorite has been compacted at points of grain contact, giving it a flattened appearance (note flattened chlorite at upper right). Small quartz overgrowths (QO) have formed locally on chlorite-free surfaces of quartz grains (Q). The EDS trace acquired from the poorly crystalline clay at left (see boxed area and spectrum below) includes potassium, suggesting the clay may represent remnants of pseudomatrix from a compacted illitic grain (possibly a shale fragment), most of which was removed during sample preparation.

Magnification: 600x



EDS analysis of illitic clay, with Al, Si, K, Fe and Mg peaks.

LONGTOM-2 ST1
Core Plug # 92
2142.34 m

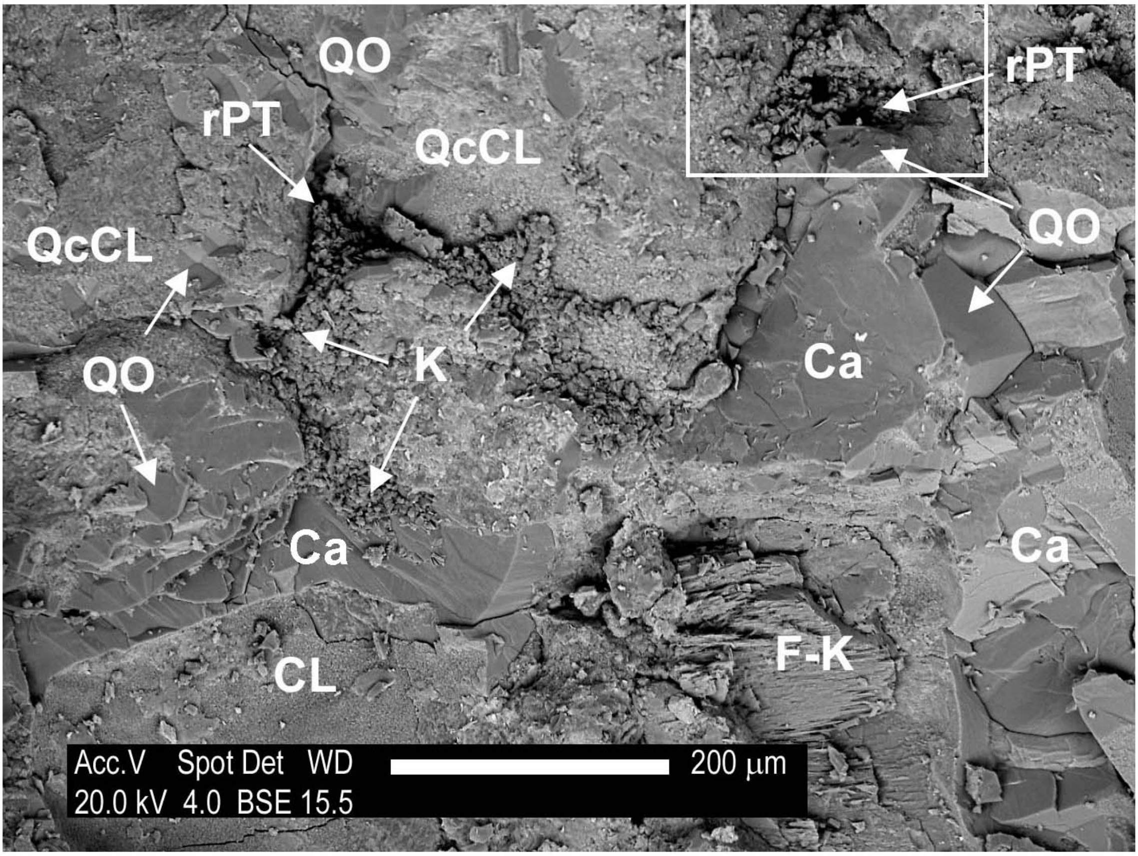


PLATE 4.24A

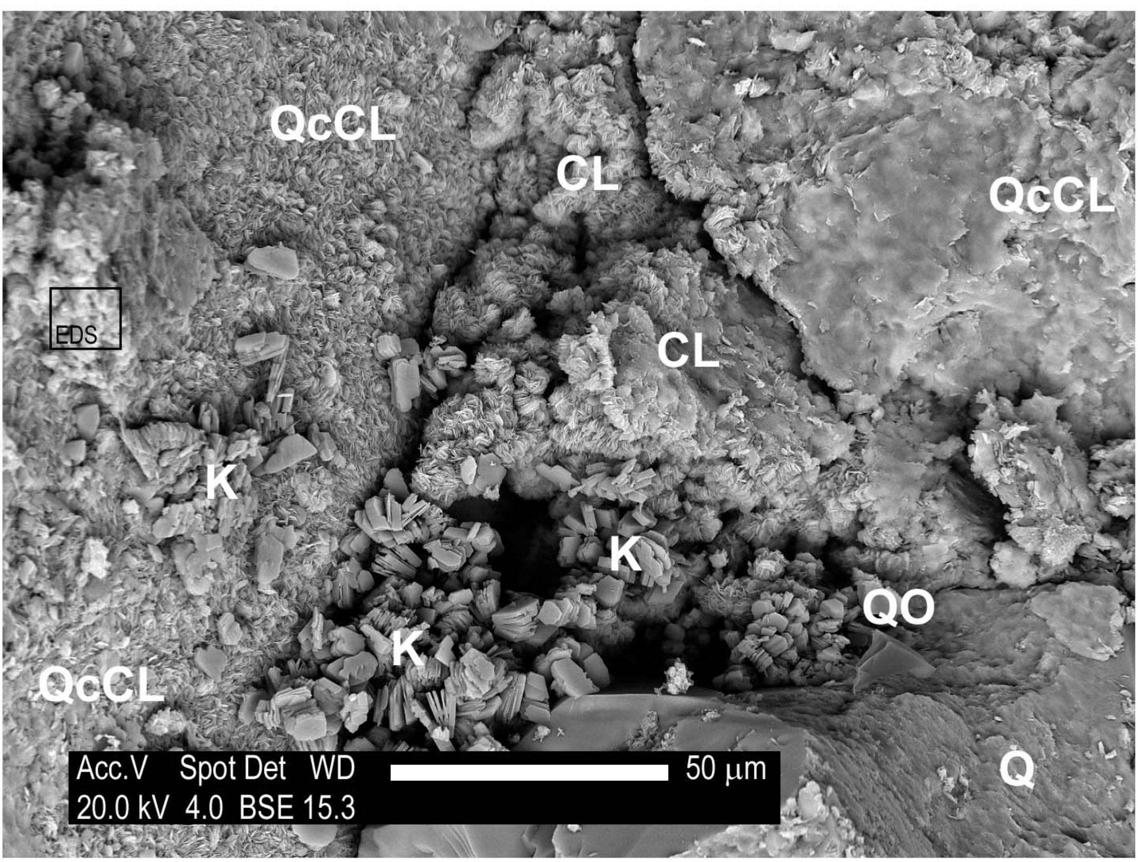


PLATE 4.24B

PLATES 4.25 to 4.33

THIN SECTION DESCRIPTIONS

AND PHOTOMICROGRAPHS

CUTTINGS SAMPLES

LONGTOM-2
CUTTINGS SAMPLE
2188 m

Argillaceous Siltstone (50%):	Medium silt grade, massive.		
Folk Classification:	N/A	Sorting:	N/A
Ave Grain Size (mm):	0.03 (medium silt)	Angularity:	Angular
Max Grain Size (mm):	0.10 (upper very fine)	Sphericity:	Equant
Grain Contacts:	Point, floating	Visible Porosity:	None
Porosity Types:	None		
Porosity Controls:	Clay matrix.		

Grains comprise quartz silt with common carbonaceous fragments and minor muscovite. Matrix comprises greenish, possibly chloritic clay.

Claystone (40%):	Massive, slightly silty.		
Folk Classification:	N/A	Sorting:	N/A
Ave Grain Size (mm):	N/A	Angularity:	N/A
Max Grain Size (mm):	N/A	Sphericity:	N/A
Grain Contacts:	Floating	Visible Porosity:	None
Porosity Types:	None		
Porosity Controls:	Clay matrix.		

Generally slightly silty and with common carbonaceous fragments. Some claystone cuttings contain calcareous planktonic foraminifera and foram debris.

Sandstone (10%):	Fine grained, well sorted, angular to subrounded, massive.		
Folk Classification:	Feldspathic litharenite/lithic arkose	Sorting:	Good
Ave Grain Size (mm):	0.15 (lower fine)	Angularity:	Angular-Subround
Max Grain Size (mm):	0.25 (lower medium)	Sphericity:	Equant-Subelongate
Grain Contacts:	Planar > Point	Visible Porosity:	Poor - fair
Porosity Types:	Intergranular > dissolution		
Porosity Controls:	Compaction, pore-filling kaolinite, pore-lining chlorite clay.		

Grains are moderately packed, comprising mainly quartz with common degraded feldspar (untwinned and plagioclase), volcanic rock fragments (glassy and microlitic), clay-replaced grains, chert and minor detrital chlorite. Clays include authigenic kaolinite and pore-lining chlorite. Visible porosity is mainly poor to fair intergranular, except where reduced by calcite cement, where it is very poor.

OTHERS: Trace loose polycrystalline quartz grains (granule-sized).

PLATE 4.25A

Low magnification photomicrograph showing a fine grained, feldspathic litharenite to lithic arkose sandstone cutting at centre (SST - note similarity with sandstones of the cored interval), with silty claystone fragments visible towards upper left (CLYST). Most of the other "cuttings" in this view are thought to comprise small clumps of claystone and sandstone fragments bound by drilling mud.

(28X, Plane-polarised Light)

PLATE 4.25B

Close-up view of the sandstone cutting illustrated at the centre of Plate 4.25A above. Grains are mainly monocrystalline quartz (MQ) with common glassy volcanic rock fragments (VRFg), degraded (dFspr) and partly leached feldspar (lFspr), chert (Cht), clay-replaced grains (CRG) and shale fragments (ShFr). Porosity is poor and mainly intergranular (IP), restricted by compaction, pore-lining chlorite (plChl), pore-filling kaolinite (K) and localised quartz overgrowths (QO).

(130X, Plane-polarised Light)

LONGTOM-2 ST1
CUTTINGS SAMPLE
2188 m

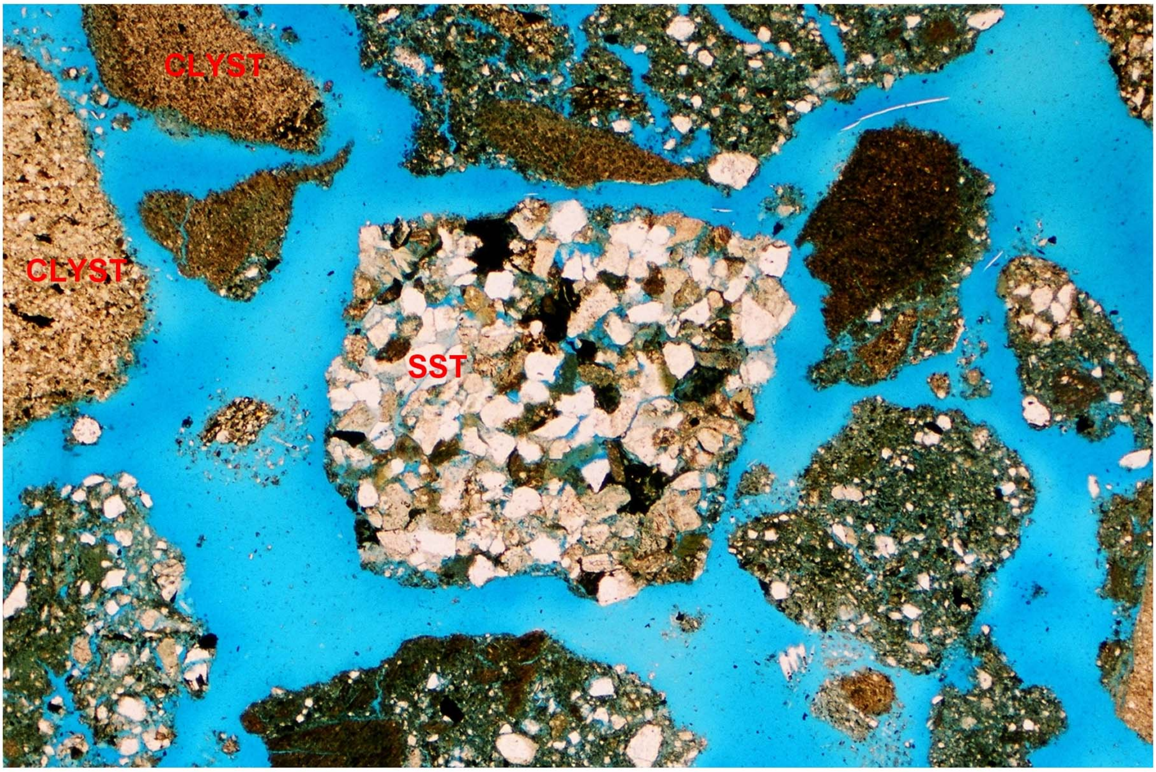
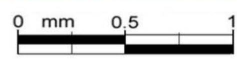


