SANTOS – AWE- MITSUI

COMPILED FOR

SANTOS LIMITED

(A.B.N. 80 007 550 923)

CASINO-4

INTERPRETED DATA REPORT

PREPARED BY:
R. Subramanian
(Consultant)
October 2005

CASINO-4

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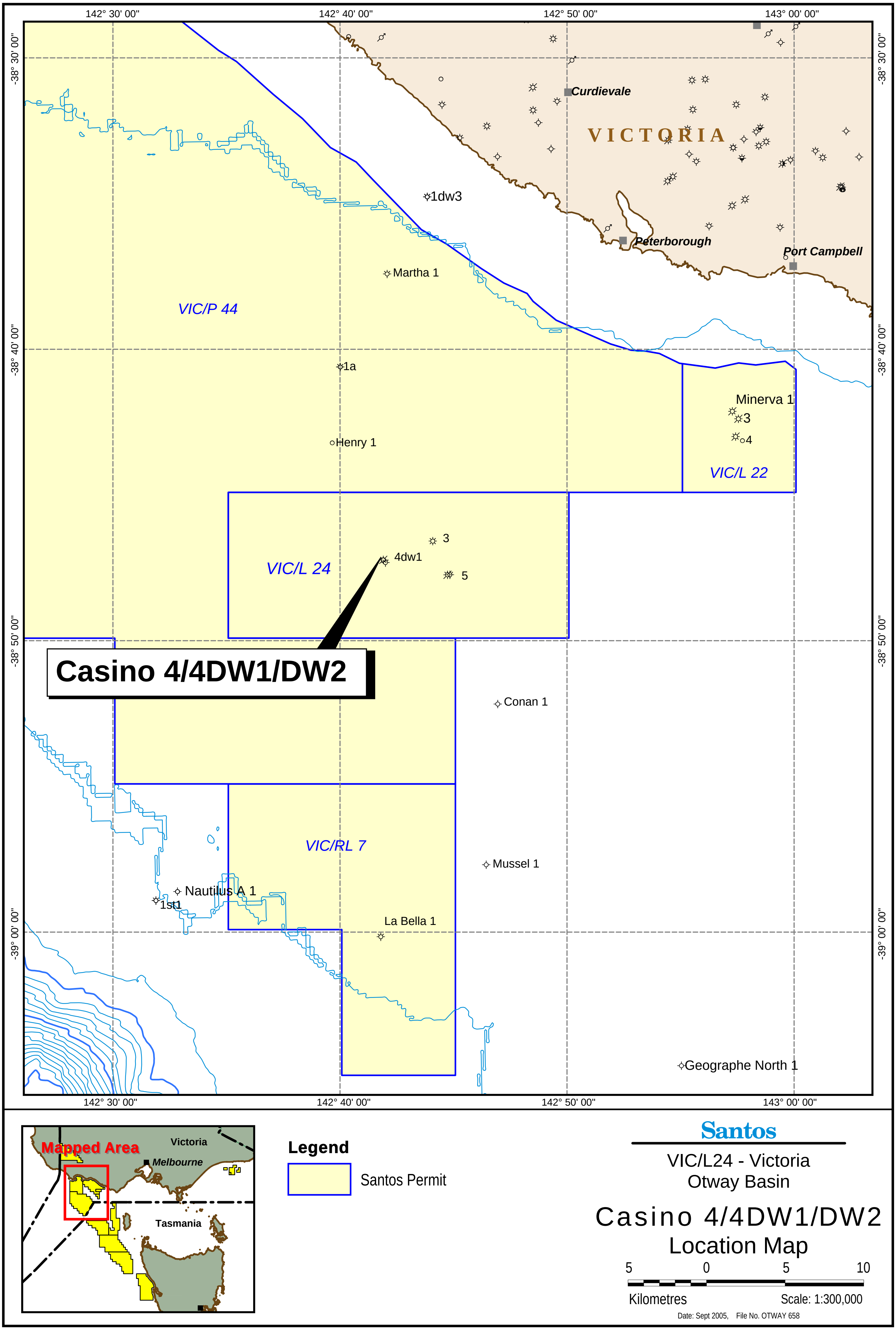
LOCATION MAP

LOCATION MAP



142° 30' 00"
142° 40' 00"
142° 50' 00"
143° 00' 00"
-38° 30' 00"
-38° 40' 00"
-38° 50' 00"
-39° 00' 00"
Curdievale
VICTORIA
Peterborough
Port Campbell
1dw3
Martha 1
VIC/P 44
1a
Henry 1
Minerva 1
3
4
VIC/L 22
VIC/L 24
3
4dw1
5
Casino 4/4DW1/DW2
Conan 1
VIC/RL 7
Mussel 1
Nautilus A 1
1st1
La Bella 1
Geographe North 1
Mapped Area
Victoria
Melbourne
Tasmania
Legend
Santos Permit
Santos
VIC/L24 - Victoria
Otway Basin
Casino 4/4DW1/DW2
Location Map
5
0
5
10
Kilometres
Scale: 1:300,000
Date: Sept 2005, File No. OTWAY 658

WELL CARD

WELL: CASINO-4	**WELL CATEGORY**: Offshore Gas Development Well (Vertical Pilot Hole) **WELL INTENT:** Gas	**SPUD:** 07-05-05 **TD REACHED:** 19-05-05 **RIG RELEASED**: 21-05-05 **CMPLT**: - **RIG**: OCEAN PATRIOT			
SURFACE LOCATION: (GDA94) **LAT:** 38° 47’ 13.03” S **LONG:** 142° 41’ 54.49” E **NORTHING:** 5705495.28m **EASTING:** 647518.19m		**STATUS**: Plugged back & Sidetracked to Casino-4DW1 **REMARKS**:			
SEISMIC SURVEY: Casino 3D Inline 6074 Xline 2742					
ELEVATION SEA FLOOR: -70.8m LAT **RT** +22.0m LAT					
BLOCK/LICENCE: Victoria – Otway Basin VIC/P44					
TD 1825 m (Logr Extrap) 1825 m (Drlr)					
PBTD m (Logr) 1308 m (Drlr) **TYPE STRUCTURE**: TILTED FAULT BLOCK		**HOLE SIZE**	**CASING SIZE**	**SHOE DEPTH**	**TYPE**
TYPE COMPLETION: NIL		914mm	762mm	137.4m	460 kg/m X56
ZONE(S): -		445mm	340mm	727.8m	107 kg/m L80 BTC

AGE	FORMATION OR ZONE TOPS	DEPTH (M) Loggers RT (m)	Subsea (m)	THICK-NESS (m)	HIGH (H) LOW (L)
Mid-Late Miocene	Seabed (Top Heytesbury Group)	92.8	70.8	675	
Eocene – Oligocene	Nirranda Group: Narrawaturk Marl	700.0	678.0	140	
Eocene	Nirranda Group: Mepunga Fm	768.0	746.0	72	5m Low
Eocene	Wangerrip Group: Dilwyn Fm	840.0	818.0	155	1m High
Palaeocene	Pebble Point Formation	995.0	972.9	116	5m High
Late Cretaceous	Timboon Sandstone	1111.5	1089.0	192	On depth
Late Cretaceous	Paarate Formation	1304.0	1281.1	256	6m Low
Late Cretaceous	Skull Creek	1561.0	1537.4	179	2.6m High
Early - Late Cretaceous	Waarre Formation	1740.0	1715.9	85	7m High
	Total Depth (Logger Extrap)	1825.0	1801.0		

TYPE OF LOG	FROM (m)	TO (m)	REPEAT SECTION	TIME SINCE LAST CIRC	BHT
MWD 311mm (12.25”) Gamma Ray, Resistivity, Vibration, Surveys (3 runs)	742	1825			
Run 1: DLL-MLL-GR-SP-CAL					
GR	1770	1700	1700 to 1782.5m	18.5 hours	68.3 C
DLL	1776	1700			(155 F)
MLL	1781	1700			
SP	1758	1700			
CAL	1781	1700			
Run 2: MREX-ZDL-CN-GR				9.0 hours	69.4 C
MPHE	1805	1700			(157 F)
ZDL	1803	1700			
CN	1797	1700			
GR	1795	1700			

LOG INTERPRETATION						PERFORATIONS	
INTERVAL(m)	Ø %	SW %	INTERVAL(m)	Ø %	SW %	FORMATION	INTERVAL
Waarre Formation :			**Waarre Formation:**				
1740-1760m:			**1760-1791.5m:**				
Net Pay: 2.4m	12.3	34	Net Pay: 21.2m	12.6	31		

CORES			
NO.	INTERVAL	CUT	REC
1	1761m-1794m	33.0m	32.4m

PRODUCTION TEST RESULTS

No production tests were conducted at Casino-4

SUMMARY:

Casino-4 was drilled as an Otway Basin gas exploration well in the Victoria Offshore VIC/P44 licence. The Surface Location is Latitude: 38° 47’ 13.03” S Longitude: 142° 41’ 54.49” E (GDA94), Northing: 5705495.28m, Easting: 647518.19m (MGA-94), with a seismic reference of Inline 6074, Xline 2742, Casino-3D Survey 2001. The location lies 220 m northwest of Casino-1. The water depth at the well location was 70.8m LAT.

The primary purpose of the Casino development drilling campaign was to drill and complete a production well in each of the Casino reservoirs thus developing the reserves of the Casino gas field. Casino-4 was a vertical pilot hole in the Waarre A reservoir while Casino-4DW1 was the Waarre A production well. The reservoir modelling work carried out as part of development planning studies highlighted the uncertainty concerning the Waarre A reservoir properties, especially the intrinsic formation permeability. To address this uncertainty it was decided to drill, core and evaluate a vertical pilot hole (designated as Casino-4) in the Waarre A reservoir. A key objective of this well was to recover a full core which would be immediately subjected to routine core analysis for porosity and permeability and selected plugs would also be subjected to special core analysis for relative permeability and petrophysical properties. The data obtained from this well would be used to understand the subsequent production performance of the Waarre A reservoir at Casino and would also be important to justify future exploration surrounding Casino targeting potential Waarre A gas accumulations.

Casino-4 was spudded at 01:00 hrs on the 7th of May 2005 utilising the semi-submersible drilling facility "Ocean Patriot". The 914mm (36") phase was drilled from seafloor at 92.8m to section total depth at 137.4m in one bit run with all returns to the seafloor. A string of 762mm (30") conductor casing was run and set at 137.4m. The 445mm (17.5”) hole section from 137.4m to 742m was also drilled in one bit run and a string of 340mm (13.375”) casing was run and set at 727.87m. The 311 mm (12.25”) phase was drilled using two bit runs along with MWD tools and a Sperry Sun GEOPILOT steerable unit from 742m to the core point at 1761m. A core was cut from 1761m to 1794m with 98.2% recovery. Thereafter, Baker Atlas wireline was rigged up and recorded Run 1: DLL-MLL-CAL-SP-GR. A wiper trip was required since the tools were hung up at 1672m. During the wiper trip, the well was drilled further to 1825m to provide additional logging rathole. The Total Depth of 1825m was reached at 02:00hrs on the 19th of May 2005. Run 2: MREX-ZDL-CN-GR was then recorded and Baker Atlas were rigged down. The 311mm (12 ¼”) section was logged while drilling with Sperry Sun MWD tools to record Gamma Ray, Resistivity, Vibration/Shock, Annular Pressure and Deviation Survey data.

While drilling Casino-4, the penetrated depths of most formations in Casino-4 were within 7m of their respective prognosed depths as can been seen in the table in the Well Card. Casino-4 encountered the top of the Waarre Formation at 1740m RT (-1715.9m SS) which was 7m high to prognosis. The well penetrated 85m (using logger extrapolated depth) of Waarre Formation terminating in the Waarre A unit.

In the Waarre Formation which was the primary target for the pilot well and the production well Casino-4DW, background gas ranged increased significantly to range between 500 and 1200 units over a general background of about 60 units. These gas readings were consistent during drilling and coring operations. The general composition of the gas was 96/2/1/1/trace %. Log analysis of the Waarre Formation indicates 2.4m Net Pay in the interval 1740m to 1760m (Average porosity 12.3% Average Sw 34%) and 21.2m Net Pay in the interval 1760m to 1791.5m (Average Porosity 12.6% Average Sw 31%).

After rigging down Baker Atlas, one cement abandonment plug was set across the reservoir as per program, Plug 1: 1684m-1825m. Another Plug 2: 1255m-1405m was set as a kick-off plug. A steering assembly was to run in hole to kick-off the sidetrack designated Casino-4DW1 at 1308m. All activities on Casino-4 ceased at 09:30 hrs on 21-05-05.

AUTHOR: R. SUBRAMANIAN **DATE**: October 2005

1. GEOLOGY

1.1 INTRODUCTION

The Casino gas field is located in the southeast corner of the offshore Otway Basin. The field lies in 70m of water and is 29km southwest of Port Campbell and 250km southwest of Melbourne. The permit holders are: Santos Limited (50%) Operator, Peedamullah Petroleum Pty Ltd (AWE) (25%), Mittwell Energy Resources Pty Limited (Mitsui) (25%)

Casino-4 was drilled in the Otway Basin in the Victoria Offshore VIC/P44 licence. The Surface Location is Latitude: 38° 47' 13.03" South, Longitude: 142° 41' 54.49" East (GDA94), Northing: 570549.5m, Easting: 647518.19m (MGA-94). The Seismic Reference is the Casino 3D Survey Inline 6074 Xline 2742. The location lies 220 m northwest of Casino-1.

Casino-4 is located in 70.8m of water and was drilled by the semi-submersible drilling rig "Ocean Patriot".

The primary purpose of the Casino development drilling campaign was to drill and complete a production well in each of the Casino reservoirs thus developing the reserves of the Casino gas field. Casino-4 was a vertical pilot hole in the Waarre A reservoir well while Casino-4DW1 was the Waarre A production well.

The reservoir modelling work carried out as part of development planning studies highlighted the uncertainty concerning the Waarre A reservoir properties, especially the intrinsic formation permeability. To address this uncertainty it was decided to drill, core and evaluate a vertical pilot hole in the Waarre A reservoir. This well was designated as Casino-4. A key objective of this well was to recover a full core which would be immediately subjected to routine core analysis for porosity and permeability and selected plugs would also be subjected to special core analysis for relative permeability and petrophysical properties. The data obtained from this well would be used to understand the subsequent production performance of the Waarre A reservoir at Casino and would also be important to justify future exploration surrounding Casino targeting potential Waarre A gas accumulations.

Following conclusion of evaluation operations on Casino-4 the well was to be plugged back and sidetracked to drill and complete a Waarre A development well, Casino-4DW1. The key objective of the directional well would be to develop the Waarre A gas reserves via a sub-horizontal completion in the Waarre A reservoir. The well path would be located so as to contact the full stratigraphic succession apart from the lowermost zone known as the calcite cemented zone.

1.2 FIELD DESCRIPTION

Introduction:

While detailed discussions on the petroleum geology of the Casino field are available elsewhere, the field can be generally summarised as follows. The structure is a tilted fault block with dip closure to the west, north and east. Prior to drilling Casino-4, the Casino field has been penetrated by three wells namely Casino-1, Casino-2 and Casino-3. The reservoir comprises Turonian aged sandstones from the Waarre Sandstone unit, part of the Shipwreck Sub Group, Sherbrook Group. Two reservoir intervals are present; the older Waarre A and the overlying Waarre C. The sandstones were deposited in fluvial to shallow marine environments. The two reservoir intervals are in separate pressure regimes. The deeper Waarre A is almost 200 psi over-pressured compared the regional aquifer gradient. The Waarre C is only slightly over-pressured at 14 psi above the regional gradient.

In the Casino area, the Waarre A gas bearing interval is approximately 50m thick and is subdivided into upper and lower units, ~20m and ~30m thick respectively. The Waarre A sands have fair reservoir properties with an average log porosity of 20%. Due to the absence of definitive core data significant uncertainty remains in the permeability of the Waarre A reservoir with average permeabilities expected to be in the range 5 – 100 mD.

The Waarre C is not present at Casino-1 having been eroded by a later erosive event. This truncation of the reservoir makes the Waarre C accumulation a combination structural/stratigraphic trap. The gross, gas bearing intervals in Casino-2 and Casino-3 have a similar thickness; 38.6m and 43.8m respectively. The Waarre C reservoir has excellent reservoir qualities, with an average porosity of 22% and permeability ranging from 100s mD to greater than 10,000mD.

The gross Waarre A gas column is 206 m, with the GWC at -1839mSS. The Waarre C gas column is 304m with the GWC at -1999mSS.

Casino-4 was a vertical pilot hole in the Waarre A reservoir well. The reservoir modelling work carried out as part of development planning studies highlighted the uncertainty concerning the Waarre A reservoir properties, especially the intrinsic formation permeability. To address this uncertainty was agreed to drill, core and evaluate a vertical pilot hole in the Waarre A reservoir via the Casino-4 well. A key objective of this well was to recover a full core which will be immediately subjected to routine core analysis for porosity and permeability and selected plugs will also be subjected to special core analysis for relative permeability and petrophysical properties. The data obtained from this well will be used to understand the subsequent production performance of the Waarre A reservoir at Casino and will also be important to justify future exploration surrounding Casino targeting potential Waarre A gas accumulations.

Following conclusion of evaluation operations on Casino-4 the well would be plugged back and sidetracked to drill and complete Waarre A development well, Casino-4DW1, the key objective which was to develop the Waarre A gas reserves via a sub-horizontal completion in the Waarre A reservoir. The well path would be located so as to contact the full stratigraphic succession apart from the lowermost zone known as the calcite cemented zone.

Working back from the heel of the sub horizontal section, the vertical pilot hole is located some 220m northwest of Casino-1. The location of the pilot hole was optimised in order to penetrate a Lower Waarre A interval predicted to be of good quality.

The only circumstances in which the Casino-4DW1 well would not be drilled were if the results of the pilot hole indicated that drilling, completion and connection of Casino-4DW1 is not economically viable.

Objectives:

The primary aim of this vertical well was to acquire a comprehensive dataset over the Waarre A reservoir, especially the Lower Waarre A, in order to better understand the reservoir properties of this interval. To achieve this aim a core was to be cut and an extensive wireline logging programme carried out. The well would be drilled to TD in 12 ¼” hole.

Casino-4 is located 220m northwest of Casino-1. The location for Casino-4 has been based on the appropriate surface location to allow the Waarre A production well, Casino-4DW1 to reach its subsurface targets.

The primary aim of the coring programme was to obtain the maximum information from the lower part of the Lower Waarre A. A 36m core will be cut.

At Casino-4 an estimated thickness of 59m was expected for the Waarre A section (Upper Waarre A 13m, Lower Waarre A1&2 34.5m, Calcite Cemented Zone 11.5m). This compares to 60m (Upper Waarre A 19m, Lower Waarre A1&2 31m, Calcite Cemented Zone 10m) at Casino-1.

The core point would be 1760m MDRT, 2.5m below the prognosed depth at the top of the Lower Waarre A zone and 32.5m above the prognosed depth to the top of the Calcite Cemented Zone. This would ensure the best quality part of the Lower Waarre A is cored and if the prognosis is correct provide some information on the nature of the calcite zone. In the event that for operational reasons coring is terminated after 27m or the lower section of the core is lost this should still provide for core material to be obtained over the main reservoir section. Following the recovery of the core it will be shipped to Portland for fast track permeability measurement via a probe permeameter.

1.3 WELL LOCATION

The Casino gas field is located in the southeast corner of the offshore Otway Basin. The field lies in 70m of water and is 29km southwest of Port Campbell and 250km southwest of Melbourne. The water depth at the well location was 70.8m LAT.

The Surface Surveyed Location for Casino-4 is :

Latitude:	38° 47’ 13.03” South
Longitude:	142° 41’ 54.49” East (GDA-94).
Easting:	647 518.19 m
Northing:	5705 495.28 m (MGA-94)
Rig	Diamond Offshore - Ocean Patriot

The Seismic Location for Casino-4 is:

Inline 6074, Xline 2742.
2001 Casino-3D seismic dataset.

2. RESULTS OF DRILLING

2.1 STRATIGRAPHY & GEOPHYSICAL PROGNOSIS

While drilling Casino-4, the penetrated depths of most formations in Casino-4 were within 7m of their respective prognosed depths as can been seen in the table in the Well Card.

The Waarre Formation, which constitutes the main reservoir, is a prominent and generally reliable seismic reflector. However due to the extremely complex post-depositional faulting in the area, the reflector is very broken-up in a regional sense. During the drilling of Casino-4 the primary objective Waarre Formation was penetrated 7m high to the prognosed depth. The depth prognosis was reasonably accurate. Depth conversion was not considered an issue. The gas sand has a strong amplitude anomaly confirming the effectiveness of the prognosis.

The well penetrated 85m of Waarre Formation (including core) and terminated after penetrating the “calcite zone”.

2.2 STRATIGRAPHY & DEPOSITIONAL ENVIRONMENT (Drillers MDRT Depths)

The well card at the front of this report tables the subsea elevations and thickness of formations penetrated in Casino-4. A brief description of lithology and interpreted environments of deposition follows. More detailed descriptions can be found in Section 2.1 of the Basic Data Report.

Total depth for Casino-4 was reached at 1825m (D). The Upper Waarre A Formation was penetrated at 1740m (L) and a core was cut as per the program from 1761m to 1794m. The hole was deepened to 1825m for a logging rathole.

The Waarre Formation makes up the oldest formation of the Sherbrook Group and is dated to be Turonian in age (Partridge, 1997). The Waarre Formation which was intersected at 1740m (L), was deposited as the initial post-rift sequence at the commencement of Turonian time. Microplankton at the base of the Waarre formation record the first evidence of wholesale marine incursion into the Otway Basin. The section is sub-divided into three sub-units – Waarre “A”, “B” & “C”.

Casino-4 penetrated 85m of “A” unit which represents a basal transgressive systems tract (TST) characterised by flooding of an incised valley with sediments deposited under marginal marine/estuarine conditions. Lithologically, the unit is similar to the underlying Eumeralla Formation from which it is sourced. The unit is comprised of fine to coarse grained lithic sandstone, interbedded with thin beds of silty carbonaceous mudstone. Onshore the sandstones are dominantly fluvial, but offshore marine conditions are indicated by coarsening upward beds.

In the cuttings samples, the sandstone is translucent, off-white to light brownish-grey to light grey, very fine to medium in size, though becoming fine to coarse grained with depth. The grains are subangular to subrounded, poorly to moderately sorted, generally contain a weak to moderate silica cement and locally abundant calcareous cement. There is trace to common light grey argillaceous matrix throughout, clear to opaque quartz grains, and minor black carbonaceous detritus. The sandstone is moderately hard, has poor visible porosity without any hydrocarbon fluorescence. The sandstone packages are generally blocky in shape. The basal Waarre is interpreted to be shallow marine to marginal marine. After the transgression in the lower part of the Waarre, the formation became more regressive, depositing the best reservoir sands in the lower coastal and delta areas.

In the Otway Basin, the Waarre Formation was transgressed by another flooding event (conformably overlain) by the **Flaxmans Formation** which is commonly the seal for the Waarre reservoir. In the Casino-4 well the Flaxmans Formation was not present.

The **Skull Creek Mudstone,** (sometimes considered part of the Paaratte Formation), unconformably overlies the Waarre Formation in Casino-4. The Skull Creek Mudstone consists of a thick siltstone which affords an excellent seal for hydrocarbons. The Belfast Mudstone and Nullawarre Greensand were not evidenced at Casino-4. The top of the Skull Creek Mudstone was encountered at 1561m and is 179m thick. The formation was penetrated 2.6m low to prognosis which is reasonably close to where it was expected. It comprises a medium to dark brown to brownish-grey siltstone which is argillaceous and grades to a silty claystone. The Skull Creek Mudstone commonly has dispersed fine to medium quartz grains, trace glauconite, trace carbonaceous specks and trace disseminated pyrite. It is soft to firm and occasional moderately hard and generally subblocky. A pro-delta environment of deposition and an age of Santonian has been attributed to the Skull Creek Mudstone.

The top of the youngest formation of the Sherbrook Group, the **Timboon Sandstone** was intersected at 1111.5m. The formation is 192m thick and is made up of thin to fairly thick sandstone packages, interbedded with siltstone. The sandstone is pale grey to grey, clear to translucent, predominantly medium grained to minor coarse grained. The sandstone is moderately well sorted and the grains are subrounded to subangular in part. The sandstone has a weak siliceous cement, has trace lithic fragments and traces of disseminated pyrite. The sandstone is friable to loose, and occasionally in moderately hard aggregates. No hydrocarbon fluorescence was observed. The interbedded siltstone is light to medium brown to brown grey, arenaceous, slightly calcareous with minor disseminated pyrite. The siltstone is firm to moderately hard and subblocky. The Timboon Sandstone was deposited in a deltaic environment, in this case, presumably delta plain, and has been dated to be Campanian to Maastrichtian in age in the Otway Basin.

Unconformably overlying the Timboon Sandstone is the oldest unit in the **Wangerrip Group**, the **Pebble Point Formation**. At Casino-4, the Pebble Point is 116 thick and was intersected at 995m. The formation is composed of interbedded claystone and sandstone. Sandstone is pale grey, clear to translucent, predominantly medium grained with minor coarse grained, becoming coarser with depth, moderately well sorted, with subangular to minor angular grains and occasionally subrounded grains. The sandstone has trace weak to moderately hard siliceous cement. It is partly friable to moderately hard, generally loose and has fair inferred porosity but no hydrocarbon fluorescence. The interbedded claystone is medium grey and medium to dark brown, slightly arenaceous, siliceous in part, partly silty, soft to firm, occasionally very hard, dispersive, amorphous to subblocky. The environment of deposition for the Pebble Point is interpreted to be shallow water, nearshore, restricted marine with periodic influxes of coarse detrital material. Various megafossils and microfossils have been identified in the formation that indicate an age ranging from Maastrichtian for the oldest strata, to Palaeocene, and even Late Palaeocene (Abele *et al*, 1995).

The **Dilwyn Formation** unconformably overlies the Pebble Point Formation at Casino-4 and was penetrated at 840m and is 155m thick. The section consists predominantly of sandstone with minor interbedded silty claystone. The sandstone is pale to medium grey, also minor pale yellow, is medium to coarse grained, moderately well sorted, with predominantly subrounded to rounded grains and partly subangular grains, with trace pyrite cement, with trace lithic fragments and commonly loose. The sandstone has a fair inferred porosity but no hydrocarbon fluorescence. The claystone is medium to dark grey and dark brown, soft to firm, occasionally hard, with trace pyrite and is very soft, very dispersive and non fissile.

Both macrofossils and microfossils from the Dilwyn have been dated to be Early Eocene. The environment of deposition is interpreted to be shallow marine, with the cleaner sandy portions representing shoreface deposits of a coastal barrier system and the interbedded section possibly back beach lagoon sediments, with some breaching occurring. Another interpretation is that the Dilwyn could have formed in a lower delta plain area with the sands, distributary channels and mouth bars, and the clays, the interdistributary bay fills (Abele *et al*., 1995).

The Dilwyn Formation is the youngest unit of the Wangerrip Group, and is unconformably overlain by the **Mepunga Formation**, the oldest formation of the **Nirranda Group**. In the Casino-4 well the Mepunga was intersected at 768m and is 72m thick. The massive sandstone is medium brown to occasionally dark brown, partly medium yellow brown, coarse to very coarse grained and minor medium grained, moderately well sorted, with grains that are subrounded to occasionally rounded and minor subangular. The sandstone has a weak siliceous cement and common Fe-staining. There are traces of glauconite and trace pyrite. The sandstone is poorly consolidated and loose in part and partly friable to moderately hard. The porosity is inferred to be fair with no hydrocarbon fluorescence being observed. There are trace of claystone which is medium brown, slightly to very silty in part, with abundant dispersed very fine to grit-sized brown-stained quartz grains in places. It is slightly calcareous in part, with a trace of glauconite, trace to common pyrite and is very soft, very dispersive and non fissile. According to dating of forams, molluscs and palynomorphs discovered within the Mepunga, an age of Middle Eocene to Early Oligocene has been given. The sandstones have been interpreted as being deposited in beach and nearshore locations as barrier islands, whereas the claystones regarded as estuarine and some as deep lagoonal in origin (Abele *et al*, 1995).

The **Narrawaturk Marl** overlies the Mepunga Formation with a conformable contact. The marl was encountered behind the casing shoe at 700m (GR pick). No cuttings of the Narrawaturk Marl were studied in the Casino-4 well since drilling was riserless. Based on offset well information, the formation is generally made up of a calcareous claystone which is intergraded with and intergrading to marl and commonly has fossil fragments of echinoid spines and bryozoa. The fossil fragments have been dated to be Late Eocene to Early Oligocene, but no older than Oligocene in age. The marl was deposited in an open marine environment, mostly below storm wave base.

Formations younger than the Narrawaturk Marl are behind casing and were not studied. These include formations (typically limestones) of the **Heytesbury Group** like the Clifton Formation which grades into the **Gellibrand Marl** which is overlain, with a transitional contact, by the **Port Campbell Limestone**, the topmost formation of the Heytesbury Group. The Port Campbell Limestone is Middle to Late Miocene in age and was deposited in a moderate-energy, continental shelf environment, above fair weather wave base. It is uncertain if all these formations were penetrated Casino-4 prior to installing the marine riser when all returns were to the seafloor.

2.3 HYDROCARBON SUMMARY

Ditch gas values were monitored and recorded in units (U) by RESERVAL Total Gas detector, where one unit is equivalent to 200 ppm (parts per million) of methane gas in air. The ditch gas was also monitored for hydrocarbon gas composition by the RESERVAL chromatograph. Gas composition refers to percent components of the hydrocarbon alkane series: (methane, ethane, propane, butane and pentane). Gas compositions are quoted as the percentage ratios of these five gases (i.e. 94/2/1/1/1 denotes 94% C1, 2% C2, 1% C3, 1% C4 and 1% C5). Ditch cuttings were tested for hydrocarbon fluorescence by using an ultra-violet fluoroscope.

Since returns were to the seafloor in the 914mm (36") and 445mm (17.5") sections, gas readings are not available from Spud to 742m. After drilling out the 340mm (13-3/8") casing shoe at 728m returns were to the surface and realtime gas monitoring was possible. From 742m to 1225m (middle of the Timboon Sandstone), Total Gas in trace quantities was recorded and consisted of 100% C1. From 1225m to 1526m (top of the Paaratte Gas Sand), background gas ranging from traces to 50 units was recorded and had a hydrocarbon composition typically 99/1/trace/trace %. From 1526m to 1740m (top of Upper Waarre A Formation), the background gas increased marginally to range generally between 30 and 100 units and comprised of 99/1/trace % to 98/2/trace/trace %.

In the Waarre Formation which was the primary target for the well and the production well Casino-4DW, background gas ranged increased significantly to range between 500 and 1200 units over a general background of about 60 units. These gas readings were consistent during drilling as well as coring operations. The general composition of the gas was 96/2/1/1/trace %. Log analysis of the Waarre Formation indicates 2.4m Net Pay in the interval 1740m to 1760m (Average porosity 12.3% Average Sw 34%) and 21.2m Net Pay in the interval 1760m to 1791.5m (Average Porosity 12.6% Average Sw 31%).

The gas levels dropped off in the underlying Calcite cemented interval (1791.5m to Total Depth at 1825m) to range between 7 and 70 units with a composition of 97/2/1/trace/trace %. No pay was identified by log analysis in this interval.

2.4 SUMMARY

Casino-4 was drilled as an Otway Basin gas exploration well in the Victoria Offshore VIC/P44 licence. The Surface Location is Latitude: 38° 47’ 13.03” S Longitude: 142° 41’ 54.49” E (GDA94), Northing: 5705495.28m, Easting: 647518.19m (MGA-94), with a seismic reference of Inline 6074, Xline 2742, Casino-3D Survey 2001. The location lies 220 m northwest of Casino-1. The water depth at the well location was 70.8m LAT.

The primary purpose of the Casino development drilling campaign was to drill and complete a production well in each of the Casino reservoirs thus developing the reserves of the Casino gas field. Casino-4 was a vertical pilot hole in the Waarre A reservoir while Casino-4DW1 was the Waarre A production well. The reservoir modelling work carried out as part of development planning studies highlighted the uncertainty concerning the Waarre A reservoir properties, especially the intrinsic formation permeability. To address this uncertainty it was decided to drill, core and evaluate a vertical pilot hole (designated as Casino-4) in the Waarre A reservoir. A key objective of this well was to recover a full core which would be immediately subjected to routine core analysis for porosity and permeability and selected plugs would also be subjected to special core analysis for relative permeability and petrophysical properties. The data obtained from this well would be used to understand the subsequent production performance of the Waarre A reservoir at Casino and would also be important to justify future exploration surrounding Casino targeting potential Waarre A gas accumulations.

Casino-4 was spudded at 01:00 hrs on the 7th of May 2005 utilising the semi-submersible drilling facility "Ocean Patriot". The 914mm (36") phase was drilled from seafloor at 92.8m to section total depth at 137.4m in one bit run with all returns to the seafloor. A string of 762mm (30") conductor casing was run and set at 137.4m. The 445mm (17.5”) hole section from 137.4m to 742m was also drilled in one bit run and a string of 340mm (13.375”) casing was run and set at 727.87m. The 311 mm (12.25”) phase was drilled using two bit runs along with MWD tools and a Sperry Sun GEOPILOT steerable unit from 742m to the core point at 1761m. A core was cut from 1761m to 1794m with 98.2% recovery. Thereafter, Baker Atlas wireline was rigged up and recorded Run 1: DLL-MLL-CAL-SP-GR. A wiper trip was required since the tools were hung up at 1672m. During the wiper trip, the well was drilled further to 1825m to provide additional logging rathole. The Total Depth of 1825m was reached at 02:00hrs on the 19th of May 2005. Run 2: MREX-ZDL-CN-GR was then recorded and Baker Atlas were rigged down. The 311mm (12 ¼”) section was logged while drilling with Sperry Sun MWD tools to record Gamma Ray, Resistivity, Vibration/Shock, Annular Pressure and Deviation Survey data.

While drilling Casino-4, the penetrated depths of most formations in Casino-4 were within 7m of their respective prognosed depths as can been seen in the table in the Well Card. Casino-4 encountered the top of the Waarre Formation at 1740m RT (-1715.9m SS) which was 7m high to prognosis. The well penetrated 85m (using logger extrapolated depth) of Waarre Formation terminating in the Waarre A unit.

In the Waarre Formation which was the primary target for the pilot well and the production well Casino-4DW, background gas ranged increased significantly to range between 500 and 1200 units over a general background of about 60 units. These gas readings were consistent during drilling and coring operations. The general composition of the gas was 96/2/1/1/trace %. Log analysis of the Waarre Formation indicates 2.4m Net Pay in the interval 1740m to 1760m (Average porosity 12.3% Average Sw 34%) and 21.2m Net Pay in the interval 1760m to 1791.5m (Average Porosity 12.6% Average Sw 31%).

After rigging down Baker Atlas, one cement abandonment plug was set across the reservoir as per program, Plug 1: 1684m-1825m. Another Plug 2: 1255m-1405m was set as a kick-off plug. A steering assembly was to run in hole to kick-off the sidetrack designated Casino-4DW1 at 1308m. All activities on Casino-4 ceased at 09:30 hrs on 21-05-05.

3. REFERENCES

Santos, 2003	Casino-4 Well Proposal, Prepared for Santos Ltd, (unpublished).
Subramanian, R., 2003	Casino-4 Basic Data Report, Prepared for Santos Limited, (unpublished).
Subramanian, R., 2002	Casino-1 Interpreted Data Report, Prepared for Santos Limited, (unpublished).
Subramanian, R., 2002	Casino-2 Interpreted Data Report, Prepared for Santos Limited, (unpublished).
Santos, 2001	Penryn-1 Well Completion Report, Prepared for Santos Limited, (unpublished).
Abele, C., Pettifer, G., Tabassi, A. 1995	The Stratigraphy, Structure, Geophysics, and Hydrocarbon Potential of The Eastern Otway Basin. Department of Agriculture, Energy And Minerals of Victoria. Geological Survey of Victoria, Geological Survey Report 103.
Partridge, A., 1997	New Upper Cretaceous Palynology of The Sherbrook Group Otway Basin. Biostrata Pty. Ltd. In PESA News, April/May.

APPENDIX I : LOG ANALYSIS

Log analysis of the Waarre Formation indicates 2.4m Net Pay in the interval 1740m to 1760m (Average porosity 12.3% Average Sw 34%) and 21.2m Net Pay in the interval 1760m to 1791.5m (Average Porosity 12.6% Average Sw 31%).

The Log analysis report is presented overleaf.

CASINO – 4

LOG ANALYSIS

Casino-4

Casino-4 was drilled to a total depth (TD) of 1825m(MDRT) as a pilot hole to identify the reservoir top and quality prior to drilling a horizontal sidetrack.. A 914mm surface hole was drilled to 137.4m where 762mm surface casing was set. A 445mm hole was then drilled to 727.8m where a 340mm intermediate casing string was set. A 311mm hole was then drilled to the coring point at 1761m. A single core was cut from 1761m to 1794m with 98.2% recovery. Run 1 of the wireline logging program was run with the tools hanging up at 1672m. During the subsequent wiper trip the hole was deepened to 1825m to provide additional logging rathole.

Casino-4 wireline logs were analysed over the interval 1700m – 1800m (MDRT), which included the Late Cretaceous Waarre Formation. Pay has been identified within both the Upper and Lower Waarre A zones.

Casino-4 was then plugged back to 1308m (MDRT) where the Casino-4DW1 production hole was kicked off.

Unless otherwise specified, all depths mentioned below are wireline depths referenced to the drill floor.

Pay Summary

Waarre Formation	Pay 23.6m, Ave Porosity 12.6%, Ave S_w 31%

Logs Acquired

MWD	GR	1825 – 742m
	Resistivity	1825 – 742m
Run 1	GR	1770 – 1700m
		1782.5 – 1700m
	DLL	1776 – 1700m
	MLL	1781 – 1700m
	SP	1758 – 1700m
	CAL	1781 – 1700m
Run 2	MREX	1805 – 1700m
	ZDL	1803-1700m
	CN	1797 – 1700m
	GR	1795 – 1700m

Cores

A single core was cut from 1761m to 1794m with 98.2% recovery. The recovered core has had both routine and special core analysis carried out.

Mud Parameters

Mud Type	KCl/IDCAP D
Mud Density	1.3 g/cc
KCl	6.0%
Rm (ZDL,CN)	0.089 ohmm @ 25^oC
Rmf (ZDL,CN)	0.072 ohmm @ 75^oC
Rmc (ZDL,CN)	0.259 ohmm @ 75^oC
MRT	69.4^oC (9hrs)

Remarks

- Hole conditions were considered to be satisfactory for the logging runs.
- Data acquired was of good quality and considered to be fit for purpose.
- Post logging verification indicated that the tools were within calibration.
- The results from both the nuclear magnetic resonance logging (MREX) and the routine and special core analysis have been used in conjunction with the MWD and wireline logs responses in the interpretation of this well.

Log Processing

- The GR was corrected for environmental effects such as mud-weight, KCl content and borehole size using measurements from the MLL caliper.
- The DLL was corrected for borehole, shoulder bed effects and formation invasion.
- The ZDL and CN were corrected for borehole and environment effects.
- The R_w values used for this analysis were obtained from previously interpreted offset wells.

Interpretation Procedures

The GEOLOG Multimin Probabilistic method was used in the section with all logs. This method focuses wireline logging tools response to the environment being logged. Response equations for predicting each measurement in the logging suite are posed in terms of summing all the volumes of minerals and fluids that influenced each sensor. These volumes were adjusted to give the optimum or most probable match of the measured and predicted readings across the suite of measurements being modelled. From this most likely solution, the volumes of minerals were derived, as were the fluid volumes and hence, porosity and fluid saturations of the modelled formation.

In general, the tool response equation can be defined as:

$$tool = (toola.xwa)(vxwa) + (toola.xga)(vxga) + (toola.xoi)(vxoi) + \sum_{i=1}^{nm}(toola.i)(v.i) +$$
$$\sum_{i=1}^{nclays}((toola_{cl}.i)(1-\phi_{cl}.i) + (toola.xbw)(\phi_{cl}.i)(v_{cl}.i))$$

Where

tool	=	Input log such as ρ_b, ϕ_N, *DT etc.*
toola.xwa	=	The response parameter for flushed fluid
vxwa	=	Volume of flushed fluid
toola.xga	=	The response parameter for gas
vxga	=	Volume of gas
toola.xoi	=	The response parameter for oil
vxoi	=	Volume of oil
nm	=	Number of formation minerals, excluding clay
toola.i	=	The response parameter for mineral *i*
v.i	=	The volume of mineral *i*
nclays	=	The number of clays in the formation
$toola_{cl}.i$	=	The dry clay response parameter for clay *i*
$\phi_{cl}.i$	=	Clay *i* porosity
tools.xbw	=	The response parameter for bound water
$v_{cl}.i$	=	The volume of clay *i*

Water saturation was calculated using the Multimin Dual Water (Linear) saturation model.

Separate Multimin models were created for the Skull Creek Formation, for the Upper Waarre A Formation, for the Lower Waarre A Formation and for the calcite cemented zone of the basal Waarre A Formation. The complete parameters for the models used are attached as Appendix 1 of this report.

Interpretation Parameters

Following are tabulations of the analysis parameters utilised in each of the interpreted intervals in the well.

Interval =	*Skull Creek Formation (1695 – 1740m)*			
Model =	*casino4_scal_skullcreek.model*			
	R_w = 0.42 ohmm @ 25°C			
Mineral	*GR_cor (GAPI)*	*Rho_cor (g/cc)*	*Nphi_cor (v/v)*	*CEC (meq/100g)*
Quartz	12	2.645	-0.05	
Illite	265	2.776	0.30	30
Kaolinite	110	2.636	0.451	12

Interval =	*Upper Waarre A (1740 – 1760m)*			
Model =	*casino4_scal_upperwaarrea.model*			
	R_w = 0.42 ohmm @ 25°C			
Mineral	*GR_cor (GAPI)*	*Rho_cor (g/cc)*	*Nphi_cor (v/v)*	*CEC (meq/100g)*
Quartz	12	2.685	-0.05	
Orthoclase	280	2.541	-0.05	
Illite	265	2.776	0.30	30
Kaolinite	110	2.636	0.451	12

Interval =	*Lower Waarre A (1760 – 1791.5m)*			
Model =	*casino4_scal_lowerwaarrea.model*			
	R_w = 0.42 ohmm @ 25^{o}C			
Mineral	*GR_cor (GAPI)*	*Rho_cor (g/cc)*	*Nphi_cor (v/v)*	*CEC (meq/100g)*
Quartz	12	2.685	-0.05	
Orthoclase	280	2.541	-0.05	
Illite	265	2.776	0.30	30
Kaolinite	110	2.636	0.451	12

Interval =	*Basal Waarre A Calcite Zone (1791.5 – 1801m)*			
Model =	*casino4_scal_calcitewaarrea.model*			
	R_w = 0.42 ohmm @ 25^{o}C			
Mineral	*GR_cor (GAPI)*	*Rho_cor (g/cc)*	*Nphi_cor (v/v)*	*CEC (meq/100g)*
Quartz	12	2.685	-0.05	
Calcite	15	2.710	0.00	
Orthoclase	280	2.541	-0.05	
Illite	265	2.776	0.30	30

Pay Summary

The definitions of ‘sand’, ‘conventional pay’, and ‘non-conventional (LDG) pay’ as utilised in this analysis, are as follows:

- Gross sand is defined as any interval where PHIE > 2%.
- Conventional nett sand is defined as any interval where PHIE > 10%.
- Conventional pay is any interval where PHIE > 10%, S_w < 70% and V_{sh} < 45%
- Non-conventional (LDG) nett sand is defined as any interval where PHIE > 4%
- Non-conventional (LDG) pay is any interval where PHIE > 4%, S_w < 70% and V_{sh} < 45%

Following are tabulations of conventional pay intervals interpreted in the Casino-4 well.

Formation	**Interval (m)**	**Gross Sand (m)**	**Nett Sand (m)**	**Avg PHIs (%)**	**Nett Pay (m)**	**Avg PHIp (%)**	**Avg Sw (%)**
Upper Waarre A Fm	1740-1760	15.9	2.4	12.3	2.4	12.3	34.0
Lower Waarre A Fm	1760-1791.5	31.5	21.2	12.6	21.2	12.6	31.0
Totals					23.6	12.6	31.3

Following are tabulations of non-conventional (LDG) pay intervals interpreted in the Casino-4 well.