PLATE 4.25A



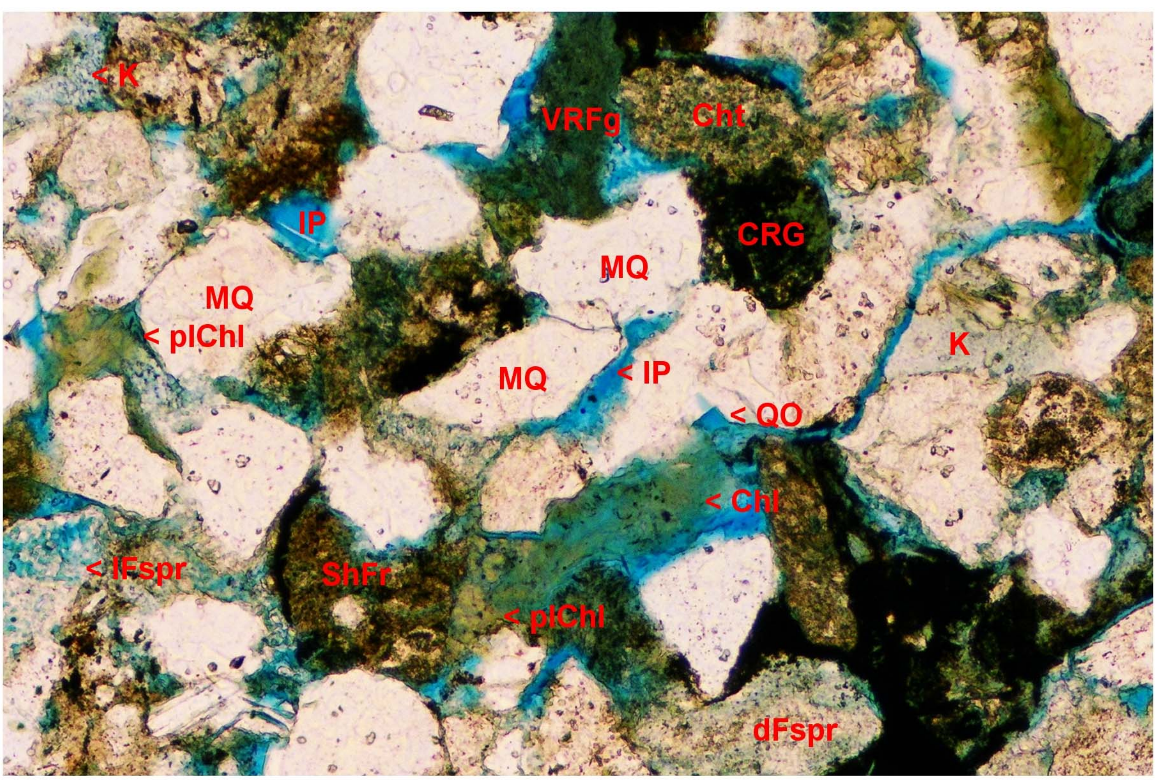
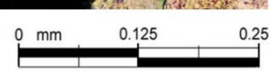


PLATE 4.25B



LONGTOM-2
CUTTINGS SAMPLE
2225 m

Claystone (50%):	Massive, slightly silty.		
Folk Classification:	N/A	Sorting:	N/A
Ave Grain Size (mm):	N/A	Angularity:	N/A
Max Grain Size (mm):	N/A	Sphericity:	N/A
Grain Contacts:	Floating	Visible Porosity:	None
Porosity Types:	None		
Porosity Controls:	Clay matrix.		

Generally slightly silty and with minor carbonaceous fragments. No forams observed.

Sandstone (30%):	Very fine to fine, mod well sorted, angular to subround, massive.		
Folk Classification:	Feldspathic litharenite/lithic arkose	Sorting:	Moderately good
Ave Grain Size (mm):	0.15 (lower fine)	Angularity:	Angular-Subround
Max Grain Size (mm):	0.30 (lower medium)	Sphericity:	Equant-Subelongate
Grain Contacts:	Planar > Point	Visible Porosity:	Generally poor
Porosity Types:	Intergranular > dissolution		
Porosity Controls:	Compaction, pore-filling kaolinite, pore-lining chlorite clay.		

Grain size varies from very fine to fine. Grains are moderately packed, mainly quartz with common degraded feldspar (untwinned and plagioclase), volcanic rock fragments (glassy and microlitic), clay-replaced grains, chert, minor detrital chlorite and trace biotite. Clays include authigenic kaolinite and pore-lining chlorite. Visible porosity is mainly poor intergranular. Rare calcite cement occurs in some cuttings.

Argillaceous Siltstone (20%):	Medium to coarse silt grade, massive.		
Folk Classification:	N/A	Sorting:	N/A
Ave Grain Size (mm):	N/A	Angularity:	Angular
Max Grain Size (mm):	0.03 (medium silt)	Sphericity:	N/A
Grain Contacts:	0.07 (lower very fine)	Visible Porosity:	Equant
Porosity Types:	None		
Porosity Controls:	Clay matrix		

Grains are mainly monocrystalline quartz silt with common carbonaceous fragments. Abundant detrital clay matrix. Grades towards very fine grained sandstone as described above.

OTHERS: Trace loose, very coarse grained polycrystalline quartz.
Trace degraded volcanic fragments.

PLATE 4.26A

Low magnification view of a fine grained, feldspathic litharenite to lithic arkose sandstone cutting (SST) surrounded by locally silty claystone (CLYST) and calcareous sandstone (CaSST) cuttings. The sandstone is similar in texture and mineralogy to the sandstones encountered in the cored interval of Longtom-2 ST1.

(28X, Plane-polarised Light)

PLATE 4.26B

High magnification view of the sandstone shown at the centre of Plate 4.26A above. Grains include monocrystalline (MQ) and polycrystalline quartz (PQ; locally degraded, dPQ), degraded (dFspr) and partly leached feldspar (lFspr), volcanic rock fragments (VRF), chert (Cht) and shale fragments (ShFr). Visible porosity is poor, mainly intergranular (IP), reduced by compaction, pore-lining chlorite (plChl), pore-filling kaolinite (K) and localised slightly ferroan calcite cement (Ca).

(130X, Plane-polarised Light)

LONGTOM-2 ST1
CUTTINGS SAMPLE
2225 m

PLATE 4.26A

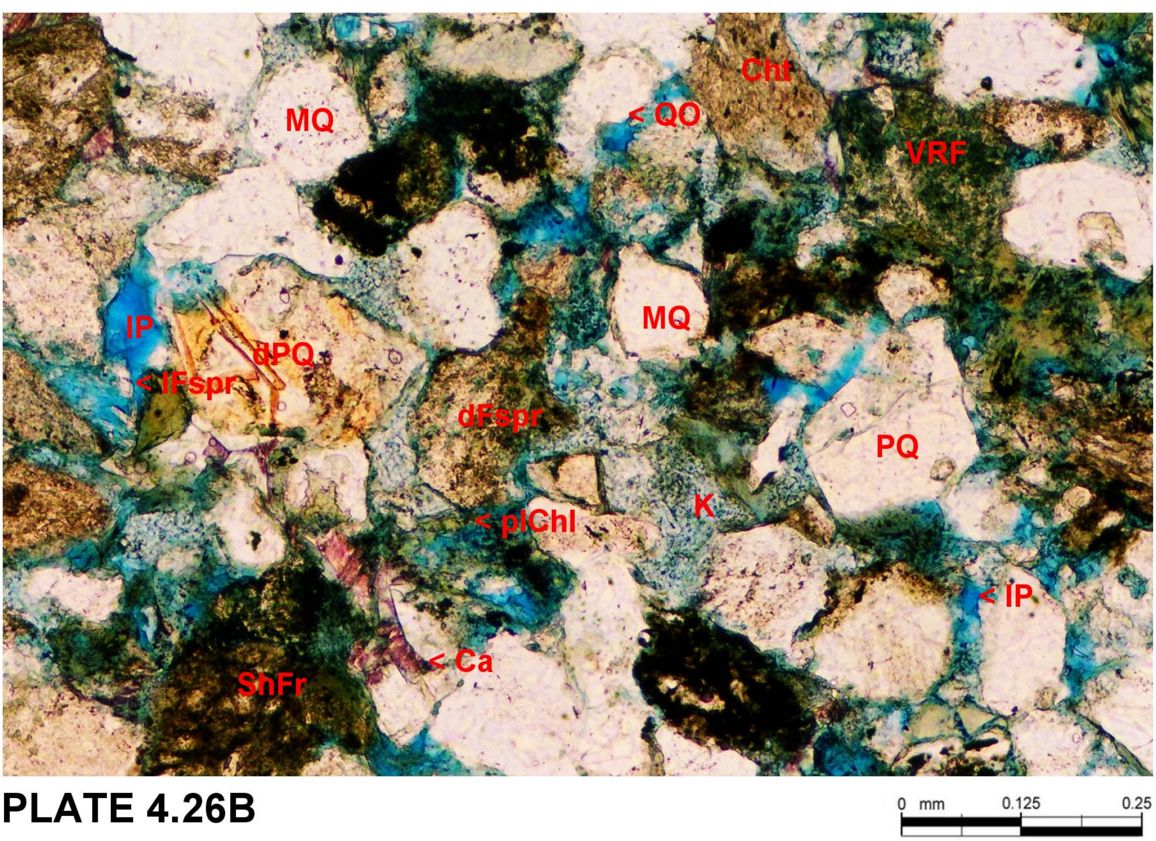


PLATE 4.26B

LONGTOM-2
CUTTINGS SAMPLE
2240 m

Claystone (50%):	Massive, slightly silty.		
Folk Classification:	N/A	Sorting:	N/A
Ave Grain Size (mm):	N/A	Angularity:	N/A
Max Grain Size (mm):	N/A	Sphericity:	N/A
Grain Contacts:	Floating	Visible Porosity:	None
Porosity Types:	None		
Porosity Controls:	Clay matrix.		

Generally slightly silty and with minor carbonaceous fragments. No forams observed.

Sandstone (40%):	Very f to f, locally med, mod to mod well sorted, ang to subrnd, massive.		
Folk Classification:	Feldspathic litharenite/lithic arkose	Sorting:	Moderate-mod good
Ave Grain Size (mm):	0.17 (lower fine)	Angularity:	Angular-Subround
Max Grain Size (mm):	0.40 (upper medium)	Sphericity:	Equant-Subelongate
Grain Contacts:	Planar > Point	Visible Porosity:	Very poor to poor
Porosity Types:	Intergranular > dissolution		
Porosity Controls:	Compaction, pore-filling kaolinite, pore-lining chlorite clay, localised calc cement.		

Very fine to fine and locally lower medium grained. Grain packing is moderate. Grains are mainly quartz with common degraded feldspar (untwinned and plagioclase), volcanic rock fragments (glassy and microlitic), clay-replaced grains, shale fragments, chert and minor detrital chlorite. Clays include authigenic kaolinite and pore-lining chlorite. Visible porosity is very poor to poor. Localised calcite cement is observed.

Argiillaceous Siltstone (10%):	Medium to coarse silt grade, massive.		
Folk Classification:	N/A	Sorting:	N/A
Ave Grain Size (mm):	N/A	Angularity:	Angular
Max Grain Size (mm):	0.03 (medium silt)	Sphericity:	N/A
Grain Contacts:	0.07 (lower very fine)	Visible Porosity:	Equant
Porosity Types:	None		
Porosity Controls:	Clay matrix		

Grains are mainly monocrystalline quartz silt with common to very common carbonaceous fragments. Abundant detrital clay matrix. Grades towards very fine grained sandstone as described above.

OTHERS: Trace degraded volcanic glass.
Trace coarse grained, pyrite-cemented, quartzose sandstone.

PLATE 4.27A

Low magnification view showing a large cutting of fine to medium grained, moderately to moderately well sorted, slightly calcareous feldspathic litharenite to lithic arkose sandstone (SST), which is mineralogically and texturally similar to the sandstone encountered in the cored interval. Also shown are silty claystone (CLYST) and argillaceous siltstone fragments (ArgSLTST).

(28X, Plane-polarised Light)

PLATE 4.27B

High magnification view of the sandstone shown in Plate 4.27A above. Grains include monocrystalline quartz (MQ), degraded (dFspr) and partly leached feldspar (lFspr), chert (Cht), microlitic (VRFml) and glassy volcanic rock fragments (VRFg), clay-replaced grains (CRG) and chlorite mica (DetChl). Visible porosity is poor to very poor, mainly intergranular (IP), reduced by compaction, calcite cement (Ca), pore-lining chlorite (plChl) and pore-filling kaolinite (K).

(130X, Plane-polarised Light)

LONGTOM-2 ST1
CUTTINGS SAMPLE
2240 m

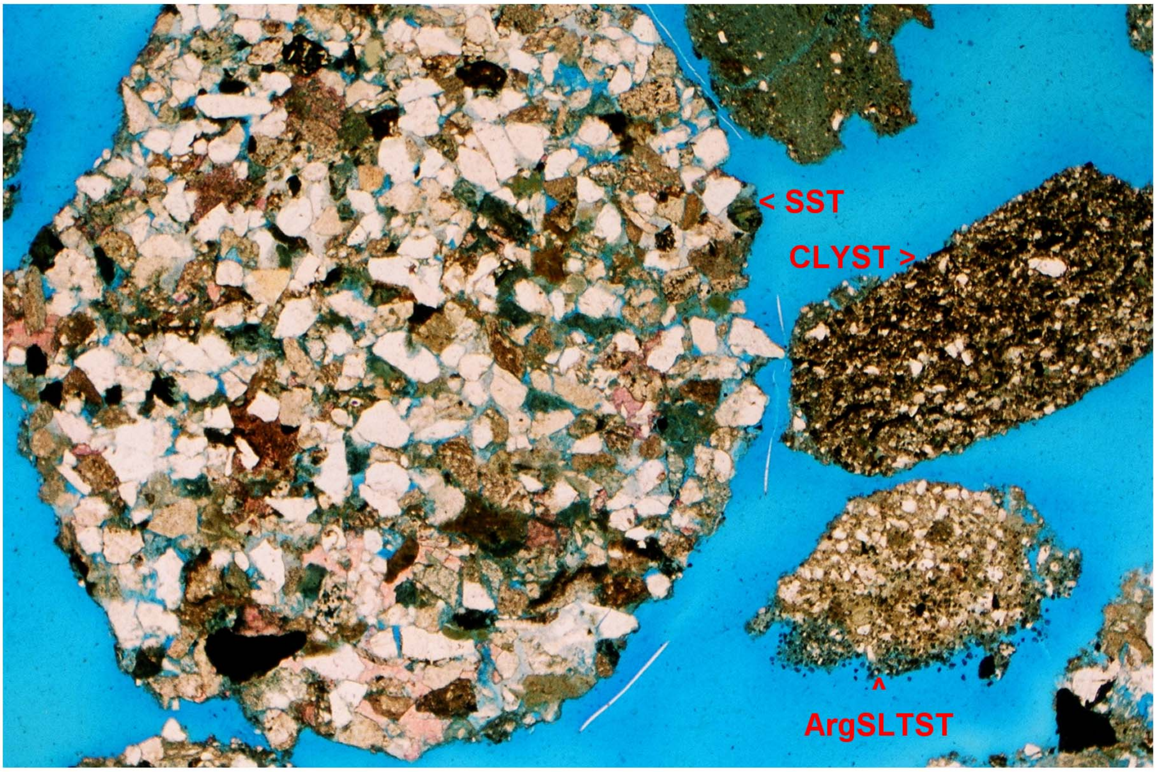


PLATE 4.27A

0 mm 0.5 1

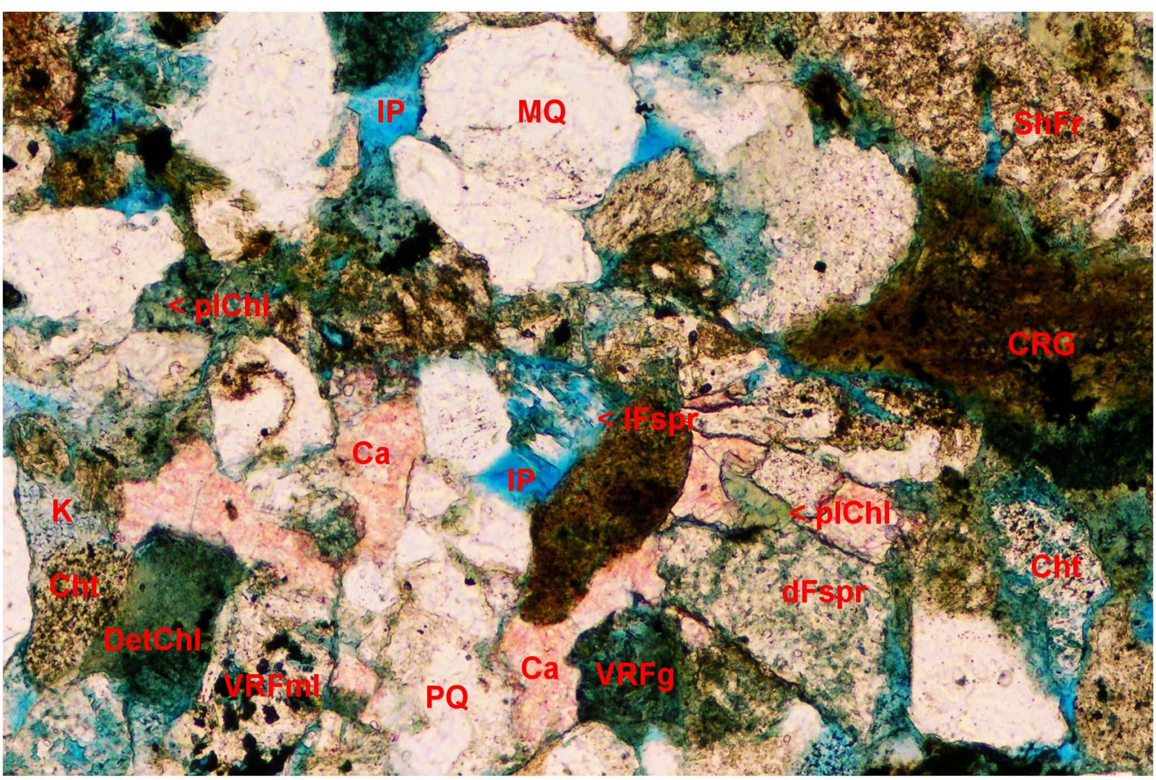


PLATE 4.27B

0 mm 0.125 0.25

LONGTOM-2
CUTTINGS SAMPLE
2275 m

Argillaceous Siltstone (40%):	Medium to coarse silt grade, massive.			
Folk Classification:	N/A		Sorting:	N/A
Ave Grain Size (mm):	N/A		Angularity:	Angular
Max Grain Size (mm):	0.03	(medium silt)	Sphericity:	N/A
Grain Contacts:	0.07	(lower very fine)	Visible Porosity:	Equant
Porosity Types:	None			
Porosity Controls:	Clay matrix			

Grains are mainly monocrystalline quartz silt with common to very common carbonaceous fragments and minor detrital chlorite. Abundant detrital clay matrix. Grades towards very fine grained sandstone as described below.

Sandstone (40%):	Very fine to fine, mod to mod well sorted, angular to subround, massive.			
Folk Classification:	Feldspathic litharenite/lithic arkose		Sorting:	Moderate-mod good
Ave Grain Size (mm):	0.15	(lower fine)	Angularity:	Angular-Subround
Max Grain Size (mm):	0.40	(lower medium)	Sphericity:	Equant-Subelongate
Grain Contacts:	Planar > Point		Visible Porosity:	Very poor to poor
Porosity Types:	Intergranular > dissolution			
Porosity Controls:	Compaction, pore-filling kaolinite, pore-lining chlorite clay, localised calc cement.			

Very fine to fine and locally lower medium grained. Grain packing is moderate. Grains are mainly quartz with common degraded feldspar (untwinned and plagioclase), volcanic rock fragments (glassy and microlitic), clay-replaced grains, shale fragments, chert and minor detrital chlorite. Clays include authigenic kaolinite and pore-lining chlorite. Visible porosity is very poor to poor. Localised calcite cement is observed.

Claystone (20%):	Massive, slightly silty.		
Folk Classification:	N/A	Sorting:	N/A
Ave Grain Size (mm):	N/A	Angularity:	N/A
Max Grain Size (mm):	N/A	Sphericity:	N/A
Grain Contacts:	Floating	Visible Porosity:	None
Porosity Types:	None		
Porosity Controls:	Clay matrix.		

Generally slightly silty with minor to common carbonaceous fragments. Grades locally towards argillaceous siltstone. Rare globigerinid-like forams observed in one cuttings fragment (possibly caved?).

OTHERS: Single large, degraded **echinoderm fragment** (probably caved).

PLATE 4.28A

Low magnification overview showing several fragments of moderately to moderately well sorted, feldspathic litharenite to lithic arkose sandstone, ranging from very fine grained (vfSST) to fine and locally medium grained (fSST). A large fragment of silty claystone is shown to the lower right (CLYST).

(28X, Plane-polarised Light)

PLATE 4.28B

High magnification view of the fine to medium grained sandstone cutting depicted at the centre of Plate 4.28A above. Grains include monocrystalline quartz (MQ), polycrystalline quartz (PQ), untwinned feldspar (UFspr), degraded (dVRF) and possibly glassy volcanic rock fragments (VRFg?), clay-replaced grains (CRG), sandstone rock fragments (SRF), shale fragments (ShFr) and biotite (Bi). Visible porosity is poor to very poor, confined to a few small intergranular pores. The main porosity reducing agents are compaction, pore-filling kaolinite (K) and pore-lining chlorite (plChl).

(130X, Plane-polarised Light)