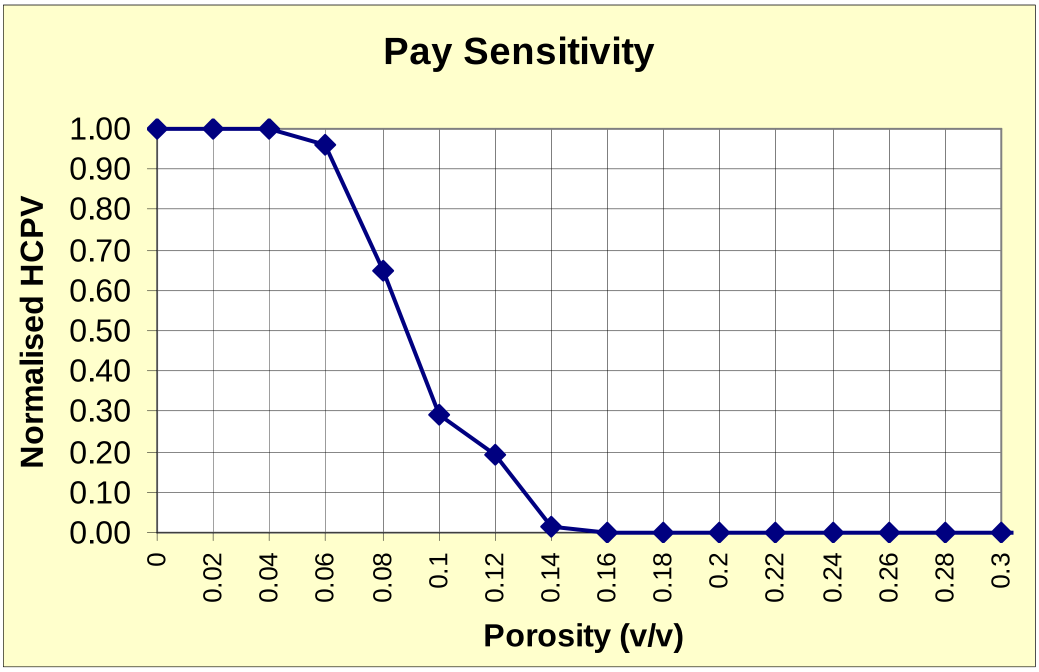
Formation	**Interval (m)**	**Gross Sand (m)**	**Nett Sand (m)**	**Avg PHIs (%)**	**Nett Pay (m)**	**Avg PHIp (%)**	**Avg Sw (%)**
Upper Waarre A Fm	1740-1760	15.9	15.5	8.0	15.2	8.3	47.0
Lower Waarre A Fm	1760-1791.5	31.5	31.0	11.1	31.0	11.1	34.0
Totals					46.2	10.2	38.3

Pay Sensitivity Plots

Pay Sensitivity data and plots have been produced at 2% porosity increments and are included as follows:

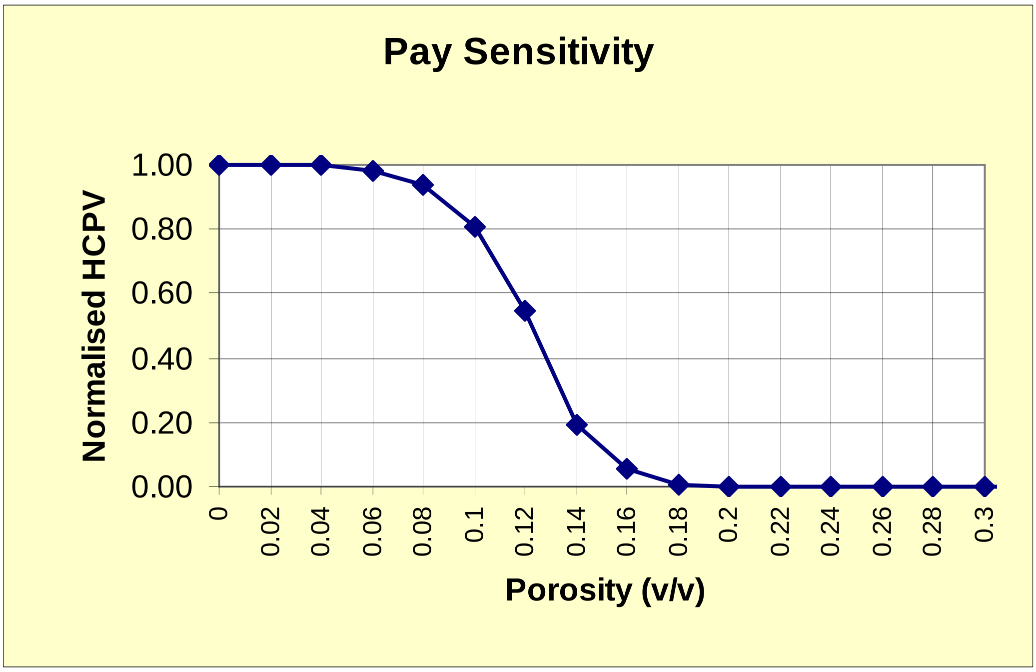
CASINO_4
UPPER WAARRE A

PHIE Cutoff	SWT Cutoff	AVG PHIE V/V	AVG SWT V/V	Phie*H	HCPV Sg*Phie*H	NET (m)	NHCPV
0	0.7	0.083	0.47	1.268	0.672	15.2	1.00
0.02	0.7	0.083	0.47	1.268	0.672	15.2	1.00
0.04	0.7	0.083	0.47	1.268	0.672	15.2	1.00
0.06	0.7	0.087	0.459	1.191	0.645	13.7	0.96
0.08	0.7	0.098	0.419	0.753	0.437	7.7	0.65
0.1	0.7	0.123	0.339	0.295	0.195	2.4	0.29
0.12	0.7	0.129	0.322	0.194	0.131	1.5	0.19
0.14	0.7	0.141	0.288	0.014	0.01	0.1	0.01
0.16	0.7	0	0	0	0	0	0.00
0.18	0.7	0	0	0	0	0	0.00
0.2	0.7	0	0	0	0	0	0.00
0.22	0.7	0	0	0	0	0	0.00
0.24	0.7	0	0	0	0	0	0.00
0.26	0.7	0	0	0	0	0	0.00
0.28	0.7	0	0	0	0	0	0.00
0.3	0.7	0	0	0	0	0	0.00



CASINO_4
LOWER WAARRE A

PHIE Cutoff	SWT Cutoff	AVG PHIE V/V	AVG SWT V/V	Phie*H	HCPV Sg*Phie*H	NET (m)	NHCPV
0	0.7	0.11	0.345	3.451	2.261	31.5	1.00
0.02	0.7	0.11	0.345	3.451	2.261	31.5	1.00
0.04	0.7	0.111	0.343	3.432	2.255	31	1.00
0.06	0.7	0.114	0.338	3.347	2.217	29.3	0.98
0.08	0.7	0.119	0.329	3.166	2.123	26.7	0.94
0.1	0.7	0.126	0.315	2.672	1.832	21.2	0.81
0.12	0.7	0.137	0.288	1.744	1.242	12.7	0.55
0.14	0.7	0.152	0.257	0.579	0.43	3.8	0.19
0.16	0.7	0.171	0.216	0.154	0.121	0.9	0.05
0.18	0.7	0.181	0.198	0.018	0.014	0.1	0.01
0.2	0.7	0	0	0	0	0	0.00
0.22	0.7	0	0	0	0	0	0.00
0.24	0.7	0	0	0	0	0	0.00
0.26	0.7	0	0	0	0	0	0.00
0.28	0.7	0	0	0	0	0	0.00
0.3	0.7	0	0	0	0	0	0.00



Conclusions

- Casino-4 log analysis has identified 23.6m of pay in the Waarre A Fm (average porosity of 12.6% and average S_w of 31%).

- Casino-4 log analysis has identified 46.2m of non-conventional (LDG) pay in the Waarre A Fm (average porosity of 10.2% and average S_w of 38%).

- Casino-4 has been plugged back to 1308m(MDRT) where the Casino-4DW1 production hole was kicked off.

- Casino-4 analysis results have been graphically presented in the well evaluation summary (WES) plot - */data/wes_ot/casino4_05050_waarre.wes*

Appnedix 1. – Multimin Models

```
*************************************
*                                   *
*          MULTIMIN REPORT          *
*                                   *
*    Project : PETRO_RDSM           *
*    User id : spira                *
*    Date    : 10-Nov-2005 10:03:17 *
*                                   *
*************************************
```

MULTIMIN REPORT for well CASINO_4 interval SKULL CREEK FM (TOP OF DATA) (1695.00 - 1739.96 metres) Project PETRO_RDSM

Reported by spira on 10-Nov-2005 at 10:03

Analysed by spira on 05-Oct-2005 at 10:10

Model Name = CASINO4_SCAL_SKULLCREEK

MODELS:

Type	Name	Cond#	Cutoff	Expression
Primary	CASINO4_SCAL_SKUL	2.712	10.0	

FORMATION FLUID PARAMETERS:

Fluid properties option = DEPTH

Oil Gravity Degrees API = 30.00 dapi   Gas specific gravity = 0.650

Rws = 0.4200 @ 25.00 degC   Cwbs = - @ - degC   Rmfs = 0.0850 @ 17.88 degC

BOREHOLE PARAMETERS:

Mud base = WATER   Mud density = 1.300 g/c3   KCl concentration of mud = 6.00 %

SHT = -   BHT = -

Rms = 0.1040 @ 18.17 degC   Rmcs = 0.301 @ 18.54 degC   Total depth = - metres

Average temperature of 75.65 degC by method.

Average pressure of 21727.37 kpa by method.

PRIMARY MODEL CASINO4_IGP_SKULLCREEK_SCAL:
Cementation factor m = 2.000 Saturation exponent n = 2.000 Linear dual-water w = 1.89
Expansion of clay bound water is enabled.

Component	QUARTZ	ILLITE	KAOLIN	XBNDWAT	XFREWAT	UBNDWAT	UFREWAT
Error of prediction	0.0337	0.0396	0.0666	0.0114	0.0223	0.0124	0.0220

EQUATION RESPONSES:

Log	Method	Uncertainty	QUARTZ	ILLITE	KAOLIN	XBNDWAT	XFREWAT	UBNDWAT	UFREWAT
Formation density [G/C3] RHO_COR	Linear	RHO_COR_UNC	2.645	2.776	2.636	1.051	1.051	0.000	0.000
Neutron [V/V] TNPH_COR	Linear	TNPH_COR_UNC	-0.050	0.300	0.451	0.940	0.940	0.000	0.000
Total gamma [GAPI] GR_COR	Linear	6.0000	12.0	265.0	110.0	0.0	28.8	0.0	0.0
Unflushed conductivity [MH/M] CT	Dual-water linear	0.0703I	0.00	0.00	0.00	0.00	0.00	14.24	4.97
Flushed conductivity [MH/M] CXO	Dual-water linear	0.1780I	0.00	0.00	0.00	22.01	28.69	0.00	0.00

CONSTRAINTS:

Constraint	Value	Type	Uncertainty	QUARTZ	ILLITE	KAOLIN	XBNDWAT	XFREWAT	UBNDWAT	UFREWAT
<PROG UNITY>	1.000	Tool	0.0100	1.000	1.000	1.000	0.000	0.000	1.000	1.000
<PROG POROSITY>	0.000	Tool	0.0100	0.000	0.000	0.000	1.000	1.000	-1.000	-1.000
<PROG X BNDWAT>	0.000	Tool	0.0100	0.000	0.212	0.080	-1.000	0.000	0.000	0.000
<PROG U BNDWAT>	0.000	Tool	0.0100	0.000	0.326	0.123	0.000	0.000	-1.000	0.000

PROPERTIES AND BOUNDS:

	QUARTZ	ILLITE	KAOLIN	XBNDWAT	XFREWAT	UBNDWAT	UFREWAT
Mineral grain density	2.645	2.780	2.620	0.000	0.000	0.000	0.000
Mineral cation exchange capacity	0.000	30.000	12.000	0.000	0.000	0.000	0.000
Lower Bound	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Upper Bound	1.000	1.000	1.000	0.500	0.500	0.500	0.500

MULTIMIN REPORT for well CASINO_4 interval UPPER WARRE A (1740.03 - 1760.00 metres)   Project PETRO_RDSM
Reported by spira   on 10-Nov-2005 at 10:03
Analysed by spira   on 05-Oct-2005 at 10:10

Model Name = CASINO4_SCAL_UPPERWAARREA

MODELS:

Type	Name	Cond#	Cutoff	Expression
Primary	CASINO4_SCAL_UPPE	3.101	10.0	

FORMATION FLUID PARAMETERS:
Fluid properties option = DEPTH
Oil Gravity Degrees API = 30.00 dapi   Gas specific gravity = 0.650
Rws = 0.4200 @ 25.00 degC   Cwbs = - @ - degC   Rmfs = 0.0850 @ 17.88 degC

BOREHOLE PARAMETERS:
Mud base = WATER   Mud density = 1.300 g/c3   KCl concentration of mud = 6.00 %
SHT = -   BHT = -
Rms = 0.1040 @ 18.17 degC   Rmcs = 0.301 @ 18.54 degC   Total depth = - metres

Average temperature of 76.97 degC by method.
Average pressure of 22138.51 kpa by method.

MULTIMIN REPORT for well CASINO_4 interval UPPER WARRE A (1740.03 - 1760.00 metres) Project PETRO_RDSM

PRIMARY MODEL CASINO4_IGP_UPR_WARRE_SCAL:
Cementation factor m = 2.000 Saturation exponent n = 2.000 Linear dual-water w = 1.89
Expansion of clay bound water is enabled.

Component	QUARTZ	ORTHOCL	ILLITE	KAOLIN	XGAS	XBNDWAT	XFREWAT	UGAS	UBNDWAT	UFREWAT
Error of prediction	0.0417	0.0534	0.0637	0.0701	0.0260	0.0145	0.0356	0.0352	0.0195	0.0425

EQUATION RESPONSES:

Log / Method	Uncertainty	QUARTZ	ORTHOCL	ILLITE	KAOLIN	XGAS	XBNDWAT	XFREWAT	UGAS	UBNDWAT	UFREWAT
Formation density [G/C3] RHO_COR Linear	RHO_COR_UNC	2.645	2.541	2.776	2.636	0.026	1.050	1.050	0.000	0.000	0.000
Neutron [V/V] TNPH_COR Linear	TNPH_COR_UNC	-0.050	-0.050	0.300	0.451	0.358	0.940	0.940	0.000	0.000	0.000
Photoelectric absorption [B/C3] U Linear	U_UNC	4.78	7.29	11.73	4.50	0.02	0.84	0.84	0.00	0.00	0.00
Total gamma [GAPI] GR_COR Linear	GR_COR_UNC	12.0	280.0	265.0	110.0	0.0	0.0	28.8	0.0	0.0	0.0
Unflushed conductivity [MH/M] CT Dual-water linear	CT_UNC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	14.43	5.04
Flushed conductivity [MH/M] CXO Dual-water linear	0.1793I	0.00	0.00	0.00	0.00	0.00	22.43	29.08	0.00	0.00	0.00

CONSTRAINTS:	Value	Type	Uncertainty	QUARTZ	ORTHOCL	ILLITE	KAOLIN	XGAS	XBNDWAT	XFREWAT	UGAS	UBNDWAT	UFREWAT
<PROG UNITY>	1.000	Tool	0.0100	1.000	1.000	1.000	1.000	0.000	0.000	0.000	1.000	1.000	1.000
<PROG POROSITY>	0.000	Tool	0.0100	0.000	0.000	0.000	0.000	1.000	1.000	1.000	-1.000	-1.000	-1.000
<PROG X BNDWAT>	0.000	Tool	0.0100	0.000	0.000	0.212	0.080	0.000	-1.000	0.000	0.000	0.000	0.000
<PROG U BNDWAT>	0.000	Tool	0.0100	0.000	0.000	0.326	0.123	0.000	0.000	0.000	0.000	-1.000	0.000
<PROG WATER MUD>	0.000	<=	-	0.000	0.000	0.000	0.000	0.000	1.000	1.000	0.000	-1.000	-1.000

PROPERTIES AND BOUNDS:

	QUARTZ	ORTHOCL	ILLITE	KAOLIN	XGAS	XBNDWAT	XFREWAT	UGAS	UBNDWAT	UFREWAT
Mineral grain density	2.685	2.570	2.780	2.620	0.000	0.000	0.000	0.000	0.000	0.000
Mineral cation exchange capacity	0.000	0.000	30.000	12.000	0.000	0.000	0.000	0.000	0.000	0.000
Lower Bound	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Upper Bound	1.000	0.100	1.000	1.000	0.500	0.500	0.500	0.500	0.500	0.500

MULTIMIN REPORT for well CASINO_4 interval LOWER WARRE A (1760.08 - 1791.47 metres) Project PETRO_RDSM
Reported by spira on 10-Nov-2005 at 10:03
Analysed by spira on 05-Oct-2005 at 10:10

Model Name = CASINO4_SCAL_LOWERWAARREA

MODELS:

Type	Name	Cond#	Cutoff	Expression
Primary	CASINO4_SCAL_LOWE	3.101	10.0	

FORMATION FLUID PARAMETERS:
Fluid properties option = DEPTH
Oil Gravity Degrees API = 30.00 dapi   Gas specific gravity = 0.650
Rws = 0.4200 @ 25.00 degC   Cwbs = - @ - degC   Rmfs = 0.0850 @ 17.88 degC

BOREHOLE PARAMETERS:
Mud base = WATER   Mud density = 1.300 g/c3   KCl concentration of mud = 6.00 %
SHT = -   BHT = -
Rms = 0.1040 @ 18.17 degC   Rmcs = 0.301 @ 18.54 degC   Total depth = - metres

Average temperature of 78.01 degC by method.
Average pressure of 22464.90 kpa by method.

PRIMARY MODEL CASINO4_IGP_LWR_WARRE_SCAL:
Cementation factor m = 2.000 Saturation exponent n = 2.000 Linear dual-water w = 1.89
Expansion of clay bound water is enabled.

Component	QUARTZ	ORTHOCL	ILLITE	KAOLIN	XGAS	XBNDWAT	XFREWAT	UGAS	UBNDWAT	UFREWAT
Error of prediction	0.0417	0.0534	0.0637	0.0700	0.0260	0.0145	0.0356	0.0351	0.0195	0.0424

EQUATION RESPONSES:

Log / Method / Uncertainty	QUARTZ	ORTHOCL	ILLITE	KAOLIN	XGAS	XBNDWAT	XFREWAT	UGAS	UBNDWAT	UFREWAT
Formation density [G/C3] RHO_COR_UNC RHO_COR Linear	2.645	2.541	2.776	2.636	0.028	1.049	1.049	0.000	0.000	0.000
Neutron [V/V] TNPH_COR_UNC TNPH_COR Linear	-0.050	-0.050	0.300	0.451	0.360	0.939	0.939	0.000	0.000	0.000
Photoelectric absorption [B/C3] U_UNC U Linear	4.78	7.29	11.73	4.50	0.02	0.84	0.84	0.00	0.00	0.00
Total gamma [GAPI] GR_COR_UNC GR_COR Linear	12.0	280.0	265.0	110.0	0.0	0.0	28.8	0.0	0.0	0.0
Unflushed conductivity [MH/M] CT_UNC CT Dual-water linear	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	14.58	5.10
Flushed conductivity [MH/M] 0.1803I CXO Dual-water linear	0.00	0.00	0.00	0.00	0.00	22.77	29.38	0.00	0.00	0.00

CONSTRAINTS:

Constraint	Value	Type	Uncertainty	QUARTZ	ORTHOCL	ILLITE	KAOLIN	XGAS	XBNDWAT	XFREWAT	UGAS	UBNDWAT	UFREWAT
<PROG UNITY>	1.000	Tool	0.0100	1.000	1.000	1.000	1.000	0.000	0.000	0.000	1.000	1.000	1.000
<PROG POROSITY>	0.000	Tool	0.0100	0.000	0.000	0.000	0.000	1.000	1.000	1.000	-1.000	-1.000	-1.000
<PROG X BNDWAT>	0.000	Tool	0.0100	0.000	0.000	0.212	0.080	0.000	-1.000	0.000	0.000	0.000	0.000
<PROG U BNDWAT>	0.000	Tool	0.0100	0.000	0.000	0.326	0.123	0.000	0.000	0.000	0.000	-1.000	0.000
<PROG WATER MUD>	0.000	<=	-	0.000	0.000	0.000	0.000	0.000	1.000	1.000	0.000	-1.000	-1.000

PROPERTIES AND BOUNDS:

Property	QUARTZ	ORTHOCL	ILLITE	KAOLIN	XGAS	XBNDWAT	XFREWAT	UGAS	UBNDWAT	UFREWAT
Mineral grain density	2.685	2.570	2.780	2.620	0.000	0.000	0.000	0.000	0.000	0.000
Mineral cation exchange capacity	0.000	0.000	30.000	12.000	0.000	0.000	0.000	0.000	0.000	0.000
Lower Bound	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Upper Bound	1.000	0.100	1.000	1.000	0.500	0.500	0.500	0.500	0.500	0.500

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 MULTIMIN REPORT for well CASINO_4 interval CALCITE (1791.55 - 1825.00 metres)         Project PETRO_RDSM
      Reported by spira            on 10-Nov-2005 at 10:03
      Analysed by spira            on 05-Oct-2005 at 10:10

Model Name = CASINO4_SCAL_CALCITEWAARREA

 MODELS:
        Type    Name              Cond# Cutoff Expression

      Primary   CASINO4_SCAL_CALC 3.313  10.0


 FORMATION FLUID PARAMETERS:
      Fluid properties option = DEPTH
      Oil Gravity Degrees API = 30.00 dapi    Gas specific gravity = 0.650
      Rws = 0.4200  @ 25.00 degC              Cwbs = -  @ - degC                      Rmfs = 0.0850  @ 17.88 degC


 BOREHOLE PARAMETERS:
      Mud base = WATER                        Mud density = 1.300 g/c3                KCl concentration of mud = 6.00 %
      SHT = -                                 BHT = -
      Rms = 0.1040  @ 18.17 degC              Rmcs = 0.301  @ 18.54 degC              Total depth = - metres

      Average temperature of 79.16 degC by  method.
      Average pressure of 22824.17 kpa by  method.
```

MULTIMIN REPORT for well CASINO_4 interval CALCITE (1791.55 - 1825.00 metres)   Project PETRO_RDSM

PRIMARY MODEL CASINO4_IGP_CALCITE_SCAL:
Cementation factor m = 2.000   Saturation exponent n = 2.000   Linear dual-water w = 1.89
Expansion of clay bound water is enabled.

Component	QUARTZ	CALCITE	ORTHOCL	ILLITE	XGAS	XBNDWAT	XFREWAT	UGAS	UBNDWAT	UFREWAT
Error of prediction	0.0567	0.0558	0.0676	0.0728	0.0273	0.0181	0.0426	0.0316	0.0262	0.0523

EQUATION RESPONSES:

Log	Method	Uncertainty	QUARTZ	CALCITE	ORTHOCL	ILLITE	XGAS	XBNDWAT	XFREWAT	UGAS	UBNDWAT	UFREWAT
Formation density [G/C3] RHO_COR	Linear	RHO_COR_UNC	2.645	2.710	2.541	2.776	0.029	1.048	1.048	0.000	0.000	0.000
Neutron [V/V] TNPH_COR	Linear	TNPH_COR_UNC	-0.050	0.000	-0.050	0.300	0.363	0.938	0.938	0.000	0.000	0.000
Photoelectric absorption [B/C3] U	Linear	U_UNC	4.78	13.77	7.29	11.73	0.02	0.84	0.84	0.00	0.00	0.00
Total gamma [GAPI] GR_COR	Linear	GR_COR_UNC	12.0	15.0	280.0	265.0	0.0	0.0	28.8	0.0	0.0	0.0
Unflushed conductivity [MH/M] CT	Dual-water linear	CT_UNC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	14.77	5.16
Flushed conductivity [MH/M] CXO	Dual-water linear	0.1815I	0.00	0.00	0.00	0.00	0.00	23.20	29.77	0.00	0.00	0.00

CONSTRAINTS:

Constraint	Value	Type	Uncertainty	QUARTZ	CALCITE	ORTHOCL	ILLITE	XGAS	XBNDWAT	XFREWAT	UGAS	UBNDWAT	UFREWAT
<PROG UNITY>	1.000	Tool	0.0100	1.000	1.000	1.000	1.000	0.000	0.000	0.000	1.000	1.000	1.000
<PROG POROSITY>	0.000	Tool	0.0100	0.000	0.000	0.000	0.000	1.000	1.000	1.000	-1.000	-1.000	-1.000
<PROG X BNDWAT>	0.000	Tool	0.0100	0.000	0.000	0.000	0.212	0.000	-1.000	0.000	0.000	0.000	0.000
<PROG U BNDWAT>	0.000	Tool	0.0100	0.000	0.000	0.000	0.326	0.000	0.000	0.000	0.000	-1.000	0.000
<PROG WATER MUD>	0.000	<=	-	0.000	0.000	0.000	0.000	0.000	1.000	1.000	0.000	-1.000	-1.000

PROPERTIES AND BOUNDS:

	QUARTZ	CALCITE	ORTHOCL	ILLITE	XGAS	XBNDWAT	XFREWAT	UGAS	UBNDWAT	UFREWAT
Mineral grain density	2.685	2.710	2.570	2.780	0.000	0.000	0.000	0.000	0.000	0.000
Mineral cation exchange capacity	0.000	0.000	0.000	30.000	0.000	0.000	0.000	0.000	0.000	0.000
Lower Bound	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Upper Bound	1.000	0.120	0.100	1.000	0.500	0.500	0.500	0.500	0.500	0.500

```
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*                                   *
*          MULTIMIN REPORT          *
*                                   *
*       *** End of Report ***       *
*                                   *
*    Project : PETRO_RDSM           *
*    User id : spira                *
*    Date    : 10-Nov-2005 10:03:18 *
*    Pages   :   8                  *
*                                   *
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APPENDIX II: HYDROCARBON SHOW REPORT

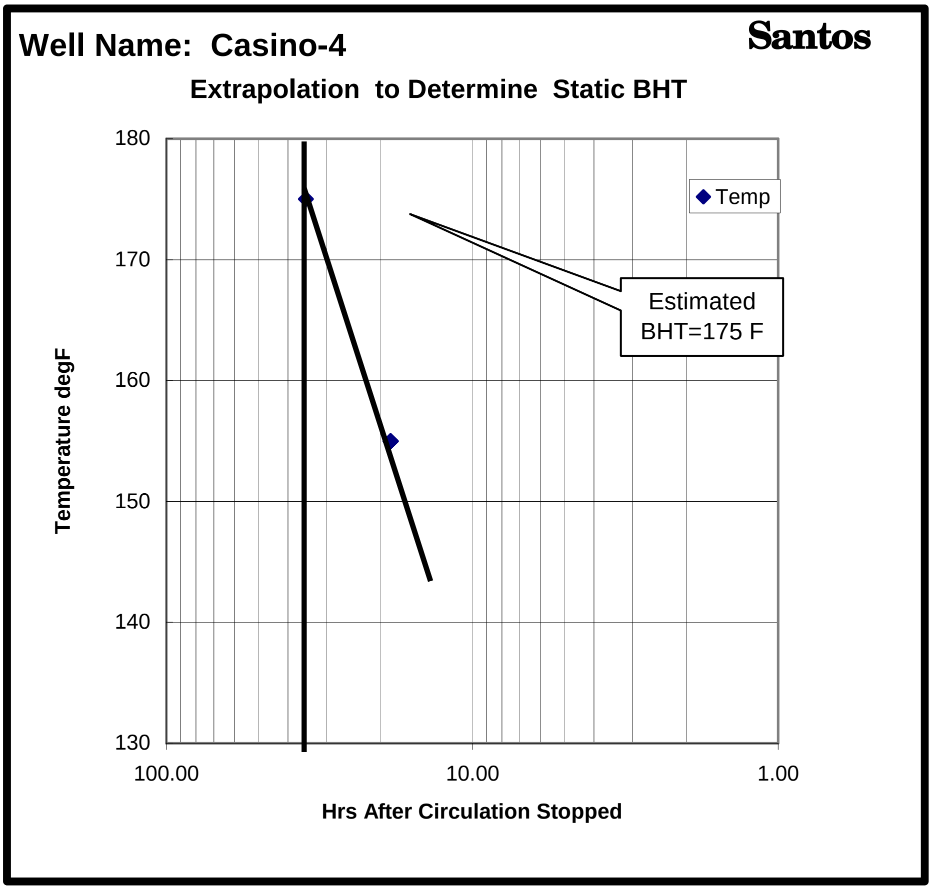
No Hydrocarbon Fluorescence was observed in Casino-4.

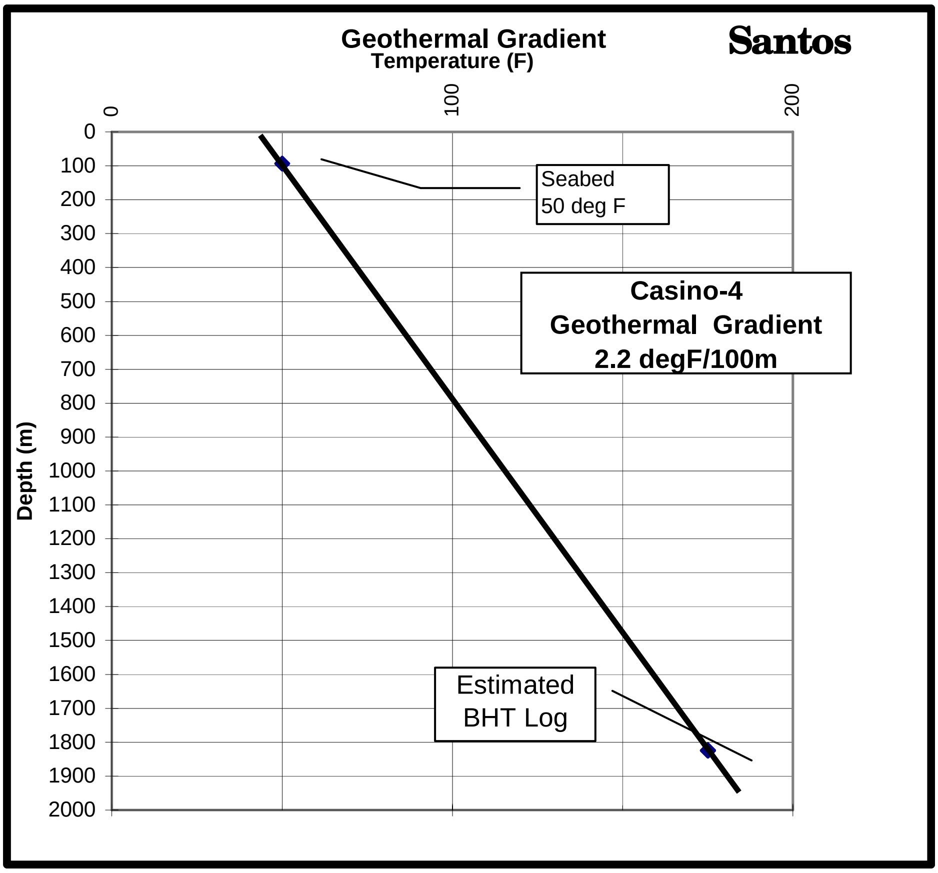
APPENDIX III : GEOTHERMAL GRADIENT

Data from Wireline Logs were used to estimate a Geothermal Gradient. An extrapolated static bottom hole temperature of 175°F at 1825m and a geothermal gradient of 2.2°F/100m were calculated from downhole temperatures recorded during logging operations.

LOG	TEMP (°C)	TEMP (°F)	DEPTH	TIME SINCE LAST CIRC
COMBO	68.3°C	155	1782m	18.50 hrs
MREX	69.4°C	157	1797m	9.00 hrs
SEABED	10°C	50	93m	

The results are depicted graphically overleaf.


Well Name: Casino-4
Santos
Extrapolation to Determine Static BHT
Temperature degF
180
170
160
150
140
130
100.00
10.00
1.00
Hrs After Circulation Stopped
Temp
Estimated
BHT=175 F


Geothermal Gradient
Temperature (F)
Santos
0
100
200
Depth (m)
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
Seabed
50 deg F
Casino-4
Geothermal Gradient
2.2 degF/100m
Estimated
BHT Log

APPENDIX IV : CORE REPORT (SCAL)

A summary of SCAL results is presented overleaf.
The final SCAL report will be forwarded when upon completion.

CASINO 4

SAMPLE NUMBER	DEPTH (m)	800psig NOB PRESSURE PERMEABILITY Kinf (md)	Kair (md)	POROSITY (%)	POROSITY (v/v)	GRAIN DENSITY (g/cc)	COMMENTS
Core 1							
1	1782.53	35.8	40.3	22.0	0.220	2.671	
2	1784.13	0.498	0.705	15.6	0.156	2.659	
3	1790.10	43.3	48.8	22.5	0.225	2.667	
4	1790.72	3.91	4.97	17.7	0.177	2.692	
5	1791.70	0.008	0.014	4.4	0.044	2.705	
6	1765.70	0.876	1.23	15.7	0.157	2.685	
7	1766.57	0.886	1.26	16.5	0.165	2.727	
8	1767.15	0.282	0.437	15.0	0.150	2.689	
9	1773.24	218	267	21.3	0.213	2.690	
10	1773.85	1.52	2.07	19.2	0.192	2.684	
11	1761.20	399	430	25.5	0.255	2.657	
12	1763.32	12.5	14.8	20.5	0.205	2.711	
13	1770.37	97.3	114	21.8	0.218	2.690	
14	1786.32	5.61	6.98	20.3	0.203	2.669	
15	1787.92	0.222	0.356	13.9	0.139	2.680	
16	1761.50	21.3	23.9	18.5	0.185	2.637	
17	1761.80	103	117	21.9	0.219	2.688	
18	1762.10	1090	1180	24.3	0.243	2.687	
19	1762.33	2.67	3.06	13.9	0.139	2.663	
20	1762.60	86.2	97.5	22.3	0.223	2.653	
21	1762.87	16.9	19.7	21.1	0.211	2.684	
22	1763.61	2.66	3.44	18.5	0.185	2.699	
23	1763.90	4.25	5.32	18.1	0.181	2.679	
24	1764.20	0.524	0.790	16.6	0.166	2.679	
25	1764.50	1.16	1.63	17.6	0.176	2.686	
26	1764.82	1.37	1.89	17.6	0.176	2.691	
27	1765.12	0.685	0.975	15.9	0.159	2.726	
28	1765.41	0.008	0.015	8.4	0.084	2.714	
29	1766.04	1.64	2.22	17.6	0.176	2.727	
30	1766.30	1.01	1.42	17.5	0.175	2.705	
31	1766.93	0.461	0.589	14.9	0.149	2.689	Humidity Dried
32	1767.50	0.211	0.344	14.9	0.149	2.691	
33	1767.81	0.531	0.673	16.2	0.162	2.687	
34	1768.10	0.612	0.901	16.5	0.165	2.702	
35	1768.40	0.174	0.281	13.8	0.138	2.666	
36	1768.71	1.97	2.61	18.0	0.180	2.680	
37	1768.97	2.58	3.34	18.3	0.183	2.673	
38	1769.30	1.34	1.85	17.7	0.177	2.683	
39	1769.63	13.8	16.1	20.1	0.201	2.663	
40	1769.91	121	137	21.8	0.218	2.732	
41	1770.15	427	466	24.3	0.243	2.701	
42	1770.70	0.053	0.102	11.6	0.116	2.687	
43	1770.98	1.18	1.66	17.4	0.174	2.681	
44	1771.29	2.52	3.27	18.3	0.183	2.680	
45	1771.60	7.47	9.12	19.0	0.190	2.669	
46	1771.91	29.3	33.5	20.7	0.207	2.668	Humidity Dried

CASINO 4

SAMPLE NUMBER	DEPTH (m)	800psig NOB PRESSURE PERMEABILITY Kinf (md)	Kair (md)	POROSITY (%)	POROSITY (v/v)	GRAIN DENSITY (g/cc)	COMMENTS
47	1772.30	2.27	3.01	18.4	0.184	2.676	
48	1772.56	2.05	2.73	18.3	0.183	2.681	
49	1772.92	0.706	1.02	16.4	0.164	2.691	
50	1773.50	4.04	5.14	19.1	0.191	2.657	Humidity Dried
51	1774.20	2.16	2.85	18.8	0.188	2.690	
52	1774.50	0.538	0.815	17.6	0.176	2.691	
53	1774.80	0.685	1.01	17.6	0.176	2.691	
54	1775.10	0.705	1.02	17.4	0.174	2.691	
55	1775.40	3.48	4.45	20.0	0.200	2.690	
56	1775.72	8.07	9.80	20.3	0.203	2.670	Humidity Dried
57	1775.98	4.45	5.64	20.1	0.201	2.687	
58	1776.30	25.3	28.7	21.5	0.215	2.668	
59	1776.60	1.50	2.02	18.1	0.181	2.674	
60	1776.92	5.40	6.65	19.3	0.193	2.662	
61	1777.20	2.82	3.61	19.3	0.193	2.691	
62	1777.50	2.53	3.30	18.9	0.189	2.674	
63	1777.83	44.2	49.3	22.1	0.221	2.680	
64	1778.10	6.03	7.36	19.0	0.190	2.678	
65	1778.45	136	153	23.7	0.237	2.662	
66	1778.70	182	209	24.7	0.247	2.664	
67	1779.03	5.89	7.33	20.4	0.204	2.666	
68	1779.30	2.85	3.67	18.8	0.188	2.678	Humidity Dried
69	1779.60	0.750	1.08	17.2	0.172	2.692	
70	1779.90	0.230	0.366	14.3	0.143	2.727	
71	1780.20	0.266	0.428	14.0	0.140	2.676	
72	1780.54	0.021	0.033	9.5	0.095	2.717	
73	1780.80	0.191	0.246	12.7	0.127	2.676	
74	1781.10	0.736	1.06	17.1	0.171	2.683	
75	1781.40	3.29	4.19	19.3	0.193	2.698	
76	1781.70	4.08	5.04	18.4	0.184	2.678	
77	1781.98	17.3	20.0	20.9	0.209	2.674	Humidity Dried
78	1782.30	15.3	17.7	21.0	0.210	2.675	
79	1782.90	121	133	23.8	0.238	2.668	
80	1783.20	133	151	23.1	0.231	2.673	
81	1783.50	504	540	25.5	0.255	2.665	
82	1783.84	4.34	5.57	16.5	0.165	2.706	
83	1784.48	-	-	-	-	-	Failed while drilling
84	1784.70	23.1	27.5	18.9	0.189	2.664	Humidity Dried
85	1784.97	118	141	21.9	0.219	2.663	
86	1785.30	0.522	0.650	15.6	0.156	2.833	
87	1785.64	0.530	0.675	16.9	0.169	2.715	
88	1785.90	0.904	1.27	17.1	0.171	2.664	Humidity Dried
89	1786.50	5.52	6.85	19.5	0.195	2.659	Humidity Dried
90	1786.81	3.93	4.89	19.9	0.199	2.692	
91	1787.10	0.011	0.019	8.6	0.086	2.704	
92	1787.44	-	-	-	-	2.691	Shale parting
93	1787.70	0.088	0.166	15.6	0.156	2.701	
94	1788.24	0.080	0.137	11.9	0.119	2.671	
95	1788.52	1.29	1.64	17.2	0.172	2.683	

CASINO 4

SAMPLE NUMBER	DEPTH (m)	800psig NOB PRESSURE PERMEABILITY Kinf (md)	Kair (md)	POROSITY (%)	POROSITY (v/v)	GRAIN DENSITY (g/cc)	COMMENTS
96	1788.80	0.408	0.667	16.5	0.165	2.701	
97	1789.10	0.633	0.724	18.5	0.185	2.693	
98	1789.40	7.15	8.71	19.9	0.199	2.680	
99	1789.68	1.01	1.29	14.2	0.142	2.651	Humidity Dried
100	1790.40	27.7	31.6	22.9	0.229	2.688	
101	1791.04	0.672	0.981	15.5	0.155	2.690	
102	1791.30	0.014	0.029	8.9	0.089	2.698	
103	1792.05	0.011	0.019	2.0	0.020	2.717	
104	1792.90	0.010	0.024	11.7	0.117	2.738	
105	1793.27	0.007	0.015	13.8	0.138	2.724	

CASINO 4

SAMPLE NUMBER	DEPTH (m)	800psig NOB PRESSURE PERMEABILITY Kinf (md)	Kair (md)	POROSITY (%)	GRAIN DENSITY (g/cc)	COMMENTS
Core 1						
1V	1761.40	542	589	22.8	2.802	
2V	1762.25	2.49	3.58	21.7	2.674	
3V	1763.50	2.98	3.87	19.4	2.677	
4V	1763.80	1.10	1.56	17.7	2.719	
5V	1764.35	0.520	0.776	16.9	2.688	
6V	1765.30	0.008	0.016	8.8	2.780	
7V	1766.20	0.476	0.708	16.8	2.683	
8V	1768.60	0.305	0.489	16.9	2.681	
9V	1771.10	0.574	0.873	17.4	2.680	
10V	1771.80	19.6	23.4	21.8	2.664	
11V	1774.40	0.820	1.18	18.7	2.669	
12V	1775.80	7.98	9.66	21.0	2.680	
13V	1777.60	2.95	3.85	19.7	2.675	
14V	1778.60	76.9	87.3	22.4	2.672	
15V	1779.50	0.168	0.293	16.5	2.696	
16V	1782.10	1.91	2.59	20.4	2.679	
17V	1782.80	36.6	41.6	22.8	2.660	
18V	1786.80	2.09	2.77	19.7	2.678	
19V	1786.40	5.92	7.37	21.4	2.681	
20V	1789.10	0.067	0.082	17.0	2.700	
21V	1790.00	8.50	10.2	21.7	2.654	

CASINO 4

Summary of NMR data

Te = 0.32ms

Sample ID	Depth m	K_{air} mD	Helium ϕ %	NMR ϕ %	FZI μm	RQI μm	T_2 geom ms	Fznmr	T_2 geom s	ρSgv s^{-1}	$1/\rho S_{gv}$ s
1	1782.53	40.3	22.0	22.2	1.51	0.425	65.1	0.285	0.065	4.37	0.229
9	1773.24	267	21.3	21.7	4.11	1.112	90.7	0.277	0.091	3.05	0.328
11	1761.20	430	25.5	25.5	3.77	1.289	98.5	0.342	0.099	3.47	0.288
17	1761.80	117	21.9	22.1	2.59	0.726	72.8	0.284	0.073	3.90	0.257
18	1762.10	1180	24.3	24.1	6.82	2.188	118	0.318	0.118	2.69	0.372
37	1768.97	3.34	18.3	18.6	0.60	0.134	37.4	0.229	0.037	6.11	0.164
39	1769.63	16.1	20.1	19.9	1.12	0.281	55.3	0.249	0.055	4.50	0.222
40	1769.91	137	21.8	21.7	2.82	0.787	76.0	0.278	0.076	3.65	0.274
41	1770.15	466	24.3	24.0	4.28	1.375	143	0.316	0.143	2.22	0.451
43	1770.98	1.66	17.4	17.7	0.46	0.097	33.1	0.216	0.033	6.52	0.153
45	1771.60	9.12	19.0	19.4	0.93	0.218	50.3	0.240	0.050	4.77	0.210
51	1774.20	2.85	18.8	19.3	0.53	0.122	31.8	0.239	0.032	7.54	0.133
60	1776.92	6.65	19.3	19.6	0.77	0.184	46.3	0.244	0.046	5.27	0.190
63	1777.83	49.3	22.1	22.2	1.65	0.469	58.8	0.286	0.059	4.86	0.206
64	1778.10	7.36	19.0	19.5	0.83	0.195	42.3	0.242	0.042	5.72	0.175
65	1778.45	153	23.7	23.6	2.57	0.798	109	0.308	0.109	2.83	0.354
75	1781.40	4.19	19.3	19.6	0.61	0.146	38.5	0.244	0.038	6.34	0.158
78	1782.30	17.7	21.0	20.9	1.08	0.288	57.7	0.264	0.058	4.58	0.218
79	1782.90	133	23.8	23.6	2.38	0.742	94.8	0.309	0.095	3.26	0.307
81	1783.50	540	25.5	25.5	4.22	1.445	141	0.342	0.141	2.42	0.413
85	1784.97	141	21.9	21.8	2.84	0.797	84.1	0.278	0.084	3.30	0.303
86	1785.30	0.650	15.6	16.7	0.35	0.064	10.5	0.201	0.011	19.11	0.052
98	1789.40	8.71	19.9	19.9	0.84	0.208	33.0	0.249	0.033	7.54	0.133
100	1790.40	31.6	22.9	22.8	1.24	0.369	59.2	0.295	0.059	4.99	0.200

CASINO 4

Pro perm at Multi NOBP

SAMPLE NO.	DEPTH (m)	GRAIN DENSITY (g/cc)	At 800 psi NOBP		At 1000 psi NOBP		At 1500 psi NOBP		At 1900 psi NOBP	
			Kair (md)	Porosity (%)	Kair (md)	Porosity (%)	Kair (md)	Porosity (%)	Kair (md)	Porosity (%)
18	1762.10	2.687	1180	24.3	1140	24.0	1100	23.8	1080	23.6
39	1769.63	2.663	16.1	20.1	15.7	19.9	15.1	19.7	14.8	19.6
51	1774.20	2.690	2.85	18.8	2.72	18.4	2.62	18.2	2.56	18.1
60	1776.92	2.662	6.65	19.3	6.64	19.2	6.45	19.0	6.33	18.9
65	1778.45	2.662	153	23.7	148	23.4	144	23.2	141	23.1
78	1782.30	2.675	17.7	21.0	17.5	20.9	17.0	20.7	16.7	20.6

CASINO 4

Cation exchange capacity analysis results.