LONGTOM-2 ST1
CUTTINGS SAMPLE
2275 m

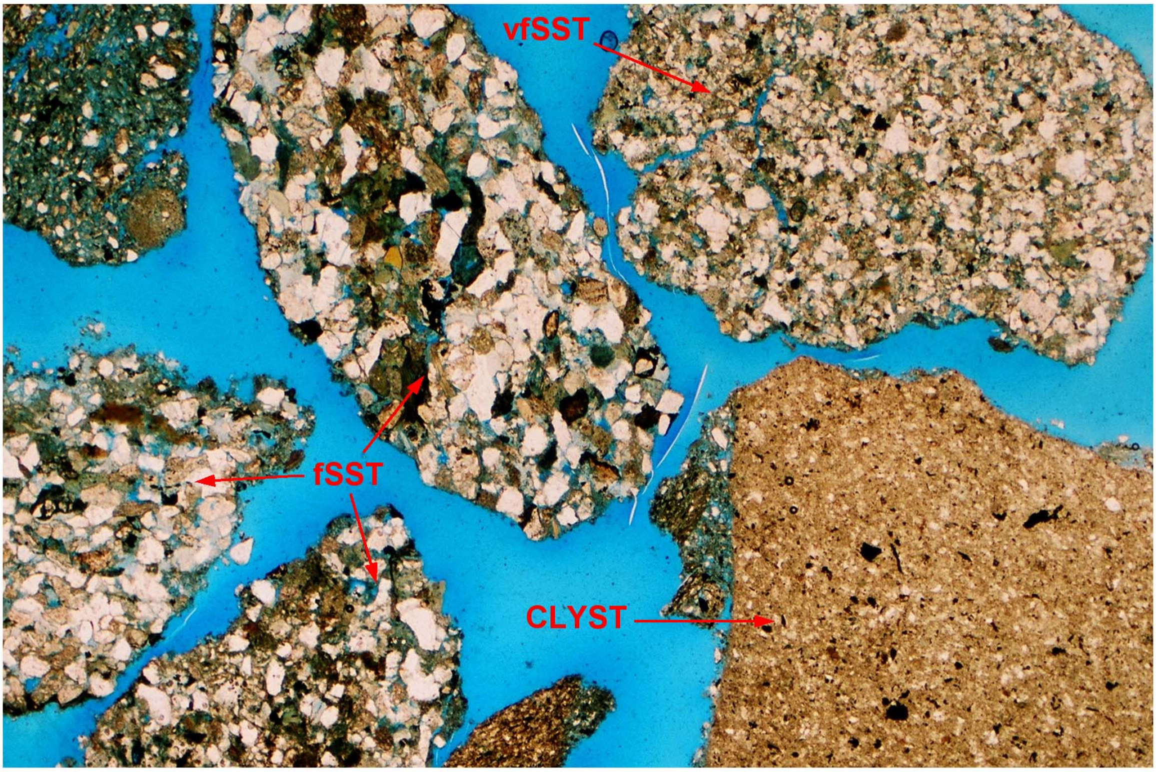


PLATE 4.28A

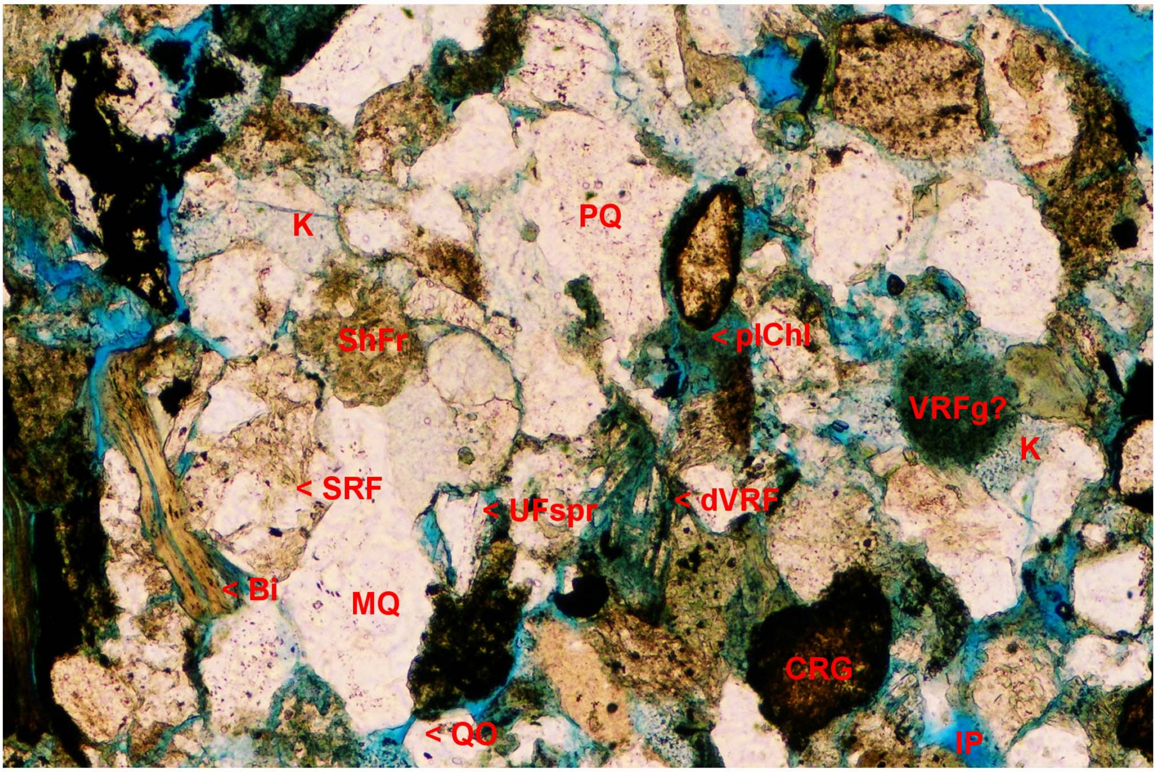


PLATE 4.28B

LONGTOM-2
CUTTINGS SAMPLE
2300 m

Sandstone (40%):	V f to f, locally med, pr to moderately sorted, angular to subround, massive.			
Folk Classification:	Feldspathic litharenite/lithic arkose		Sorting:	Poor to moderate
Ave Grain Size (mm):	0.15	(lower fine)	Angularity:	Angular-Subround
Max Grain Size (mm):	0.40	(lower medium)	Sphericity:	Equant-Subelongate
Grain Contacts:	Planar > Point		Visible Porosity:	Very poor to poor
Porosity Types:	Intergranular > dissolution			
Porosity Controls:	Compaction, authigenic kaolinite and chlorite, local calcite cement.			

Very fine to fine, locally medium, with moderate to tight grain packing. Grains in vf to f SST mainly quartz, common degraded feldspar, volcanic rock fragments, clay-replaced grains, shale frags, chert and minor chlorite. Clays include authigenic kaolinite and pore-lining chlorite. Coarse grained SST comprises mainly poly quartz, feldspar and chert set within chlorite matrix. Very poor to poor visible porosity. Localised calcite cement observed in finer sandstone.

Claystone (30%):	Massive, slightly silty.			
Folk Classification:	N/A		Sorting:	N/A
Ave Grain Size (mm):	N/A		Angularity:	N/A
Max Grain Size (mm):	N/A		Sphericity:	N/A
Grain Contacts:	Floating		Visible Porosity:	None
Porosity Types:	None			
Porosity Controls:	Clay matrix.			

Generally slightly silty and with minor to common carbonaceous fragments. Grades locally towards argillaceous siltstone.

Argillaceous Siltstone (20%):	Medium to coarse silt grade, massive.			
Folk Classification:	N/A		Sorting:	N/A
Ave Grain Size (mm):	N/A		Angularity:	Angular
Max Grain Size (mm):	0.03	(medium silt)	Sphericity:	N/A
Grain Contacts:	0.07	(lower very fine)	Visible Porosity:	Equant
Porosity Types:	None			
Porosity Controls:	Clay matrix			

Grains are mainly monocrystalline quartz silt with common to very common carbonaceous fragments and minor detrital chlorite. Abundant detrital clay matrix. Grades towards very fine grained sandstone as described above.

OTHERS:

10% Tuffaceous Claystone: angular to subangular monocrystalline quartz grains and rare lithic shale fragments set within brown, argillaceous matrix (matrix has appearance of partly devitrified volcanic ash).

Trace degraded, partly devitrified microlitic volcanic fragments (poss lava?). Microlites appear to be degraded plagioclase.

PLATE 4.29A

Low magnification view of fine grained, moderately well sorted lithic arkose/feldspathic litharenite sandstone (SST), carbonaceous, argillaceous siltstone (ArgSLTST), and silty to sandy claystone (CLYST).

(28X, Plane-polarised Light)

PLATE 4.29B

A second low magnification view showing medium grained, moderately sorted subarkose to sublitharenite sandstone (SST; note the chloritic clay matrix, ChlMtx), silty claystone (CLYST), a possible tuffite or sandy, tuffaceous claystone (Tft) and what appears to be a fragment of crystal tuff (XtlTf). Phenocrysts in this tuff are mainly plagioclase.

(28X, Plane-polarised Light)

LONGTOM-2 ST1
CUTTINGS SAMPLE
2300 m

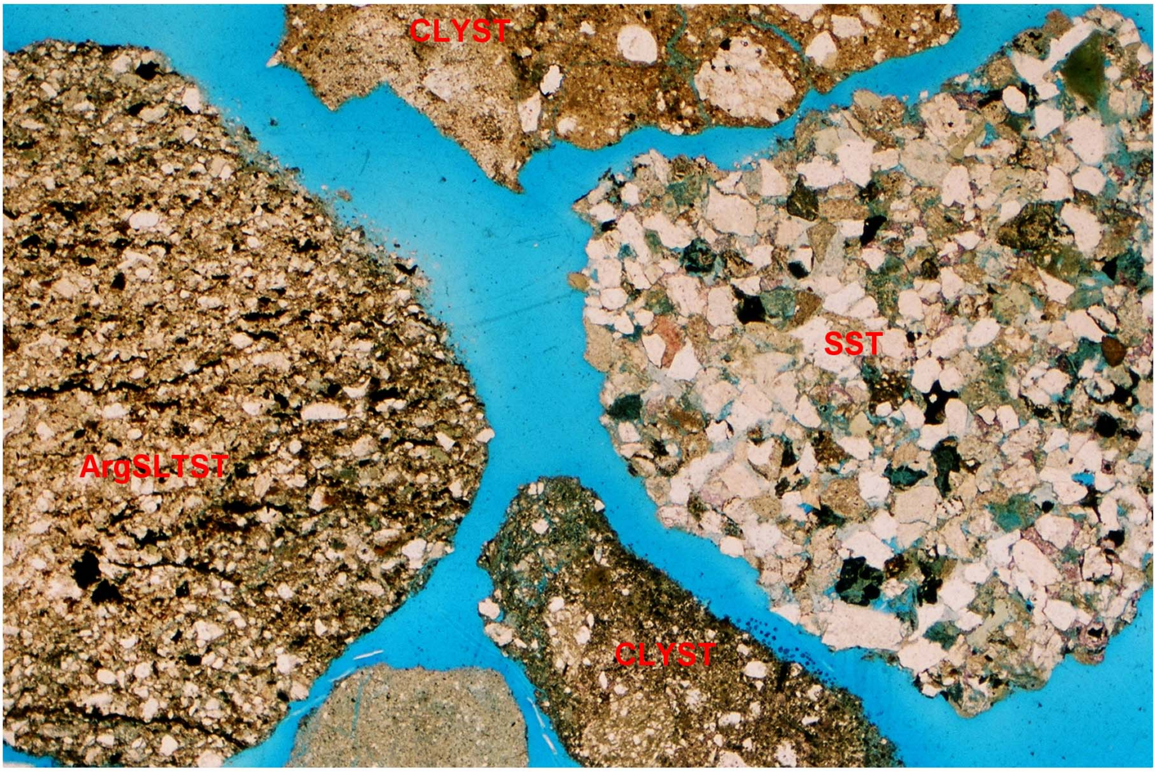


PLATE 4.29A

0 mm 0.5 1

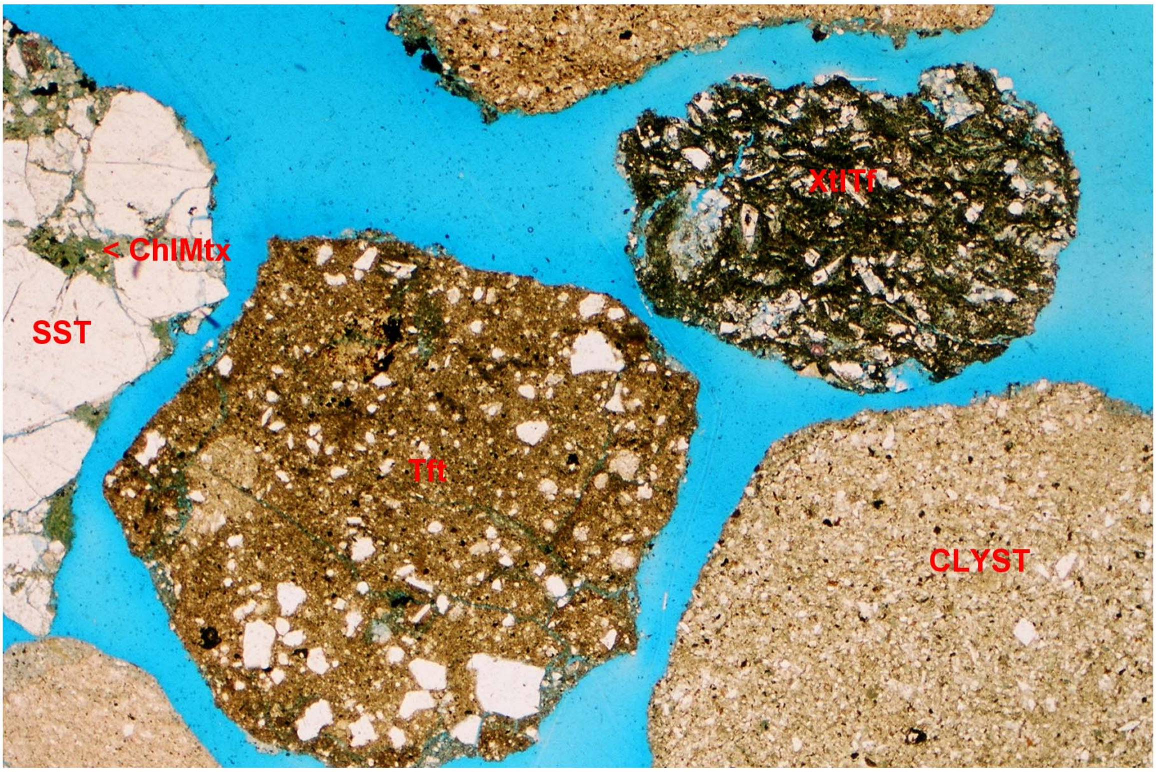


PLATE 4.29B

0 mm 0.5 1

LONGTOM-2
CUTTINGS SAMPLE
2320 m

Claystone (90%):	Massive, locally silty		
Folk Classification:	N/A	Sorting:	N/A
Ave Grain Size (mm):	N/A	Angularity:	N/A
Max Grain Size (mm):	N/A	Sphericity:	N/A
Grain Contacts:	Floating	Visible Porosity:	None
Porosity Types:	None		
Porosity Controls:	Clay matrix.		

Generally slightly silty. Generally rare carbonaceous fragments. Grades locally towards argillaceous siltstone. Localised sphaerosiderite clusters observed in some cuttings.

Chert (10%):	Possibly devitrified tuff or tuffite.		
Folk Classification:	N/A	Sorting:	N/A
Ave Grain Size (mm):	N/A	Angularity:	N/A
Max Grain Size (mm):	N/A	Sphericity:	N/A
Grain Contacts:	Floating	Visible Porosity:	None
Porosity Types:	None		
Porosity Controls:	Microcrystalline silica matrix.		

Interpreted to be of volcanic or volcaniclastic origins. Extremely fine grained to microcrystalline, with occasional larger grain-like or crystal-like quartz, and minor lath-shaped to tabular plagioclase crystals. Texture resembles tuff or tuffite (reworked tuff). Some grains exhibit fine quartz veins. No visible porosity.

Sandstone (Tr):	Very fine, moderately sorted, angular-subangular, massive.		
Folk Classification:	Arkose to subarkose	Sorting:	Moderate
Ave Grain Size (mm):	0.10 (upper very fine)	Angularity:	Angular-subangular
Max Grain Size (mm):	0.20 (upper fine)	Sphericity:	Equant-subelongate
Grain Contacts:	Planar > Point, or floating	Visible Porosity:	None
Porosity Types:	None		
Porosity Controls:	Clay matrix or compaction		

A few cuttings of subarkosic to arkosic, very fine grained sandstone are encountered. Fabric ranges from loosely packed with abundant clay matrix, to tightly packed with minor clay matrix. No visible porosity was observed.

OTHERS: A single **echinoid fragment** was observed (probably caved).

PLATE 4.30A

Low magnification view showing two large chert cuttings (Cht) adjacent to silty claystone (CLYST). Much of the chert is suspected to represent devitrified tuff, or tuffaceous sandstone and siltstone.

(28X, Plane-polarised Light)

PLATE 4.30B

Cross-polarised view of Plate 4.30A above. Although there are no diagnostic features in the chert to indicate any definite volcanic affinity, the presence of fresh, euhedral plagioclase grains (Plag) and what appear to be reworked quartz grains (Qtz) suggest tuffite or tuffaceous sedimentary origins.

(28X, Cross-polarised Light)

LONGTOM-2 ST1
CUTTINGS SAMPLE
2320 m

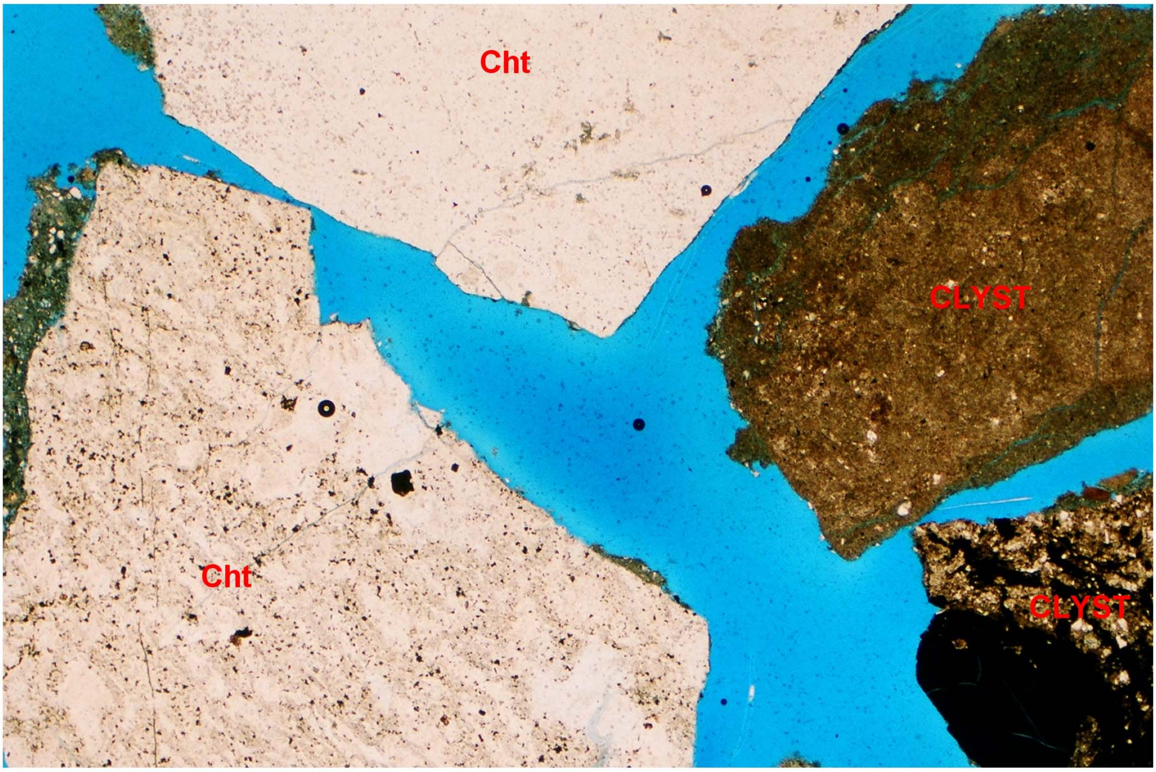


PLATE 4.30A

0 mm 0.5 1

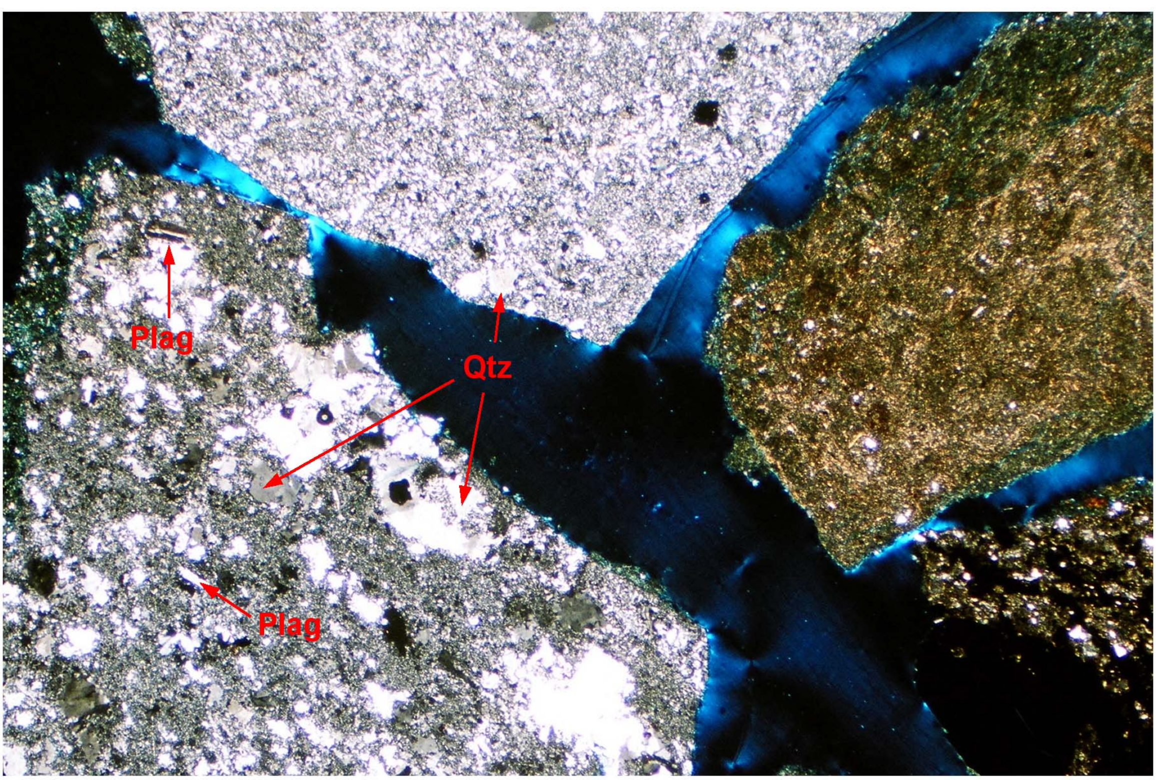


PLATE 4.30B

0 mm 0.5 1

LONGTOM-2
CUTTINGS SAMPLE
2380 m

Chert (50%):	Possibly devitrified tuff or tuffite.		
Folk Classification:	N/A	Sorting:	N/A
Ave Grain Size (mm):	N/A	Angularity:	N/A
Max Grain Size (mm):	N/A	Sphericity:	N/A
Grain Contacts:	Floating	Visible Porosity:	None
Porosity Types:	None		
Porosity Controls:	Microcrystalline silica matrix.		

Possibly of volcanic or volcaniclastic origins. Extremely fine grained to microcrystalline, with occasional larger grain-like or crystal-like quartz, and minor lath-shaped to tabular plagioclase crystals. Texture resembles tuff or tuffite (reworked tuff). Some grains exhibit fine quartz veins. No visible porosity.

Loose Quartz (30%)	Silt to fine grained, moderately to poorly sorted.		
Folk Classification:	N/A	Sorting:	Moderate to poor
Ave Grain Size (mm):	0.20 (upper fine)	Angularity:	Very angular-subangular
Max Grain Size (mm):	0.30 (lower medium)	Sphericity:	Equant-elongate
Grain Contacts:	N/A	Visible Porosity:	N/A
Porosity Types:	N/A		
Porosity Controls:	N/A		

Mostly silt to fine grained, moderately to poorly sorted, very angular to subangular monocrystalline with minor polycrystalline quartz fragments. Straight to slightly undulose extinction. Locally embayed

Sandstone (15%):	V f to f grained, mod to poorly sorted, angular to subangular, massive.		
Folk Classification:	Subarkose to arkose	Sorting:	Moderate to poor
Ave Grain Size (mm):	0.13 (lower fine)	Angularity:	Angular-subangular
Max Grain Size (mm):	0.35 (lower medium)	Sphericity:	Equant-subelongate
Grain Contacts:	Planar, convex > point	Visible Porosity:	None
Porosity Types:	None		
Porosity Controls:	Tight packing, clay matrix.		

Mostly fine grained subarkosic sandstone with tight grain packing, clay matrix (locally appears to be chlorite) and no visible porosity. Locally grades to argillaceous sandstone. Grains are mainly monocrystalline and polycrystalline quartz with minor plagioclase, indeterminate clay-replaced lithics (generally compacted into pseudomatrix), rare muscovite mica and heavy minerals (tourmaline). Quartz extinction is straight to strongly undulose.

OTHERS:

5% Porphyritic volcanics with microlites of plagioclase (locally showing trachytic texture), localised larger plagioclase phenocrysts, trace possible epidote.
Trace loose fragments of **calcite cement**.
Trace loose **plagioclase feldspar**.
Trace **Claystone** with planktonic forams.

PLATE 4.31A

Moderate magnification view showing poorly sorted argillaceous, possibly tuffaceous sandstone (ArgSST), and a volcanic fragment (VOLC) consisting almost entirely of plagioclase laths and a larger plagioclase phenocryst set within a partly devitrified glassy groundmass. Small fragments in the vicinity include shards of chert (Cht), sandstone (SST) and loose quartz (Lse Qtz)

(56X, Plane-polarised Light)

PLATE 4.31B

Cross-polarised view of Plate 4.31A above. Note the dark, almost isotropic, partly devitrified glassy groundmass of the volcanic fragment to the right of the view. Clay matrix in the argillaceous sandstone to the left of centre is also almost isotropic, indicating that much of the matrix may have been ash-derived.