Sample no.	Depth (m)	Permeability to air (mD)	Porosity (%)	CEC (meq/100 gm)	Grain density (gm/cc)
1	1782.53	40.3	22	2.37	2.67
9	1773.24	267	21.3	1.95	2.69
17	1761.80	117	21.9	2.23	2.69
18	1762.10	1180	24.3	1.62	2.69
39	1769.63	16.1	20.1	3.05	2.66
41	1770.15	466	24.3	2.63	2.70
45	1771.60	9.1	19	4.02	2.67
51	1774.20	2.85	18.8	3.48	2.69
60	1776.92	6.7	19.3	2.59	2.66
64	1778.10	7.36	19	2.99	2.68
65	1778.45	153	23.7	3.62	2.66
75	1781.4	4.19	19.3	2.73	2.70
78	1782.3	17.7	21	3.79	2.68
79	1782.9	133	23.8	2.34	2.67
81	1783.5	540	25.5	2.69	2.67
85	1784.97	141	21.9	2.09	2.66
86	1785.3	0.65	15.6	6.56	2.83
100	1790.4	31.6	22.9	2.25	2.69

CASINO 4

Formation Resistivity Factor At 1900psi NOBP.

Sample no.	Depth (ft)	K air at NOBP (md)	Porosity at NOBP (%)	FRF at NOBP	Cementation exponent "m"
18	1762.10	1080	23.6	12.88	1.77
39	1769.63	14.8	19.6	22.63	1.91
51	1774.20	2.56	18.1	24.69	1.88
60	1776.92	6.33	18.9	23.31	1.89
65	1778.45	141	23.1	15.00	1.85
78	1782.30	16.7	20.6	21.94	1.95

Average Cementation Exponent "m" (forced r 1.88

APPENDIX V : PALYNOLOGY REPORT

The Palynology Report is presented overleaf.

SANTOS STRATIGRAPHIC SERVICES
EXPLORATION SERVICES DEPARTMENT

Palynology Report No. 2005/19

Author: G.R. WOOD
Approved by: G.R. WOOD
& C. HANNAFORD
Date: 29th September, 2005

PALYNOLOGICAL REPORT NO. 2005/19
PALYNOSTRATIGRAPHICAL ANALYSIS
CASINO NO. 4

Santos Ltd
A.B.N. 80 007 550 923

Introduction

Nine full-hole core samples from Casino No.4 located in VIC/P44 were examined palynologically so as to assess their palynostratigraphic position and palaeoenvironment.

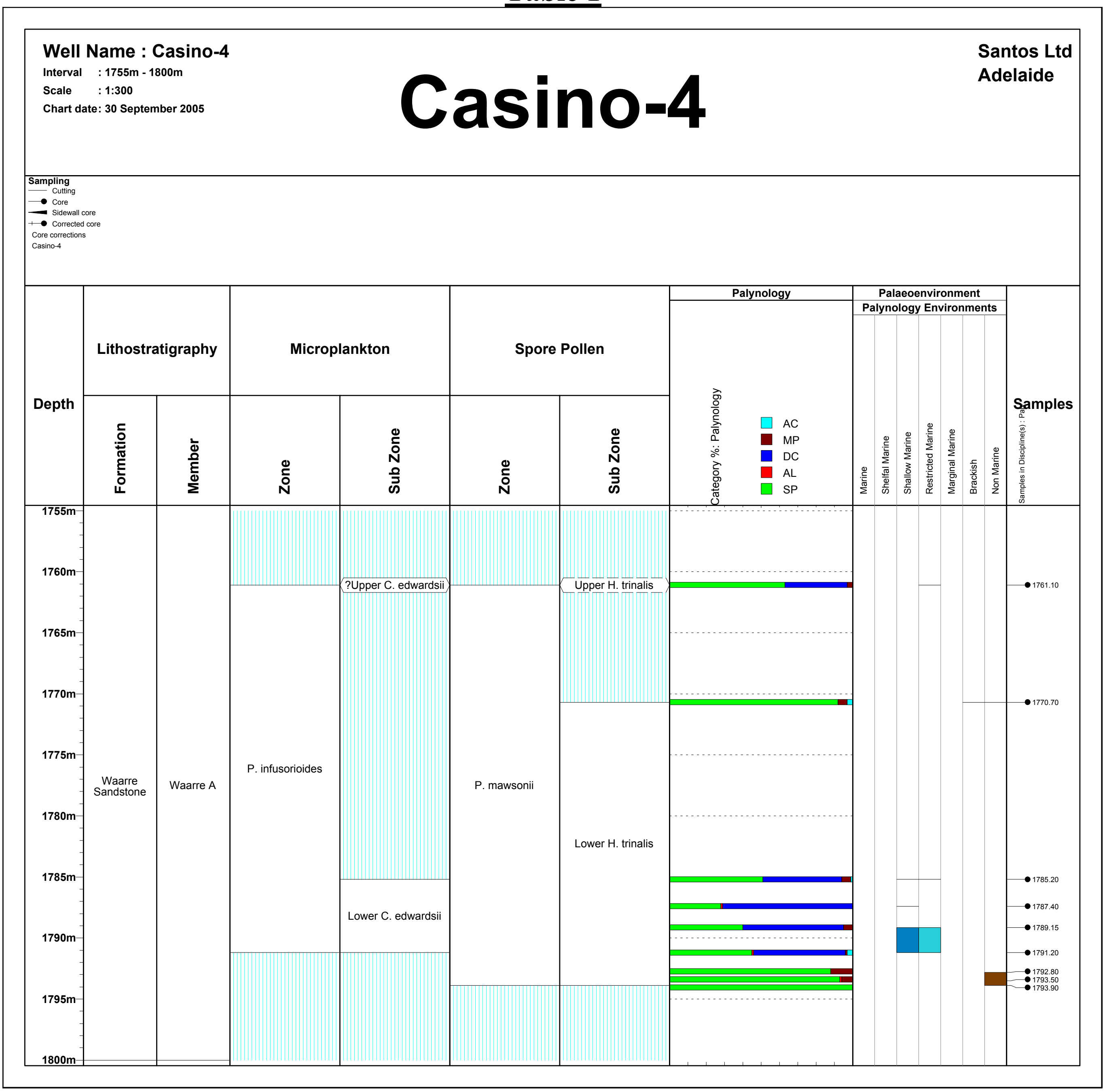
A summary of the results of this study are presented on Table 1. The palynostratigraphic results are presented in more detail on Table 2. Figure 1 outlines the palynostratigraphic scheme adopted and the known relationships of the palynological zones to the lithostratigraphy. Assemblage data utilised in assessing the palaeoenvironments are shown in Table 3. Range charts of the palynomorphs identified in this study are presented in Appendix 1.

G.R Wood

C. Hannaford

SAMPLE	DEPTH	Sieve (μm)	Yield	LITHOLOGY
CORE	1761.1m	10	good	light olive gray (5Y6/1) fine granular siltstone
CORE	1770.7m	10	good	"
CORE	1785.2m	10	good	"
CORE	1787.4m	10	good	"
CORE	1789.15m	10	good	"
CORE	1791.2m	10	good	"
CORE	1792.8m	10	very poor	yellowish gray (5Y8/1) very fine sandstone
CORE	1793.5m	10	good	light gray N7 siltstone
CORE	1793.9m	10	good	medium light gray N6siltstone

Table 1



Well Name : Casino-4
Interval : 1755m - 1800m
Scale : 1:300
Chart date: 30 September 2005
Casino-4
Santos Ltd
Adelaide
Sampling
Cutting
Core
Sidewall core
Corrected core
Core corrections
Casino-4
Depth
Lithostratigraphy
Formation
Member
Microplankton
Zone
Sub Zone
Spore Pollen
Zone
Sub Zone
Palynology
Category %: Palynology
AC
MP
DC
AL
SP
Palaeoenvironment
Palynology Environments
Marine
Shelfal Marine
Shallow Marine
Restricted Marine
Marginal Marine
Brackish
Non Marine
Samples
Samples in Discipline(s) : Pa
1755m
1760m
1765m
1770m
1775m
1780m
1785m
1790m
1795m
1800m
Waarre Sandstone
Waarre A
?Upper C. edwardsii
P. infusorioides
Lower C. edwardsii
Upper H. trinalis
P. mawsonii
Lower H. trinalis
1761.10
1770.70
1785.20
1787.40
1789.15
1791.20
1792.80
1793.50
1793.90

POINTS OF SIGNIFICANCE – PALYNOSTRATIGRAPHY

1. Samples from 1761.1 to 1791.2m yielded Turonian *P. infusioroides/ C. edwardsii, P. mawsonii/H. trinalis* assemblages typical of the Waarre Formation, Waarre A unit.

2. The base of observed microplankton in the cored sequence in Casino-4 occurs at 1791.2m. The first recorded uphole microplankton in the Waarre A sequences in Casino-1 & Casino-2 occur in cuttings samples from 1795m & 1866m respectively.

POINTS OF SIGNIFICANCE – PALAEOENVIRONMENTAL DATA

1. Assemblages from 1793.9 to 1792.8m contain only spores and pollen and considered non marine. Fern spores and gymnosperm pollen dominate these assemblages with only minor bryophyte and lycopod elements.

2. Samples from the interval 1791.2 to 1785.2m yielded assemblages with moderate to high proportions (43 to 71%) of microplankton These assemblages contain a low diversity microplankton component and most samples contain foram liners. The dominance of *Cyclonephelium spp* together with a prominent *Exochosphaeridium & Oligosphaeridium spp* component suggests restricted to shallow marine conditions. The proportions of terrestrially derived materials in these kerogen slides suggest a strong fluvial influence.

3. No microplankton were noted in the assemblage from 1770.7m and only the very small proportion of leiospheres would suggest a brackish to non-marine environment.

4. The shallowest sample studied from 1761.1m yielded a restricted marine assemblage containing prominent *C. edwardsii, Palaeoperidinium cretaceum & Oligosphaeridium spp.* The proportion of terrestrially derived materials in the kerogen slides suggests a strong fluvial influence.

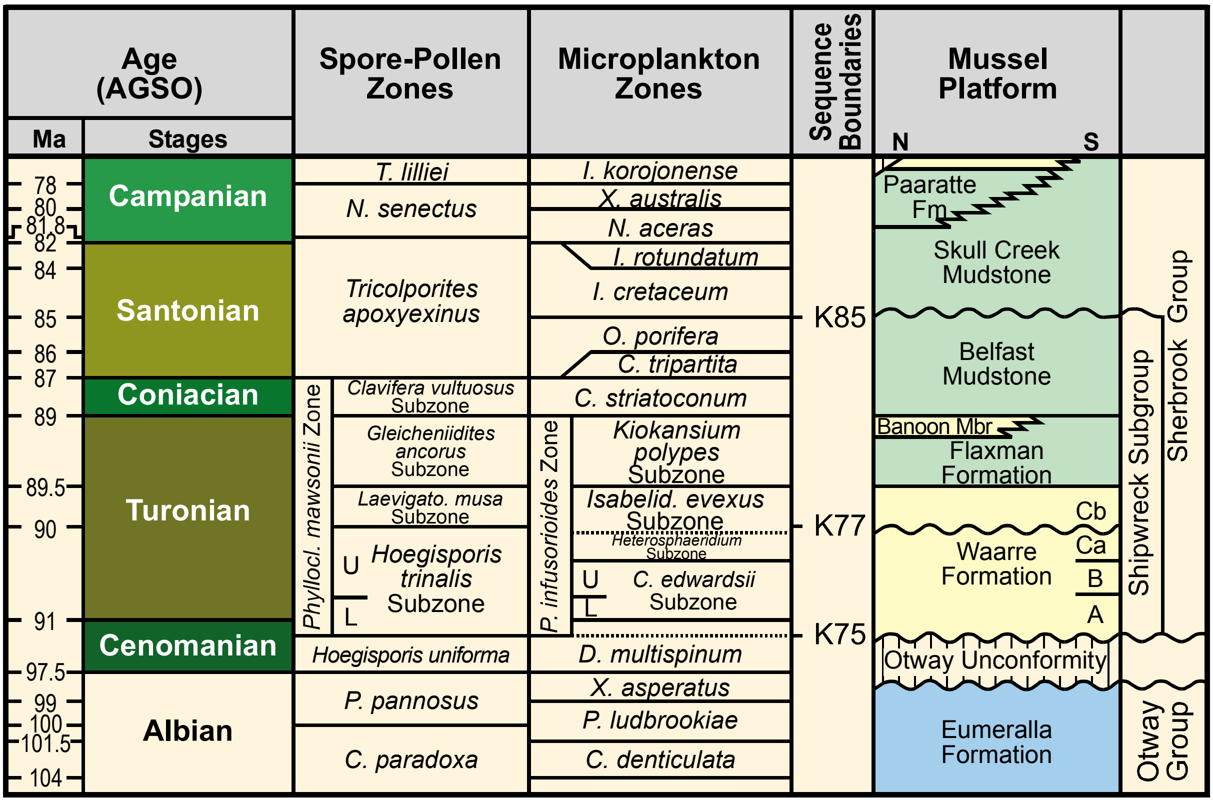


Figure 1: From Sharp & Wood, 2003.

Stratigraphy of the Eastern Mussel Platform.

The stratigraphic succession deposited and preserved over the Mussel Platform comprises sequences from the Early Cretaceous to present day. The stratigraphy herein will concentrate on the economically significant late Cenomanian to Campanian section. Three major sequence boundaries (informally termed K75, K77 and K85 in Santos reports) are responsible for the present day distribution of the reservoir targets across the Mussel Plateau. Stratigraphic discussion will focus on the following chronostratigraphically significant sequences:

Pre K75 :	Eumeralla formation
K75 – K77	Lower to mid Waarre Sandstone
K77 – K85	Upper Waarre to Belfast Mudstone
Post K85	Skull Creek Mudstone and younger

Relationship to the existing lithostratigraphic schemes is based when possible to nomenclature discussed in a revision of the stratigraphy of the Upper Cretaceous Sherbrook Group by Partridge (2001) and an earlier published informal subdivision of the Waarre Sandstone by Buffin (1989). Both of these earlier studies were based on the study of mostly onshore well sequences in the adjoining Port Campbell Embayment. Early Otway Basin stratigraphic frameworks (Bock & Glenie, 1965, Douglas & Ferguson, 1988, Tickell et al, 1992, Moreton et al, 1994) were characterised by markedly diachronous lithological units. Partridge (2001) through utility of improved palynological data for key onshore reference and type sections (Partridge, 1996), proposed a revision of the lithostratigraphic units to more closely represent time-rock units than in previously described schemes. These efforts have been continued in this study of the Casino Field and wells in the Shipwreck Trough and the Mussel Plateau (Fig.1).

The first attempt to subdivide the Waarre section into regional intra-formational units was by Buffin (1989) who described four informal units A, B & C based primarily on electric log character in onshore wells. The Waarre Sandstone is not represented in outcrop and facies interpretation is dependant on limited core and mostly cuttings information. Buffin (1989) described the distribution of facies within the context of a beach barrier-bar system with lagoonal, tidal channel, beach and tidal delta facies proposed in an overall regressive sequence. Maps of the extent of these units were based on the available well coverage in the Port Campbell Embayment. There was no attempt by Buffin (1989) to hypothesise about the extension of the Waarre depositional systems southwards as there was only very limited offshore exploration data available. Subsequent offshore wells drilled both within and on the flanks of the Shipwreck Trough with Waarre reservoirs as a primary target have provided sufficient coverage to trace the southerly extent of these units. Later work by Partridge (1994, 1999) and recent Santos operated wells in the Port Campbell Embayment have been instrumental in providing palynological criteria for greater resolution of this intra-formational sub-division.

Armed with the palynostratigraphic data from the Port Campbell Embayment for comparison, the Waarre data from the Mussel Platform and nearby Shipwreck Trough wells were similarly scrutinised for possible co-eval events. Because of the mostly marginal marine character of the Waarre sequences, spore pollen and dinoflagellate datasets were interrogated and both provided useful datums although in some wells data quality was hampered by sparse sampling of some intervals and the effect of depositional environment on some dinoflagellate taxa. A benefit of applying an adaptation of the Port Campbell Embayment schemes was the ability to then map depositional trends from the abundance of onshore reservoir intersections into the comparatively more sparse offshore datasets.

Biostratigraphic Framework

During the 1980's most of the palynology undertaken in the Otway Basin was expressed either in terms of the eastern Australian Mesozoic zonation developed by the Minad/APG group (Peter Price and co-workers) or the pan-Australian HMP scheme (Helby, Morgan & Partridge, 1987). Both of these schemes relied on classical interval zone concepts and lacked resolution in the predominantly non-marine to marginal marine Waarre Sandstone and to a certain extent the underlying Eumeralla Formation. By the mid 1990's the Morgan group had begun to develop an event stratigraphy (Morgan& Hooker *in* LaBella WCR) and Partridge (2001 Fig.2)

Published a review and substantial up-date of the Late Cretaceous part of the HMP scheme, introducing a number of subzones based on both interval zone criteria and event features (acmes). The Partridge (2001) Waarre subdivision was based primarily on Port Campbell Embayment on-shore sequences. We have adopted the Partridge scheme but require more precision to satisfactorily label the sands in and below the Waarre "Ca" interval (i.e. below the base of *I. evexus*) in the offshore Otway sequences with expanded Waarre A to Ca sections. Modifications and further subdivision of the Partridge subzones are outlined in Figure 2.

OTWAY BASIN ZONATION SCHEME FOR THE TURONIAN TO CONIACIAN

Defining Events	**Spore Pollen Zones**	**Microplankton Zones**	Defining Events
	C. vultuosus	**Upper *C. striatoconus***	Top *C. striatoconus*
Base *C. vultuosus*			Base *C. striatoconus*
Top *A. distocarinatus*	***G. ancoras***	**Lower *C. striatoconus***	
			Base *G. hymenophora*
			Base *Trythyrodinium "marshalii"*
		K. polypes	Top consistent *V. griphus*
			Base *V. griphus, Spinidinium sp A*
Top consistent *L. musa*	***L. musa***	**Upper *I. evexus***	
			Base prominent *A. cruciformis*
Top consistent *H. trinalis*	**Upper *H. trinalis***	**Lower *I. evexus***	
Base *A. obscurus*			Consistent *I. evexus*
		***Heterosphaeridium* acme Zone**	Top prominent *Heterosphaeridium*
			Base prominent *Heterosphaeridium*
Base consistent *P. mawsonii*		**Upper *C. edwardsii***	Base *I. evexus / "waarriense"*
Base consistent *L. musa*	**Lower *H. trinalis***		Base consistent *K. polypes, Heterosphaeridium spp*, prominent *C. edwardsii*
		Lower *C. edwardsii*	
			Base dinoflagellates
Base *H. Trinalis, V. Admirabilis, L.musa, C. Triplex, P. Mawsonii / eunichus*			

Figure 2

Palaeoenvironmental Analysis

Definition of palaeoenvironments used in this study

Non-marine – No marine influence (nil or only monospecific proximal dinocyst component) - fluvial, swamp, lacustrine, coastal plain

Marginal Marine – paralic environments with an interaction of freshwater influx and marine influence (low yield, very low diversity microplankton assemblages) – upper delta plain, coastal lagoon, estuarine.

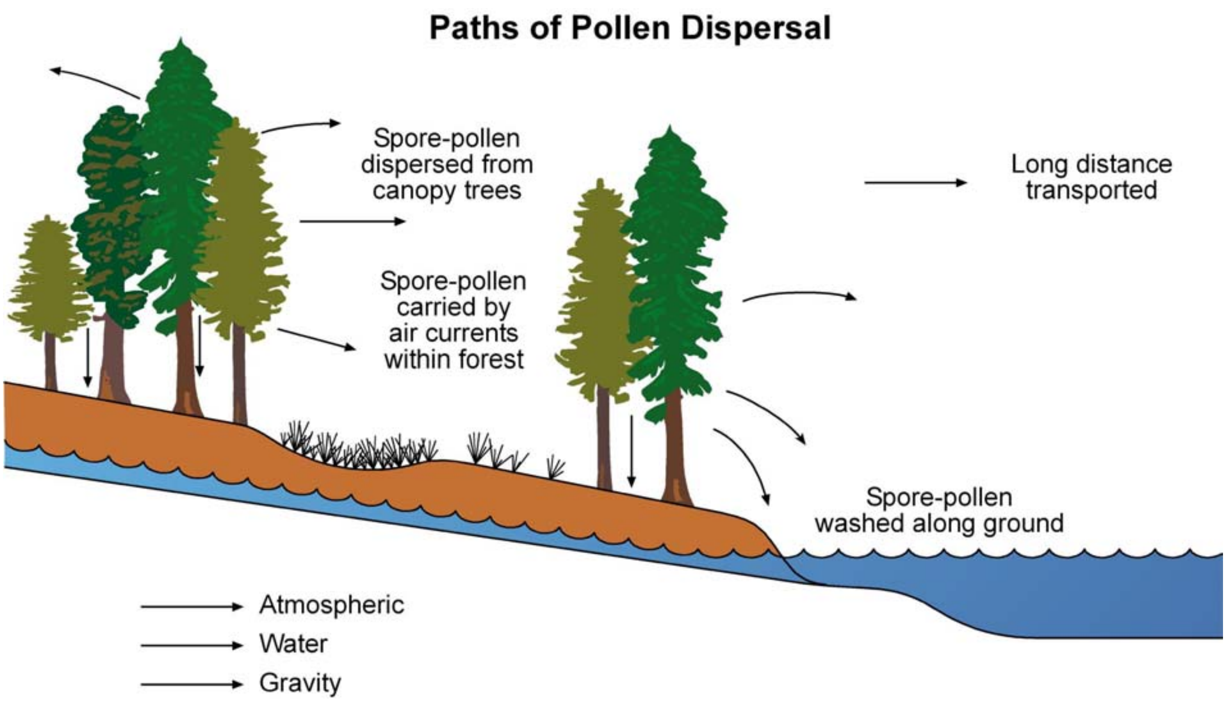
Restricted Marine –marine environment influenced by higher salinities, freshwater influx or turbidity (moderate yield, low diversity microplankton assemblages) – estuarine, lower delta plain, inner to middle neritic environments.

Shallow Marine – fully marine environment with minimum freshwater influence (low to moderate yields, moderate to high diversity assemblages) – inner to middle neritic environments.

Shelfal Marine - fully marine environment with minimum freshwater influence (moderate to high yields, moderate to high diversity assemblages) –middle to outer neritic environments.

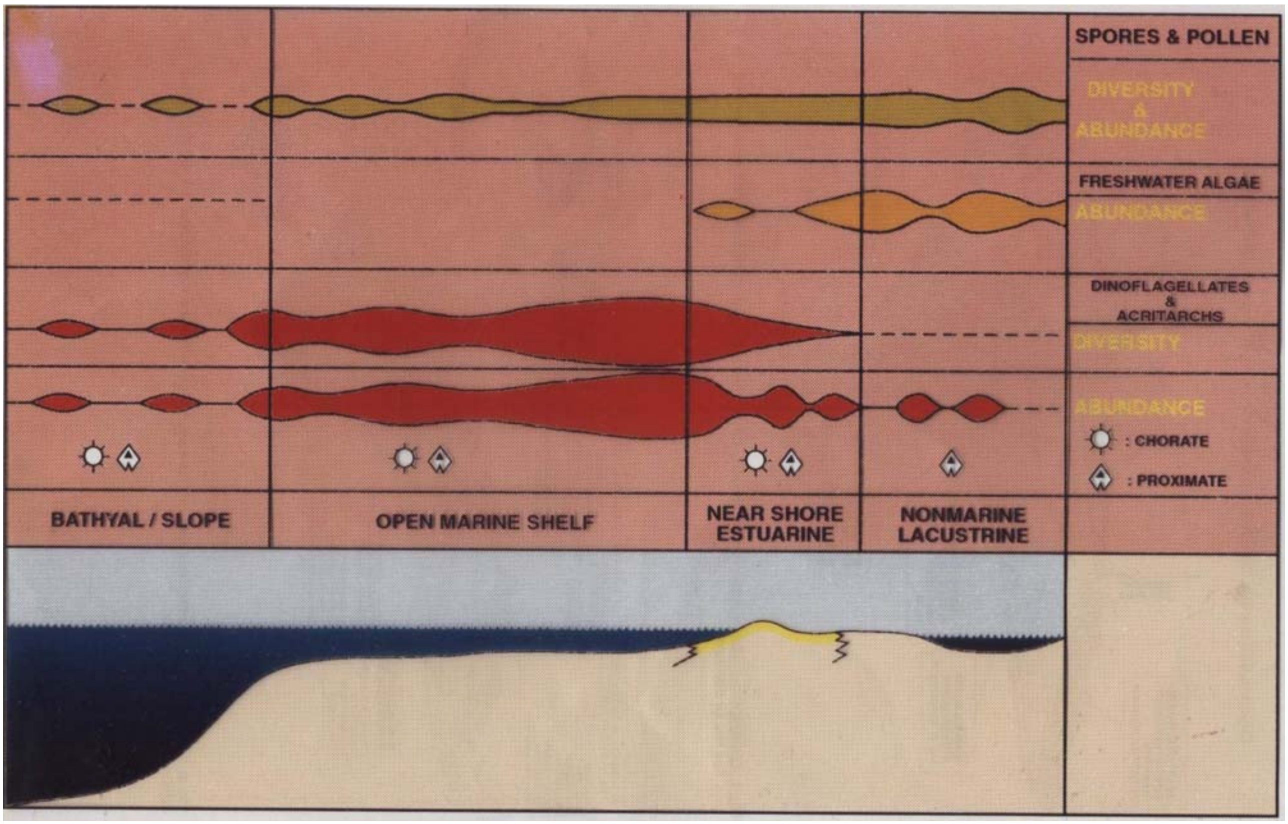
Palaeoenvironmental Analyses

The analysis of the relative abundances of spore and pollen grains, dinoflagellates and acritarchs in assemblages can provide useful palaeonenvironmental data.Plots of relative abundances of palynomorph groups can be related to transgressive-regressive phases and distances from the shoreline. The most commonly measured ratio is that of the marine (dinoflagellates + acritarchs) versus terrestrial (spores + pollen) palynomorphs.



Relative proportions of spores (ferns, lycopods & bryophytes), pollen (gymnosperm & angiosperm) in the terrestrial component can provide evidence of the floristic composition of the depocentre and its surrounding hinterland.

Organic-walled cyst producing dinoflagellates can provide evidence of the surface water physio-chemical conditions in marine influenced depositional settings. Modern and Quaternary dinocyst studies indicate that the cyst-forming dinoflagellates principally thrive in relatively shallow marine environments with their highest diversities reached along shelves and continental rises (Dale, 1996). Studies on the distribution pattern of modern dinocysts have shown that apart from nutrient availability and water temperature, cyst diversity strongly depends on the relative stress (turbidity & salinity) in the ecosystem. As these stress elements are often related to shoreline proximity, the dinocyst diversity signal is a useful palaeoenvironmental indicator (Pross & Brinkhuis, 2005).



The proximal / distal signal is expressed by changes in the assemblage composition, assemblage diversity and cyst abundances.

Actuopalaeontological and Quaternary studies as well as more recently dinocyst ecobiostratigraphic studies in Tertiary basins (Pross & Brinkhuis, 2005; Sluijs, et al, 2005) have refined existing and furnished new concepts of palaeoenvironmental reconstructions utilising dinocysts. Analysis of Paleogene dinocyst assemblages have been integrated with models of sea-surface productivity, temperature, salinity and stratification (Sluijis et al, 2005).

Similar ecobiostratigraphic studies of Cretaceous dinocyst assemblages are rare. A high resolution, quantitative study of Late Cretaceous assemblages from the Western Interior Basin, USA by Harris & Tocher (2000) identified criteria for discerning salinity contrasts across the basin. There are some common elements in the Late Cretaceous assemblages in the Otway Basin.

Organic-walled dinoflagellate cysts as paleoenvironmental indicators in the Paleogene

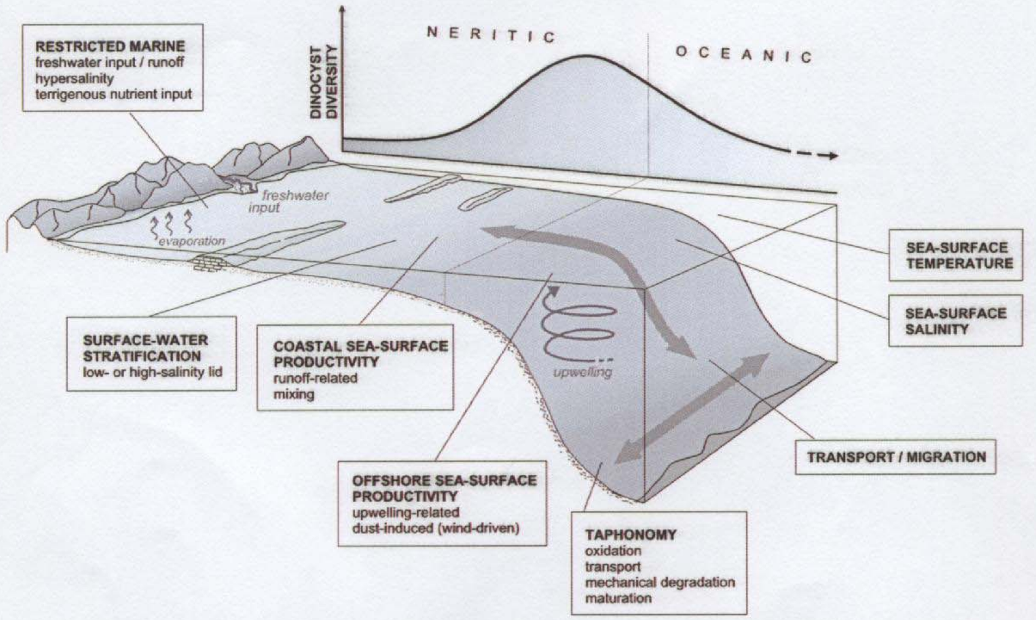


Fig. 1. Schematic illustration of main factors influencing the distribution of dinoflagellates and their organic-walled cysts.

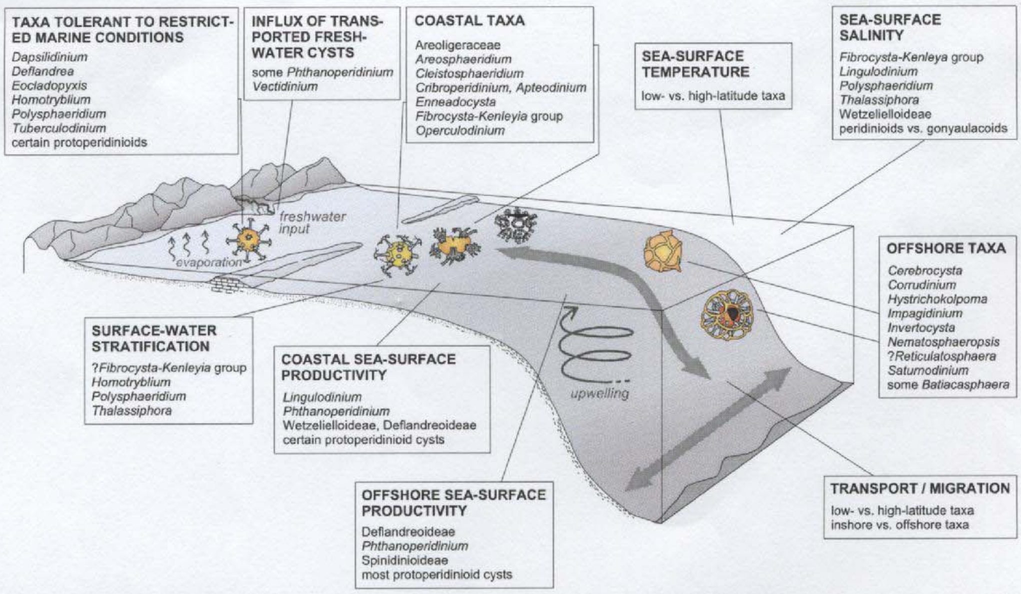


Fig. 2. Typical Paleogene dinoflagellate cysts indicative of specific environmental conditions. Compiled after various authors.

Example of a detailed Paleogene palaeoenvironmental transect. (from Pross & Brinkhuis, 2005)

Palynofacies

Palynological slides taken from core in Casino 4 were examined for palynofacies styles.

The samples studied contained low diversity microplankton assemblages. The dinoflagellate types recorded are generally indicative of shallow marine settings. No abundance peaks of what are considered deeper marine indices were noted. The samples above 1787 are interpreted to be fluvially influenced nearshore marine, whilst those below are interpreted to be non marine, fluvial.
All core depths are drillers depths, with no shift applied.

Table 2 summarises the palynofacies for the wells studied. Figures 1a and 1b provides an explanation of the palynofacies codes.

Table 2: Summary of Palynofacies (NB: Core depths are drillers depth, no shift has been applied)

Sample depth (m)	Palynofacies Code	Palynofacies
1761.1	VII	P2, P4 common. Rare Dinos, very woody. Marginal marine, fluvial influence.
1770.7	IX	P2 dominant, P4 common. No Dinos. Non marine, fluvial influence.
1785.2	VII	P2 dominant, P4 common. Low Dinos. Very woody. Marginal marine, fluvial influence.
1787.4	VII	P2 dominant, P4 common. Common Dinos, restricted assemblage. Very woody. Very shallow marine, fluvial influence.
1789.15	VII	P2 dominant, P4 common. Common Dinos, restricted assemblage. Very woody. Very shallow marine, fluvial influence.
1791.2	VII	P2 dominant, P4 common. Common Dinos, restricted assemblage. Very woody. Very shallow marine, fluvial influence.
1792.8	IX	Low yield, P1 dominant, P2 common. No Dinos, non-marine, fluvial.
1793.5	IX	Low yield, P1 dominant, P2 common. No Dinos, non marine, fluvial.
1793.9	XI	P2 dominant, very woody. No Dinos, low energy fluvial.

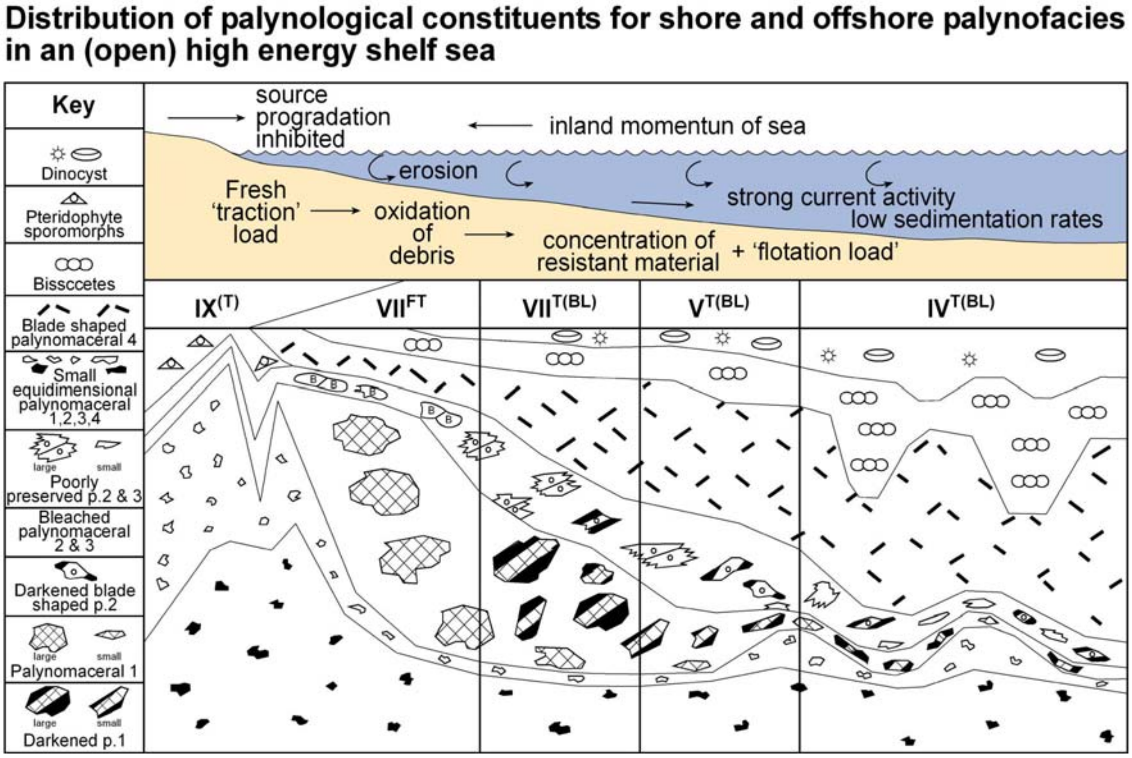
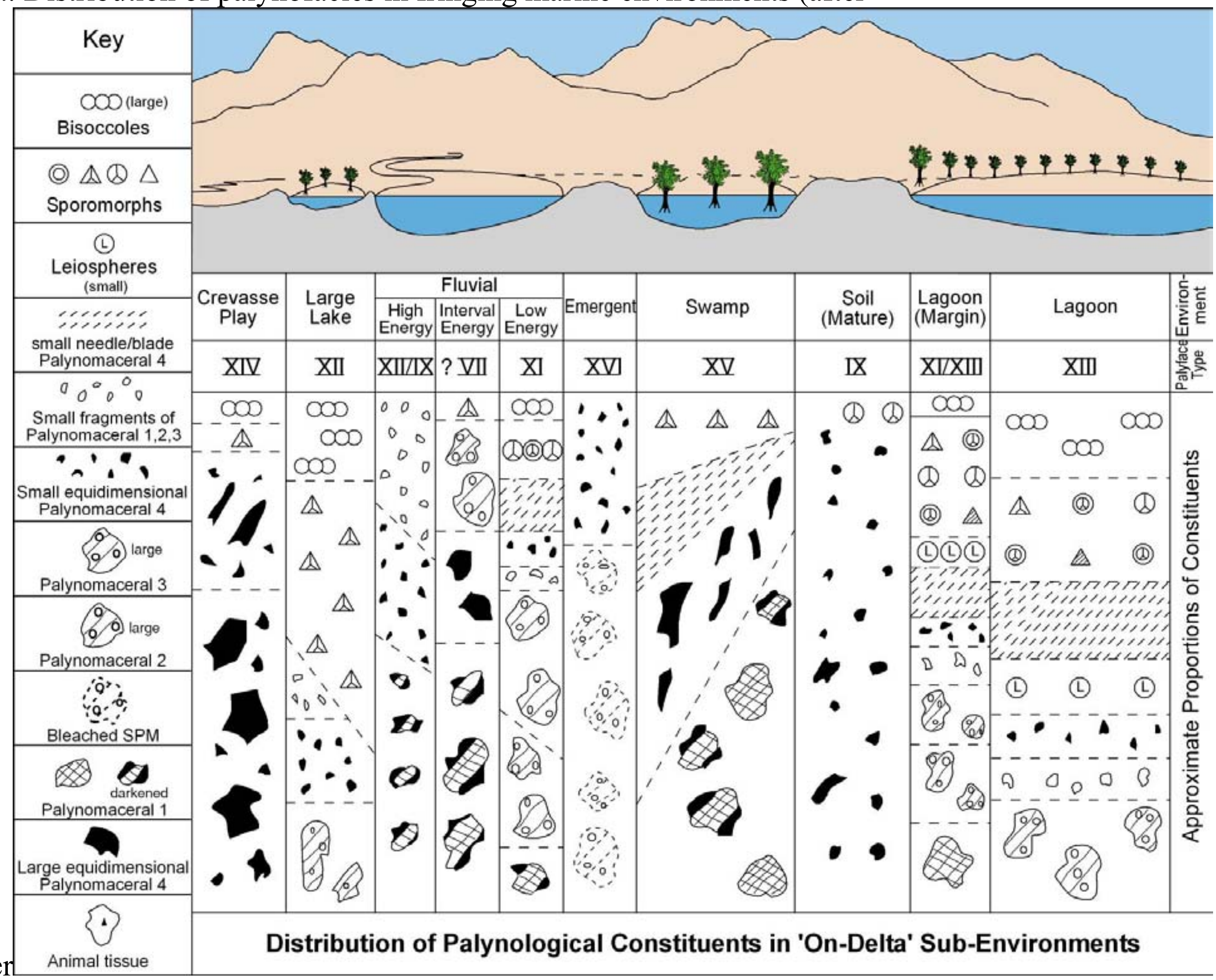


Figure 1a: Distribution of palynofacies in fringing marine environments (after



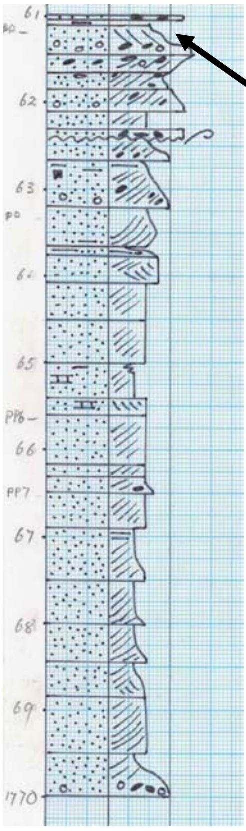
Whittaker

Figure 1b: Distribution of palynofacies in delta top environment (after Whittaker)