(56X, Cross-polarised Light)

LONGTOM-2 ST1
CUTTINGS SAMPLE
2380 m

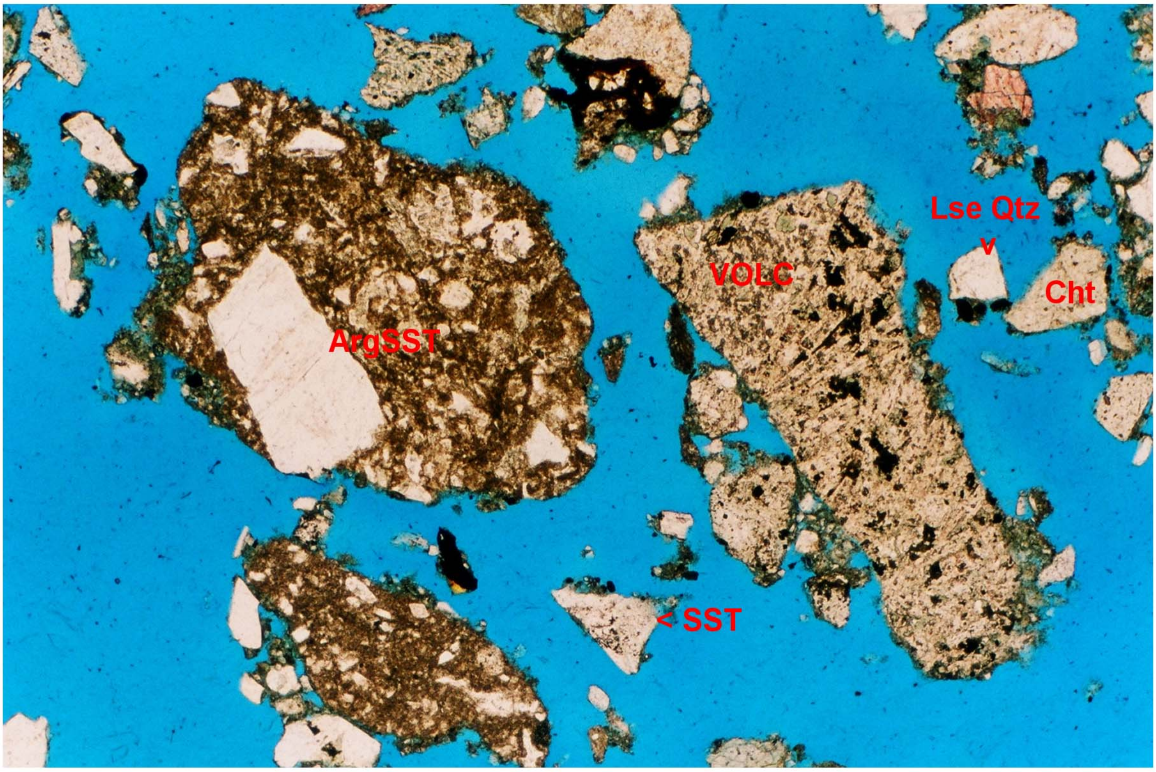


PLATE 4.31A

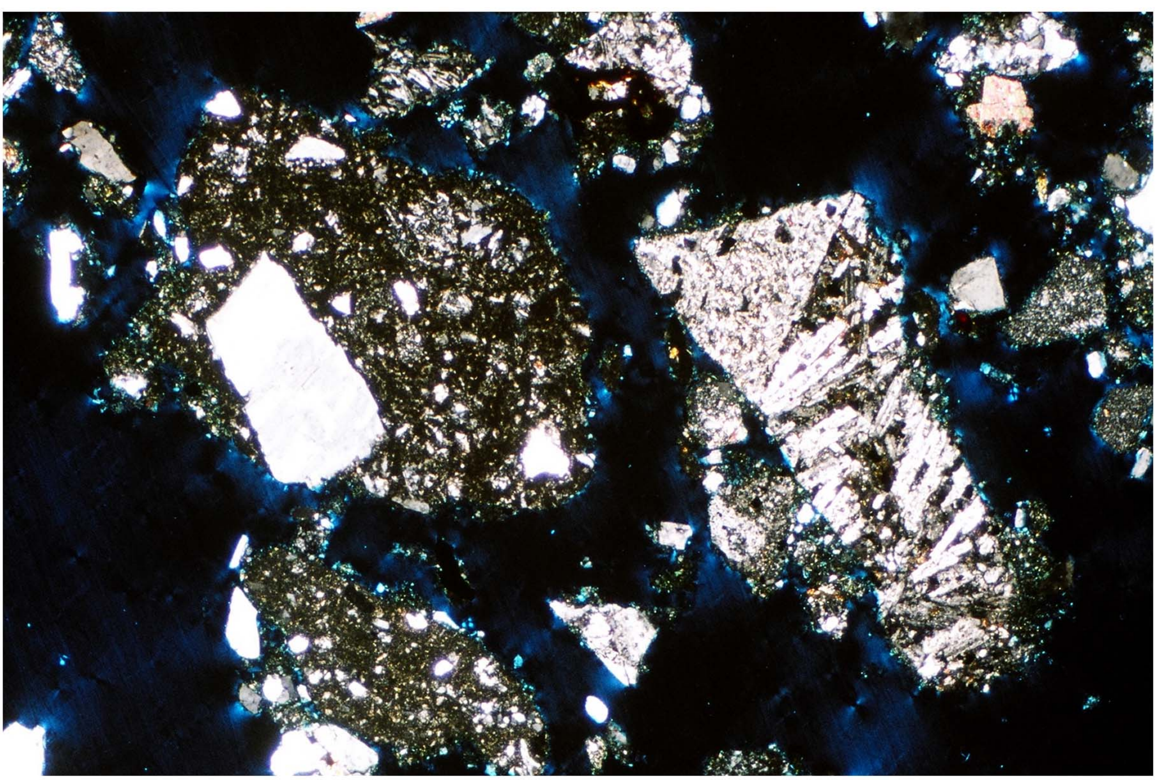


PLATE 4.31B

LONGTOM-2
CUTTINGS SAMPLE
2400 m

Chert (50%):	Possibly devitrified tuff or tuffite, locally silicified sandstone.		
Folk Classification:	N/A	Sorting:	N/A
Ave Grain Size (mm):	N/A	Angularity:	N/A
Max Grain Size (mm):	N/A	Sphericity:	N/A
Grain Contacts:	Floating	Visible Porosity:	None
Porosity Types:	None		
Porosity Controls:	Microcrystalline silica matrix.		

Possibly of volcanic or volcaniclastic origins. Extremely fine grained to microcrystalline, with occasional larger grain-like or crystal-like quartz, and minor lath-shaped to tabular plagioclase crystals. Texture resembles tuff or tuffite (reworked tuff), although some fragments show vf-f sandstone texture. Some cuttings exhibit fine quartz veins. No visible porosity.

Loose Quartz (40%)	Silt to fine grained, moderately to poorly sorted.		
Folk Classification:	N/A	Sorting:	Moderate to poor
Ave Grain Size (mm):	0.18 (upper fine)	Angularity:	Very angular-subangular
Max Grain Size (mm):	0.45 (upper medium)	Sphericity:	Equant-elongate
Grain Contacts:	N/A	Visible Porosity:	N/A
Porosity Types:	N/A		
Porosity Controls:	N/A		

Mostly silt to fine grained, moderately to poorly sorted, very angular to subangular monocrystalline with minor polycrystalline quartz fragments. Straight to slightly undulose extinction. Locally embayed

Sandstone (10%):	V f to crse grained, mod to poorly sorted, angular to subangular, massive.		
Folk Classification:	Subarkose to felspathic litharenite	Sorting:	Moderate to poor
Ave Grain Size (mm):	0.15 (lower fine)	Angularity:	Angular-subangular
Max Grain Size (mm):	0.60 (lower coarse)	Sphericity:	Equant-subelongate
Grain Contacts:	Planar, convex > point	Visible Porosity:	None
Porosity Types:	None		
Porosity Controls:	Tight grain packing, clay matrix.		

Very fine to coarse grained subarkosic sandstone with tight grain packing, clay matrix (locally appears to be chlorite) and no visible porosity. Grains are mainly monocrystalline and polycrystalline quartz (straight to strongly undulose extinction) with minor plagioclase, localised chert, indeterminate clay-replaced and sericitised grains (locally compacted into pseudomatrix), rare muscovite mica and heavy minerals.

OTHERS:

Trace **Porphyritic Volcanics** with lath-shaped and microlitic plagioclase (locally showing trachytic texture), localised larger plagioclase phenocrysts, trace possible epidote.
Trace **Claystone**.
Trace loose **Plagioclase Feldspar**.
Trace globigerinid-like **Planktonic Forams**.

PLATE 4.32A

Medium magnification view showing a fragment of microlitic volcanic rock (VOLC; microlites are mainly plagioclase feldspar), common loose quartz sand (LseQtz), small fragments of chert (Cht) and chlorite (Chl).

(56X, Plane-polarised Light)

PLATE 4.32B

Medium magnification view of a tight, medium grained, moderately sorted sandstone of possible subarkosic composition (SST). Note the very poor porosity in this sandstone, on account of tight grain packing and brown coloured interstitial clay matrix. Most of the surrounding material comprises loose quartz (LseQtz) or shards of chert (Cht).

(56X, Plane-polarised Light)

LONGTOM-2 ST1
CUTTINGS SAMPLE
2400 m

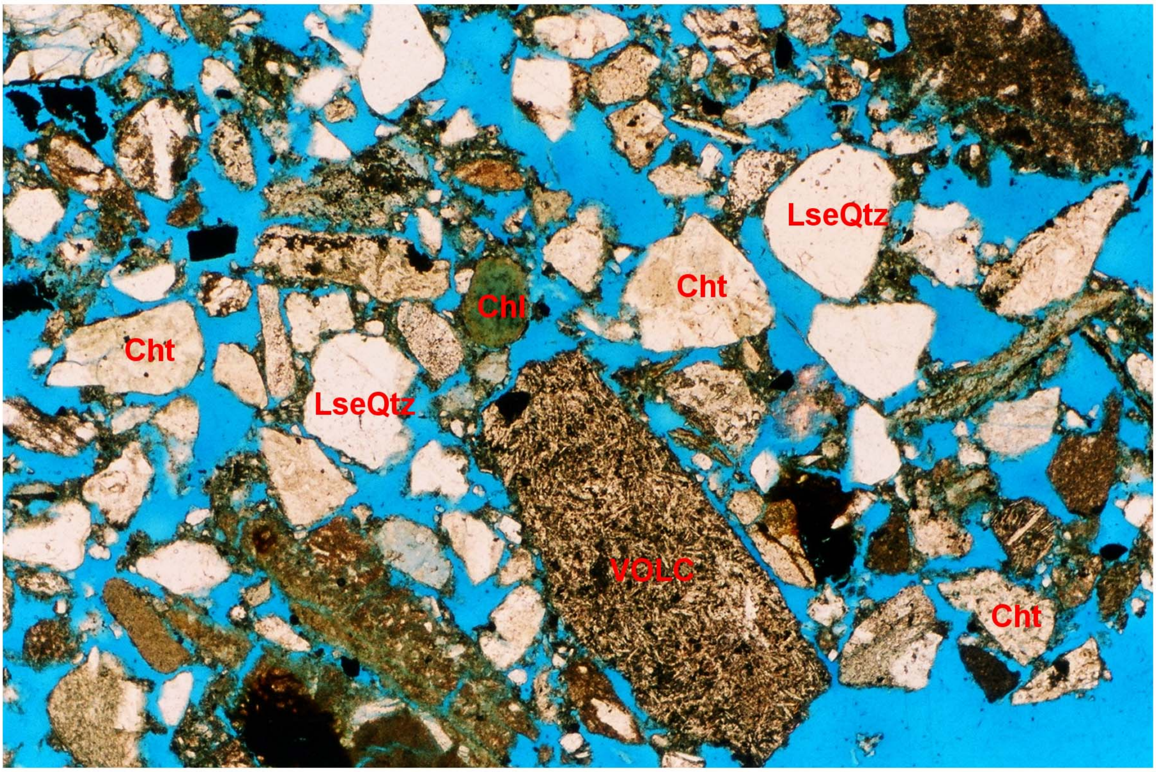
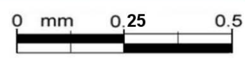