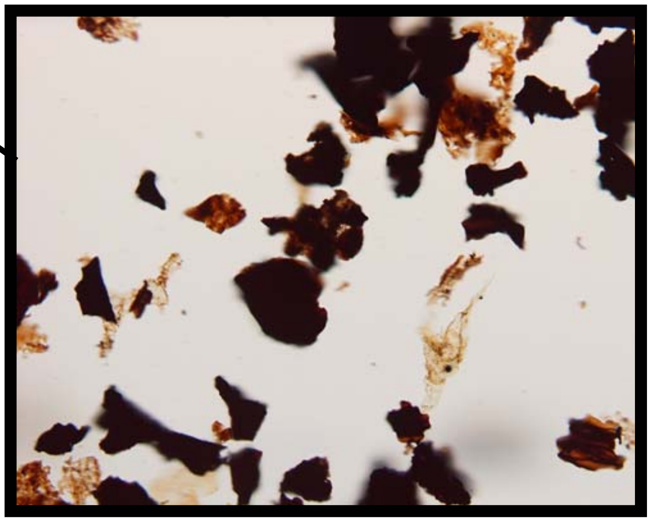
Palynofacies photos – Casino No.4

Casino 4

1761



1761.1m

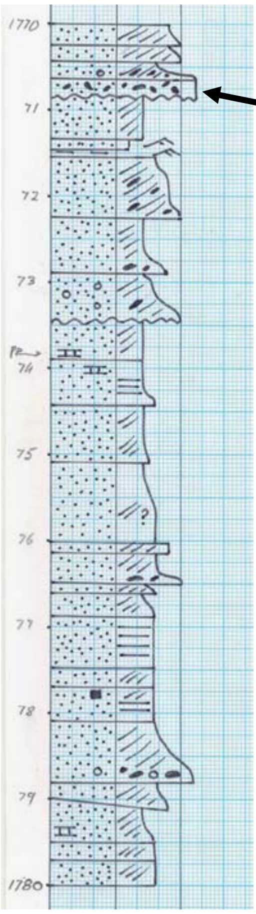


VII

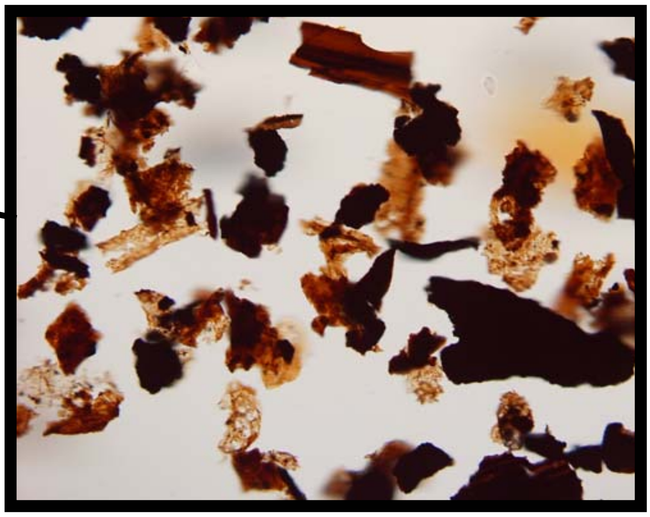
1770

1770.7m

1770



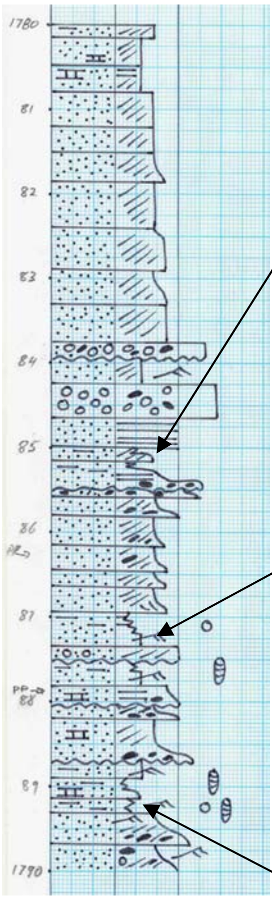
1780



IX

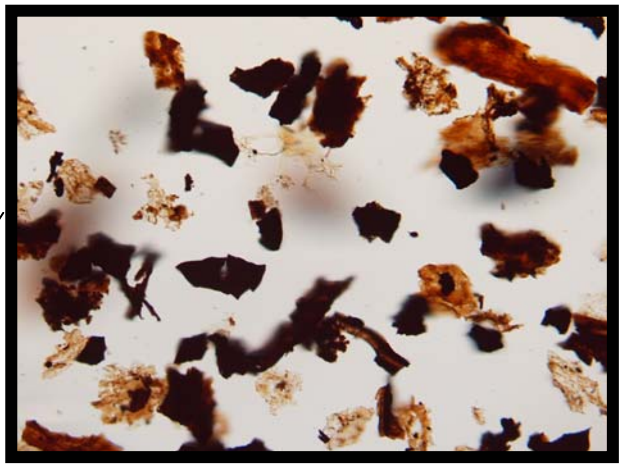
Casino 4

1780



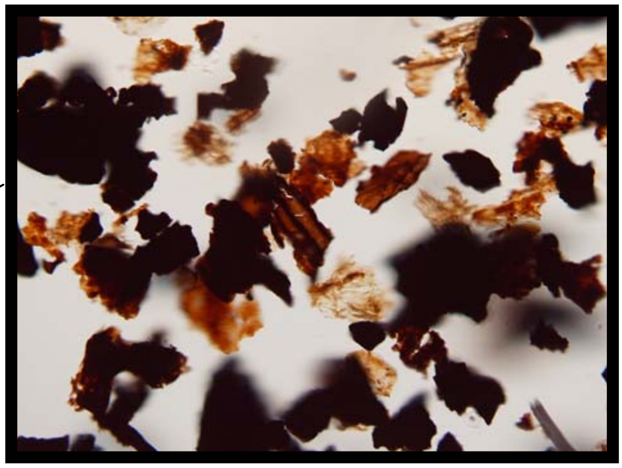
1790

1785.2m



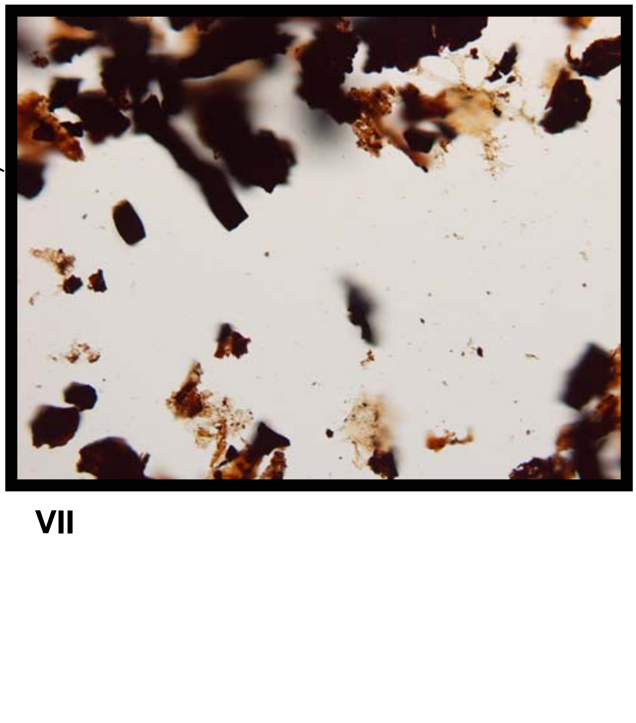
VII

1787.4m



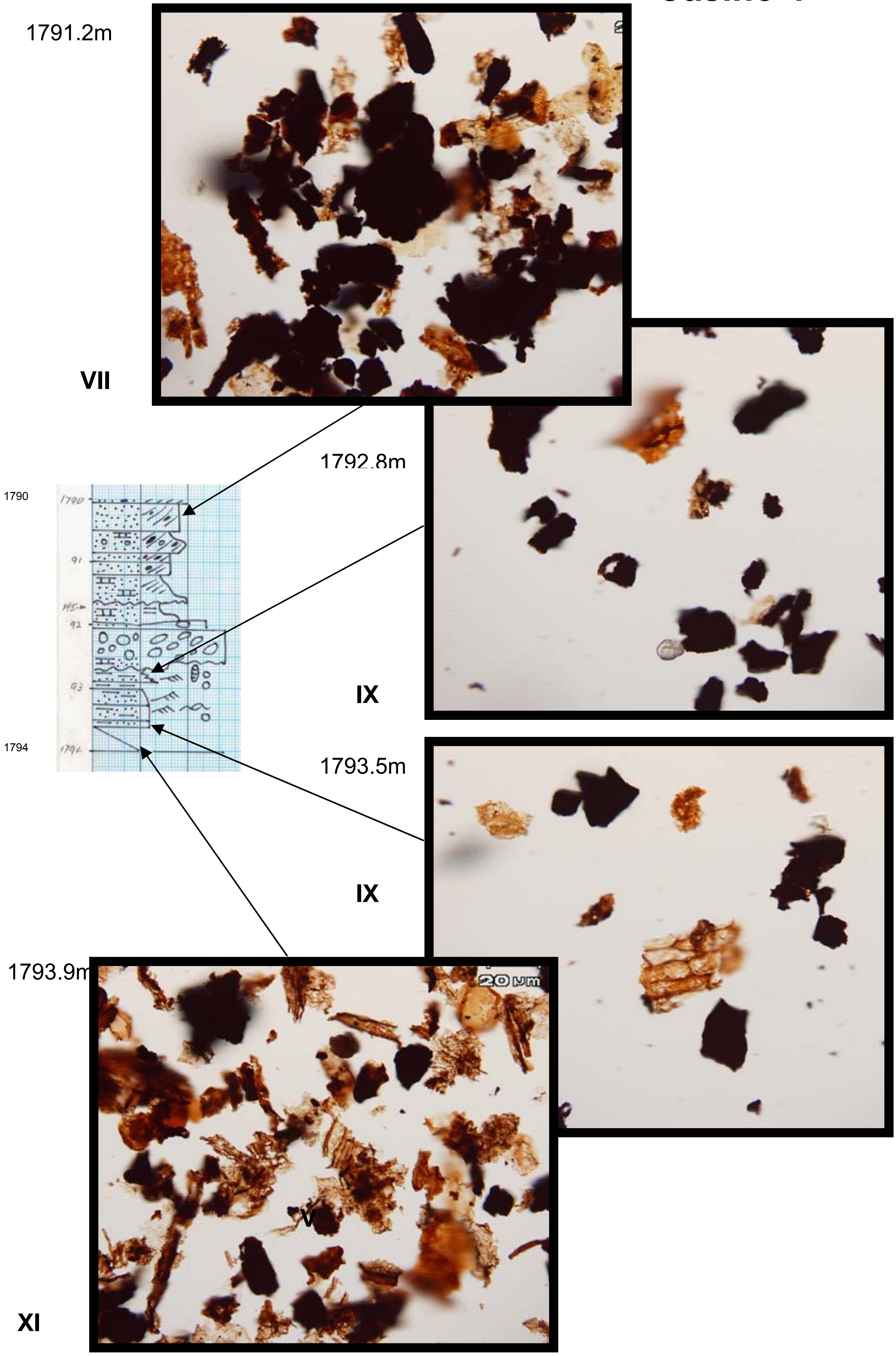
VII

1789.15m



VII

Casino 4



Well Name : Casino-4

Interval : 1755m - 1800m

Scale : 1:300

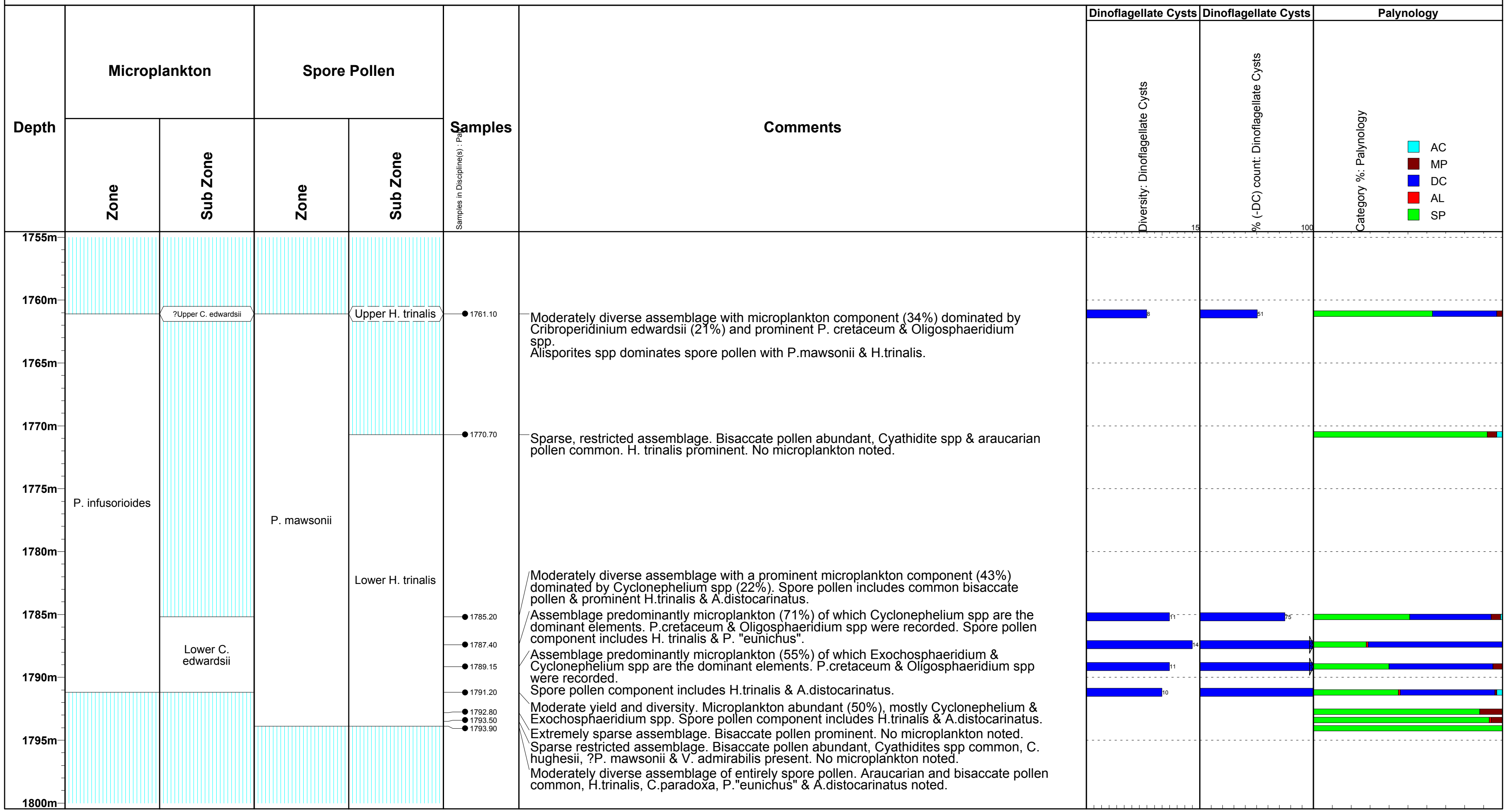
Chart date: 30 September 2005

Casino-4

Santos Ltd
Adelaide

Table 2

Sampling
Cutting
Core
Sidewall core
Corrected core
Core corrections
Casino-4



Well Name : Casino-4

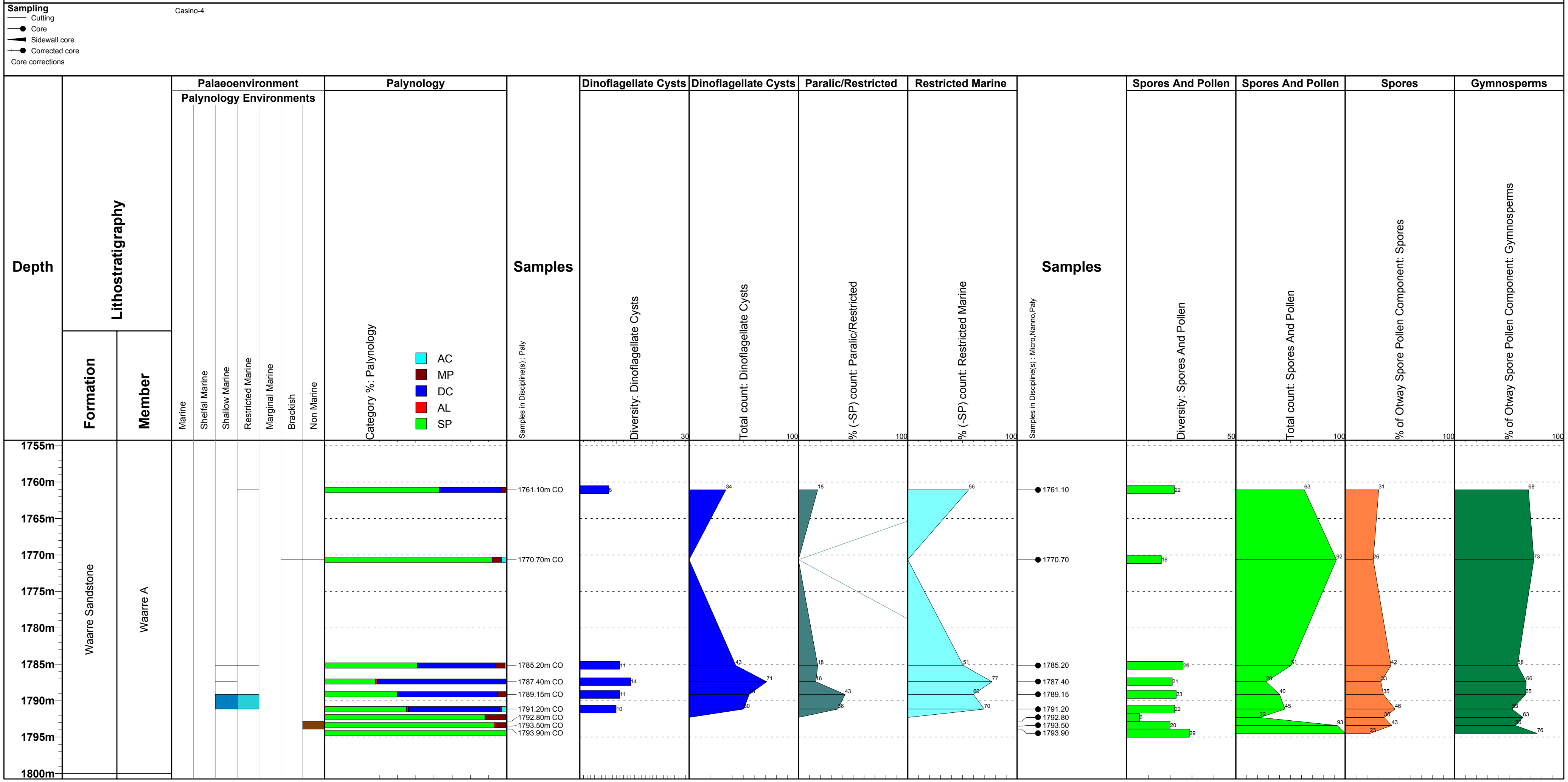
Interval : 1755m - 1800m

Scale : 1:500

Chart date: 30 September 2005

Casino-4

Santos Ltd
Adelaide



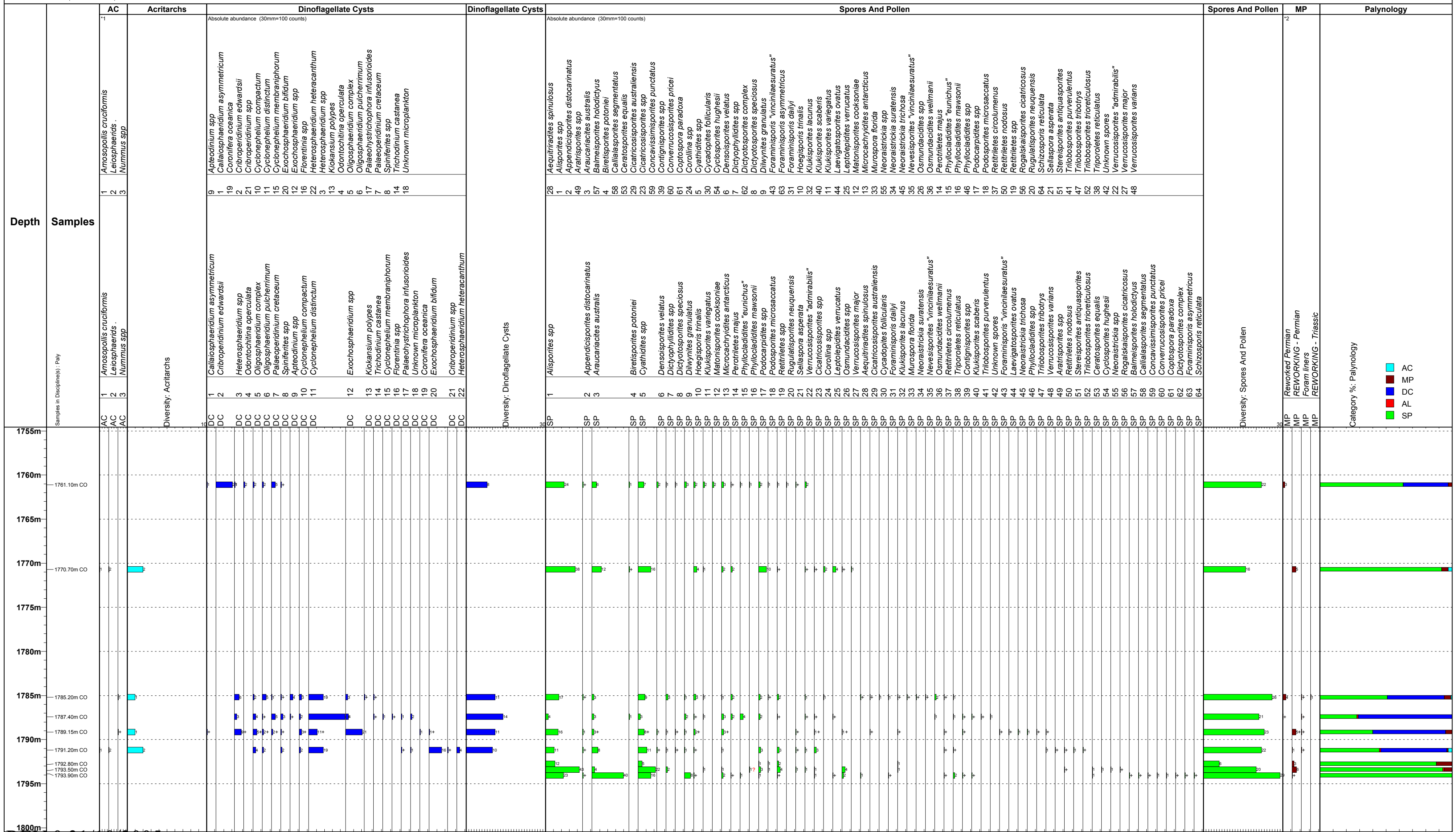
Well Name : Casino-4
Operator :
Well Code : CASINO-4
Lat/Long : 0° 0' 0.00"N 0° 0' 0.00"E
Interval : 1755m - 1800m
Scale : 1:300
Chart date: 30 September 2005

Casino-4

Santos Ltd
Adelaide

Appendix 1

Sampling
Cutting
Core
Sidewall core
Corrected core
Core corrections
Casino-4
Text Keys
*1 Absolute abundance (30mm=300 counts)
*2 Absolute abundance (30mm=100 counts)



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APPENDIX VI : PETROLOGY REPORT

Report prepared for:

SANTOS LTD
91 King William St
Adelaide
SA 5000

PETROLOGY REPORT

CASINO-4

OTWAY BASIN (VIC/P 44)

Report prepared by:

Dr S E PHILLIPS
PGPC
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October 2005

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CONTENTS

Front cover:
Thin section photomicrograph, Casino-4, core plug 18, depth 1762.10m. Plane light. Horizontal field of view 6.5mm.

1. SUMMARY

Santos Ltd submitted 15 core plug ends to PGPC from the well Casino-4 in the Otway Basin for detailed petrological description. Samples were selected from the Late Cretaceous Waarre Formation to ascertain the lithology, mineralogy, sediment provenance, depositional environments, diagenetic alteration and factors controlling reservoir quality. Grain size analysis and point counts were undertaken on all samples. Based on the core logging descriptions, two samples were selected for scanning electron microscopy and seven samples for bulk and clay X-ray diffraction.

Unit A in the Waarre Formation at Casino-4 is comprised of fine to coarse grained, very poor to very well sorted, mineralogically immature litharenites, carbonate cemented litharenites and one feldspathic litharenite. Grain size distributions are typically unimodal and symmetrical with minor variations caused by cross laminations and bedding. At the time of deposition all the sandstones could have been up to 10% more feldspathic.

Based on the detrital mineralogy, which is very similar to results from Casino-3 and Casino-2, sediment provenance was dominated by a metamorphic source. Uplift in this terrane during the early stages of Waarre deposition ceased or declined near the top of the sequence. This trend was recognised previously in Casino-3 and elsewhere on the Mussel Platform at Callister-1. The metamorphic terrane was probably the source of K-feldspars, whilst an igneous provenance could have sourced the plagioclase. Igneous lithics include both volcanic and plutonic rock types. There has been minor reworking of sediment within the depositional environment as indicated by the rip-up clasts of silty mudstone and possible recycling from older sedimentary sequences.

Deposition may have occurred in a fluvial to brackish setting as previously hypothesised for Unit A. Equant circumgranular cements of siderite formed superficial ooids, nodules and rims on pores. These cements typically form in a meteoric phreatic zone below the water table. As burial progressed there could have been mixing with sea water to allow precipitation of incipient glauconite and framboidal pyrite. Oxidation of the glauconite and unidentified lithics could have resulted from intermittent flushing by meteoric waters.

SEM studies indicated distinct zoning in the early diagenetic siderite as pore waters evolved from Fe to more Mg rich. Up to 7 phases of precipitation are apparent in both the micritic siderite and microspar. Feldspars and micas were altered to kaolinite possibly as a result of flushing by meteoric waters soon after burial. Minor quartz and feldspar overgrowths, and grain replacing illite all formed prior to the late calcite cement. Mechanical compaction had ceased prior to calcite precipitation and was influenced by both the number of lithics and early siderite cements, not depth of burial. Late diagenetic slightly ferroan calcite is the dominant authigenic mineral in Unit A, it has replaced detrital grains and filled pores. Calcite formation could be related to CO_2 released during Pleistocene/Recent igneous activity. However, the distribution of calcite is poorly understood and has been influenced by later dissolution. The final phase of carbonate spar was minor saddle dolomite the formation of which could be associated with hydrocarbon migration.

Across the Casino field Unit A is dominated by secondary dissolution pores which include grain size pores, intragranular pores in lithics and honeycomb pores where feldspars are corroded. There are minor intergranular pores, micropores associated with kaolin and grain fracturing. Reservoir quality was controlled by the distribution of pore filling carbonate cements in Unit A. Dissolution pores appear to be interconnected, possibly via grain fracturing and intergranular pores. At least some of the intergranular pores might be secondary in origin where there has been more than 6% dissolution.

2. INTRODUCTION

Santos Ltd submitted 15 core plug ends to PGPC from the well Casino-4 in the Otway Basin. Samples were selected from the Late Cretaceous Waarre Formation for detailed petrological description. The study was design to ascertain the lithology, mineralogy, sediment provenance, depositional environments, diagenetic alteration and factors controlling reservoir quality. This data was to provide a basis for comparison with previous petrology studies of the Waarre Formation.

The client supplied a sedimentological log of the cored interval, wireline logs and routine core analysis data to aid the petrology interpretation. Services listed below (Table 1) were provided by PGPC.

TABLE 1 SUMMARY OF SAMPLES & SERVICES

Core plug	Depth (m)	Unit	TS description	Grain size analysis	Point count	XRD (Bulk/clay)	SEM
5	1791.70	A	*	*	*	*	*
4	1790.72	A	*	*	*	-	-
99	1789.68	A	*	*	*	-	-
14	1786.32	A	*	*	*	-	-
84	1784.70	A	*	*	*	-	-
77	1781.98	A	*	*	*	-	-
72	1780.54	A	*	*	*	*	-
68	1779.30	A	*	*	*	*	-
56	1775.72	A	*	*	*	-	-
50	1773.50	A	*	*	*	-	-
46	1771.91	A	*	*	*	-	-
36	1768.71	A	*	*	*	*	-
31	1766.93	A	*	*	*	*	-
28	1765.41	A	*	*	*	*	*
18	1762.10	A	*	*	*	*	-

3. METHODS

Thin section
Core plugs were impregnated with araldite prior to thin section preparation by Petrographic Technical Services Pty Ltd. Blue dye was used in the araldite to facilitate description of porosity and permeability. Thin sections were prepared using standard techniques to produce a thickness of 30 microns (Adams *et al*, 1984). Those samples containing significant carbonate were half stained with alizarin red-S and potassium ferricyanide to differentiate the carbonate species (Adams *et al*, 1984). Thin sections were systematically scanned to determine lithology, composition, porosity and textural relationships. Siliciclastics have been classified according to guidelines by Folk (1974). Grain morphology (both sphericity and roundness) was estimated by comparison with charts in Pettijohn *et al* (1987), grain fabric (packing and texture) from the diagram in Tucker (2001) and sorting from diagrams by Harrell (1984). All percentages of composition given in Table 2 are counts of 500 points following the method of Stanton & Wilson (1994).

The basic data for grain size analyses was collected by measuring the long axis of 100 representative grains in thin section. The graphic mean, mode and inclusive graphic standard deviation (Folk, 1974) were then calculated.

X-ray diffraction (XRD)
To determine bulk mineralogy samples were ground in a Siebtechnick mill and back mounted into aluminium holders by Amdel Mineral Services. Continuous scans were run of these powder pressings from 3^{o} to 75^{o} 2θ , at 1^{o}/minute, using Co Kα radiation, 50kV and 35mA, on a Philips PW1050 diffractometer. For detailed clay mineralogy a less than 5 micron size fraction was separated. This was obtained by hand crushing, addition of dispersion solution, mechanical shaking for 10 minutes and settling of the dispersed material in a water column according to Stokes' Law. The less than 5 micron fraction was pipetted off and prepared as an oriented sample on ceramic plates held under vacuum. Samples were saturated with Mg solution and treated with glycerol. Continuous scans of oriented clay samples were run from 3^{o} to 45^{o} 2θ at 1^{o}/minute. Peaks were identified by comparison with JCPDS files stored in a computer program called XPLOT.

Scanning Electron Microscopy
Scanning electron microscope (SEM) studies were undertaken at Adelaide Microscopy (The University of Adelaide) on polished thin sections. The samples were evaporatively coated with carbon (15nm) prior to viewing in a Philips XL30 FEG Scanning Electron Microscope at 15kV. The elemental composition of each mineral photographed was identified using an EDAX DX-4 energy dispersive spectrometer.

4. PETROLOGY

TABLE 2 POINT COUNT DATA FOR CASINO-4

Sample No.	5	4	99	14	84	77	72
Depth (m)	1791.7	1790.72	1789.68	1786.32	1784.7	1781.98	1780.54
Framework grains							
Quartz - mono	24.2	30.4	24.2	25.0	32.4	26.4	22.4
- poly	5.4	8.8	6.2	7.0	7.6	6.2	5.0
Feldspar - Kspar	3.4	4.0	4.6	5.4	4.4	4.6	6.0
-plagioclase	0.2	0.0	0.0	0.2	0.0	0.2	0.0
Lithics - sedimentary	6.2	8.8	5.6	7.2	5.2	6.0	5.0
- metamorphic	8.6	7.4	9.6	11.8	9.8	11.4	13.0
- igneous	2.8	1.2	1.2	1.8	1.6	2.0	2.4
- unknown	2.4	2.0	1.4	2.6	1.4	2.2	3.0
Mica - muscovite	0.6	0.2	1.4	0.2	0.2	0.2	1.2
- biotite	0.0	0.0	0.0	0.0	0.0	0.0	0.2
Ooids	0.0	0.0	0.0	0.0	0.0	0.6	0.2
Accessory - zircon	0.0	0.2	0.2	0.2	0.2	0.0	0.0
- tourmaline	0.2	0.4	0.0	0.2	0.4	0.2	0.2
- rutile	0.2	0.0	0.0	0.0	0.2	0.2	0.0
- opaques	0.2	0.0	0.0	0.0	0.0	0.0	0.2
- garnet	0.0	0.0	0.2	0.0	0.0	0.0	0.0
- monazite	0.0	0.0	0.2	0.0	0.0	0.0	0.2
Matrix							
Clay	0.0	0.0	13.0	0.0	1.8	0.2	0.0
Organic matter	0.2	0.6	4.6	1.2	1.6	0.4	0.2
Authigenic minerals							
Glaucony - glauconite	0.0	0.0	0.4	0.0	0.4	0.6	0.4
- chlorite	0.0	0.0	0.0	0.0	0.2	0.0	0.0
Fe carbonate - replace	5.4	4.6	6.0	3.2	4.0	3.4	6.2
- fill pores	2.2	0.6	3.0	4.2	3.0	2.6	1.2
Clear carbonate - replace	14.6	5.4	1.0	1.8	1.6	1.2	12.8
- fill pores	13.6	8.6	1.0	2.2	1.4	1.2	12.0
Quartz	0.4	0.6	0.6	0.6	0.4	0.2	0.0
Feldspar	0.4	0.2	0.4	0.8	0.8	0.4	0.6
Illite - replace	0.0	0.6	0.2	1.4	1.4	1.8	1.4
Kaolin - replace	2.8	1.2	2.6	4.0	2.6	3.8	1.2
- fill pores	2.0	1.4	1.8	2.8	2.4	3.2	0.4
Pyrite - replace	0.2	0.4	0.2	0.4	0.2	0.4	0.4
- fill pores	0.8	0.2	0.2	0.6	0.4	0.4	0.4
Porosity							
Intergranular	0.0	2.8	1.6	2.0	4.0	5.6	0.0
Dissolution	2.4	9.0	7.8	12.4	9.8	13.6	3.6
Fracture	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Micropores	0.6	0.4	0.6	0.8	0.6	0.8	0.2
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0

TABLE 2 continued POINT COUNT DATA FOR CASINO-4

Sample No.	68	56	50	46	36	31	28	18
Depth (m)	1779.3	1775.72	1773.5	1771.91	1768.71	1766.93	1765.41	1762.1
Framework grains								
Quartz - mono	28.0	31.4	33.2	29.2	31.0	25.6	27.4	26.6
- poly	6.6	6.8	7.4	7.6	7.6	4.2	4.4	8.8
Feldspar - Kspar	5.0	5.0	3.8	4.2	4.2	3.4	2.0	5.2
-plagioclase	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.2
Lithics - sedimentary	8.2	6.0	4.8	7.6	6.8	5.4	4.0	6.0
- metamorphic	11.2	12.4	11.8	13.0	13.8	12.8	9.0	6.4
- igneous	0.8	1.8	0.4	1.0	1.4	2.4	1.4	2.4
- unknown	2.2	1.8	2.6	1.2	3.0	2.2	2.6	1.2
Mica - muscovite	0.4	0.4	0.2	0.2	0.6	0.4	0.2	0.4
- biotite	0.0	0.0	0.2	0.0	0.0	0.4	0.2	0.0
Ooids	0.2	0.0	0.0	0.0	0.0	0.2	0.2	0.0
Accessory - zircon	0.2	0.2	0.2	0.2	0.2	0.2	0.4	0.0
- tourmaline	0.2	0.2	0.4	0.2	0.2	0.2	0.2	0.0
- rutile	0.0	0.2	0.2	0.2	0.2	0.0	0.2	0.0
- opaques	0.0	0.0	0.2	0.0	0.2	0.0	0.2	0.0
- garnet	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0
- monazite	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0
Matrix								
Clay	0.6	0.0	0.0	0.0	0.2	0.0	0.0	0.0
Organic matter	0.4	0.6	0.6	0.6	1.4	0.6	0.0	1.0
Authigenic minerals								
Glaucony - glauconite	0.8	0.8	0.2	0.2	0.8	0.4	0.0	0.0
- chlorite	0.0	0.2	0.2	0.0	0.2	0.0	0.2	0.0
Fe carbonate - replace	3.0	2.4	2.6	1.6	3.4	1.0	3.0	7.0
- fill pores	1.6	1.2	1.4	1.0	0.4	0.6	1.6	2.0
Clear carbonate - replace	2.8	1.4	1.6	0.6	1.2	10.4	21.0	0.0
- fill pores	3.0	1.4	1.0	0.8	0.4	7.6	7.2	0.0
Quartz	0.8	0.4	0.4	0.8	0.2	0.2	0.2	1.8
Feldspar	0.4	0.2	0.2	0.2	0.2	0.2	0.2	0.6
Illite - replace	0.4	0.2	0.6	0.6	0.2	0.0	0.6	0.6
Kaolin - replace	4.4	5.8	5.4	4.4	4.6	6.2	4.2	1.6
- fill pores	3.2	4.8	4.0	4.2	4.4	4.4	1.8	2.2
Pyrite - replace	0.2	0.6	0.2	0.4	0.6	1.0	0.2	0.2
- fill pores	0.2	0.0	0.4	0.4	0.2	0.4	0.2	0.0
Porosity								
Intergranular	2.8	2.2	2.4	7.0	2.0	0.6	0.0	13.6
Dissolution	11.4	9.6	12.0	11.0	9.4	8.0	6.6	10.2
Fracture	0.0	0.6	0.2	0.4	0.0	0.0	0.0	1.6
Micropores	0.8	1.0	1.0	1.0	1.0	1.0	0.6	0.4
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

4.1 Casino-4, core plug 5, depth 1791.70m

Rock classification: **Carbonate cemented litharenite**

Texture:

Sedimentary structures: weak grain alignment indicates the orientation of bedding but there are no bed contacts
Average grain size: medium sand (0.38mm)
Range in grain size: very fine to coarse sand
Roundness / sphericity: angular to subrounded with low to moderate sphericity
Sorting: moderately well sorted (0.50 φ)
Texture: grain supported
Packing / grain contacts: moderately open / point & tangential grain contacts
Pore types: secondary dissolution pores of various types including grain size, intragranular & partial dissolution of carbonate cement, micropores associated with kaolin

Composition:

Framework grains: monocrystalline quartz, polycrystalline quartz with either straight or sutured crystal boundaries, dusty K-feldspars & rare examples with ?granophyric texture & tartan twinning, partially sericitised plagioclase with albite twinning, lithics of chert (fresh & dusty), chalcedony, sandy mudstone, illitic siltstone to very fine grained sandstone, shale, quartzite, micaceous schist, various igneous lithics including possible devitrified glass, ?monzonite, granite & trachyte, & other unidentified highly altered grains, splayed & bent muscovite flakes up to 0.50mm in length, accessory medium sand size tourmaline & fine sand size opaques & rutile
Matrix: blocky opaque organic matter
Authigenic minerals: remnants of euhedral quartz overgrowths prior to pore filling carbonate spar, pervasive pore filling & grain replacing twinned, poikilotopic clear carbonate spar, isolated euhedral to subhedral rhombic spar (less than 20 microns diameter) floating within the pervasive spar or clustered along grain margins, minor anhedral Fe rich micrite to microspar replacing grains (possibly including micas), examples of these Fe carbonate replaced grains are partially corroded, anhedral grain replacing kaolin booklets up to 20 microns diameter, minute anhedral pore filling kaolin, euhedral kaolin booklets up to 50 microns diameter where micas replaced, pyrite framboids up to 50 microns diameter float in the carbonate spar & are clustered along grain margins, remnants of feldspar overgrowths on dusty K feldspars lack twinning & are embayed by pore filling clear spar

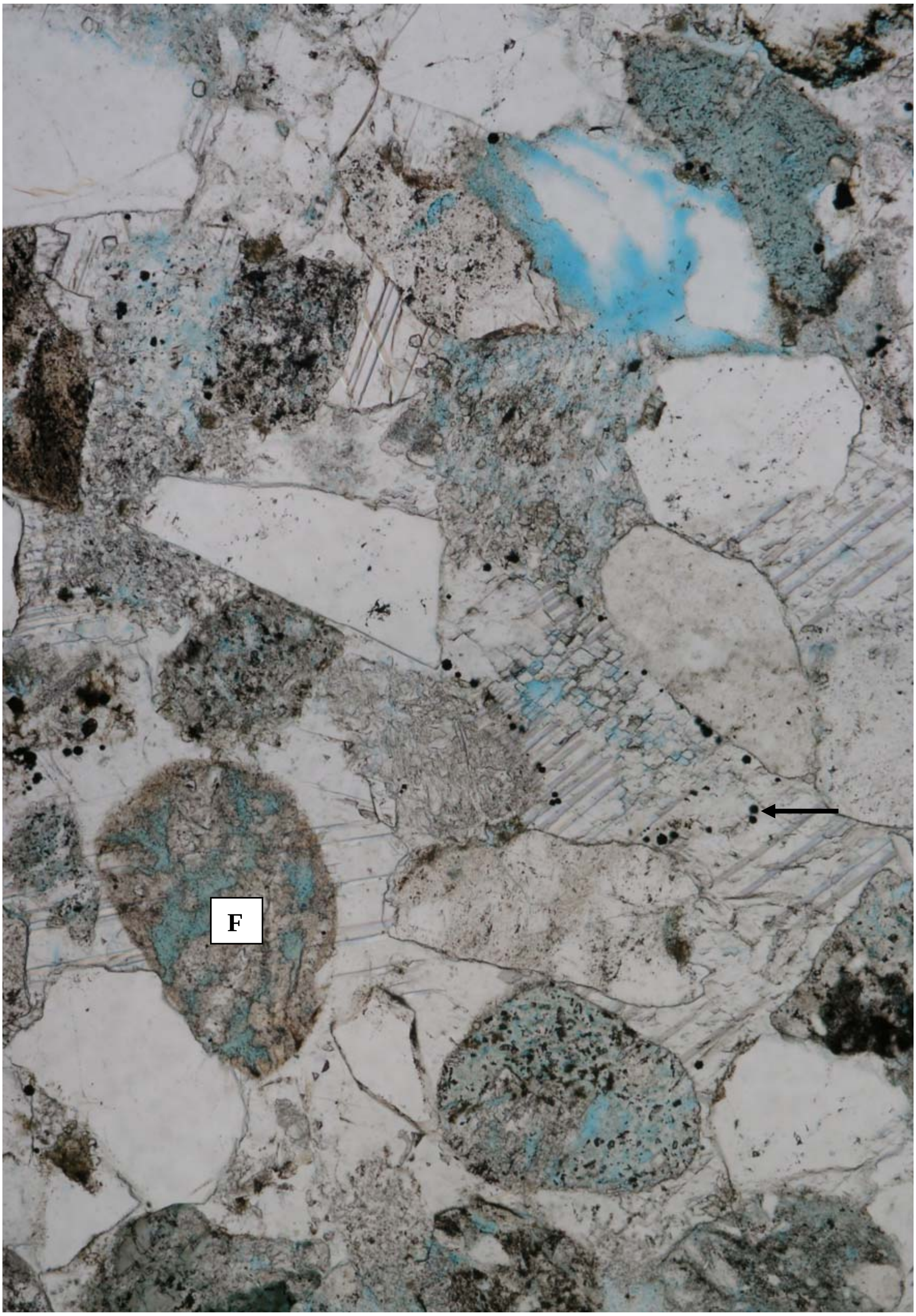


Figure 1
There appears to have been a phase of dissolution which corroded grains replaced by Fe rich carbonate (F). Pervasive pore filling twinned carbonate spar filled intergranular pores. Note the concentration of pyrite framboids along a former grain margin (arrows) that has been dissolved and then partially filled with twinned spar. Casino-4, core plug 5, depth 1791.70m. Plane light. Horizontal field of view 1.30mm.

4.2 Casino-4, core plug 4, depth 1790.72m

Rock classification: **Carbonate cemented litharenite**

Texture:

Sedimentary structures: planar laminae up to 3mm thick are outlined by the concentration of coarser sand grains & ovoid mudstone pebbles (?faecal pellets)

Average grain size: medium sand (0.49mm)

Range in grain size: fine sand to pebbles

Roundness / sphericity: angular to subrounded with low to moderate sphericity

Sorting: moderately well (0.69 φ)

Texture: grain supported

Packing / grain contacts: moderately open / point, tangential & concavo-convex grain contacts

Pore types: primary intergranular pores, grain size dissolution pores, intragranular pores within lithics (chert & unidentified), honeycomb pores & micropores associated with kaolin

Composition:

Framework grains: monocrystalline quartz, polycrystalline quartz with either straight or sutured crystal boundaries up to very coarse sand in size, dusty & corroded feldspars, rare examples with tartan twinning, feldspars with granophyric texture, lithics of chert, chalcedony, illitic siltstone & sandstone, dark brown mudstone, shale, quartzite, micaceous schist, ?granite, ?volcanics (including ??basalt & devitrified glass) & highly altered/corroded unidentified lithics, splayed muscovite up to 0.6mm in length, accessory silt to fine sand size zircon & medium sand size tourmaline

Matrix: cellular & blocky opaque organic matter

Authigenic minerals: multiple phases of carbonate; Fe rich micrite has replaced grains & forms a localised (?nodular) cement, calcite spar (stained red) has filled pores & partially replaced grains, trace amounts of ferroan calcite (stained mauve) filled pores & rarely has an irregular rim on the calcite phase, ferroan calcite (stained blue) appears to postdate the calcite & has both filled pores (including dissolution pores) & replaced grains, ferroan calcite has euhedral terminations on pore margins & is more abundant than the calcite, rare euhedral quartz overgrowths prior to calcite spar, clear feldspar overgrowths on dusty K-feldspars have been corroded, vermiform kaolin booklets up to 50 microns in diameter have probably replaced micas, other grain replacing & pore filling kaolin is 10-20 microns in diameter, pyrite framboids 15 microns in diameter on grain margins & rare blocky pyrite partially replacing grains, grains replaced by illite have been deformed

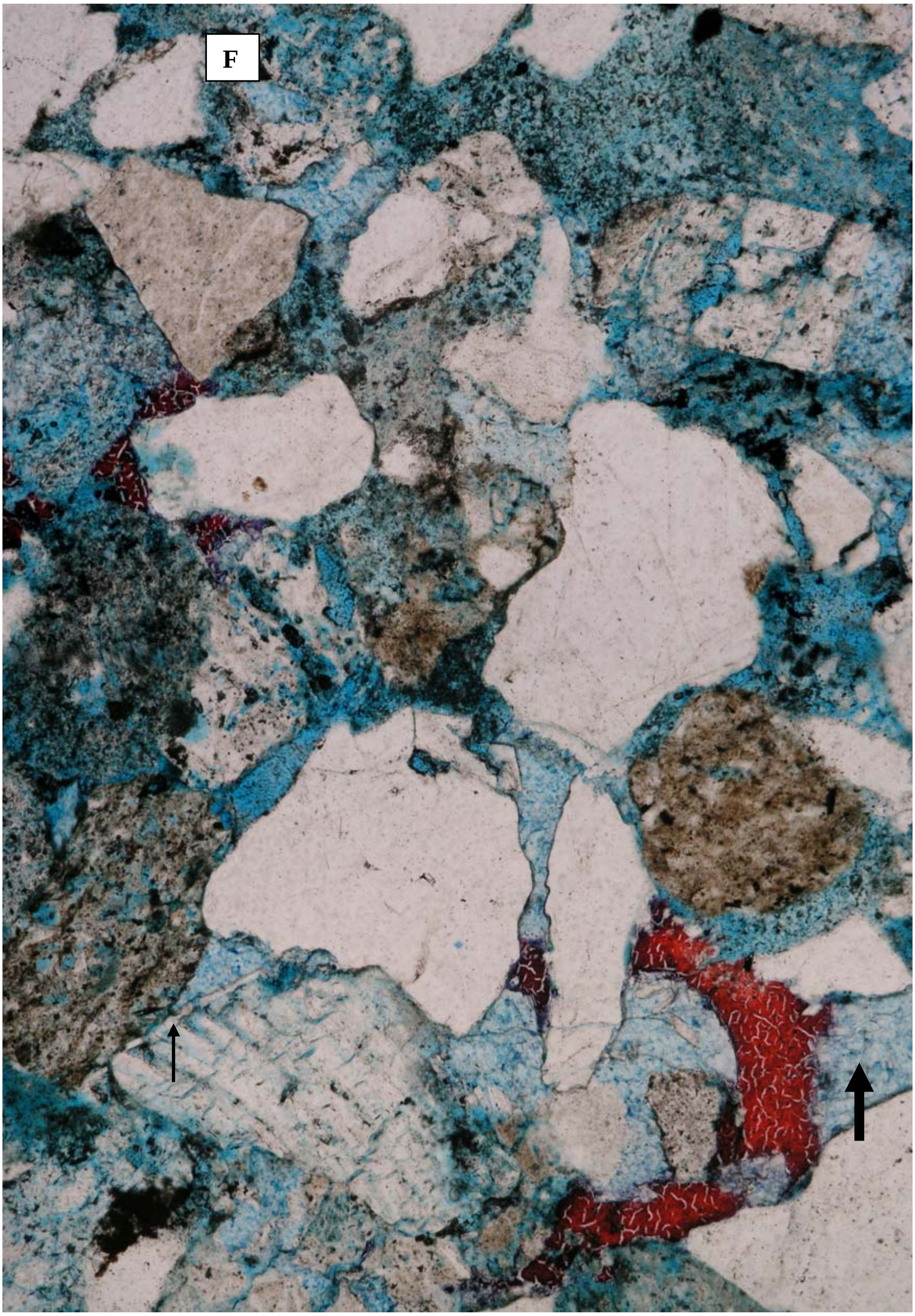


Figure 2

Carbonate cements of calcite (dark red) and ferroan calcite (blue – large arrow) are evident in this field of view. Note the intragranular pores within lithics (brown), honeycomb pores in feldspars (F) & a discontinuous feldspar overgrowth (small arrow). Casino-4, core plug 4, depth 1790.72m. Plane light. Stained section. Horizontal field of view 1.30mm.

4.3 Casino-4, core plug 99, depth 1789.68m

Rock classification: **Litharenite**

Texture:

Sedimentary structures: planar X-laminae & bedding are outlined by changes in grains size (sandstone to silty mudstone), clay & organic matter content; rip-up clasts of silty mudstone within the sandstone
Average grain size: medium sand (0.28mm)
Range in grain size: clay to very coarse sand
Roundness / sphericity: angular to subangular with low to moderate sphericity
Sorting: very poor (2.13 φ)
Texture: grain supported
Packing / grain contacts: moderately open / point & tangential grain contacts
Pore types: rare primary intergranular pores, dominantly secondary pores due to complete dissolution of grains, partial dissolution of lithics to form intragranular pores & partial dissolution of feldspars to form honeycomb pores, micropores associated with kaolin & glaucony

Composition:

Framework grains: monocrystalline quartz, polycrystalline quartz with either straight or sutured crystal boundaries, examples with straight crystal boundaries are dominant & up to very coarse sand in size, K-feldspars with tartan twinning, corroded feldspars lack twinning, other feldspars with granophyric texture, lithics of chert (fresh & dusty), chalcedony, silty mudstone, illitic siltstone & very fine grained sandstone, shale, quartzite, micaceous schist, ?granite & volcanics with remnants of trachytic texture, straight muscovite flakes up to 0.60mm in length, accessory fine sand size ?monazite & very fine sand size zircon & garnet

Matrix: brown anhedral clay only in the silty mudstone laminae, crenulated stringers, blocky & cellular opaque organic matter concentrated in the finer grained laminae, reddish organic matter in the silty mudstone

Authigenic minerals: medium sand size bright green glaucony with wormy texture & shrinkage cracks, other grains of glaucony are highly deformed, grain replacing & pore filling Fe rich micrite & microspar forms a localised cement, minor pore filling & lithic/feldspar replacing clear anhedral to subhedral carbonate spar, prismatic quartz overgrowths, grain replacing kaolin booklets up to 20 microns in diameter, pore filling & grain replacing vermiform kaolin up to 50 microns diameter, discontinuous feldspar overgrowths lack twinning & rarely appear corroded, grains of unknown origin replaced by illite, clusters of pore filling & grain replacing pyrite framboids up to 10 microns diameter

Figure 3

Rip-up clast of silty mudstone (brown) within the sandstone bed. Note the pore filling & grain replacing patches of Fe rich micrite (arrows) which appear dark brown at this magnification. Casino-4, core plug 99, depth 1789.68m. Plane light. Horizontal field of view 6.5mm.

4.4 Casino-4, core plug 14, depth 1786.32m

Rock classification: **Litharenite**

Texture:

Sedimentary structures: subtle changes in grain size could indicate the presence of bedding, contact between beds is gradational
Average grain size: medium sand (0.32mm)
Range in grain size: very fine to very coarse sand
Roundness / sphericity: angular to subangular with low sphericity
Sorting: moderately well (0.57 φ)
Texture: grain supported
Packing / grain contacts: moderately close / tangential & rare concavo-convex contacts
Pore types: rare intergranular pores, dominantly secondary pores of grain size, intragranular & honeycomb nature, micropores associated with kaolin

Composition:

Framework grains: monocrystalline quartz, polycrystalline quartz with either straight or sutured crystal boundaries, corroded & sericitised K-feldspars lack twinning & are up to very coarse sand in size, rare feldspars with tartan & pericline twinning, lithics of chert (fresh & dusty brown), chalcedony, illitic siltstone & sandstone, dark brown mudstone, shale, quartzite, micaceous schist, possible volcanics with remnants of trachytic texture & devitrified glass, & other unidentified highly altered lithics, bent muscovite flakes up to 1.6mm in length, accessory very fine to fine sand size zircon & tourmaline
Matrix: blocky opaque organic matter,
Authigenic minerals: anhedral Fe rich micrite & microspar replacing grains (micas, lithics & feldspars), euhedral rhombic microspar (trace of Fe) scattered along grain margins & trapped within dust rims of quartz overgrowths, clear blocky pore filling anhedral to euhedral spar postdates both Fe rich micrite & euhedral microspar, similar clear spar has partially replaced corroded grains &/or spar is corroded, minute anhedral grain replacing & pore filling kaolin booklets up to 5 microns diameter form localised patches prior to the Fe rich anhedral microspar, other euhedral kaolin booklets up to 25 microns within lithics, rare grains completely replaced by kaolin & filling adjacent pores, prismatic quartz overgrowths, discontinuous feldspar overgrowths lack twinning, blocky & framboidal pyrite associated with grains replaced by Fe rich microspar & partially replacing other detrital grains, grains of unknown origin replaced by illite

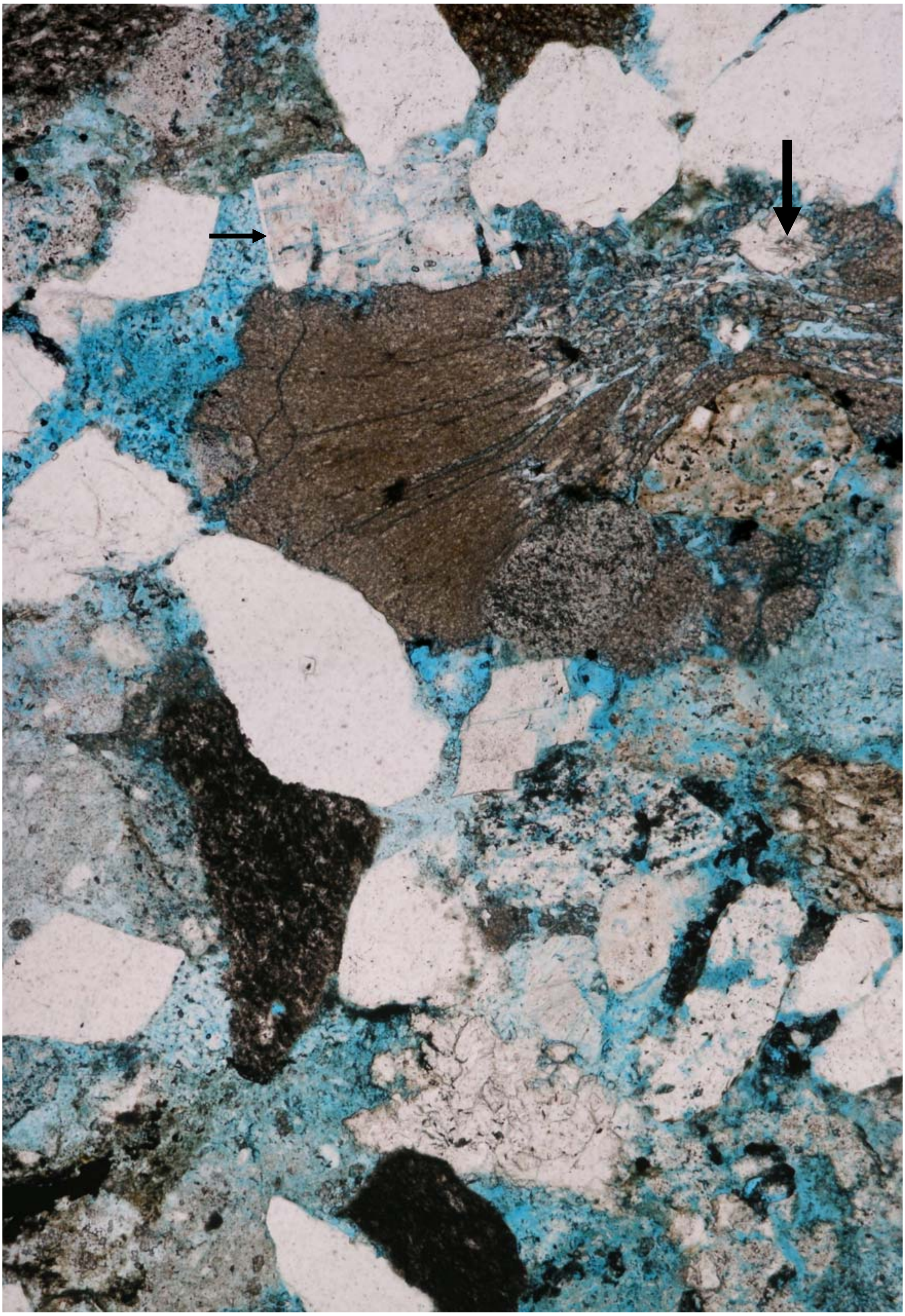


Figure 4

General field of view illustrating the replacive (probably a mica) nature of Fe rich micrite & microspar, & the later precipitation of clear anhedral spar (large arrow) within the Fe rich carbonate. Note the feldspar overgrowth (small arrow) on a partially corroded grain & other highly altered grains. Many pores are partially filled with grinding paste. Casino-4, core plug 14, depth 1786.32m. Plane light. Horizontal field of view 1.30mm.

4.5 Casino-4, core plug 84, depth 1784.70m

Rock classification: **Litharenite**

Texture:

Sedimentary structures: changes in grain size indicate the presence of cross laminae & planar muddy laminae, bed contacts are sharp

Average grain size: medium sand (0.37mm) – bimodal grain size

Range in grain size: clay to granules

Roundness / sphericity: angular to subrounded with low sphericity

Sorting: poor (1.67 φ)

Texture: grain supported

Packing / grain contacts: moderately open / point, tangential & rare concavo-convex contacts

Pore types: intergranular pores, secondary grain size pores, honeycomb pores & intragranular pores, & micropores associated with kaolin

Composition:

Framework grains: monocrystalline quartz, polycrystalline quartz with either straight or sutured crystal boundaries, corroded feldspars that lack twinning or have simple twinning up to granules in size, rare feldspars with granophyric texture & tartan twinning, lithics of banded (& possibly dusty nodular) chert, chalcedony, illitic siltstone & sandstone, dark brown mudstone, quartzite, deformed shale, micaceous schist, ?granite (coarsely crystalline intergrowths of feldspar & quartz up to very coarse sand in size), very finely crystalline ?volcanics & devitrified glass, & other unidentified lithics (?metamorphosed igneous with fibrous ?hornblende reaction rims), straight & highly altered muscovite flakes up to 0.30mm in length, accessory silt to very fine sand size zircon, fine sand size rutile & very fine to medium sand size tourmaline

Matrix: blocky opaque organic matter & crenulated stringers concentrate in muddy laminae, brown anhedral clay & silt size grains in muddy laminae

Authigenic minerals: very fine sand size bright green glaucony with a fibrous texture suggestive of chlorite, deformed fine sand size oxidised glaucony with wormy texture, Fe rich micrite has extensively replaced the detrital clay, grains replaced & adjacent pores filled with anhedral Fe rich microspar in the clean laminae, isolated crystals of euhedral clear rhombic microspar (10 microns diameter) concentrate along grain margins, anhedral clear spar replacing kaolin & framework grains & filling pores postdates the microspar, clear euhedral rhombic spar filling pores has curved crystal boundaries typical of saddle dolomite, prismatic & rhombohedral quartz overgrowths, discontinuous feldspar overgrowths that lack twinning, minute anhedral grain replacing ?kaolin up to 5 microns diameter, other grains are replaced & pores filled by booklets & verms up to 25 microns diameter, grains of unknown origin replaced by illite, clusters of pyrite framboids within pores & replacing grains

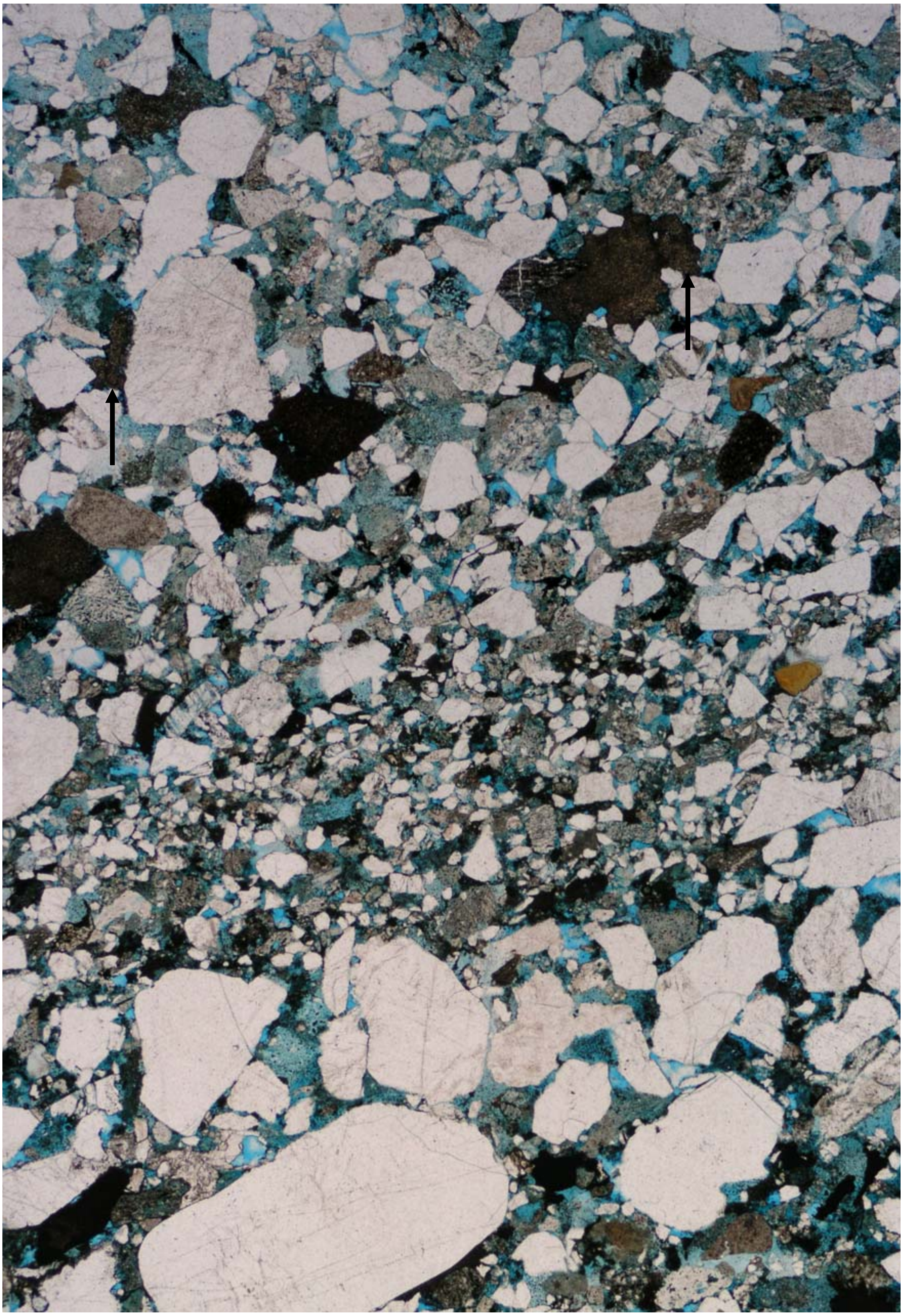


Figure 5
Cross laminae are outlined in this field of view by changes in grain size. Note the alignment of patches of Fe rich grain replacing & pore filling carbonate (arrows). Casino-4, core plug 84, depth 1784.70m. Plane light. Horizontal field of view 6.5mm.

4.6 Casino-4, core plug 77, depth 1781.98m

Rock classification: **Litharenite**

Texture:

Sedimentary structures: zonation is apparent in the degree of alteration & dissolution which gives the artificial appearance of bedding (dissolution may have been controlled originally by detrital mineralogy)

Average grain size: medium sand (0.33mm)

Range in grain size: very fine to coarse sand

Roundness / sphericity: angular to subangular with low to moderate sphericity

Sorting: moderately well (0.57 φ)

Texture: grain supported

Packing / grain contacts: moderately close / tangential & concavo-convex

Pore types: secondary pores dominant with examples of grain size, honeycomb & intragranular pores within metamorphic & chert lithics, rare intergranular pores in the zone where there has been maximum dissolution, micropores

Composition:

Framework grains: monocrystalline quartz, polycrystalline quartz with either straight or sutured crystal boundaries, sericitised & corroded K-feldspars lack twinning, rare examples of relatively fresh feldspars with pericline & tartan twinning, lithics of chert (including banded, dusty & fresh), chalcedony, illitic siltstone, dark brown mudstone, quartzite, shale, finely crystalline ?volcanics, volcanics with trachytic texture, ?granite & other unidentified lithics, superficial ooids of Fe rich carbonate are ovoid, less than 0.1mm diameter & have only one weakly developed lamella, bent & partially kaolinised muscovite flakes up to 0.70mm in length, accessory fine sand size rutile & tourmaline

Matrix: stringers of brown anhedral clay & traces of blocky opaque organic matter

Authigenic minerals: slightly oxidised pale yellow to pale green incipient medium sand size grains of glaucony with wormy texture, pore filling & grain replacing Fe rich micrite/microspar is most abundant in the zone with least dissolution, isolated crystals of euhedral clear microspar scattered along grain margins, clear anhedral spar has filled pores & partially replaced grains especially in the zone of maximum dissolution, rarely this spar appears to be corroded, grain replacing & pore filling anhedral to subhedral kaolin booklets & verms up to 50 microns in diameter, blocky & framboidal grain replacing & pore throat filling pyrite postdates the Fe rich micrite, rare feldspars with discontinuous overgrowths that lack twinning, prismatic quartz overgrowths, grains of unknown origin replaced by illite

Figure 6

Contact between the zone of ?dissolution with abundant porosity (blue) and zone which has Fe rich carbonate cement & possibly more lithics. Casino-4, core plug 77, depth 1781.98m. Plane light. Horizontal field of view 3.25mm.

4.7 Casino-4, core plug 72, depth 1780.54m

Rock classification: **Carbonate cemented litharenite**

Texture:

- Sedimentary structures: very weak grain alignment may indicate the orientation of bedding
- Average grain size: medium sand (0.27mm)
- Range in grain size: very fine to coarse sand
- Roundness / sphericity: angular to subangular with low sphericity
- Sorting: moderately well (0.55 φ)
- Texture: grain supported
- Packing / grain contacts: moderately close / tangential & concavo-convex where ductile grains have been deformed
- Pore types: grain size dissolution pores, honeycomb & intragranular pores, micropores associated with kaolin

Composition:

- Framework grains: monocrystalline quartz, polycrystalline quartz with dominantly straight crystal boundaries, rare examples with sutured crystal boundaries, relatively fresh & corroded K-feldspars with tartan twinning, other feldspars lack twinning & are commonly corroded &/or dusty, rare examples have micrographic & granophyric texture, lithics of chert (including banded), chalcedony, deformed dark brown mudstone, shale, illitic sandstone, micaceous schist, quartzite, pyrophyllite, very finely crystalline ?volcanics, ?spherulitic rhyolite & other unidentified lithics, isolated superficial ooids of Fe rich carbonate, bent muscovite & biotite flakes up to 0.40mm in length, accessory silt to very fine sand size ?monazite, tourmaline & opaques
- Matrix: irregular crenulated stringers of opaque organic matter
- Authigenic minerals: rounded fine sand size yellowish grains with wormy texture typical of incipient glaucony, grain replacing dusty micrite & anhedral Fe rich microspar that did not respond to staining, the latter also occur within dissolution pores, pervasive pore filling & grain replacing calcite (stained red) spar, rare grain replacing ferroan calcite (stained blue) spar, patches of grain replacing & pore filling kaolin booklets up to 20 microns in diameter are partially replaced by Fe rich micrite, rare feldspar overgrowths lack twinning & occur on grains that are partially corroded, pyrite framboids up to 20 microns in diameter scattered along grain margins, blocky pyrite replacing grains after Fe rich microspar & filling pores, grains of unknown origin replaced by illite

Figure 7
This field of view illustrates the pervasive pore filling & grain replacing calcite spar (red). Dusty Fe rich microspar (brown) has replaced grains adjacent to a superficial ooid (arrow). Porosity (blue) is secondary and due to dissolution. Casino-4, core plug 72, depth 1780.54m. Plane light. Horizontal field of view 1.30mm.

4.8 Casino-4, core plug 68, depth 1779.30m

Rock classification: **Litharenite**

Texture:

Sedimentary structures: stringers of detrital clay & organic matter indicate the orientation of bedding

Average grain size: fine sand (0.24mm)

Range in grain size: clay to medium sand

Roundness / sphericity: angular to subrounded with low sphericity

Sorting: moderately (0.78 φ)

Texture: grain supported

Packing / grain contacts: moderately close / tangential & concavo-convex where ductile grains deformed

Pore types: primary intergranular pores, secondary dissolution pores that are grain size, intragranular & honeycomb, micropores associated with kaolin, extensive contamination from grinding paste

Composition:

Framework grains: monocrystalline quartz, polycrystalline quartz with either sutured or straight crystal boundaries, partially corroded feldspars either lack twinning or have tartan twinning, rare examples with granophyric texture & albite twinning, lithics of chert (including banded), illitic siltstone, dark brown mudstone, micaceous schist, shale, quartzite, pyrophyllite, ?granite, volcanics with trachytic texture, ?devitrified glass & other unidentified highly altered lithics, superficial ooids of Fe rich carbonate are up to 0.10mm in diameter, bent & partially altered muscovite flakes up to 0.40mm in length, accessory very fine to fine sand size zircon & tourmaline

Matrix: traces of opaque & reddish organic matter & stringers of brown anhedral clay

Authigenic minerals: fine sand size white grains with wormy texture suggestive of very incipient glaucony & bright green grains typical of mature glaucony, Fe rich micrite has replaced grains & filled pores, single euhedral rhombs of clear microspar to spar (approximately 20 microns diameter) that did not respond to staining are scattered along grain boundaries & postdate grain replacing minute kaolin booklets, incipient zoning is apparent within rare microspar to spar & single crystals occur within patches of ferroan calcite spar, ferroan calcite spar (stained blue) has replaced grains, filled pores & has euhedral terminations on pore margins, pore filling & grain replacing kaolin booklets range from 10 to 20 microns in diameter, where micas have been replaced the kaolin is 50 microns in diameter, pyrite framboids clustered along grain margins & rare blocky pyrite has replaced grains, thin (10-20 microns) feldspar overgrowths on partially corroded K-feldspars, rare euhedral terminations & straight grain contacts suggest quartz overgrowths, grains of unknown origin replaced by illite

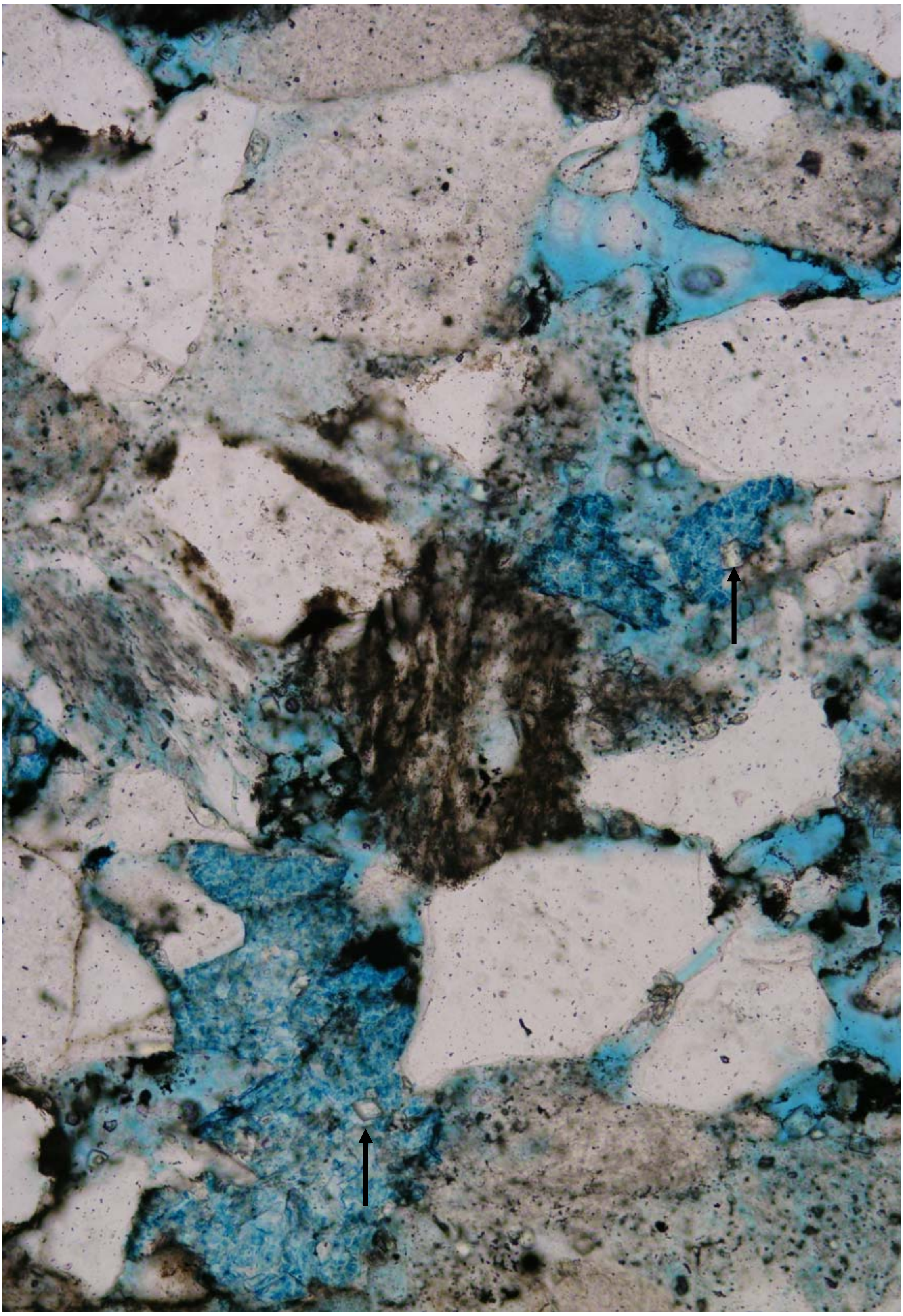


Figure 8

Pore filling euhedral ferroan calcite spar (blue) & minute rhombs of clear spar (arrows) are evident in this field of view. Much of the opaque material is contaminant grinding paste. Casino-4, core plug 68, depth 1779.30m. Plane light. Horizontal field of view 0.65mm.

4.9 Casino-4, core plug 56, depth 1775.72m

Rock classification: **Litharenite**

Texture:

Sedimentary structures: weak grain alignment may indicate the orientation of bedding but there are no bed contacts
Average grain size: medium sand (0.32mm)
Range in grain size: fine to coarse sand
Roundness / sphericity: angular to subrounded with low sphericity
Sorting: well sorted (0.49 φ)
Texture: grain supported
Packing / grain contacts: moderately close / tangential & rare concavo-convex where lithics have been deformed
Pore types: primary intergranular pores, grain size dissolution pores, honeycomb pores within feldspars, intragranular pores in lithics, micropores associated with kaolin, fracturing is parallel to ?bedding & therefore could be an artifact of sampling

Composition:

Framework grains: monocrystalline quartz, polycrystalline quartz with either straight or sutured crystal boundaries, rare oxidised grains (?hematite) of polycrystalline quartz, corroded & sericitised feldspars that lack twinning or have pericline & tartan twinning up to coarse sand in size, fresh examples with granophyric texture, lithics of chert (including banded), chalcedony, illitic siltstone, deformed mudstone, shale, micaceous schist, quartzite, ?granite, very finely crystalline ?volcanics & other unidentified highly altered grains, fresh & altered muscovite flakes up to 0.75mm in length, accessory silt to medium sand size tourmaline, zircon, rutile & garnet
Matrix: blocky opaque organic matter
Authigenic minerals: white fine sand size grains with wormy texture typical of incipient glaucony, dark green highly deformed grains replaced by ? chlorite, dusty anhedral micrite/microspar has partially replaced lithics & filled pores adjacent to organic matter, isolated crystals of clear rhombic microspar scattered along grain margins, blocky clear spar filling pores & replacing grains has been partially corroded, one ?volcanic lithic has a circumgranular rim of anhedral blocky dusty microspar, rare euhedral terminations on quartz grains suggest the presence of syntaxial prismatic & larger rhombohedral quartz overgrowths, thin feldspar overgrowths lack twinning & are preserved on corroded grains, grain replacing & pore filling kaolin booklets up to 15 microns in diameter, where micas have been replaced the kaolin booklets are much larger, grain replacing pyrite framboids up to 15 microns diameter & irregular patches of grain replacing blocky pyrite formed after the micrite, traces of illite rarely associated with grain replacing kaolin

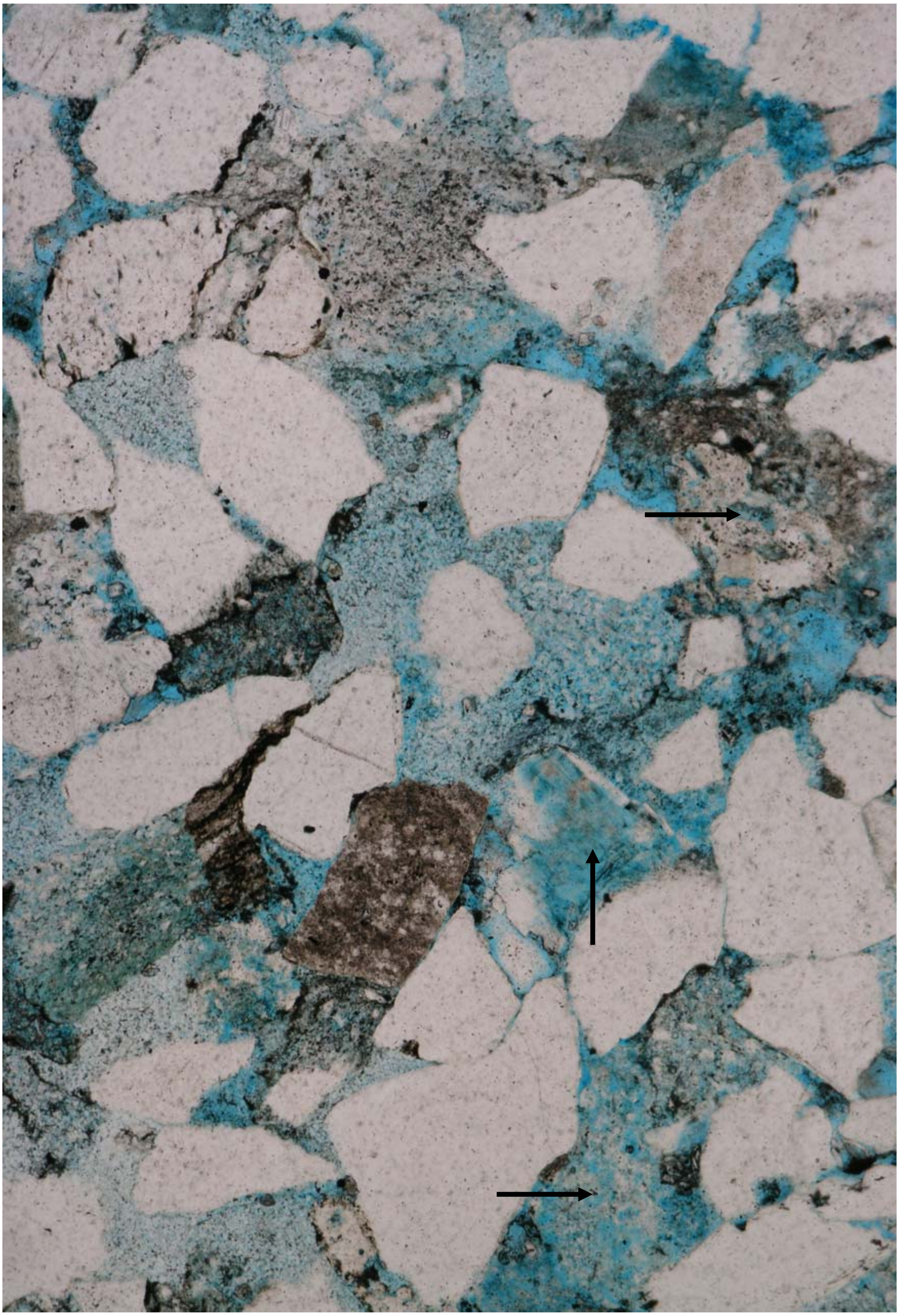


Figure 9
General field of view illustrating the dominance of secondary pores where grains are corroded (arrows) and micropores associated with kaolin (speckled). Casino-4, core plug 56, depth 1775.72m. Plane light. Horizontal field of view 1.30mm.

4.10 Casino-4, core plug 50, depth 1773.50m

Rock classification: **Litharenite**

Texture:

Sedimentary structures: weak grain alignment but no bed contacts
Average grain size: medium sand (0.27mm)
Range in grain size: fine to medium/coarse sand
Roundness / sphericity: angular to subrounded with low sphericity
Sorting: very well sorted (0.33 φ)
Texture: grain supported
Packing / grain contacts: moderately close / tangential & minor concavo-convex where lithics are deformed
Pore types: primary intergranular pores, secondary grain size, intragranular & honeycomb pores, micropores associated with kaolin, minor grain fracturing

Composition:

Framework grains: monocrystalline quartz, polycrystalline quartz with either straight or sutured crystal boundaries, corroded feldspars lack twinning or have tartan & pericline twinning, lithics of chert (banded), chalcedony, dark brown mudstone, shale, micaceous schist, quartzite, ?pyrophyllite, very finely crystalline volcanics & other highly altered lithics that could not be identified, straight fresh muscovite flakes up to 0.35mm in length, other highly altered bent micas (?biotite) are a similar size, accessory very fine to fine sand size tourmaline, rutile, opaques & zircon (rarely with hydrocarbon envelopes)
Matrix: rare stringers & blocky opaque organic matter
Authigenic minerals: fine sand size white grains with wormy texture typical of incipient glaucony, one grain replaced by dark green ?chlorite, grain replacing & pore filling anhedral Fe rich micrite & microspar that did not respond to staining, grain replacing & pore filling anhedral ferroan calcite (stained blue) spar appears to be partially corroded, anhedral kaolin booklets have replaced grains & filled adjacent pores, booklets are of variable size but typically approximately 20 microns diameter, vermiform kaolin has replaced micas, dusty euhedral microspar rhombs & ferroan calcite spar have precipitated in the kaolin, euhedral terminations on pore margins & hematite dust rims indicate the presence of quartz overgrowths, pyrite framboids scattered along grain margins are up to 25 microns diameter, rare blocky grain replacing pyrite, thin feldspar overgrowths occur on corroded grains & lack twinning, rare grains replaced by illite

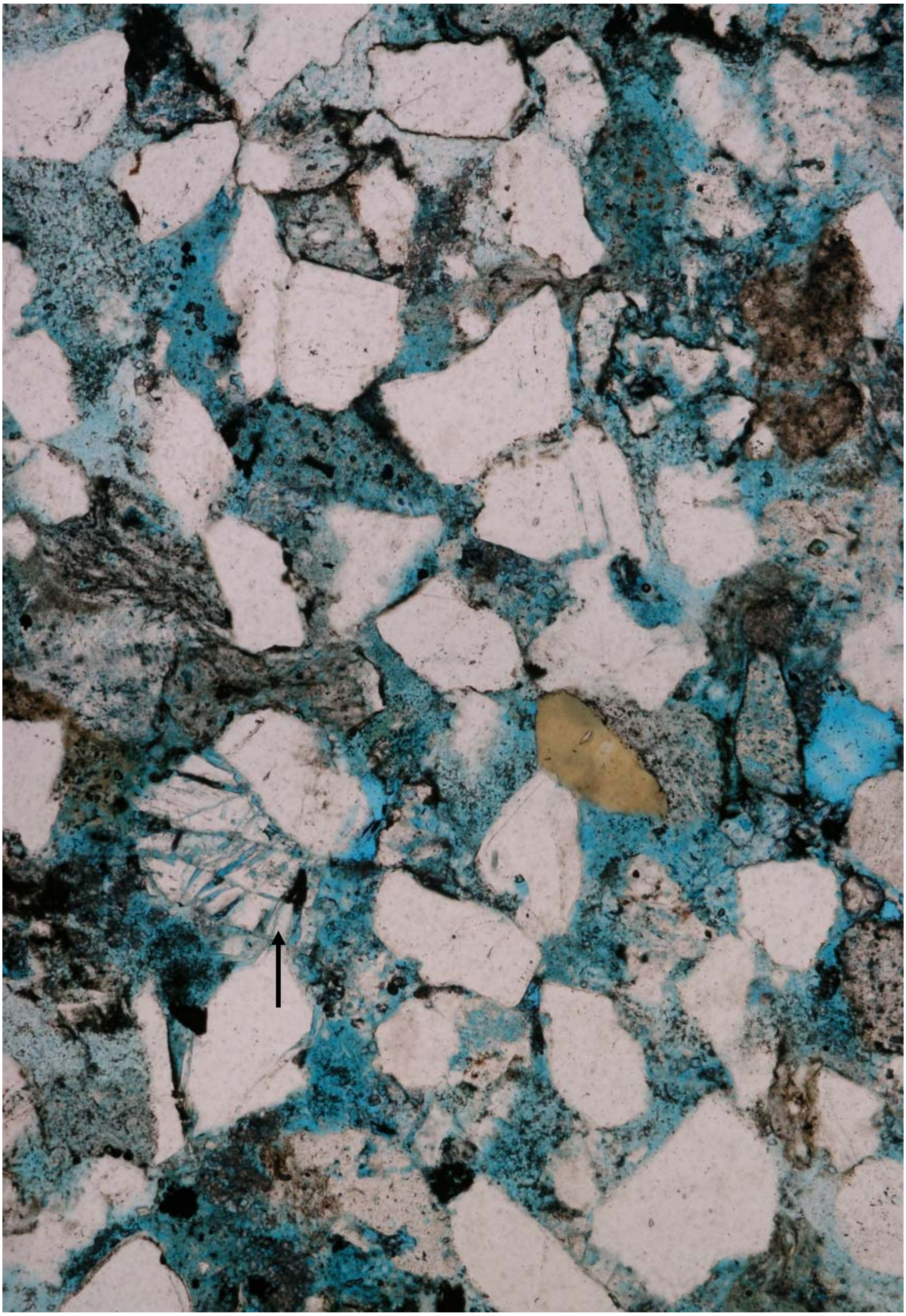


Figure 10

Rare K-feldspars are corroded and fractured (arrow). The latter is probably due to mechanical compaction. Note the yellow grain of accessory tourmaline which is almost medium sand in size. Casino-4, core plug 50, depth 1773.50m. Plane light. Horizontal field of view 1.30mm.

4.11 Casino-4, core plug 46, depth 1771.91m

Rock classification: **Litharenite**

Texture:

Sedimentary structures: weak grain alignment indicates the orientation of bedding but there do not appear to be any bed contacts

Average grain size: medium sand (0.39mm)

Range in grain size: very fine sand to granules

Roundness / sphericity: angular to subrounded with low sphericity

Sorting: moderately well (0.63 φ)

Texture: grain supported

Packing / grain contacts: moderately open / point, tangential & minor concavo-convex contacts due to ductile lithics

Pore types: primary intergranular, secondary grain size, intragranular & honeycomb pores, micropores & grain fracturing in quartz, feldspars & lithics

Composition:

Framework grains: monocrystalline quartz, polycrystalline quartz up to granules in size with straight crystal boundaries, finer grained polycrystalline quartz with sutured crystal boundaries, dusty corroded K-feldspars, relatively fresh K-feldspars with tartan twinning & granophyric texture, lithics of chert, dark brown mudstone, illitic siltstone, shale, quartzite (including examples with equant greenish-brown minerals - ?hornblende), micaceous schist, very finely crystalline ?volcanics, devitrified glass, ?granite & other highly altered unidentified lithics, bent muscovite flakes up to 0.60mm in length partially altered to kaolin, accessory very fine sand size tourmaline, zircon, rutile & ?monazite

Matrix: irregular stringers of opaque organic matter

Authigenic minerals: rounded slightly oxidised medium sand size grains with wormy texture typical of glaucony, grain replacing & pore filling dusty Fe rich anhedral micrite & microspar, grain replacing & pore filling clear rhombohedral spar that shows minor corrosion on pore margins, pore filling & grain replacing kaolin booklets & verms up to 25 microns in diameter, booklets are much larger where micas have been replaced, prismatic quartz overgrowths outlined by dust rims, thin discontinuous feldspar overgrowths on corroded detrital grains, pyrite framboids up to 15 microns diameter scattered along grain margins & blocky pyrite replacing grains, unidentified grains replaced by illite

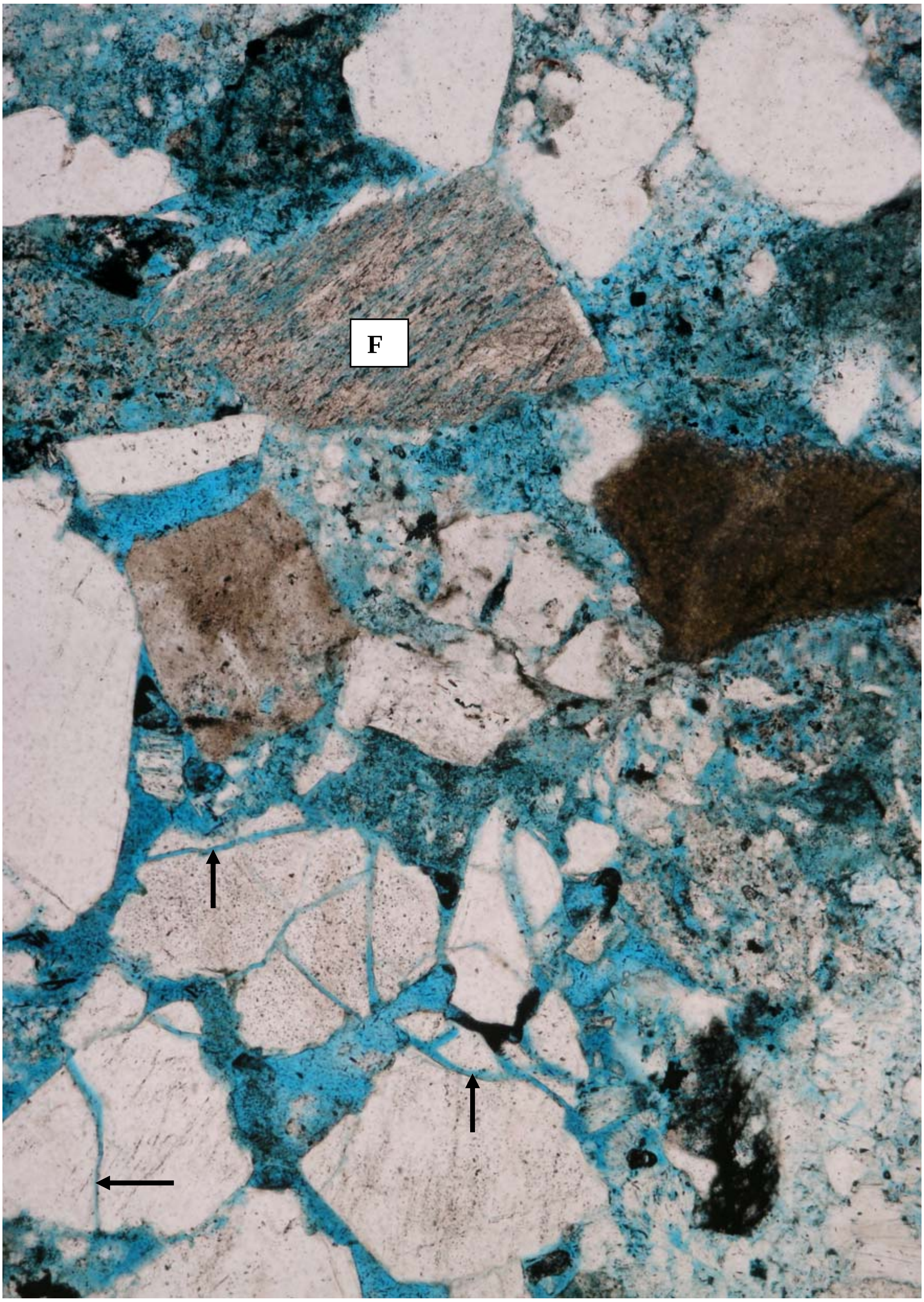


Figure 11
Grain fracturing (arrows) occurs within the centre of this core plug and is apparent in quartz grains, lithics and feldspars. Note the thin feldspar overgrowth on the corroded dusty feldspar (F) and the grain replaced by Fe rich micrite (appears brown). Casino-4, core plug 46, depth 1771.91m. Plane light. Horizontal field of view 1.30 mm.