PLATE 4.32A



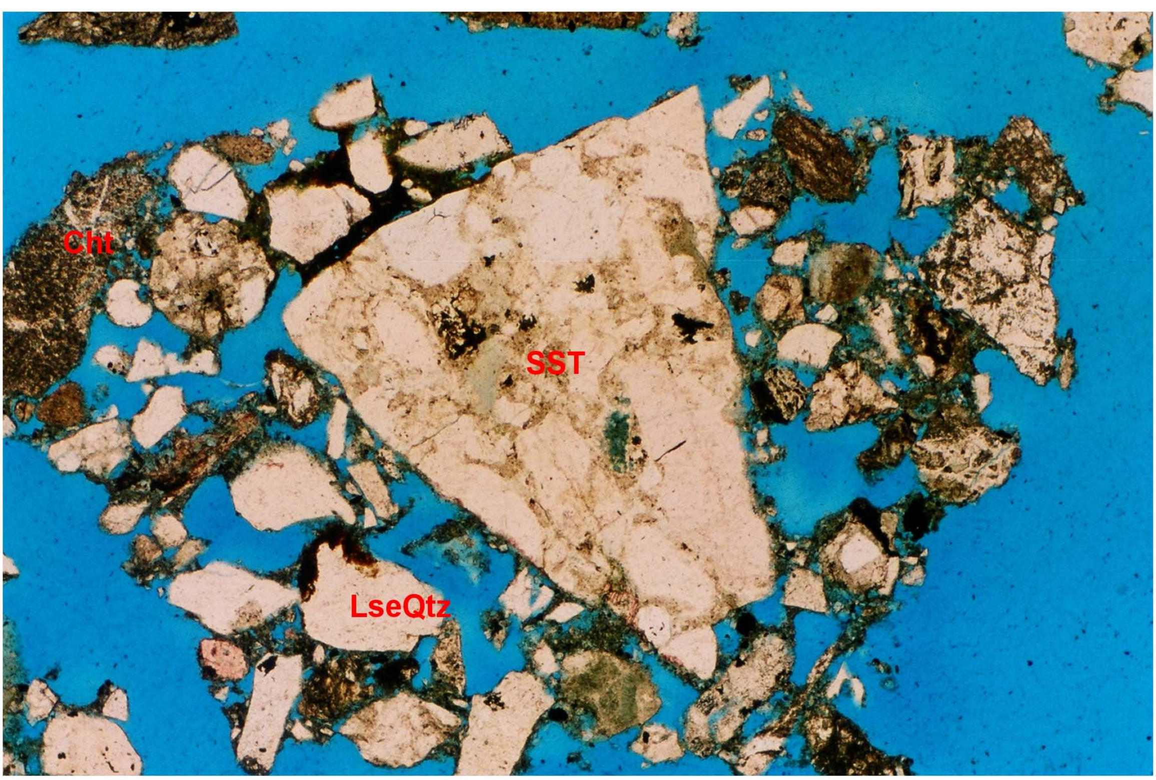
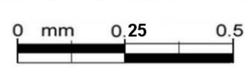


PLATE 4.32B



LONGTOM-2
CUTTINGS SAMPLE
2410 m

Chert (50%):	Possibly devitrified tuff or tuffite, locally silicified sandstone.		
Folk Classification:	N/A	Sorting:	N/A
Ave Grain Size (mm):	N/A	Angularity:	N/A
Max Grain Size (mm):	N/A	Sphericity:	N/A
Grain Contacts:	Floating	Visible Porosity:	None
Porosity Types:	None		
Porosity Controls:	Microcrystalline silica matrix.		

Possibly of volcanic or volcaniclastic origins. Extremely fine grained to microcrystalline, with occasional larger grain-like or crystal-like quartz, and minor lath-shaped to tabular plagioclase crystals. Texture resembles tuff or tuffite (reworked tuff), although some fragments show vf-f sandstone texture. Localised partial chlorite replacement, occasional epidote. Some cuttings exhibit fine quartz veins. No visible porosity.

Sandstone (20%):	V f to v crse, mod to poorly sorted, angular to subangular, massive.		
Folk Classification:	Subarkose to litharenite	Sorting:	Moderate to poor
Ave Grain Size (mm):	0.15 (lower fine)	Angularity:	Angular-subangular
Max Grain Size (mm):	1.10 (lower very coarse)	Sphericity:	Equant-subelongate
Grain Contacts:	Planar, convex > point	Visible Porosity:	None
Porosity Types:	None		
Porosity Controls:	Tight packing, clay matrix.		

Very fine to very coarse subarkosic to litharenitic sandstone (locally tuffaceous) with tight grain packing, clay matrix (locally appears to be chlorite) and no visible porosity. Grains are mainly monocrystalline and polycrystalline quartz (straight to strongly undulose extinction) with minor plagioclase, chert, indeterminate clay-replaced grains (locally compacted into pseudomatrix), locally common volcanic rock fragments, rare muscovite mica and heavy minerals.

Claystone (15%):	Generally silty, massive to faintly laminated.		
Folk Classification:	N/A	Sorting:	N/A
Ave Grain Size (mm):	N/A	Angularity:	N/A
Max Grain Size (mm):	N/A	Sphericity:	N/A
Grain Contacts:	N/A	Visible Porosity:	None
Porosity Types:	None		
Porosity Controls:	Detrital clay matrix.		

Generally silty, with localised concentration of silt into poorly defined laminae. Some cuttings contain common globigerinid planktonic foraminifera. Traces of pyrite and pyritised carbonaceous debris.

OTHERS:

10% Porphyritic Volcanics and Crystal-Lithic Tuff with lath-shaped to tabular and microlitic plagioclase (locally showing trachytic texture), localised larger plagioclase phenocrysts, trachytic fragments, race possible epidote. Locally partly chloritised.
5% Loose Quartz Sand.
Trace loose **Plagioclase Feldspar**.

PLATE 4.33A

Medium magnification view of a crystal-lithic tuff or tuffaceous sandstone fragment. Component grains include relatively pristine plagioclase phenocrysts (Plag) and a trachytic-textured volcanic rock fragment (VRF) set within a partially devitrified groundmass or matrix (Mtx).

(56X, Plane-polarised Light)

PLATE 4.33B

Medium magnification view of a tuffaceous sandstone cutting. Grains include porphyritic volcanic fragments (VRFp; with component degraded plagioclase, dPlag, and a chloritised feldspar, ChlFspr), and a microlitic volcanic fragment (VRFml) set within a glassy matrix (Mtxg). The somewhat rounded corners to these volcanic fragments suggest some degree of abrasion and sedimentary reworking.

(56X, Plane-polarised Light)

LONGTOM-2 ST1
CUTTINGS SAMPLE
2410 m

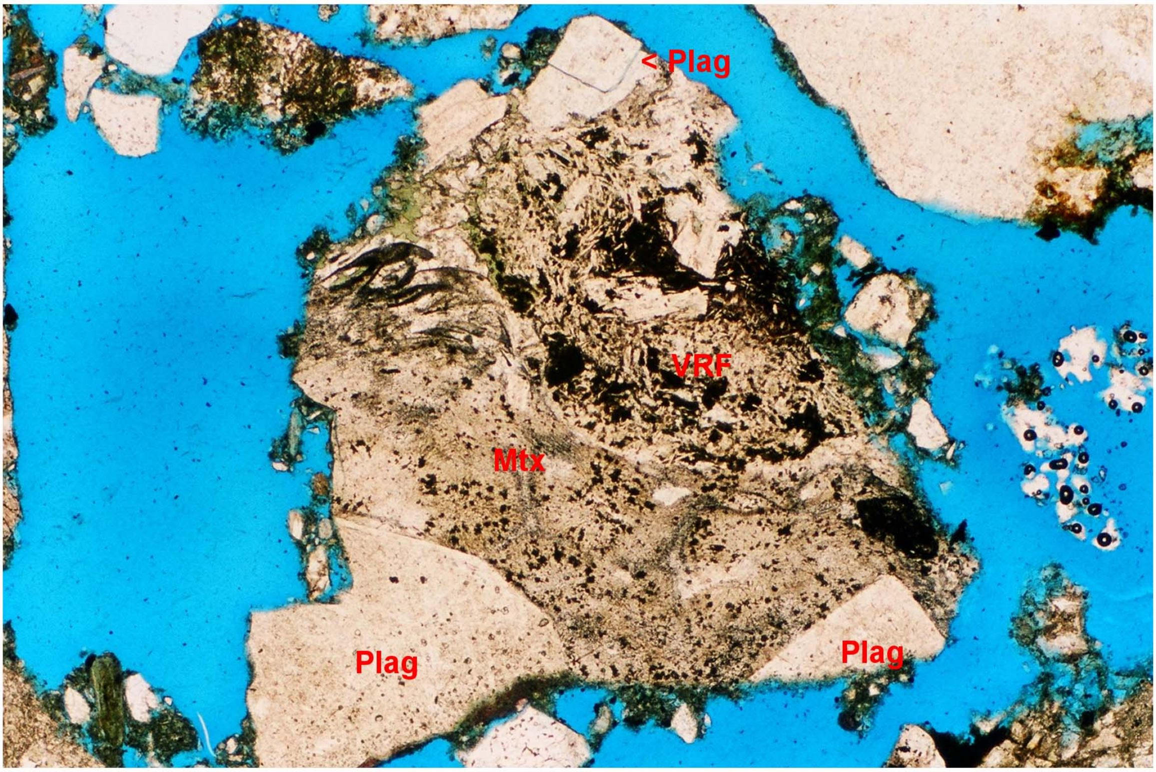
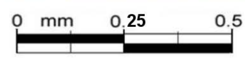