4.12 Casino-4, core plug 36, depth 1768.71m

Rock classification: **Litharenite**

Texture:

Sedimentary structures:	rare stringers of clay & organic matter
Average grain size:	medium sand (0.27mm)
Range in grain size:	very fine to medium/coarse sand
Roundness / sphericity:	subangular to subrounded with low sphericity
Sorting:	well sorted (0.47 φ)
Texture:	grain supported
Packing / grain contacts:	moderately close / tangential & concavo-convex grain contacts
Pore types:	rare intergranular pores, dominantly secondary pores that are grain size, intragranular & honeycomb, micropores associated with kaolin

Composition:

Framework grains: monocrystalline quartz, polycrystalline quartz with either straight or sutured crystal boundaries, relatively fresh K-feldspars with tartan twinning & granophyric texture, other dusty corroded feldspars lack twinning, lithics of chert, chalcedony, dark brown mudstone, illitic sandstone, shale, quartzite, micaceous schist, ?pyrophyllite, ?granite, very finely crystalline ?volcanics, devitrified glass & highly altered unidentified lithics, bent muscovite flakes up to 0.4mm in length, accessory very fine to fine sand size zircon, tourmaline, rutile & opaques

Matrix: stringers & blocky opaque organic matter & dark brown clay

Authigenic minerals: deformed fine sand size dusty grains with wormy texture typical of glaucony, one medium sand size grain replaced by bright green fibrous chlorite, grain replacing & pore filling anhedral Fe rich micrite & microspar, blocky clear spar has also partially filled intergranular & grain size pores & replaced grains & kaolin, minute (5 microns) pore filling & grain replacing kaolin booklets, traces of illite remain where kaolin has replaced micas & kaolin booklets are up to 30 microns in diameter, thin feldspar overgrowths lack twinning & remain suspended around grain size dissolution pores, prismatic quartz overgrowths on the margins of intergranular pores, rare pyrite framboids up to 15 microns diameter scattered along grain margins & blocky pyrite replaced grains

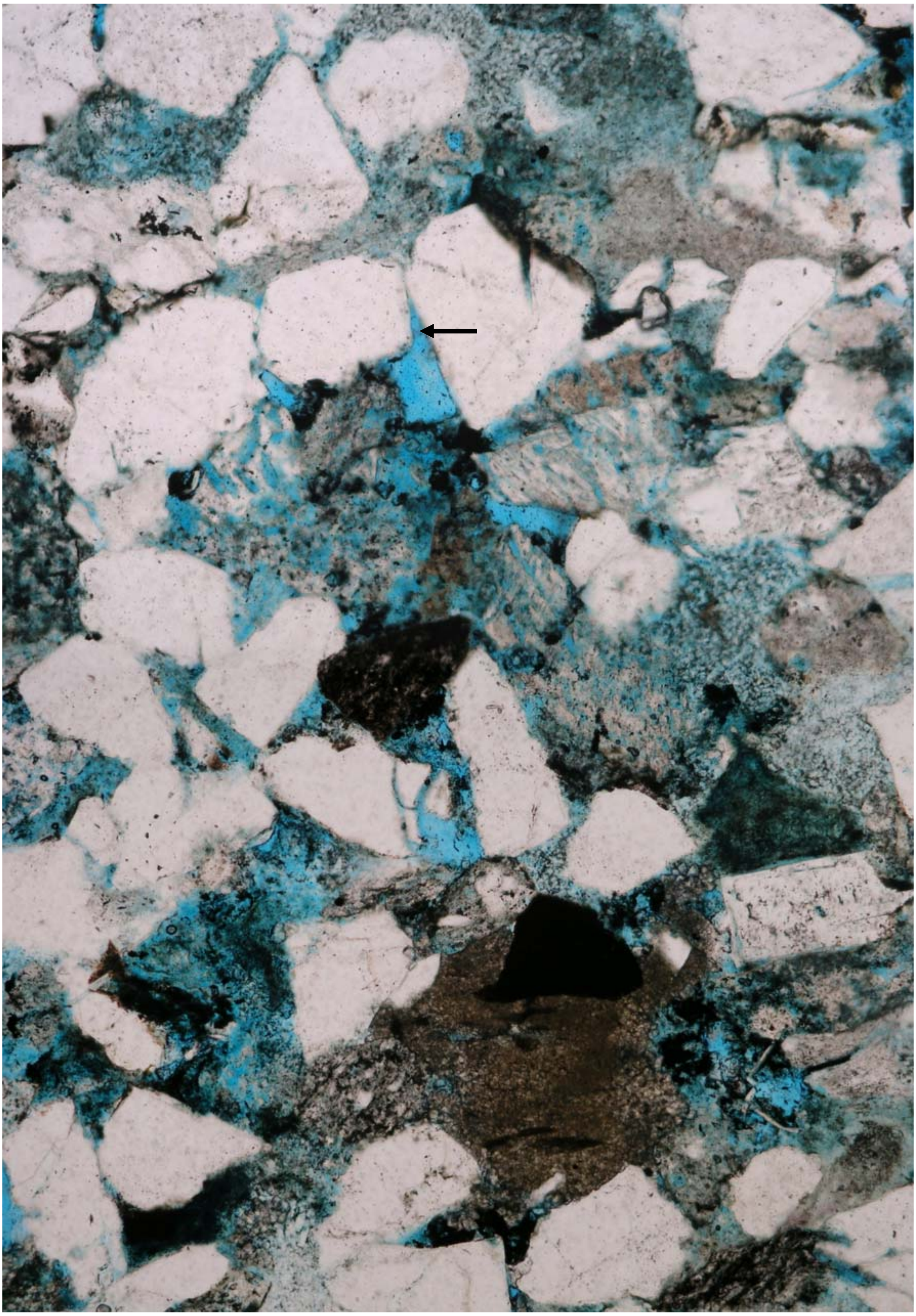


Figure 12

General field of view illustrating corroded feldspars, rare intergranular pores (arrow) & a large patch of grain replacing & pore filling/grain replacing Fe rich micrite (brown) associated with blocky pyrite (opaque). Casino-4, core plug 36, depth 1768.71m. Plane light. Horizontal field of view 1.30mm.

4.13 Casino-4, core plug 31, depth 1766.93m

Rock classification: **Carbonate cemented litharenite**

Texture:

Sedimentary structures: grain alignment indicates the orientation of bedding but there are no bed contacts
Average grain size: medium sand (0.31mm)
Range in grain size: very fine to very coarse sand
Roundness / sphericity: angular to subrounded with low sphericity
Sorting: moderately well (0.52 φ)
Texture: grain supported
Packing / grain contacts: moderately close / point, tangential & concavo-convex contacts where grains are ductile
Pore types: dominantly secondary pores which are grain size, intragranular & honeycomb, micropores are associated with kaolin, remnants of intergranular pores

Composition:

Framework grains: monocrystalline quartz, polycrystalline quartz with either straight or sutured crystal boundaries, corroded K-feldspars lack twinning or have tartan & perthite twinning, lithics of chert, dark brown mudstone, illitic siltstone, quartzite, shale, micaceous schist, ?granite, devitrified glass, finely crystalline ?volcanics & highly altered & oxidised (hematite) unidentified grains, bent flakes of muscovite up to 0.5mm in length, altered & bent biotite up to 0.4mm in length, superficial ooids up to 0.6mm in diameter with a core of Fe rich micrite & a rim of blocky spar, accessory very fine to medium sand size tourmaline & zircon
Matrix: blocky opaque & reddish organic matter
Authigenic minerals: deformed medium sand size pale green grain with wormy texture typical of glauconite, irregular patches of anhedral Fe rich micrite/microspar have replaced grains & filled pores, euhedral rhombohedra of clear microspar up to 15 microns diameter float within the spar, pervasive pore filling & grain replacing twinned poikilotopic clear spar, along secondary pore margins there appears to have been minor corrosion of the clear spar, feldspar overgrowths that lack twinning on corroded detrital feldspars, grain replacing & pore filling kaolin booklets up to 30 microns diameter, straight grain contacts & dust rims outline quartz overgrowths prior to clear spar & have a jagged contact with kaolin booklets, rare pyrite framboids up to 15 microns diameter along grain margins & blocky pyrite replacing grains

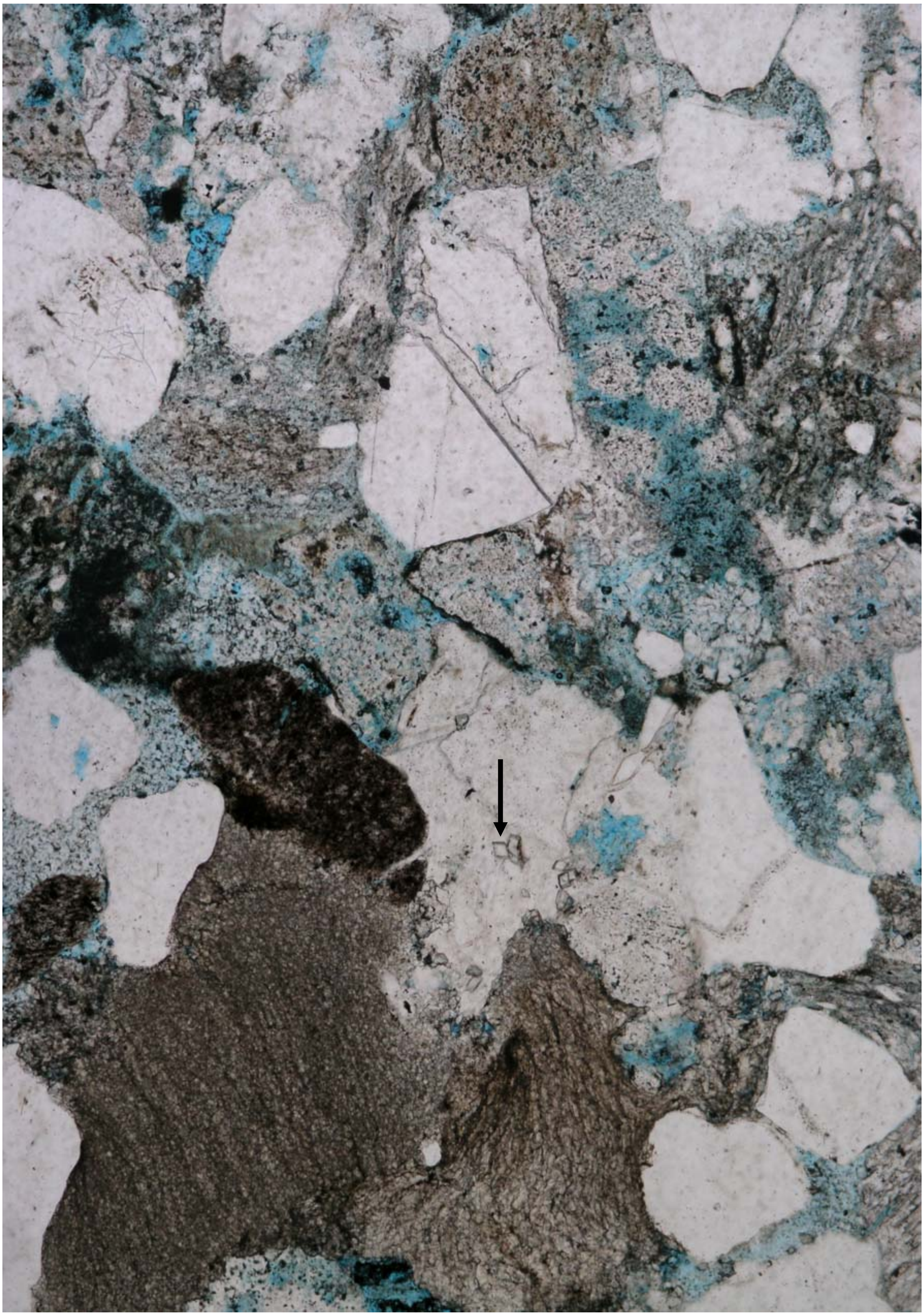


Figure 13
Fe rich micrite (dusty brown) & clear spar have both replaced grains & filled pores. Note the euhedral microspar (arrow) floating within the clear spar. Remaining pore types are either due to dissolution (blue) or micropores (speckled) hence permeability is unlikely to be good. Casino-4, core plug 31, depth 1766.93m. Plane light. Horizontal field of view 1.30mm.

4.14 Casino-4, core plug 28, depth 1765.41m

Rock classification: **Carbonate cemented litharenite**

Texture:

Sedimentary structures:	weak grain alignment
Average grain size:	medium sand (0.29mm)
Range in grain size:	very fine to coarse sand
Roundness / sphericity:	angular to subrounded with low sphericity
Sorting:	well sorted (0.48 φ)
Texture:	grain supported
Packing / grain contacts:	moderately close / point, tangential & concavo-convex contacts where ductile grains are deformed
Pore types:	dominantly grain size dissolution pores, rare intragranular & honeycomb pores, micropores associated with kaolin

Composition:

Framework grains: monocrystalline quartz, polycrystalline quartz with straight or sutured crystal boundaries, dusty corroded K-feldspars that lack twinning, relatively fresh feldspars with tartan & simple twinning & granophyric texture, lithics of chert, chalcedony, dark brown mudstone, quartzite, shale, micaceous schist, devitrified glass with fine laths replaced by carbonate, ?granite, very finely crystalline ?volcanics & other unidentified highly altered lithics including oxidised grains (both hematite & goethite), straight muscovite flakes up to 0.65mm in length, rare superficial ooids with Fe rich micrite cores & rims of blocky clear spar, accessory silt to medium sand size tourmaline, rutile, zircon & opaques

Authigenic minerals: traces of very bright green grain replacing chlorite, at least three phases of carbonate; Fe rich anhedral micrite/microspar, euhedral rhombohedra of clear microspar to spar (10-40 microns diameter) that float within pervasive pore filling & grain replacing clear twinned poikilotopic spar, pore filling & grain replacing kaolin booklets of variable size from 5 to 30 microns prior to clear spar, traces of illite associated with some grain replacing kaolin & other unidentified grains completely replaced by illite, thin feldspar overgrowths that lack twinning prior to clear spar, rare quartz overgrowths outlined by dust rims were precipitated before the clear spar, blocky pyrite replacing Fe rich micrite & rare pyrite framboids up to 30 microns diameter floating within the clear spar

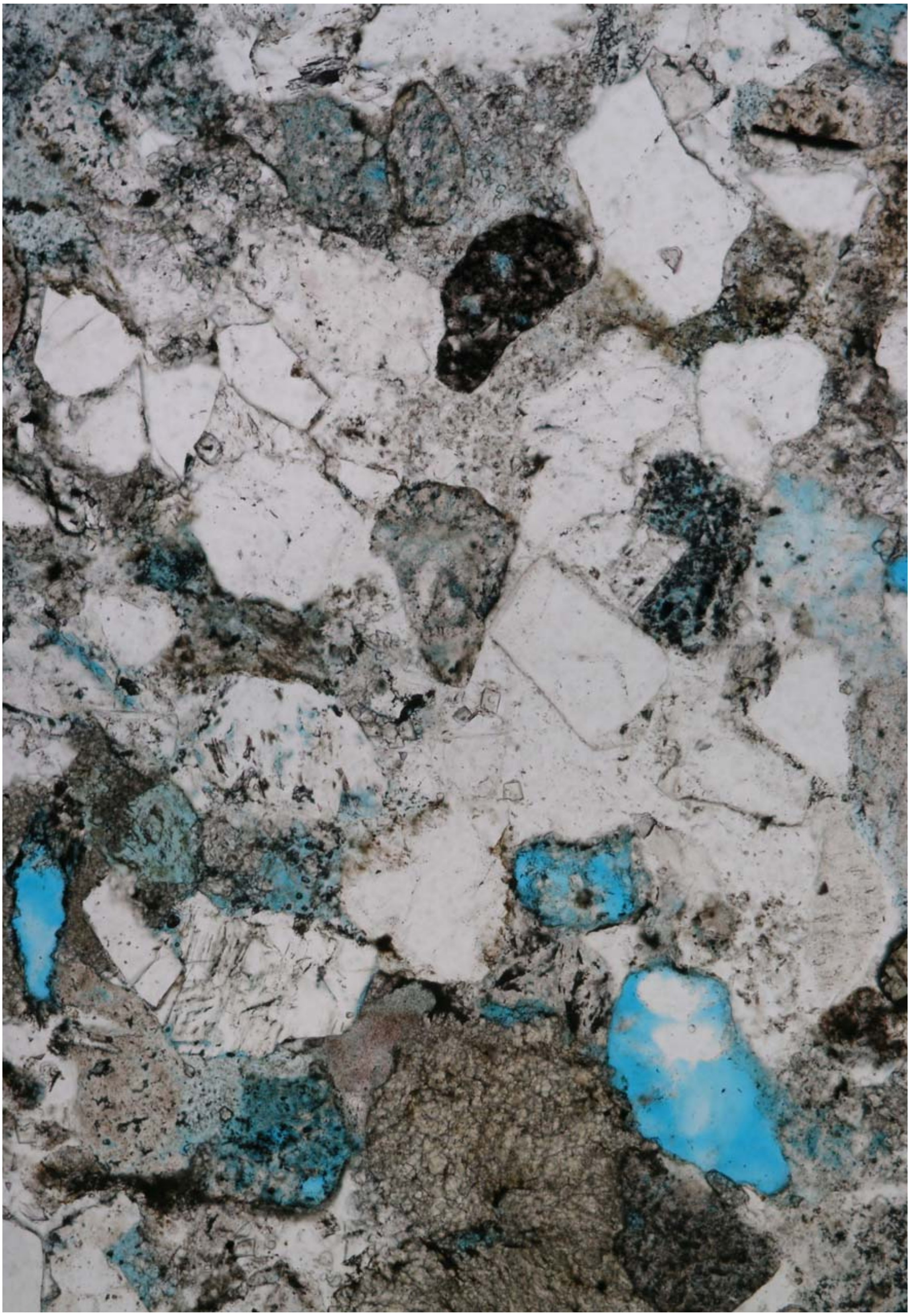


Figure 14
Grain size dissolution pores (blue) are the dominant type of secondary pores in this sandstone. Intergranular pores are typically filled with clear carbonate spar. Casino-4, core plug 28, depth 1765.41m. Plane light. Horizontal field of view 1.30mm.

4.15 Casino-4, core plug 18, depth 1762.10m

Rock classification: **Feldspathic Litharenite**

Texture:

- Sedimentary structures: cross bedding is apparent from changes in grain size, lithic content & orientation of grains, bed contacts are planar & sharp
- Average grain size: coarse sand (0.63mm)
- Range in grain size: fine sand to boulders
- Roundness / sphericity: angular to subrounded with low to moderate sphericity
- Sorting: moderately sorted (0.76 φ)
- Texture: grain supported
- Packing / grain contacts: open packing / point & tangential contacts dominant with minor concavo-convex where mudstone lithics are deformed
- Pore types: primary intergranular pores, secondary grain size, honeycomb & intragranular pores, micropores associated with kaolin, fracturing of corroded feldspars, rarely chert & quartz

Composition:

- Framework grains: monocrystalline quartz, polycrystalline quartz with either straight or sutured crystal boundaries, dusty corroded K-feldspars lack twinning, other corroded feldspars with granophyric texture & pericline twinning, lithics of chert, chalcedony, dark brown mudstone, up to boulder size deformed pale brown mudstone with minor organic matter, quartzite, shale, micaceous schist, ?granite & very finely crystalline ?volcanics, highly altered grains of unrecognisable origin, bent muscovite up to 0.30mm in length
- Matrix: blocky opaque & cellular brownish organic matter & rare opaque stringers
- Authigenic minerals: grain replacing (especially mudstone lithics) & pore filling Fe rich anhedral micrite/microspar, grain rimming (circumgranular) blocky Fe rich microspar on isolated grains of quartz, micrite, lithics & dissolution pores, euhedral terminations on pore margins indicate the presence of prismatic & rhombohedral quartz overgrowths, thin feldspar overgrowths that lack twinning appear to be corroded, blocky pyrite associated with Fe rich micrite, pore filling & grain replacing kaolin booklets & verms up to 15 microns diameter, where micas have been replaced booklets are up to 60 microns diameter, rare oxidised (hematite) chert lithics, grains of unknown origin replaced by illite

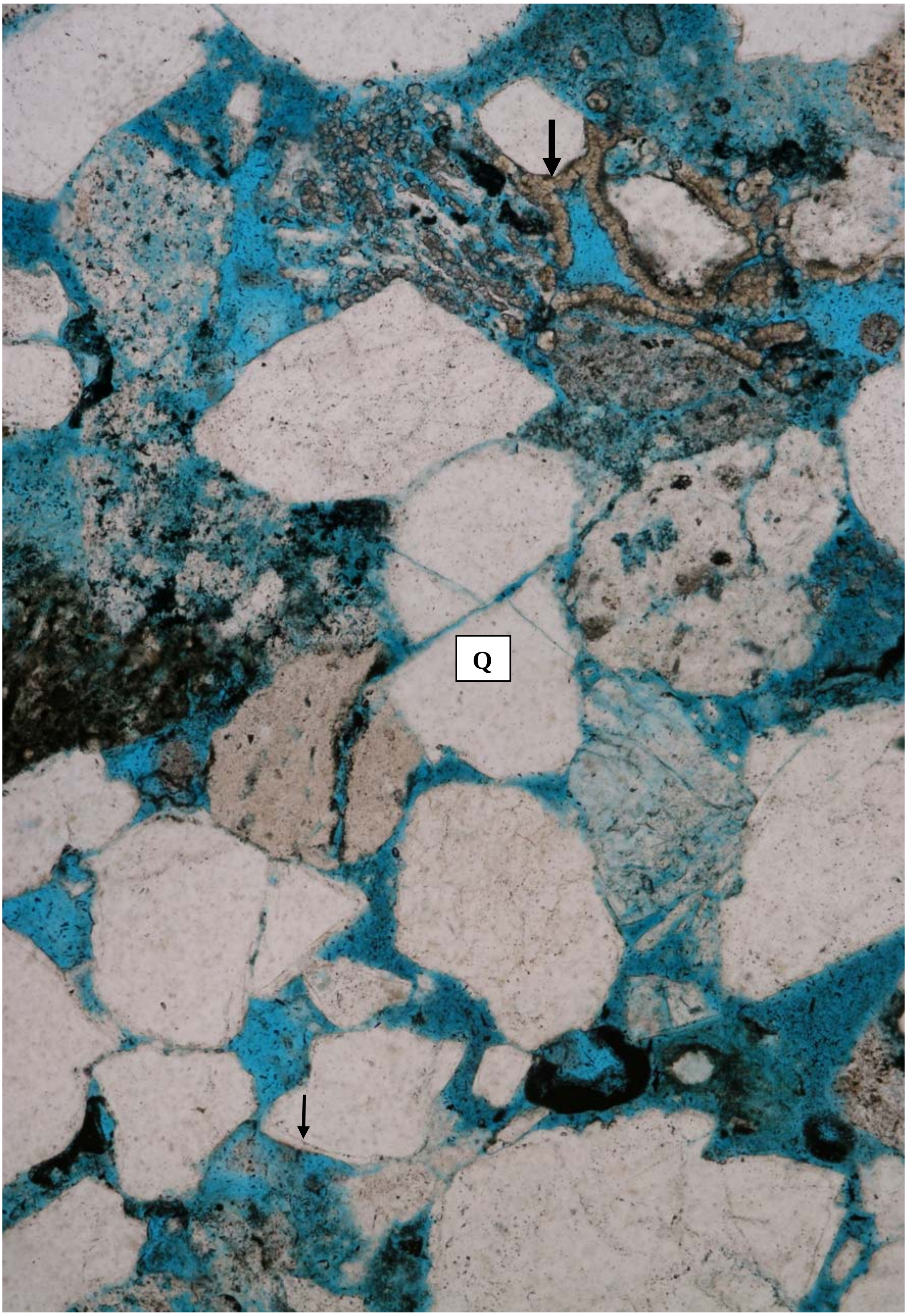


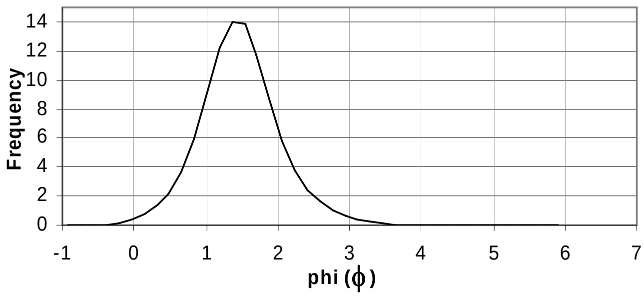
Figure 15

Equant Fe rich spar is evident partially rimming grains & an intergranular pore (large arrow) in this field of view. Note the fractured grains of slightly dusty chert & juxtaposed quartz (Q), corroded nature of lithics & relative abundance of quartz overgrowths (small arrow). Casino-4, core plug 18, depth 1762.10m. Plane light. Horizontal field of view 1.30mm.

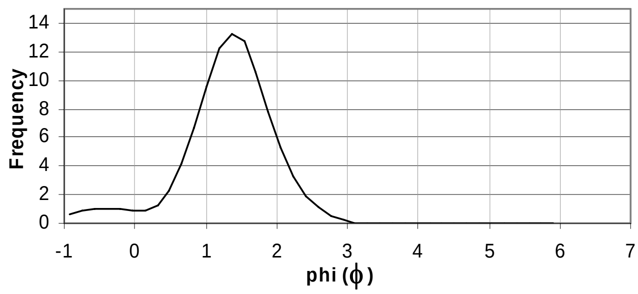
5. GRAIN SIZE ANALYSIS

Thin Section Statistics | **Frequency Distribution**

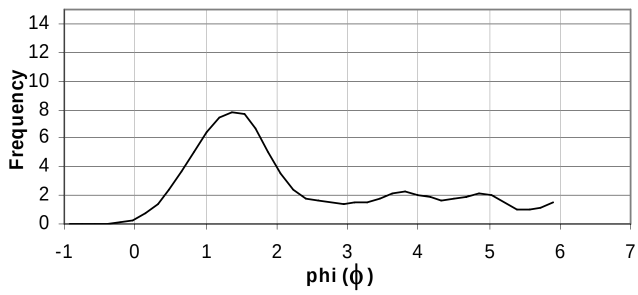
Sample:	**5**		
Depth (m)	**1791.70**		
Parameter		mm	φ
Mean		0.38	1.47
		medium sand	
Mode		0.37	1.44
		medium sand	
Range:	min	0.11	3.18
	max	0.85	0.23
Standard Deviation		0.13	0.50
		moderately well sorted	



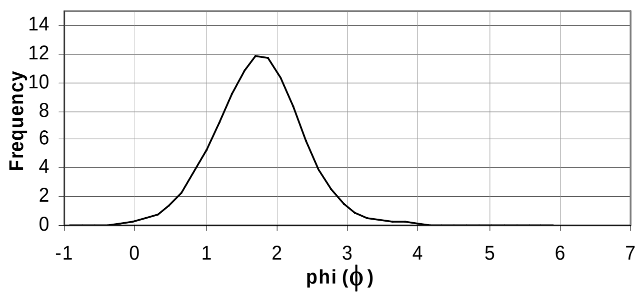
Sample:	**4**		
Depth (m)	**1790.72**		
Parameter		mm	φ
Mean		0.49	1.27
		medium sand	
Mode		0.38	1.41
		medium sand	
Range:	min	0.18	2.47
	max	5.35	-2.42
Standard Deviation		0.55	0.69
		moderately well sorted	

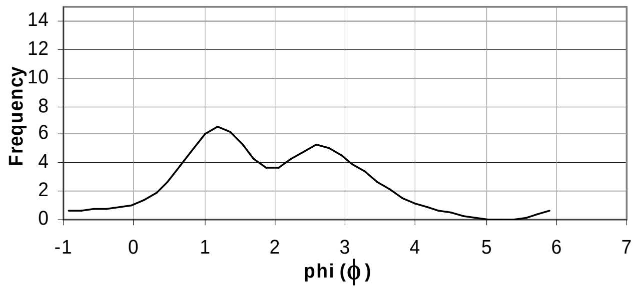
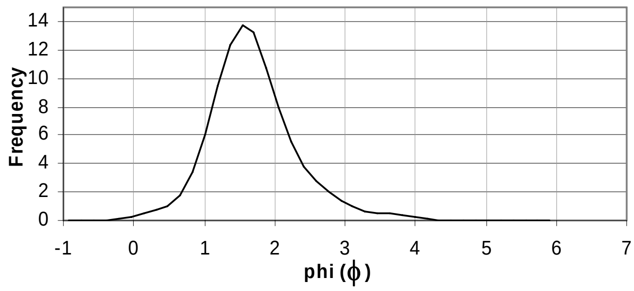
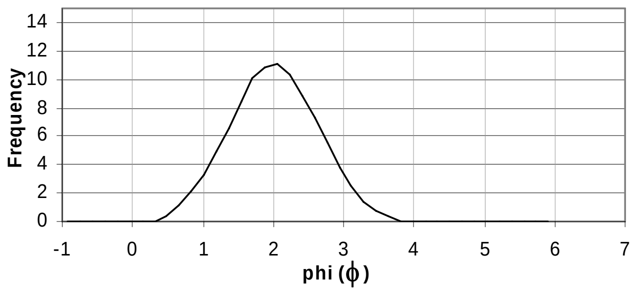
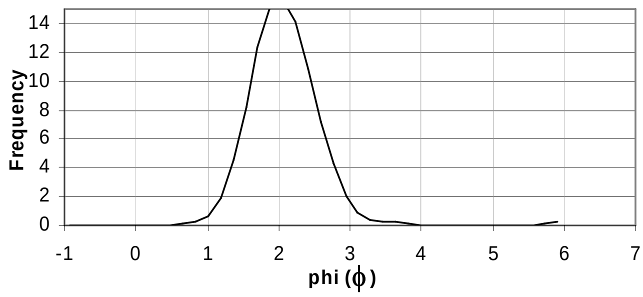


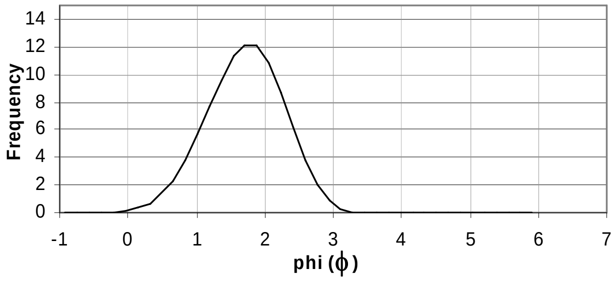
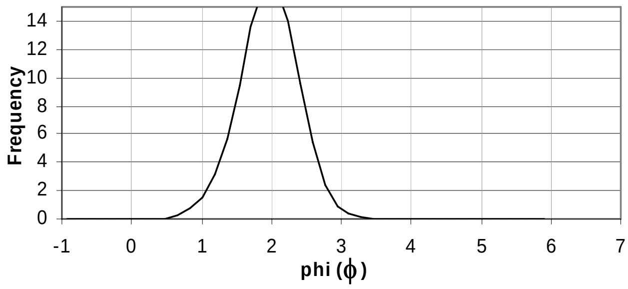
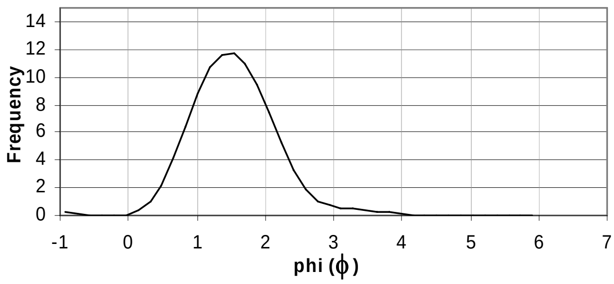
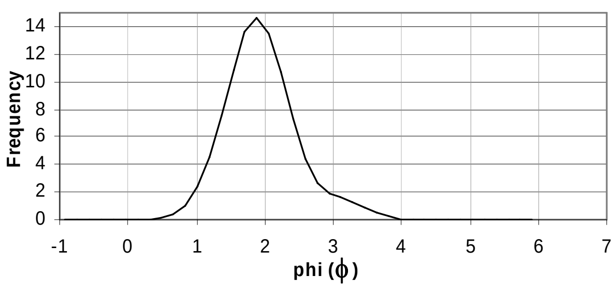
Sample:	**99**		
Depth (m)	**1789.68**		
Parameter		mm	φ
Mean		0.28	2.68
		medium sand	
Mode		0.38	1.41
		medium sand	
Range:	min	0.002	8.97
	max	0.95	0.07
Standard Deviation		0.21	2.13
		very poorly sorted	



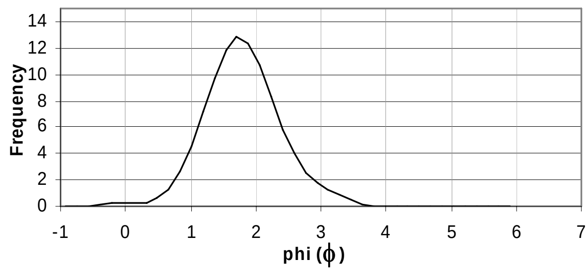
Sample:	**14**		
Depth (m)	**1786.32**		
Parameter		mm	φ
Mean		0.32	1.76
		medium sand	
Mode		0.29	1.78
		medium sand	
Range:	min	0.08	3.64
	max	0.85	0.23
Standard Deviation		0.13	0.57
		moderately well sorted	



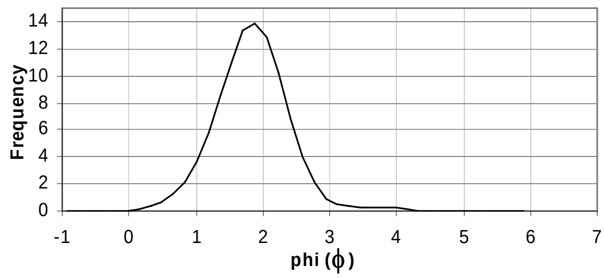
Thin Section Statistics				Frequency Distribution
Sample:		**84**		
Depth (m)		**1784.70**		
Parameter		mm	ϕ	
Mean		0.37	2.07	
		medium sand		
Mode		0.43	1.21	
		medium sand		
Range:	min	0.002	8.97	
	max	2.85	-1.51	
Standard Deviation		0.39	1.67	
		poorly sorted		
Sample:		**77**		
Depth (m)		**1781.98**		
Parameter		mm	ϕ	
Mean		0.33	1.69	
		medium sand		
Mode		0.33	1.59	
		medium sand		
Range:	min	0.07	3.84	
	max	0.87	0.20	
Standard Deviation		0.12	0.57	
		moderately well sorted		
Sample:		**72**		
Depth (m)		**1780.54**		
Parameter		mm	ϕ	
Mean		0.27	2.02	
		medium sand		
Mode		0.25	2.00	
		fine sand		
Range:	min	0.10	3.32	
	max	0.57	0.81	
Standard Deviation		0.10	0.55	
		moderately well sorted		
Sample:		**68**		
Depth (m)		**1779.30**		
Parameter		mm	ϕ	
Mean		0.24	2.14	
		fine sand		
Mode		0.25	2.01	
		fine sand		
Range:	min	0.002	8.97	
	max	0.43	1.22	
Standard Deviation		0.06	0.78	
		moderately sorted		

Thin Section Statistics				Frequency Distribution
Sample:		**56**		
Depth (m)		**1775.72**		
Parameter		mm	ϕ	
Mean		0.32 medium sand	1.71	
Mode		0.29 medium sand	1.79	
Range:	min	0.14	2.84	
	max	0.81	0.30	
Standard Deviation		0.12 well sorted	0.49	
Sample:		**50**		
Depth (m)		**1773.50**		
Parameter		mm	ϕ	
Mean		0.27 medium sand	1.95	
Mode		0.25 medium sand	1.98	
Range:	min	0.15	2.74	
	max	0.50	1.00	
Standard Deviation		0.06 very well sorted	0.33	
Sample:		**46**		
Depth (m)		**1771.91**		
Parameter		mm	ϕ	
Mean		0.39 medium sand	1.52	
Mode		0.36 medium sand	1.47	
Range:	min	0.08	3.64	
	max	3.20	-1.68	
Standard Deviation		0.31 moderately well sorted	0.63	
Sample:		**36**		
Depth (m)		**1768.71**		
Parameter		mm	ϕ	
Mean		0.27 medium sand	1.95	
Mode		0.27 medium sand	1.88	
Range:	min	0.09	3.47	
	max	0.50	1.00	
Standard Deviation		0.08 well sorted	0.47	

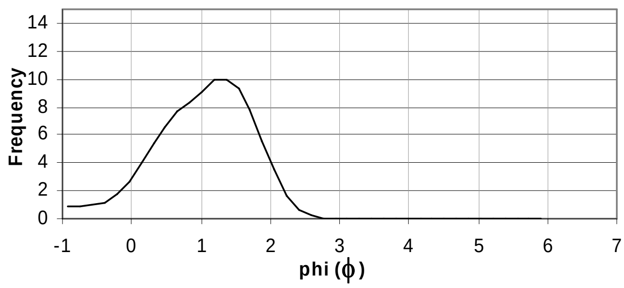
Thin Section Statistics				Frequency Distribution
Sample:		**31**		
Depth (m)		**1766.93**		
Parameter		mm	ϕ	
Mean		0.31	1.80	
		medium sand		
Mode		0.30	1.76	
		medium sand		
Range:	min	0.10	3.32	
	max	1.05	-0.07	
Standard Deviation		0.12	0.52	
		moderately well sorted		



Thin Section Statistics			
Sample:		**28**	
Depth (m)		**1765.41**	
Parameter		mm	ϕ
Mean		0.29	1.84
		medium sand	
Mode		0.28	1.84
		medium sand	
Range:	min	0.07	3.84
	max	0.72	0.47
Standard Deviation		0.10	0.48
		well sorted	



Thin Section Statistics			
Sample:		**18**	
Depth (m)		**1762.10**	
Parameter		mm	ϕ
Mean		0.63	0.96
		coarse sand	
Mode		0.41	1.28
		medium sand	
Range:	min	0.22	2.18
	max	6.30	-2.66
Standard Deviation		0.68	0.76
		moderately sorted	



6. X-RAY DIFFRACTION

All the XRD results are summarised in Tables 3 and 4 below, and the traces from which this data was obtained are presented in Figures 16 to 22. Quartz is the dominant silicate mineral in all samples with minor K-feldspar which was identified as microcline and one example of plagioclase (albite) in core plug 5. In core plug 36 the microcline is characterised by two strong peaks, one of which might indicate the presence of authigenic microcline. It is possible that the feldspar overgrowths noted in thin section are composed of authigenic microcline. At least three carbonate minerals were identified, namely calcite, dolomite and siderite. Calcite is the most abundant of these phases and occurs in association with minor siderite. Dolomite is the least abundant carbonate and was not detected in those samples with calcite. In core plug 68 the strongest siderite peak is a doublet which may indicate compositional variation within the siderite phase.

Kaolinite is the dominant clay mineral and in most samples it is highly crystalline. Muscovite and illite patterns overlap in the bulk traces but illite can be differentiated as a minor clay in the clay fraction. In addition, there are traces to minor amounts of chlorite in the clay traces. In many instances the chlorite is not apparent when the clay fraction is saturated with Mg but with the addition of glycerol a 14 Angstrom peak is clearly evident. Chlorite is not influenced by solvation therefore it must be assumed that the chlorite is interstratified with traces of smectite or vermiculite. Evidence of interstratification is apparent in the glycerol saturated trace of core 5 which has a peak at 21.2 Angstroms. However, there is insufficient interstratified chlorite to accurately identify the relative proportions of the other mineral. A small peak at 3.50 Angstroms confirms the presence of chlorite in several patterns.

TABLE 3. BULK XRD MINERALOGY CASINO-4

Core plug	Depth (m)	I/M	Kaol	Qtz	Micr	Alb	Cal	Dol	Sid	Pyr
			Strongest peak height in counts							
5	1791.70	110	229	3044	194	136	2512	-	115	-
72	1780.54	98	267	2625	238	-	931	-	111	-
68	1779.30	106	369	2798	120	-	-	88	179*	-
36	1768.71	104	401	5521	186+	-	-	47	155	32
31	1766.93	88	142	2124	83	-	1029	-	103	-
28	1765.41	-	219	2360	118	-	1023	-	250	-
18	1762.10	113	308	6247	105	-	-	56	294	-

TABLE 4. CLAY XRD MINERALOGY CASINO-4

Core plug	Depth (m)	Chlor	Illite	Kaol	Quartz	Micr	Cal	Sid
			Strongest peak height in counts					
5	1791.70	216	253	1387	983	-	618	103
72	1780.54	189	293	1661	1061	200	419	78
68	1779.30	199	373	4092	902	150	-	71
36	1768.71	202	399	4115	1044	173	-	-
31	1766.93	202	309	3264	1040	98	205	-
28	1765.41	190	224	1466	1054	122	523	78
18	1762.10	163	256	2773	1161	116	-	131

Chlor=chlorite, I/M=illite/muscovite, Kaol=kaolinite, Qtz=quartz, Micr=microcline, Alb=albite, Cal=calcite, Dol=dolomite, Sid=siderite & Pyr=pyrite

* peak doublet indicates multiple phases of siderite
\+ may include authigenic microcline

To facilitate between-sample comparisons of relative abundance for the same mineral, the results in each table are given in counts of peak height. These figures are based on the strongest line for each mineral detected. Caution should be used in assessing relative abundance from these figures since peak height is also significantly affected by factors such as crystal size and crystallinity. For these reasons the figures are even more unreliable when comparing different minerals in the same sample. For example, based on peak height alone carbonate minerals will always appear less abundant than similar proportions of quartz because of differences in crystallinity. Clay minerals will also appear to be less abundant than quartz in a bulk XRD trace because of differences in crystal size. Furthermore, comparison should not be made between peak heights given for bulk samples and those for the clay fractions because results have been influenced by the sampling and preparation methods. XRD will not detect minerals that represent less than approximately 5% of the total rock composition.

Only the strongest peaks for each mineral identified have been labeled on the XRD traces. The horizontal axis on each trace is in degrees two theta and the vertical axis is in counts of peak height. For the clay fraction both Mg saturated and glycerol traces have been included to demonstrate movements in the peaks that aided identification of clay minerals. The following abbreviations have been used on the XRD traces:

A = albite
Ca = calcite
C = chlorite
D = dolomite
I/M = illite or muscovite
K = kaolinite
M = microcline
P = pyrite
Q = quartz
S = siderite

Casino-4, core plug 5, depth 1791.70m

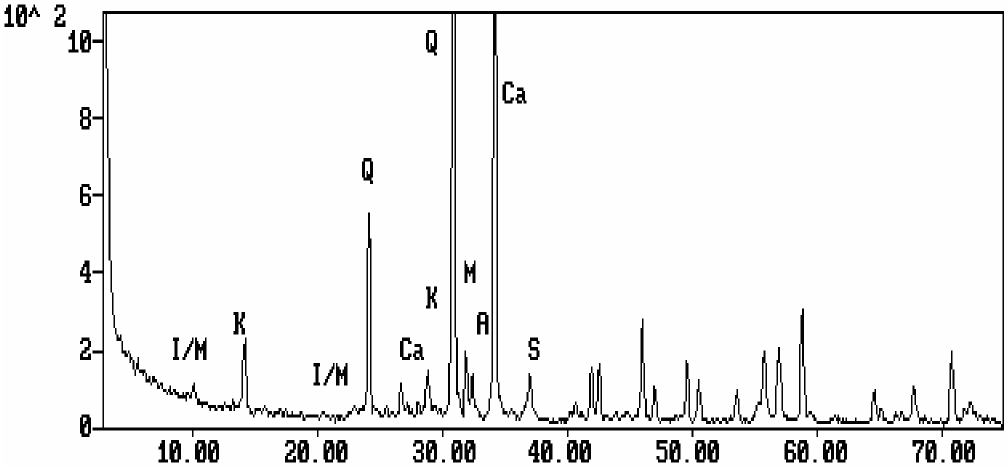


Figure 16a
Bulk XRD trace

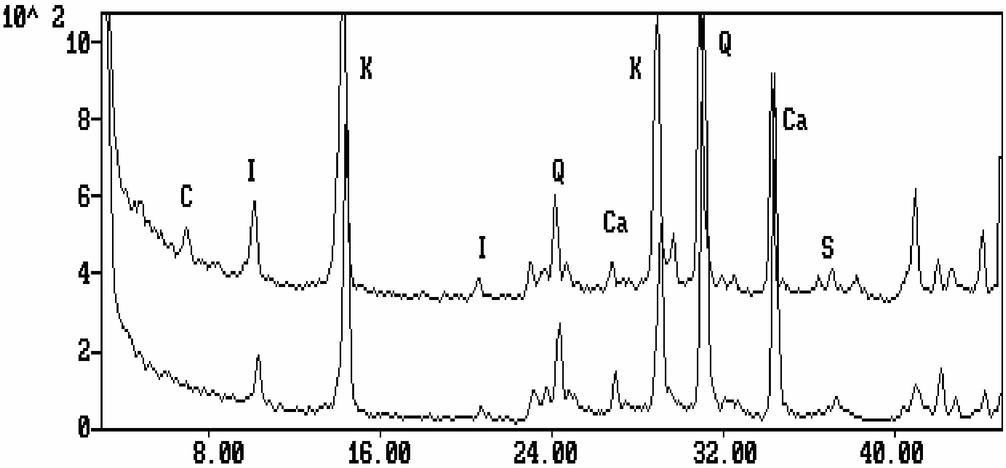


Figure 16b
Clay XRD traces. (Lower trace is Mg saturated & air dried. Upper trace is Mg & glycerol saturated & air dried).

Casino-4, core plug 72, depth 1780.54m

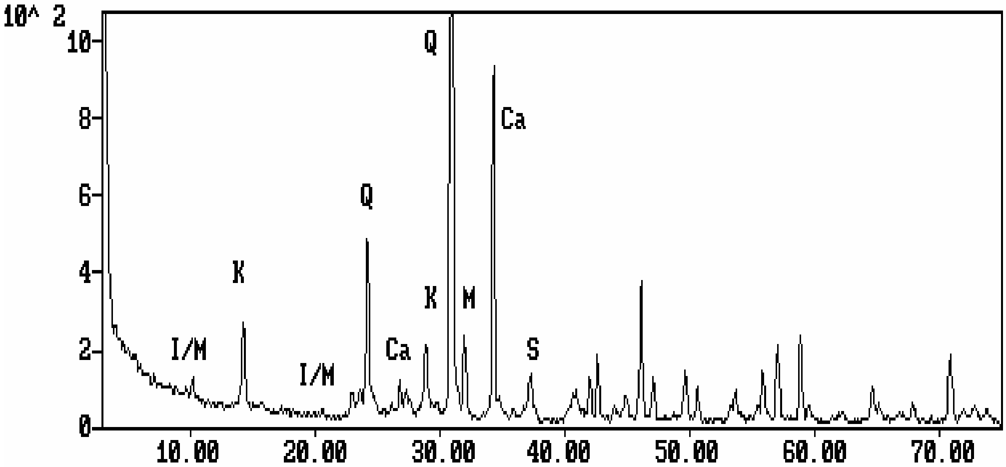


Figure 17a
Bulk XRD trace

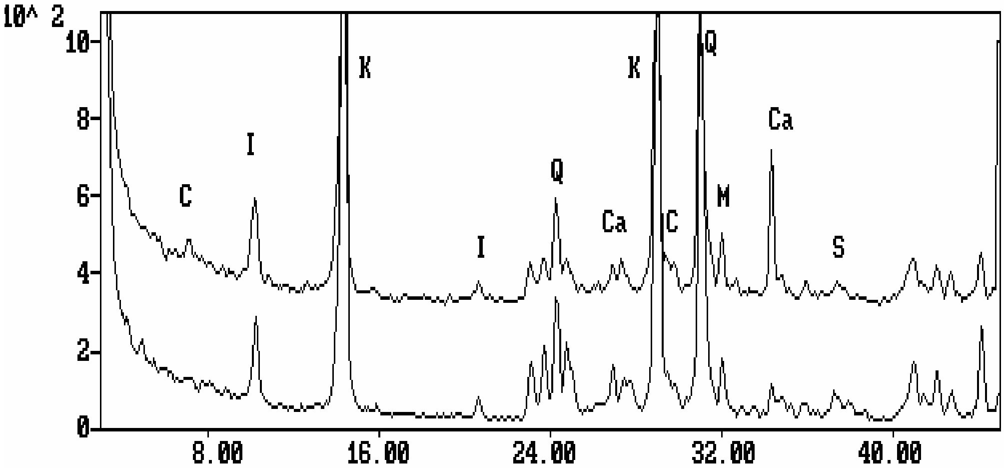


Figure 17b
Clay XRD traces. (Lower trace is Mg saturated & air dried. Upper trace is Mg & glycerol saturated & air dried).

Casino-4, core plug 68, depth 1779.30m

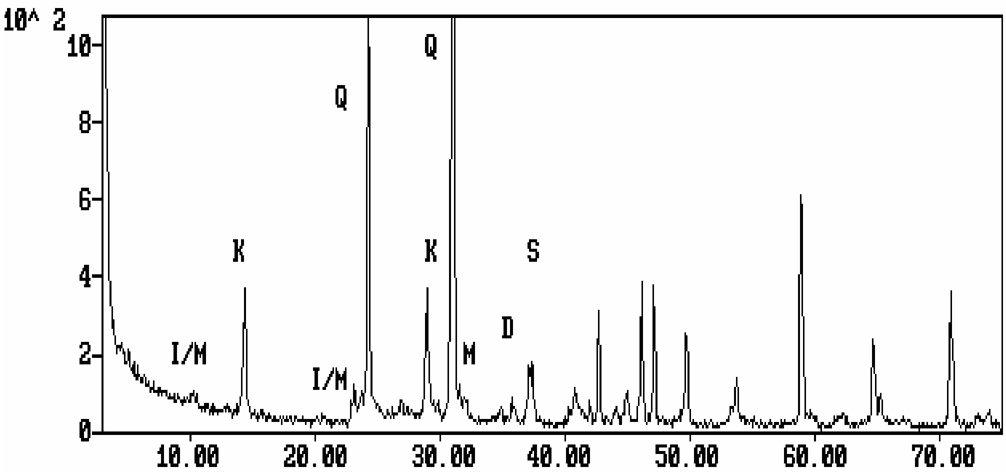


Figure 18a
Bulk XRD trace

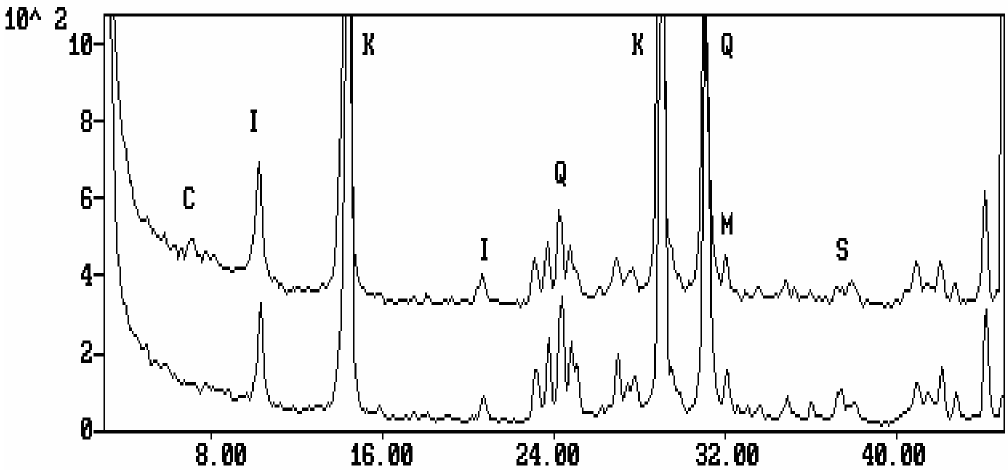


Figure 18b
Clay XRD traces. (Lower trace is Mg saturated & air dried. Upper trace is Mg & glycerol saturated & air dried).

Casino-4, core plug 36, depth 1768.71m

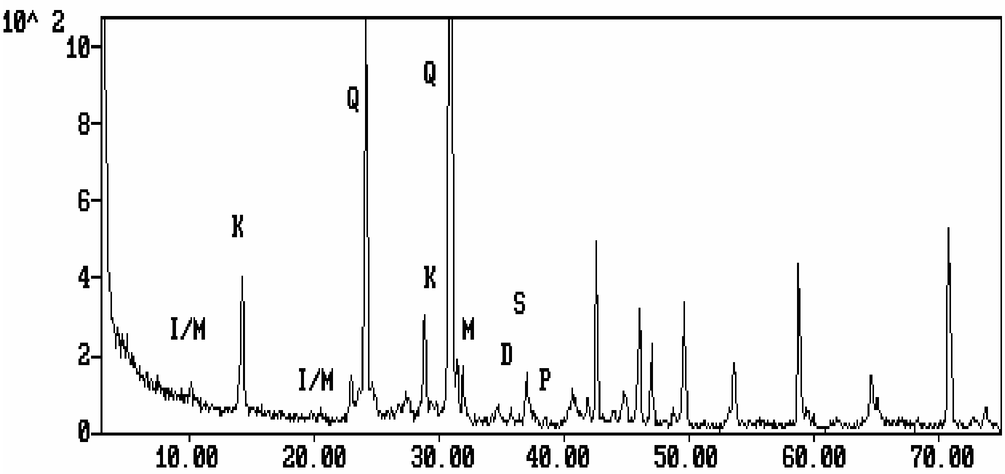


Figure 19a
Bulk XRD trace

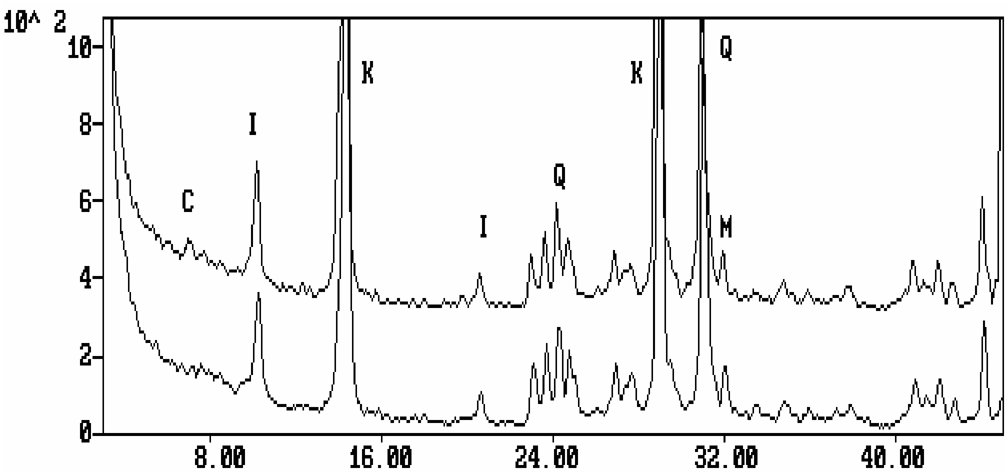


Figure 19b
Clay XRD traces. (Lower trace is Mg saturated & air dried. Upper trace is Mg & glycerol saturated & air dried).

Casino-4, core plug 31, depth 1766.93m

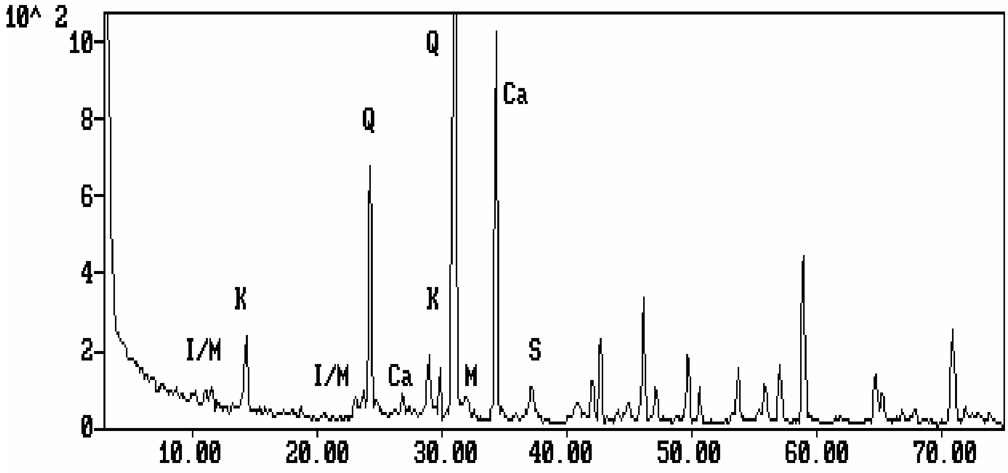


Figure 20a
Bulk XRD trace

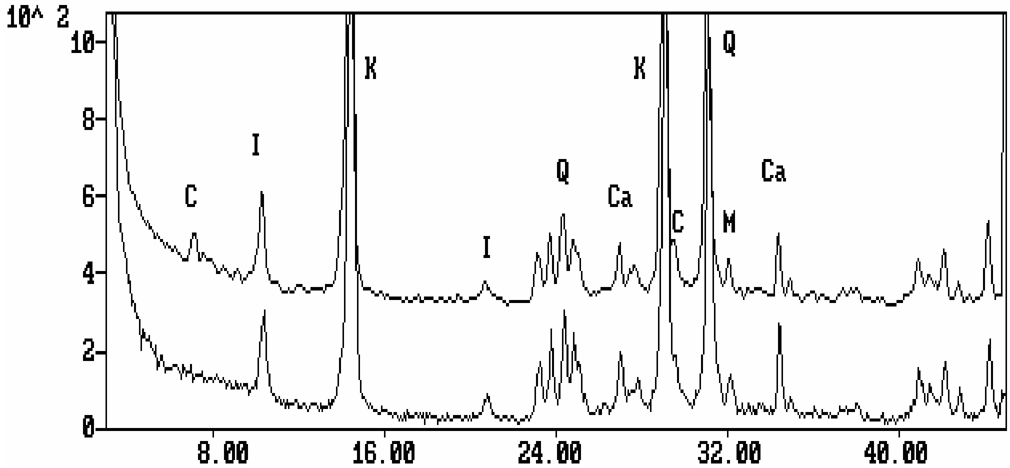


Figure 20b
Clay XRD traces. (Lower trace is Mg saturated & air dried. Upper trace is Mg & glycerol saturated & air dried).

Casino-4, core plug 28, depth 1765.41m

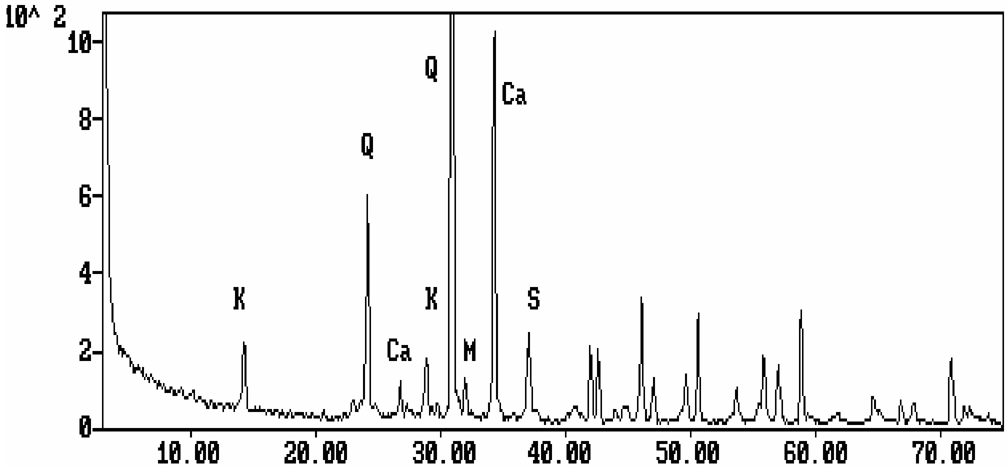


Figure 21a
Bulk XRD trace

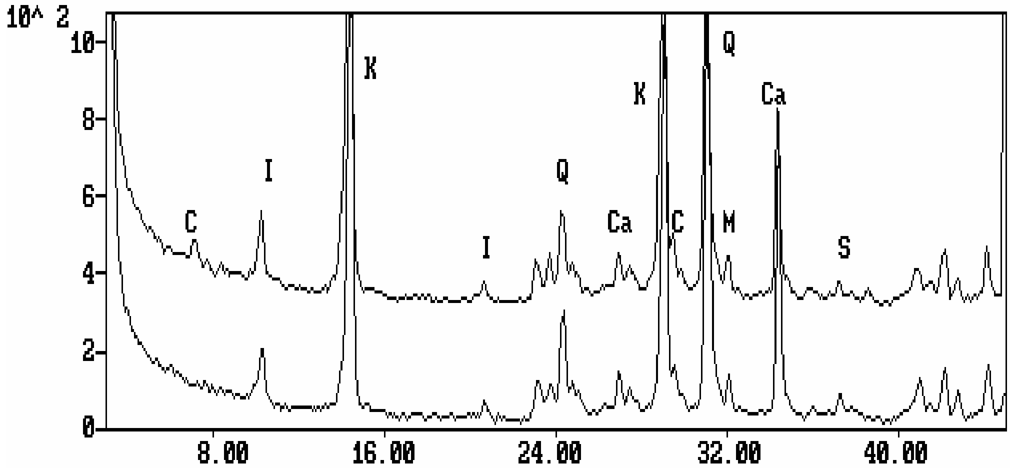


Figure 21b
Clay XRD traces. (Lower trace is Mg saturated & air dried. Upper trace is Mg & glycerol saturated & air dried).

Casino-4, core plug 18, depth 1762.10m

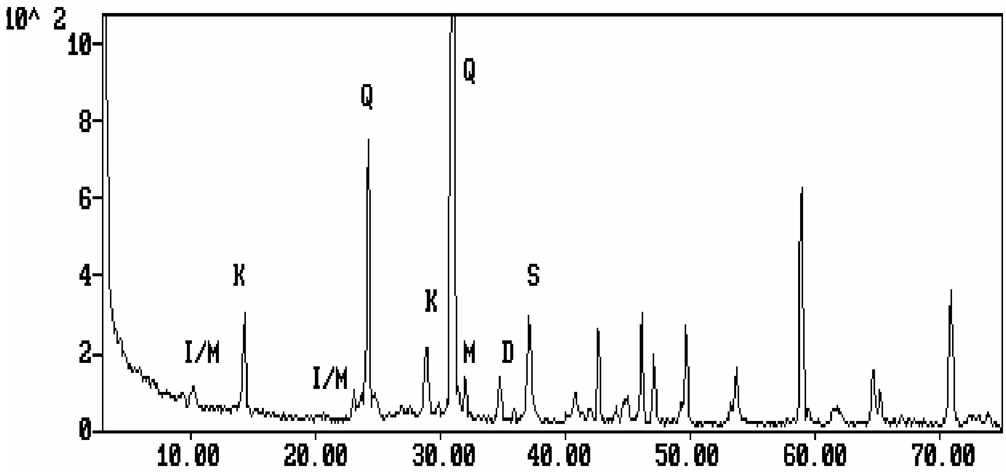


Figure 22a
Bulk XRD trace

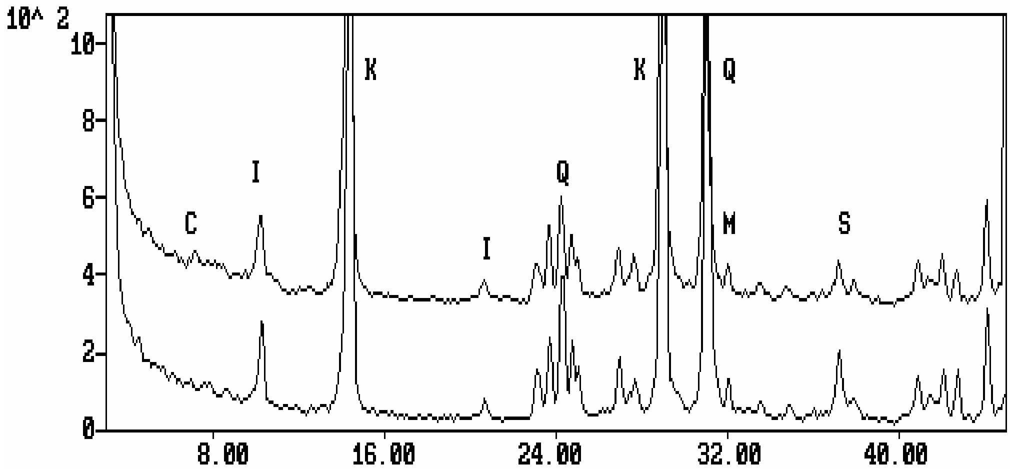


Figure 22b
Clay XRD traces. (Lower trace is Mg saturated & air dried. Upper trace is Mg & glycerol saturated & air dried).

7. SCANNING ELECTRON MICROSCOPY

7.1 Casino-4, core plug 5, depth 1791.70m

AIM:
To characterise the three carbonate phases noted in thin section and the siderite and calcite mineralogy as identified from X-ray diffraction.

RESULTS:
Fe rich carbonate (siderite) in thin section is typically anhedral micrite to subhedral microspar with a dusty reddish appearance (Fig. 23a). This phase of carbonate has replaced grains and filled pores to form diagenetic patches within the litharenite. Backscattered electron photomicrographs clearly show that the siderite is euhedral on the margins of these patches (Fig. 23b & c) and there are multiple variations in chemistry within the siderite. Up to seven zones can be recognised in some siderite crystals from differences in the colour in backscattered mode which is sensitive to chemical variations. The very lightest/brightest white colours occur in the crystal cores where there is almost pure siderite. It would appear that these zones contain the highest molecular percentages of $FeCO_3$ (Table 5) of approximately 90 mole %, and the lowest proportions of calcium and magnesium. Darker coloured zones of varying intensity contain higher percentages of calcium and magnesium and lower manganese. Siderites with greater than 10 mole % $MgCO_3$ should be described as high Mg siderite. Therefore the chemical variations show fluctuations from siderite to high Mg siderite within the same crystal. Because the zones are commonly less than one micron in thickness it was not possible to systematically characterise each of the seven zones. Each analysis uses a spot size of four microns therefore the results (Table 5) probably contain minor cross contamination from other zones. Values given in Table 5 have been normalised to eliminate those elements derived from grains replaced by the siderite.

TABLE 5 SEMIQUANTITATIVE SIDERITE EDS ANALYSES

SPC	Mole % $MgCO_3$	$CaCO_3$	$MnCO_3$	$FeCO_3$	BSE Colour
2	1.3	4.2	3.4	91.2	VB
3	11.8	13.0	1.1	74.1	B
4	19.7	8.5	0.5	71.3	B
5	25.1	13.8	1.2	59.8	VD
6	22.3	13.5	1.5	62.6	D
9	24.3	13.3	1.2	61.1	D
11	25.1	13.6	1.2	60.1	D
12	11.7	12.8	1.4	74.2	B

SPC = spectrum number location
VB=very bright, B=bright, VD=very dull, D=dull
Note: all values in this table have been normalised

Euhedral rhombs of microspar to spar up to 20 microns in diameter were identified in thin section. The lack of dusty reddish colour had suggested a different composition to the siderite. However, in backscattered mode these same crystals were identified as zoned siderite (Fig. 23d, e & f) with compositional variations similar to that identified in the anhedral phase. The only significant difference is that the cores of these euhedral crystals are not as Fe rich and this could explain the colour difference in thin section. It might also suggest the euhedral microspar formed slightly later than the Fe rich phase when rates of precipitation were slower.

Pore filling and grain replacing calcite spar is pervasive throughout core plug 5 and is the dominant carbonate cement. There does not appear to be any significant chemical variation in the composition (Table 6) even where grains have been replaced (Fig. 23e & f) by calcite.

TABLE 6 SEMIQUANTITATIVE CALCITE EDS ANALYSES

	Mole %			
SPC	$MgCO_3$	$CaCO_3$	$MnCO_3$	$FeCO_3$
8	1.0	95.4	1.0	2.6
10	0.8	94.9	1.3	3.0
13	1.8	94.1	1.1	3.1

SPC = spectrum number location

Note: all values in this table have been normalised

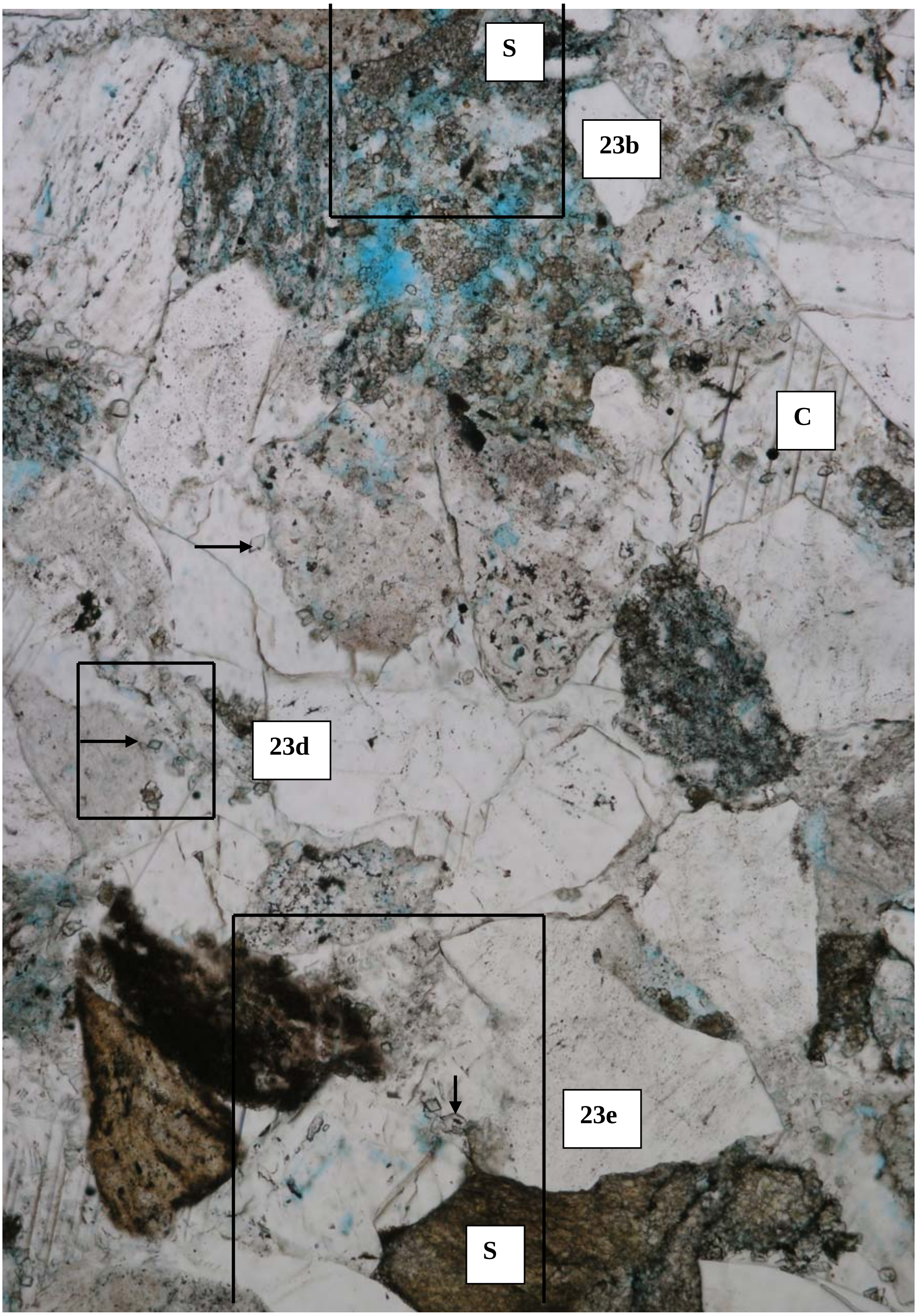


Figure 23a
Thin section photomicrograph illustrating the locations of photos in backscattered mode (23b, 23d & 23e) which are rotated 90°. Note the three phases of carbonate; anhedral dusty reddish siderite (S), euhedral crystals of microspar (arrows) and pore filling twinned poikilotopic calcite spar (C). Plane light. Horizontal field of view 1.30mm.

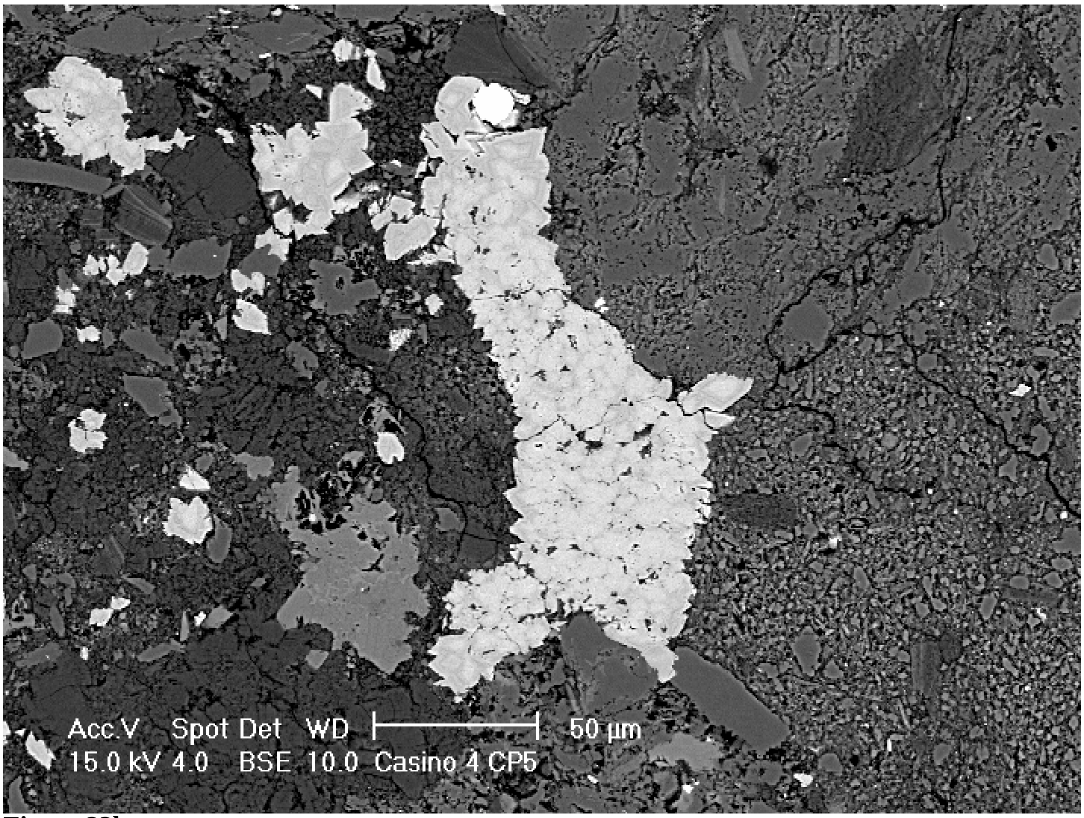


Figure 23b
Anhedral grain replacing siderite appears white to very light grey in backscattered mode. Note the euhedral terminations on the edges of the siderite. Back scattered electron photomicrograph. Bar scale 50 microns.

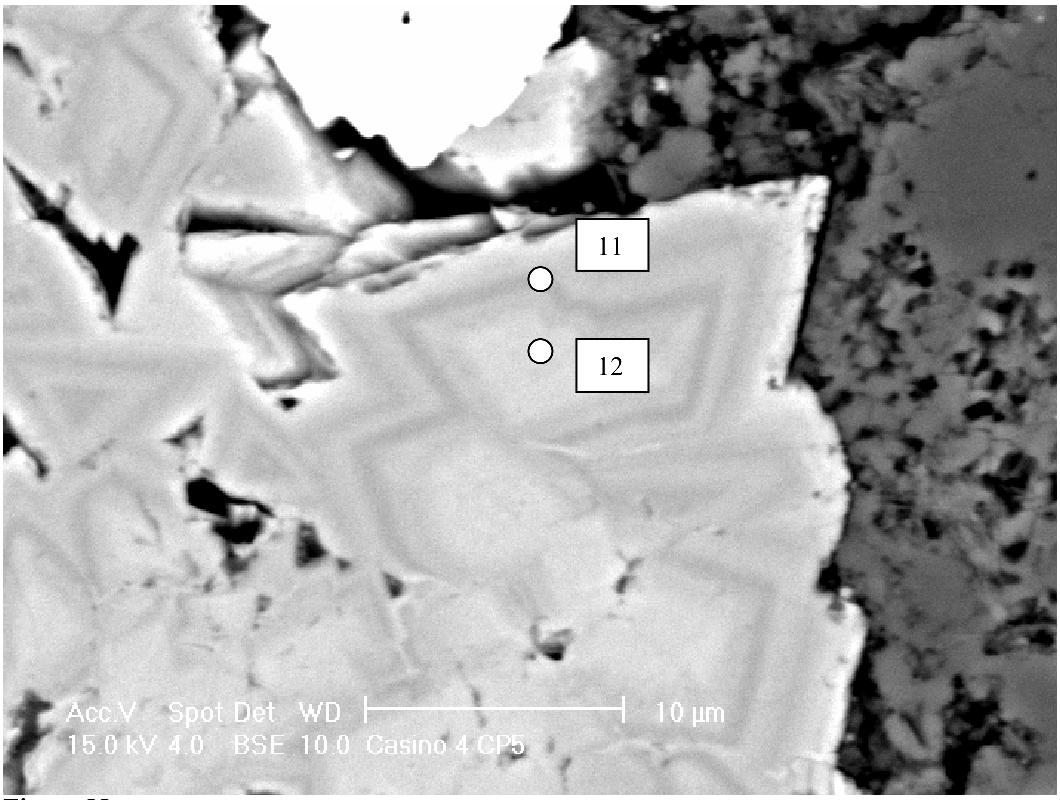


Figure 23c
Closer view of the euhedral terminations on the edge of the siderite illustrated in Figure 23b, also shows zonation in the chemistry of the siderite. Numbers refer to analyses in Table 5. Back scattered electron photomicrograph. Bar scale 10 microns.

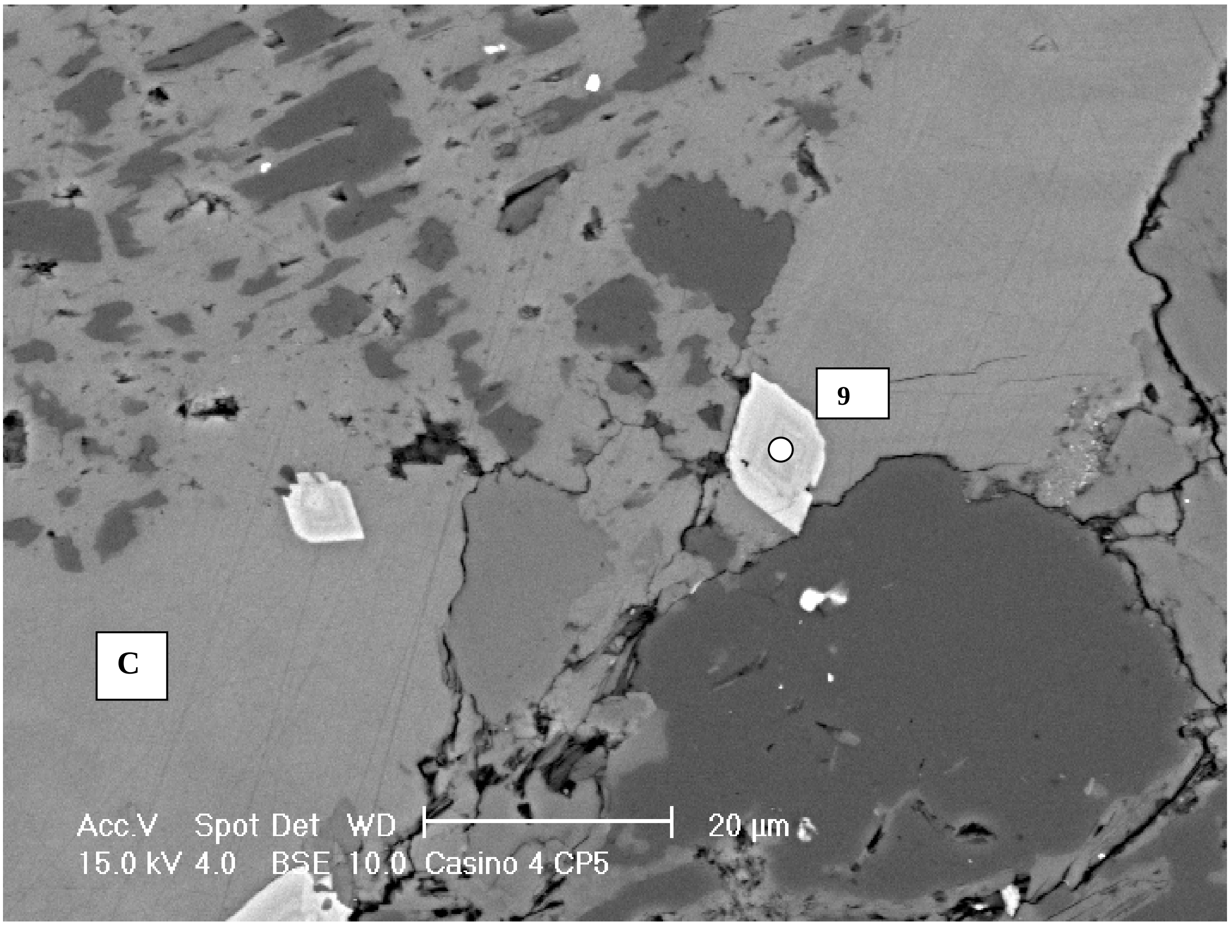


Figure 23d
Euhedral crystals of zoned siderite microspar (light colour) float within calcite cement (C). Calcite has partially replaced the grain in the top LHS but there is no apparent chemical zonation in the calcite. Number refers to analyses in Table 5. Back scattered electron photomicrograph. Bar scale 20 microns.

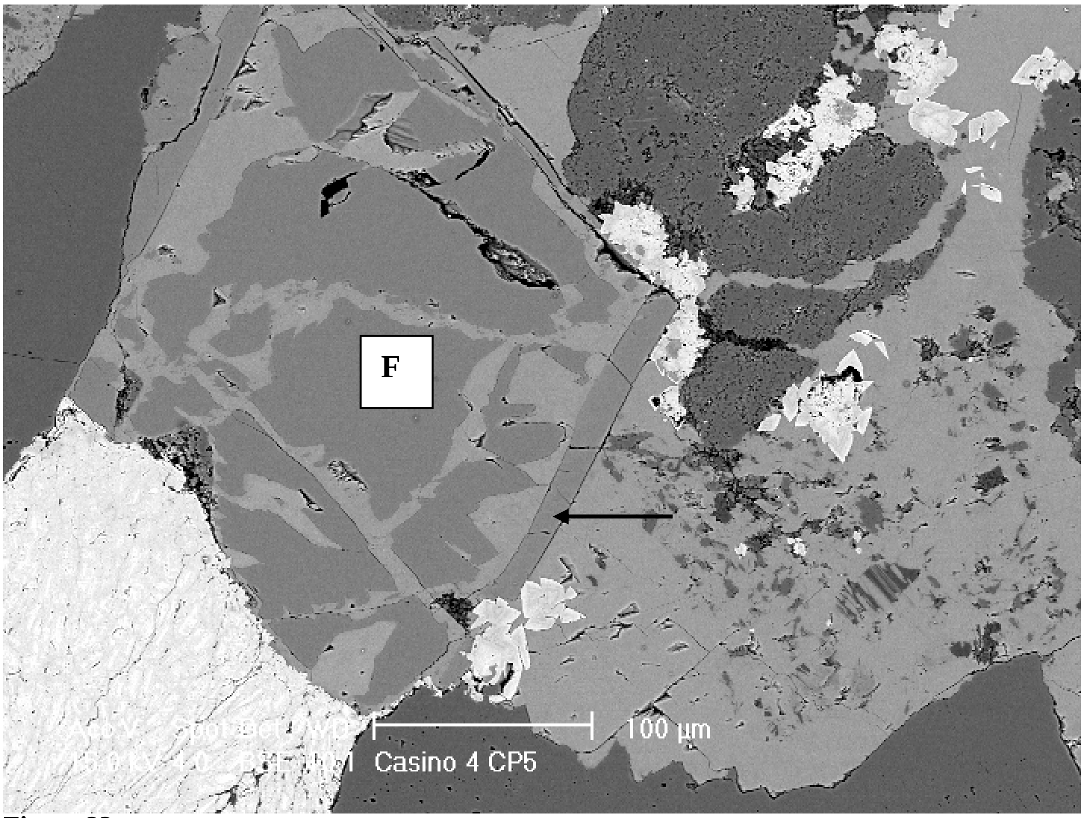


Figure 23e
Siderite (mottled light colour) has replaced a grain (bottom LHS) and occurs along grain margins. Note the K-feldspar (F) which has been partially replaced by calcite spar. The authigenic rim on this feldspar (arrow) has the same composition as the core (Si, Al & K). Back scattered electron photomicrograph. Bar scale 100 microns.

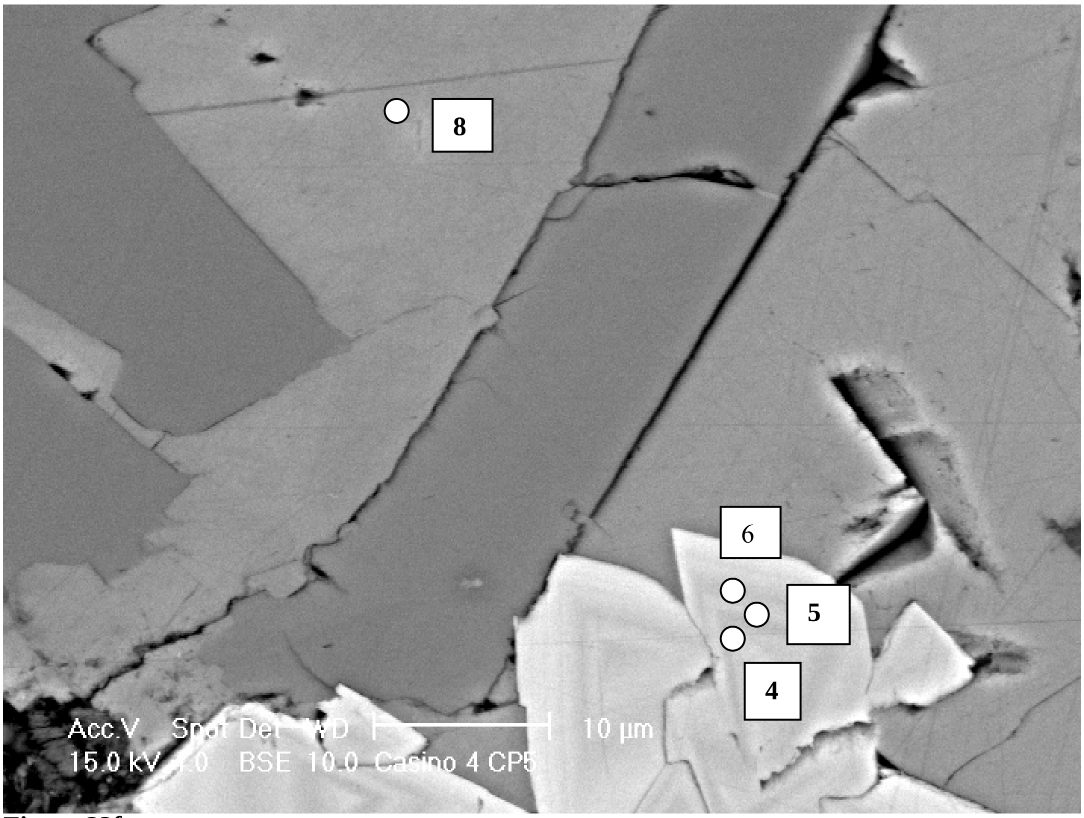


Figure 23f
Closer view of the zoned siderite in Figure 23e immediately above the scale bar. Back scattered electron photomicrograph. Numbers indicate analyses in Tables 5 & 6. Bar scale 10 microns.