PLATE 4.33A



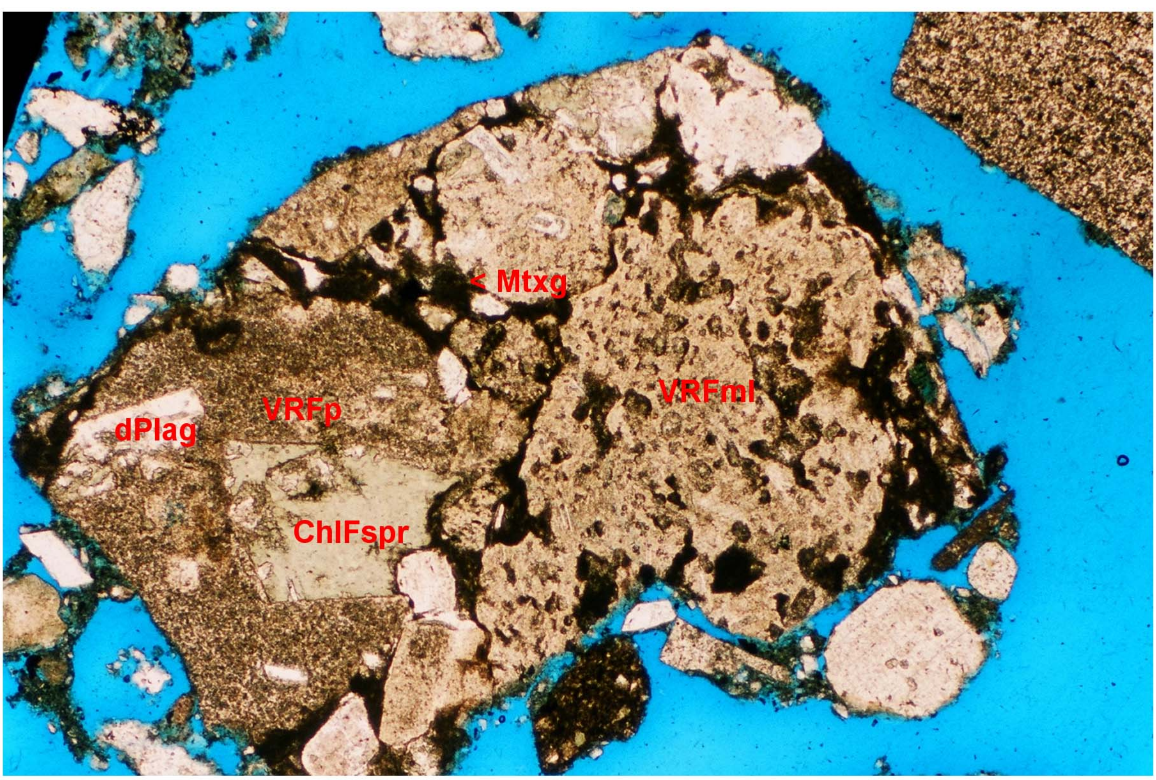
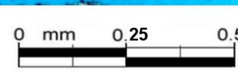
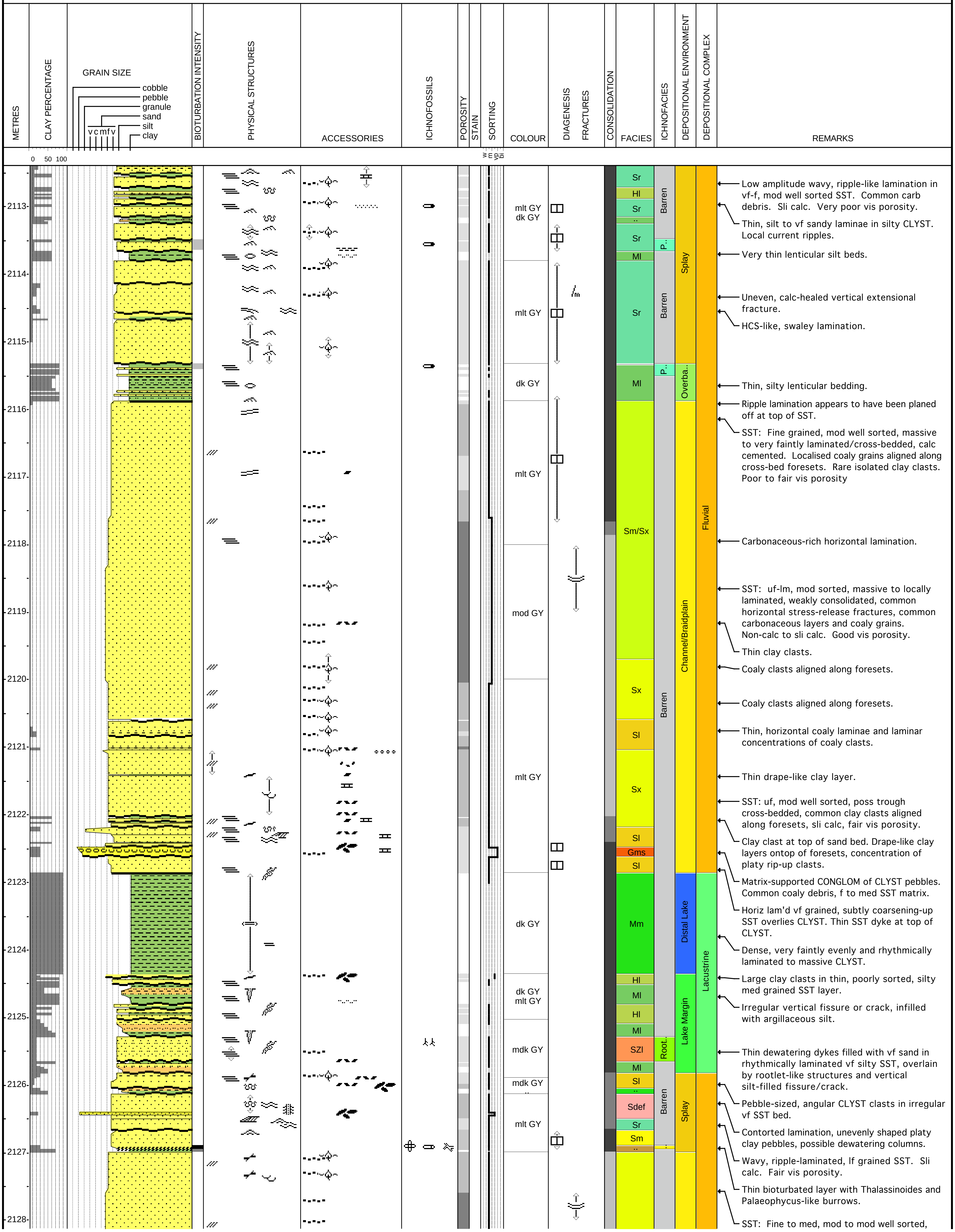


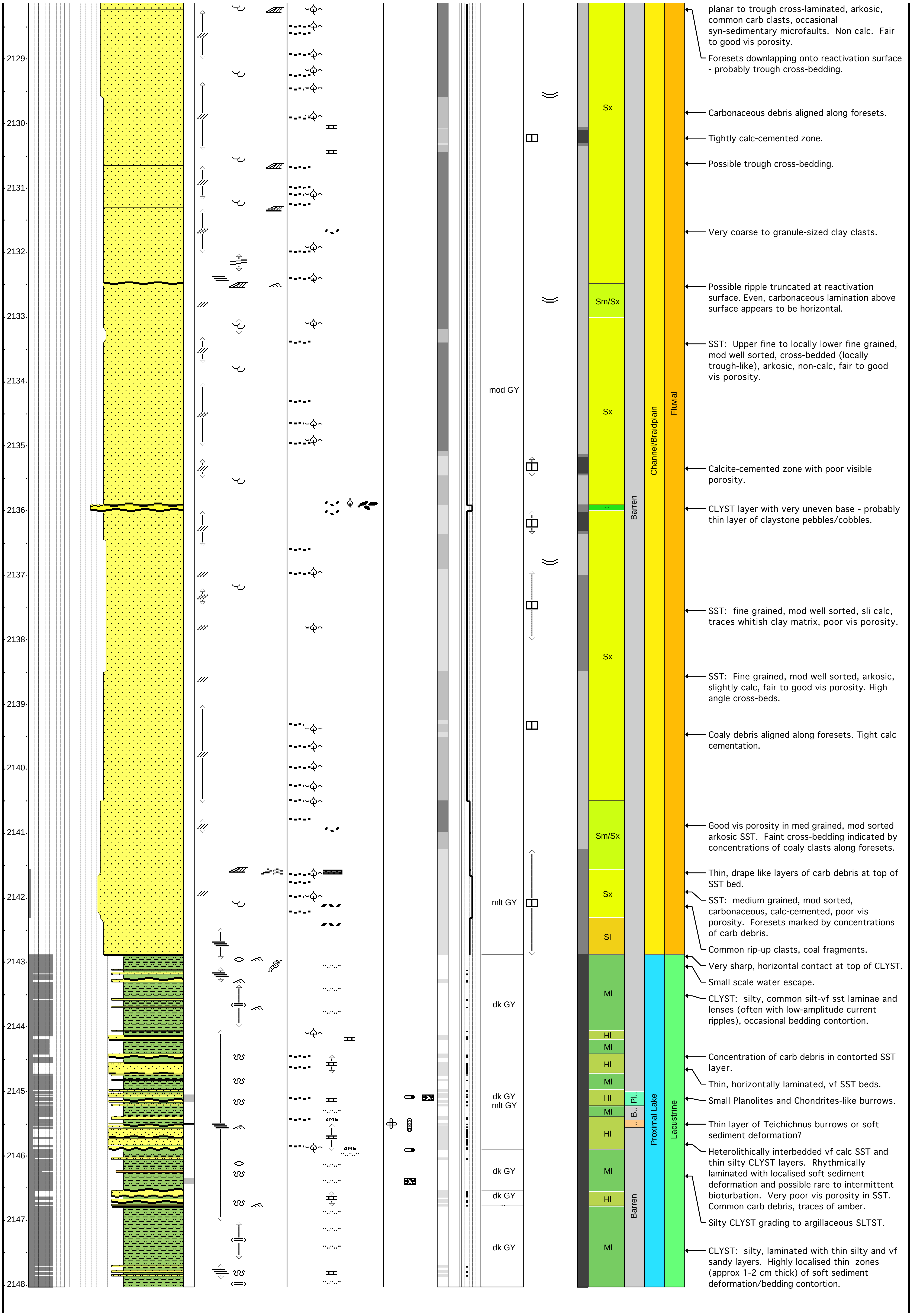
PLATE 4.33B



LONGTOM-2 ST1
APACHE ENERGY LTD

Date Logged: December 22, 2004
Logged by: Duncan Barr
Remarks: **SCALE 1:50**

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Hl
Ml
Barren
Pl..
B..
Barren
Channel/Braidplain
Fluvial
Proximal Lake
Lacustrine
planar to trough cross-laminated, arkosic, common carb clasts, occasional syn-sedimentary microfaults. Non calc. Fair to good vis porosity.
Foresets downlapping onto reactivation surface - probably trough cross-bedding.
Carbonaceous debris aligned along foresets.
Tightly calc-cemented zone.
Possible trough cross-bedding.
Very coarse to granule-sized clay clasts.
Possible ripple truncated at reactivation surface. Even, carbonaceous lamination above surface appears to be horizontal.
SST: Upper fine to locally lower fine grained, mod well sorted, cross-bedded (locally trough-like), arkosic, non-calc, fair to good vis porosity.
Calcite-cemented zone with poor visible porosity.
CLYST layer with very uneven base - probably thin layer of claystone pebbles/cobbles.
SST: fine grained, mod well sorted, sli calc, traces whitish clay matrix, poor vis porosity.
SST: Fine grained, mod well sorted, arkosic, slightly calc, fair to good vis porosity. High angle cross-beds.
Coaly debris aligned along foresets. Tight calc cementation.
Good vis porosity in med grained, mod sorted arkosic SST. Faint cross-bedding indicated by concentrations of coaly clasts along foresets.
Thin, drape like layers of carb debris at top of SST bed.
SST: medium grained, mod sorted, carbonaceous, calc-cemented, poor vis porosity. Foresets marked by concentrations of carb debris.
Common rip-up clasts, coal fragments.
Very sharp, horizontal contact at top of CLYST.
Small scale water escape.
CLYST: silty, common silt-vf sst laminae and lenses (often with low-amplitude current ripples), occasional bedding contortion.
Concentration of carb debris in contorted SST layer.
Thin, horizontally laminated, vf SST beds.
Small Planolites and Chondrites-like burrows.
Thin layer of Teichichnus burrows or soft sediment deformation?
Heterolithically interbedded vf calc SST and thin silty CLYST layers. Rhythmically laminated with localised soft sediment deformation and possible rare to intermittent bioturbation. Very poor vis porosity in SST. Common carb debris, traces of amber.
Silty CLYST grading to argillaceous SLTST.
CLYST: silty, laminated with thin silty and vf sandy layers. Highly localised thin zones (approx 1-2 cm thick) of soft sediment deformation/bedding contortion.

LEGEND

LITHOLOGY

SAND/SANDSTONE
silty sand
shaly sand

SILT/SILTSTONE
sandy silt
clayey silt

SHALE/MUDSTONE
silty shale
organic shale

matrix supported
grain supported

Lost Core

CONTACTS

Sharp
Erosional
Bioturbated
Undulating

PHYSICAL STRUCTURES

Current Ripples
Trough Cross-strat.
Oscillatory Ripples
Planar Tabular Bedding
High Angle Tabular Bedding
Low Angle Tabular Bedding
Wavy Parallel Bedding
Lenticular Bedding
Hummocky Cross-strat.
Convolute Bedding
Fault
Reactivation Surface
Mud drapes
Horizontal lamination
Faint horizontal lamination
Water escape columns
Fissure/crack
Sandstone dyke

LITHOLOGIC ACCESSORIES

Sand Lamina
Silt Lamina
Shale Lamina
Pebbles/Granules
Organic Shale Lamina
Calcareous
Rip Up Clasts
Coal Fragments
Plant remains
Shale clast
Carbonaceous laminae
Amber
Clay Pebbles
Small clay clasts

ICHNOFOSSILS

Rootlets
Planolites
Palaeophycus
Thalassinoides
Chondrites
Teichichnus
Thoroughly Bioturbated

FRACTURES

Horizontal Stress Fracs
Mineralised frac

DIAGENESIS

calcite cement

POROSITY

Excellent
Very Good
Good
Fair
Poor
Tight

BIOTURBATION

Abundant
Common
Moderate
Rare
Barren

CONSOLIDATION

Extreme
Strong
Moderate
Poor
Unconsolidated

FACIES

Gms
SZI
Sdef
Sr
Sm
Sba
Mm
Sm/Sx
Sx
Sl
Hl
Ml

ICHNOFACIES

Rootlets
Palaeophycus Association
Planolites Association
Teichichnus Association
Barren

DEPOSITIONAL ENVIRONMENT

Overbank
Channel
Distal Lake
Lake Margin
Splay
Channel/Braidplain
Proximal Lake

DEPOSITIONAL COMPLEX

Fluvial
Lacustrine