7.2 Casino-4, core plug 28, depth 1765.41m

AIM:
To characterise the three phases of carbonate identified in thin section and reconcile this information with the calcite and siderite identified from X-ray diffraction.

RESULTS:
Anhedral Fe rich micrite and microspar identified in thin section has replaced grains and filled pores (Fig. 24a). In backscattered mode the anhedral siderite has a cellular habit which grades to euhedral on the margins of these patches (Fig. 24b, c &d)). Chemical zonation within the siderite is pronounced, with at least 7 phases apparent. The cores of these crystals contain the highest percentages of $FeCO_3$ (90-93mole %) which indicates the siderite is relatively pure. $FeCO_3$ decreases as $MgCO_3$ and $CaCO_3$ increase in alternating zones away from the core. The darkest coloured zones have high $MgCO_3$ (up to 31 mole %) and $CaCO_3$ (up to 11 mole %) and should be described as high Mg siderite (Table 7). Typically these chemical zones range from approximately one to six microns in thickness and the final phase appears to be slightly more Fe rich. Therefore the gross sequence appears to be an Fe rich core followed by fluctuating high to moderate Mg and Ca, and finally a moderately Fe rich rim. Where siderite cements are surrounded by calcite spar there is an increase in the thickness of the fluctuating high to moderate Mg and Ca zones (compare Figs 24c & 24e). A similar chemical sequence is apparent in the euhedral crystals of microspar (Fig. 24f) that had previously been considered a separate carbonate phase from thin section studies. These single euhedral crystals contain less $FeCO_3$ and therefore do not have a dusty reddish colour in thin section which would normally characterise siderite.

TABLE 7 SEMIQUANTITATIVE SIDERITE EDS ANALYSES

SPC	Mole % $MgCO_3$	$CaCO_3$	$MnCO_3$	$FeCO_3$	Colour
1	2.7	3.9	3.4	90.0	VB
2	30.5	8.4	2.1	59.0	D
3	0.8	2.9	2.8	93.5	VB
4	13.9	7.2	1.1	77.8	B
5	31.6	11.5	1.8	55.2	VD

SPC = spectrum number location
VB=very bright, B=bright, VD=very dull, D=dull
Note: all values in this table have been normalised

TABLE 8 SEMIQUANTITATIVE CALCITE EDS ANALYSES

SPC	Mole % $MgCO_3$	$CaCO_3$	$MnCO_3$	$FeCO_3$
6	1.9	94.1	0.8	3.2
7	1.0	95.4	0.8	2.8
8	1.6	93.8	0.9	3.6
9	1.6	94.4	1.0	3.0

SPC = spectrum number location
Note: all values in this table have been normalised

Very minimal chemical variation is evident in the pore filling and grain replacing calcite spar (Table 8). Analysis 9 in Table 8 is from a calcite filled fracture in a quartz grain. The composition is not significantly different from pore filling calcite (analyses 6, 7 & 8).

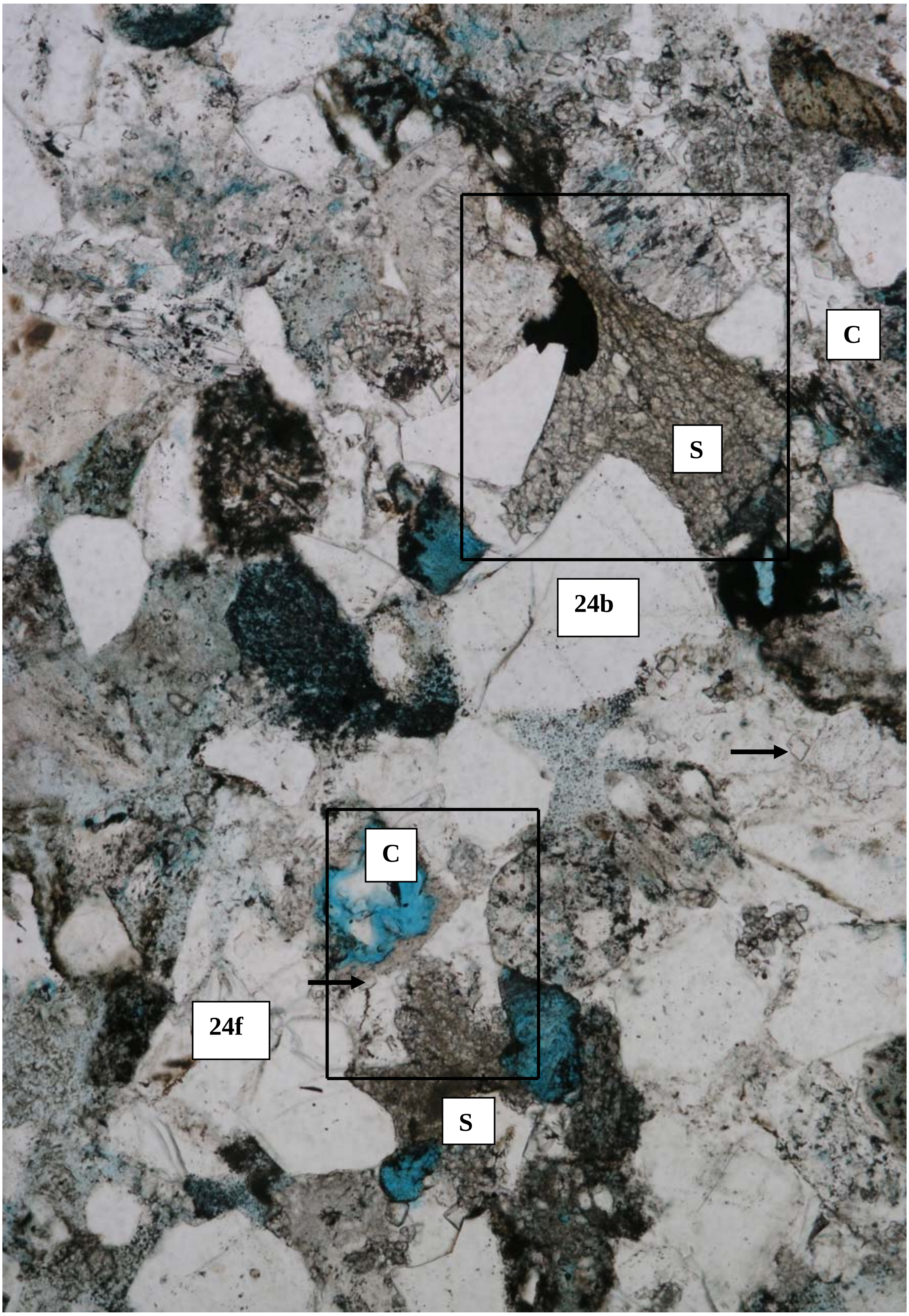


Figure 24a
Thin section photomicrograph showing the locations of Figures 24b and f. The dominant carbonate cement is a clear spar of calcite (C) and there are lesser amounts of dusty anhedral siderite (S). Rare euhedral crystals of microspar (arrow) float within the calcite spar. Plane light. Horizontal field of view 1.30mm.

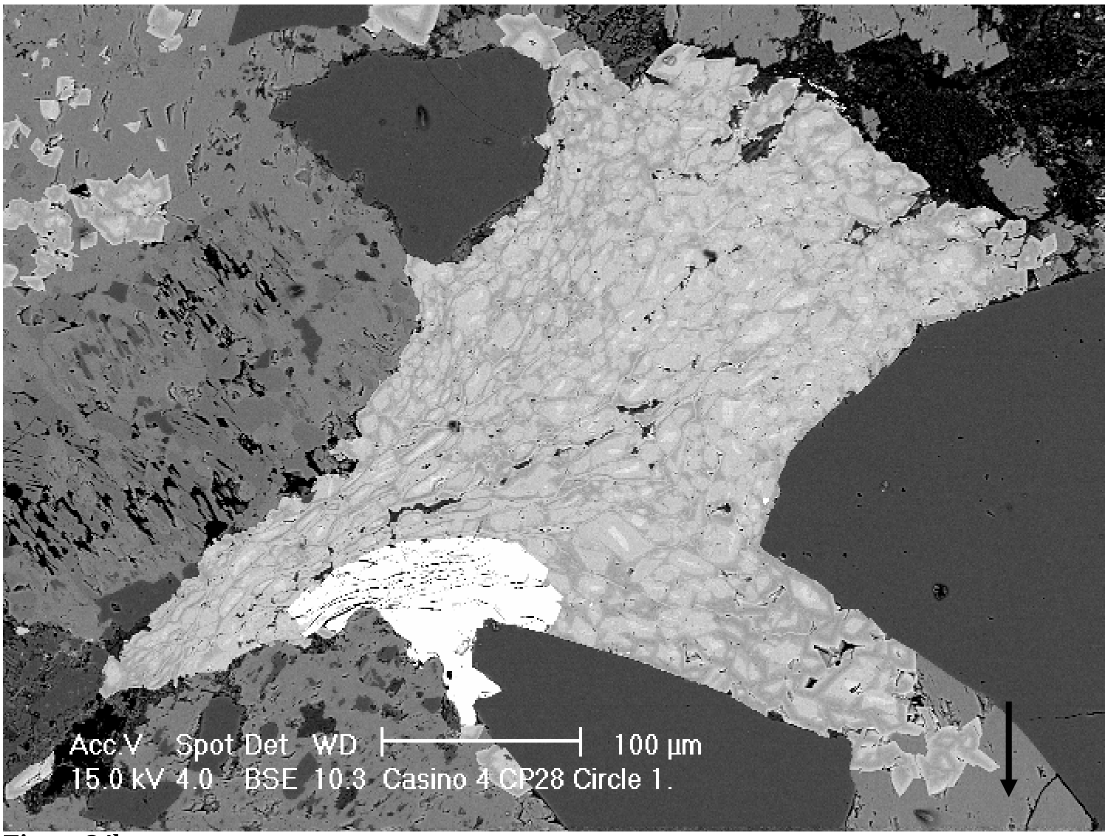


Figure 24b
Siderite has a higher Fe content near the blocky pyrite (white) and grades to more Mg and Ca rich near the calcite cement (arrow). Back scattered electron photomicrograph. Bar scale 100 microns.

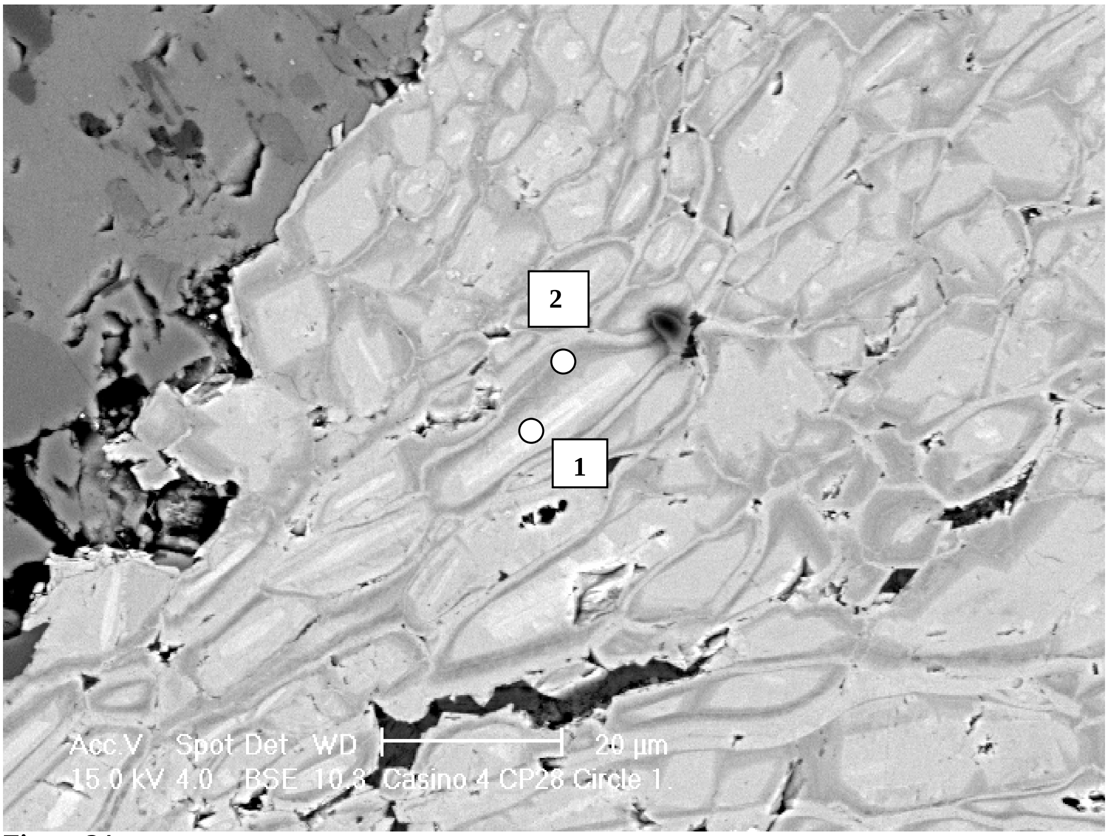


Figure 24c
Closer view of the cellular habit of Fe rich siderite near the pyrite in Figure 24b. Back scattered electron photomicrograph. Numbers indicate the locations of analyses recorded in Table 7. Bar scale 20 microns.

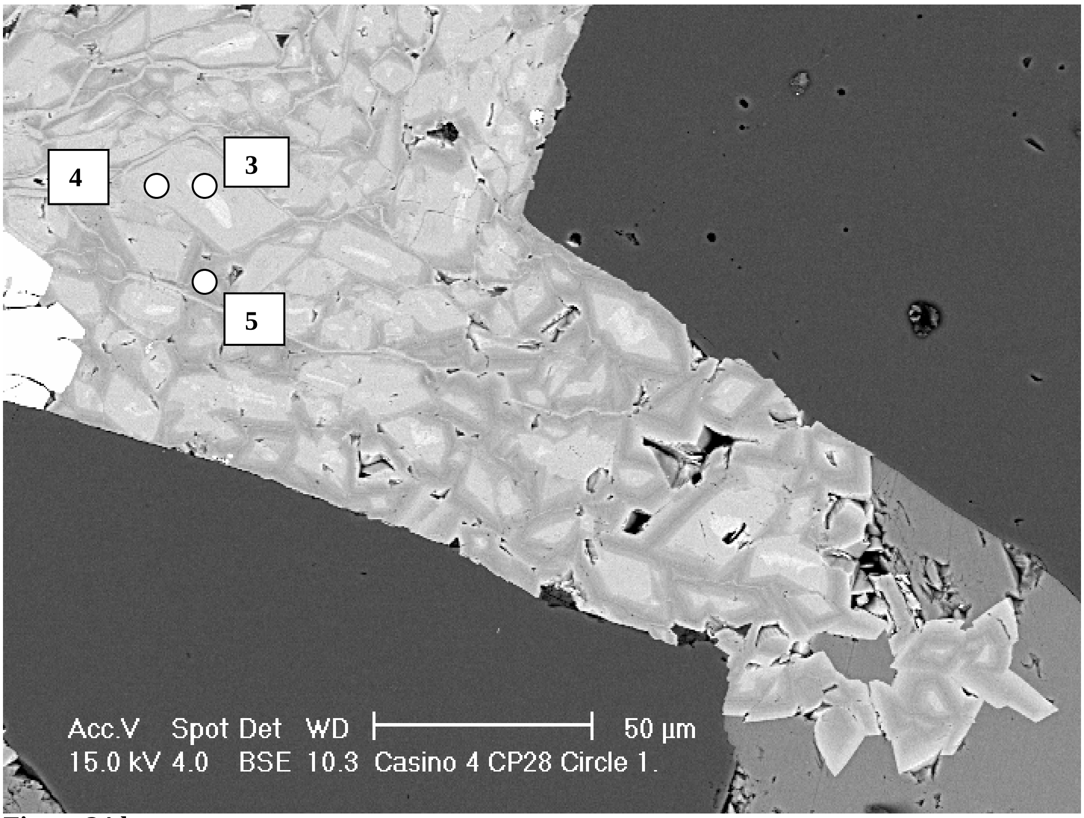


Figure 24d
Near calcite cement there is more Mg and Ca in the siderite resulting in thicker dark coloured zones. Numbers indicate the locations of analyses recorded in Table 7. Back scattered electron photomicrograph. Bar scale 50 microns.

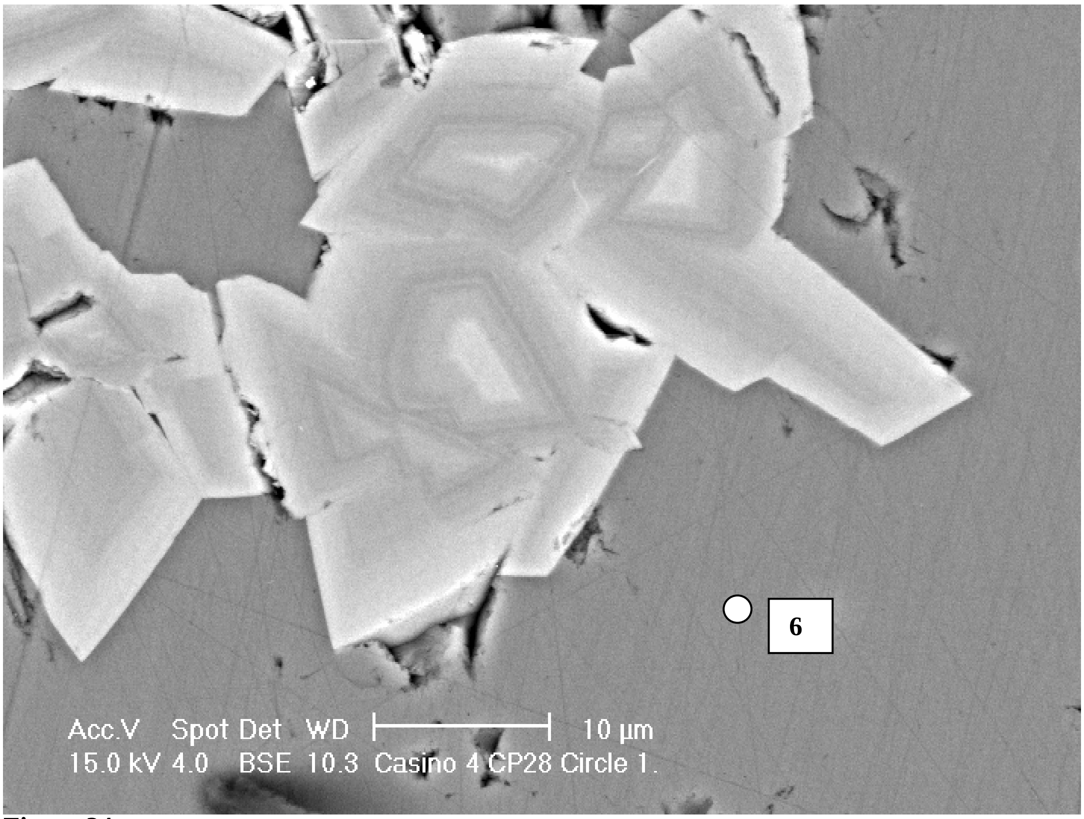


Figure 24e
This enlargement of Figure 24d shows the complex chemical zonation of euhedral siderite crystals surrounded by calcite cement. The number indicates the location of a calcite analysis recorded in Table 8. Back scattered electron photomicrograph. Bar scale 10 microns.

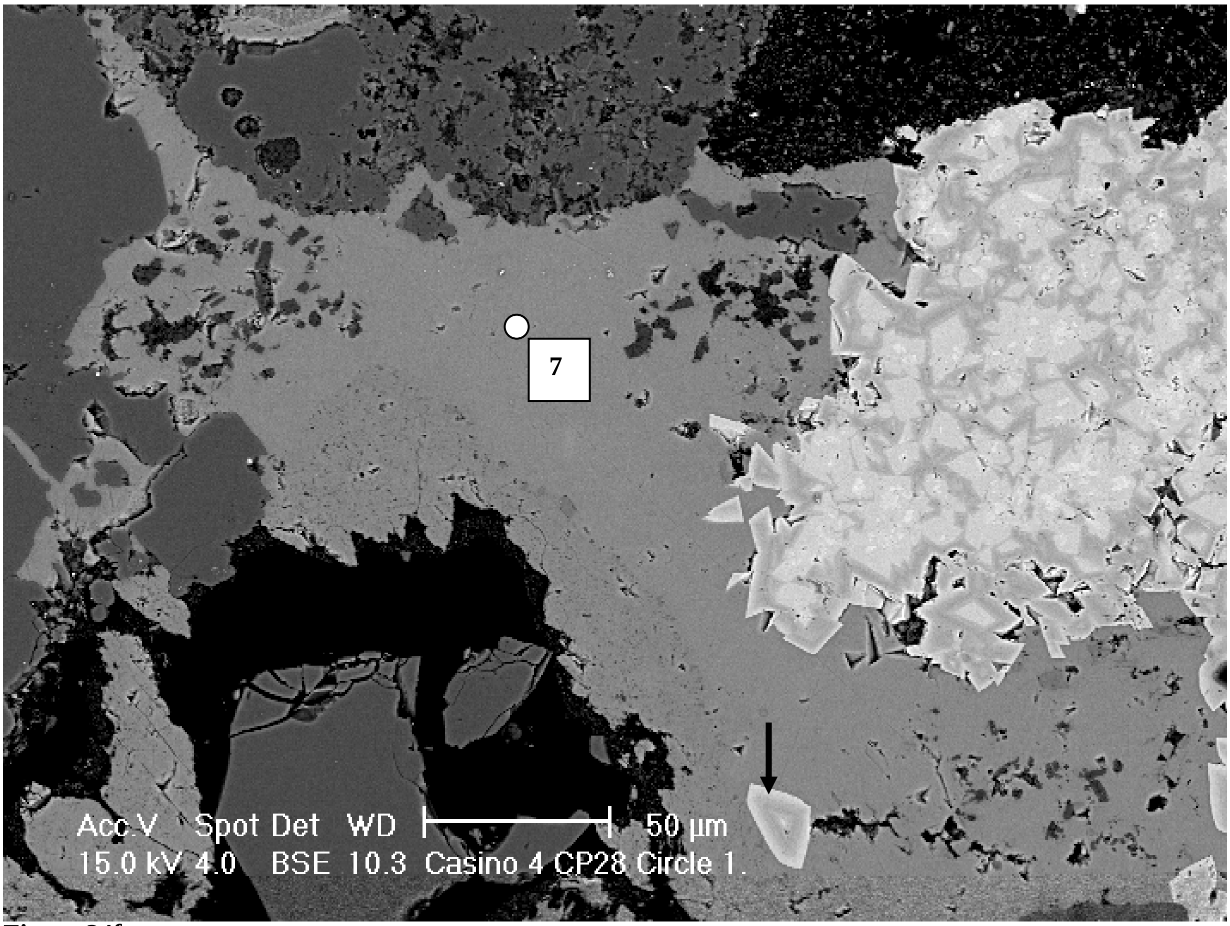


Figure 24f
Euhedral crystals of siderite microspar (arrow) contain a high percentage of the Mg and Ca rich phases. The number indicates the location of a calcite analysis recorded in Table 8. Back scattered electron photomicrograph. Bar scale 50microns.

8. DISCUSSION

8.1 Lithology

Sandstones from the Waarre Unit A at Casino-4 are lithologically very similar and comprised of fine to coarse grained, very poor to very well sorted, mineralogically immature litharenites and one feldspathic litharenite (Fig. 25a). Grain size ranges from very fine sand to boulders and typically grains are angular to subrounded with low to moderate sphericity. Grain size distributions are unimodal and symmetrical in the majority of samples where grain alignment may indicate the presence of bedding. In those litharenites with distinctive cross laminations and cross bedding these sedimentary features are reflected in the grain size distributions by positive and negative skewness. There is one example of bimodal grain size at 1784.70m (core plug 84) where cross laminae are apparent. Rip-up clasts of silty mudstone are evident at 1789.68m (core plug 99) and there are possible faecal pellets at 1790.72m (core plug 4).

These results from Casino-4 are consistent with previous lithologically descriptions from Waarre Unit A (Fig. 25b) at Casino-3 (Phillips, 2004) and Casino-2 (Phillips, 2003). The litharenites and feldspathic litharenite from Casino-4 fall within the range of lithologies previously identified from Unit A. It would appear that compositional variations are based on changes in the percentage of lithics within Unit A and can range from litharenite to feldspathic litharenite and lesser sublitharenites. Average grain size is typically fine to medium grained but there are intervals that are coarse grained. Sorting varies from poor to very well sorted.

There is evidence to suggest that the original detrital mineralogy of the sandstones in Unit A were more feldspathic at the time of deposition. Feldspars have been altered to kaolin and many feldspars could have been dissolved to produce grain size pores. It is possible that in some sandstones there were up to 10% more feldspars which might have influenced the original sandstone classifications.

8.2 Detrital mineralogy & sediment provenance

Framework grains are dominated by monocrystalline quartz (average 27.8%) with minor polycrystalline quartz (average 6.6%). The latter are up to granules in size, have both straight and sutured crystal boundaries and are rarely oxidised. K-feldspars (average 4.3%) which may include both microcline and orthoclase are more abundant than plagioclase (average 0.1%) and K-feldspars are up to granules in size. Intergrowths of alkali feldspar with quartz to form granophyric texture are apparent. Metamorphic lithics (average 10.8%) of shale, quartzite, micaceous schist and minor ?pyrophyllite are more abundant than the igneous (average 1.6%) and sedimentary (average 6.2%) lithics. Igneous lithics include fine grained (crystal diameters less than 1mm) volcanics with trachytic textures, volcanic glass and rare ?rhyolite, and possible granite. Sedimentary lithics are composed of chert, chalcedony, mudstone and rare illitic siltstone to sandstone. There are highly altered lithics (average 2.1%) in all samples which could not be identified. Muscovite flakes (average 0.5%) occur in all samples and are typically bent and altered. There are rare biotite flakes (average 0.1%) in selected samples. The accessory mineral assemblage is dominated by silt to fine sand size zircon (average 0.2%) and silt to medium sand size tourmaline (average 0.2%). In addition, there are lesser amounts of rutile, opaques, garnet and monazite.

These same framework grains were recognised at both Casino-3 and Casino-2 and relative proportions are similar. At the base of Unit A in Casino-2 there do appear to be a higher percentage of volcanic lithics but this might reflect reworking from the underlying Eumerella

Formation. In the accessory mineral assemblage it would appear that tourmaline is the dominant mineral across the field.

There is a correlation between the abundance of kaolinite and illite identified from X-ray diffraction and the percentage of sedimentary lithics at Casino-4. It is possible that mudstone lithics and rip-up clasts contain both detrital illite and kaolinite. Furthermore, the amount of interstratified chlorite may be proportional to the percentage of volcanic lithics at Casino-4. Kaolinite and illite were recognised as the dominant clay minerals at Casino-3 (Phillips, 2004). In addition, chlorite-smectite is present at Casino-2 (Phillips, 2003) where there are high percentages of volcanic lithics. Therefore it would appear that the clay mineralogy results from Casino-4 in Unit A are consistent with elsewhere in the Casino Field.

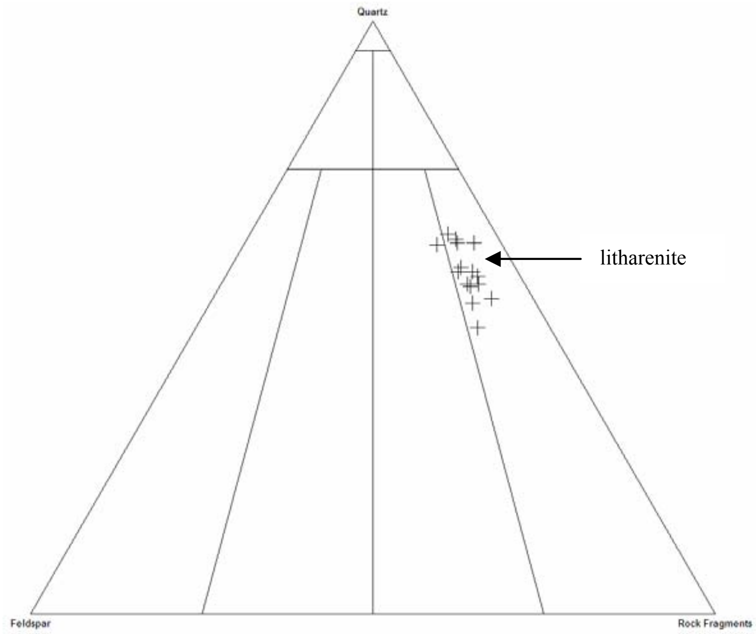


Figure 25a. Folk Sandstone Classification for samples from Casino-4.

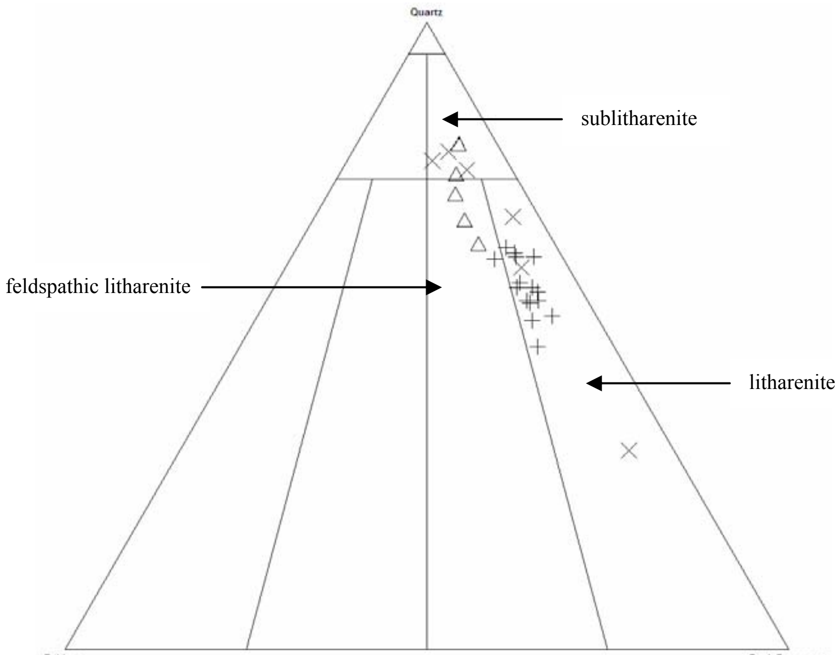


Figure 25b. Folk Sandstone Classification for samples from Waarre A in the Casino Field.
+ = Casino-4 Δ = Casino-3 X = Casino-2
Data for Casino-2 from Phillips (2003) & Casino-3 from Phillips (2004). Note that some values used for Casino--2 were visual estimates not point counts.

Based on the detrital mineralogy a metamorphic terrane was probably the primary sediment provenance with lesser amounts of sediment derived from an igneous source in Waarre Unit A. Sedimentary lithics could have been reworked within the depositional environment (especially the mudstone) and both chert and chalcedony could have been recycled from older stratigraphic units and/or are related to the volcanic source.

Depth related changes in both lithics and feldspars (Fig. 26) are consistent with those noted from Casino-3 (Phillips, 2004) and Callister-1 (Phillips, 2005). From the base of the sequence in Casino-4 there is an increase in both metamorphic lithics and K-feldspars which might indicate the K-feldspars were derived from the metamorphic terrane which was being uplifted at this time. Above approximately 1767m at Casino-4 the percentage of metamorphic lithics declined perhaps because uplift had ceased but the K-feldspars had started to decline slightly deeper at approximately 1775m. In contrast, igneous lithics and plagioclase do not show any depth related changes and therefore it might be assumed that there was no change in the rate of uplift or exposure of the igneous source area. The same break in sedimentation is evident at Casino-3 at approximately 2070m (Fig. 26) with changes in both K-feldspars and metamorphic lithics. In Casino-2 only feldspar abundance follows these trends in Unit A and the number of metamorphic and igneous lithics shows a steady decline from the base of the sequence.

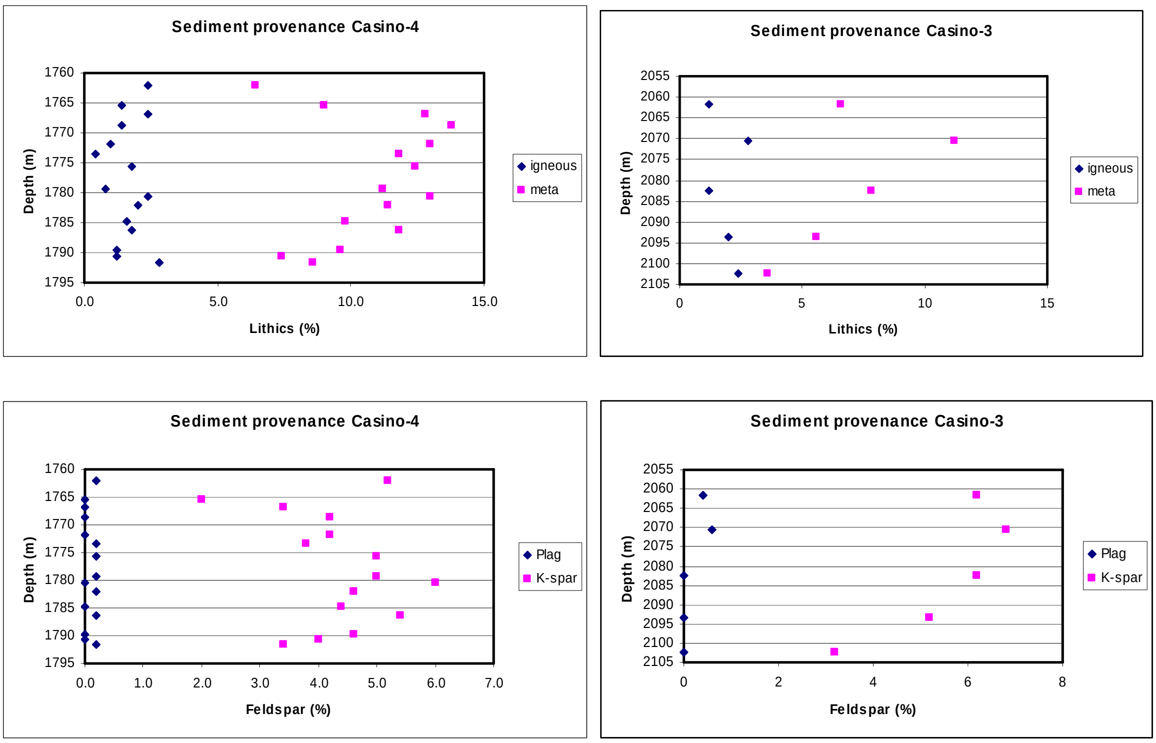


Figure 26 Comparison of data from Casino-4 and Casino-3 illustrating changes in lithics and feldspars with depth.

8.3 Depositional environments

Petrological data is consistent with a fluvial to shallow marine depositional environment for Unit A at Casino-4. Sharp and Wood (2004) identified this setting based on palynology, petrology and other results from Casino-1, -2 and -3. A terrestrial influence is suggested by the presence of organic matter in most of the litharenites at Casino-4. In Unit A at Casino-1 the organic matter includes cutinite which is derived from land plants. Angular grain shapes are more typical of fluvial settings than marine and this is consistent with the fining upward units noted from the logs at Casino-4. Slight positive skewness in the grain size distribution of the medium grained litharenite at 1789.68m (core plug 99) might also be consistent with a fluvial interpretation. Silty mudstone rip-up clasts could have been reworked from overbank deposits in this same sample. Positively skewed grain size distributions were also noted from a medium grained carbonate cemented feldspathic litharenite in Casino-3 at 2082.5m and a fine grained sublitharenite in Casino-2 at 1857m.

Oxidation of lithics and polycrystalline quartz at 1775.72m (core plug 56), 1766.93m (core plug 31) and 1765.41m (core plug 28) could be associated with the changes in sedimentation rates noted from the percentages of feldspars and metamorphic lithics (Fig. 26). This might indicate periods of exposure and consequent oxidation at these times. At Casino-2 in Unit A there are oxidised grains and rims (2.8%) near the base of the sequence (1917m) which may reflect an earlier phase of localised exposure.

Early diagenetic cements of micritic siderite and euhedral microspar could be further evidence of a meteoric influence on the depositional environment. Siderite precipitation is favoured by low sulphide activity which is normally associated with fresh water. Sea water contains too much dissolved sulphate to allow siderite formation unless there is mixing with meteoric waters. The rare superficial ooids of Fe rich carbonate noted at 1781.98m, 1780.54m and 1779.3m are thought to have formed as circumgranular rims similar to those at 1775.72m and more abundant at 1762.1m. These equant circumgranular cements probably precipitated in a meteoric phreatic zone. At Casino-3 a siderite nodule was identified at 2061.5m which might also have formed due to circumgranular cement.

Despite the terrestrial and meteoric indicators in Unit A there are suggestions of a marine influence. Grains of incipient and oxidised glauconite (average 0.3%), and pyrite framboids are consistent with identification of a marginal marine setting at Casino-4. Glauconite is absent from the two samples above the break in sedimentation at approximately 1767m and from the two carbonate cemented basal samples. Glauconite forms soon after burial when sedimentation rates are low, Eh is slightly reducing and pH is near 8. The incipient nature of many grains suggests the glauconite was not present in marine pore waters for sufficient time to absorb enough K. Oxidation of these grains might reflect flushing by meteoric waters and/or exposure due to reworking within the depositional environment. Pyrite requires more reducing conditions than glauconite and forms when sulphate is reduced by bacteria in marine pore waters and there is sufficient Fe present. Pyrite tends to form at slightly deeper depths of burial than glauconite. Framboids which range in diameter from 10 to 50 microns, are commonly clustered along grain margins, or associated with the early siderite. Pyrite framboids and rare glaucony grains are also evident at Casino-3, but there was no glaucony recognised at Casino-2. Total pyrite and glaucony at both Casino-3 and -2 is less than identified at Casino-4, which might reflect greater distance from the marine influence.

This apparent conflict in terrestrial/meteoric and marine indicators might be explained by the following hypothesis. The original depositional setting was probably meteoric vadose and then as burial started meteoric phreatic (below the water table) hence the circumgranular cements because pores were constantly filled with water. If the location was near to a marine environment then as burial progressed the sediment could have passed from meteoric phreatic into a mixed diagenetic zone. In the mixed zone there would have been periods dominated by marine pore waters and others when meteoric waters were more important. Movement in this zone can be controlled by long term events such as relative changes in sea level or short term events associated with storms and tides etc. Thus incipient glauconite and pyrite framboids precipitated when marine pore waters dominated but the glauconite was oxidised when flushed by meteoric waters.

8.4 Authigenic mineralogy & diagenetic alteration

There would appear to be an overlap between authigenic minerals formed during early diagenesis and depositional environments as described above. Glauconite, pyrite and siderite are considered very early diagenetic minerals. General conditions favouring the precipitation of these minerals have already been considered but there are complexities in the siderite which need further interpretation.

Siderite occurs as anhedral micrite and subhedral to euhedral microspar that has replaced grains (average 3.8%) and filled intergranular pores (average 1.8%) in all samples from Casino-4. The equant circumgranular habit of at least some of the siderite is convincing evidence that a phase of siderite was early diagenetic. Blocky and framboidal pyrite have replaced the siderite and therefore probably precipitated after the siderite. Cement stratigraphy indicates that clear carbonate spar (calcite and dolomite) filled any remaining pore spaces after the siderite.

X-ray diffraction of the litharenite at 1779.3m (core plug 68) revealed from a peak doublet that there are at least two phases of siderite present. This chemical variation was found to be even more complex after scanning electron microscopy on the carbonate cemented litharenites at 1791.7m (core plug 5) and 1765.41m (core plug 28). Crystals are distinctly zoned and there could be up to seven phases of siderite even in the patches of apparently anhedral micrite. The cores of these crystals tend towards pure siderite with high Fe contents but nearer the edges there is an increase in Mg in the siderite to form high Mg siderite. Chemistry of the pore waters from which these crystals precipitated fluctuated in the proportions of Ca, Mg, Mn and Fe. This was not a gradual evolution of pore waters as indicated by complex zoning in backscattered mode. Where a cellular habit is seen in the siderite it has probably replaced organic matter, but micas and other grains could also have been replaced. It is unknown whether the equant circumgranular cements also display this complex zoning.

Watson *et al* (2004) recognised a phase of early diagenetic high Mg siderite (Siderite I) in the Pretty Hill Formation and a late diagenetic Fe rich siderite (Siderite II) in the Waarre Formation. They thought that siderite cements in the Waarre Formation were related to very high CO_2 concentrations derived from degassing during Pleistocene to Recent volcanism. Based on the cement stratigraphy at Casino-4 it would appear that siderite chemistry is far more complex in the Waarre Formation than previously recognised and the siderite was early diagenetic, not late diagenetic.

Siderite crystal habits and proportions are similar in other wells from the Casino Field. In Casino-3 siderite occurs as micrite and anhedral to subhedral microspar which has precipitated where grains are replaced by kaolin, it has replaced micas and lithics (average 3.9%), and partially fills pores (average 2.5%). EDS analysis of the siderite microspar indicated that it was a high Mg variety which is consistent with the final phase in Casino-4. Zoning was not recognised in Casino-3 because the SEM work was undertaken on rough chips of the samples, not polished thin sections. Zoning was noted within a ?nodule in Casino-2 (Swc 7, depth 1917m) which is probably equivalent to the superficial ooids described from Casino-4.

There is abundance evidence of partial to complete dissolution (average 9.1%) of labile grains in the litharenites from Casino-4. It is possible that intragranular pores within lithics and some honeycomb pores in feldspars could have developed or been initiated during transport, but the grain size pores must have developed in situ. Where circumgranular cements remain suspended around grain size pores (core plug 18, depth 1762.1m) this might suggest that dissolution occurred after this phase of siderite.

Dissolution of feldspars to produce a source of Si and Al for the precipitation of kaolin probably resulted from flushing by meteoric waters in Casino-4. Slightly acid pore waters (pH 4-7) favour kaolinite precipitation when there is minimal K^+ activity. Kaolin booklets range from minute crystals of 5 microns diameter to booklets and vermiform habits which are up to 50 microns in diameter. These larger diameters are probably associated with the slow replacement of micas. Kaolin is present as kaolinite based on the clay XRD results and has both replaced grains (average 3.7%) and filled adjacent intergranular pores (average 2.9%). Kaolin precipitated before the siderite microspar and before the late pore filling clear carbonate spar. Rare jagged contacts between quartz overgrowths and kaolin might also indicate the kaolin formed before quartz. Trace amounts of illite associated with grain replacing kaolin could reflect compositional zoning in the feldspars that have been replaced. Elsewhere in Unit A at Casino-3 and Casino-2 there are similar proportions of kaolinite and the timing of formation is consistent with results from Casino-4.

When feldspars are replaced by kaolin there is an excess of silica remaining from this reaction which can result in the formation of quartz overgrowths. Prismatic and rare rhombohedral quartz overgrowths (average 0.5%) are poorly developed in most samples from Casino-4 and slightly better in the feldspathic litharenite from 1762.1m (core plug 18) where they represent 1.8% of the total rock composition. Quartz overgrowths were present prior to the late clear carbonate cements and have a jagged contact with kaolin. Unit A in Casino-3 has an average of 1% quartz overgrowths and in Casino-2 it was 0.6%. These differences are not considered significant. Quartz overgrowths are limited by the number of lithics in Unit A which reduced the available sites for silicification.

There are a relatively high percentage of altered grains (average 2.1%) of unknown origin in Unit A at Casino-4. These grains could represent weathered lithics that were altered during transport, or they might have been partially oxidised soon after deposition when meteoric waters flushed the sediment. Similarly the original nature of grains replaced by illite (average 0.7%) is also unknown. Illite forms when pore waters are weakly acid to neutral (pH 5.5-7) and there is sufficient K, Si and Al available. Usually these elements are derived from feldspars but they might also be sourced from altered glauconite. This alteration may have occurred after the majority of feldspars had been converted to kaolin and K^+ activity had increased.

Discontinuous thin feldspar overgrowths (average 0.4%) that lack twinning are evident on corroded grains of K-feldspar in Casino-4 and all the other wells studied from the Casino Field. These overgrowths are most pronounced in Unit A and could be related to alteration of feldspars within the volcanic lithics that are also confined to Unit A (Phillips, 2004). Previous petrology studies were unable to identify when the feldspar overgrowths developed. In Casino-4 it is apparent that overgrowths formed prior to development of grain size dissolution pores and before the precipitation of clear carbonate spar. Possible identification of authigenic microcline in the bulk XRD of core plug 36 (1768.71m) is consistent with the elemental analysis of feldspar overgrowths in Casino-3.

The most abundant authigenic mineral in Casino-4 is clear, twinned poikilotopic calcite spar which formed after the kaolin, siderite, quartz and feldspar overgrowths. Calcite has filled pores and replaced grains and it is most abundant in selected samples at 1791.7m (core plug 5), 1780.54m (core plug 72), 1766.93 (core plug 31) and 1765.41m (core plug 28) where it represents greater than 15% of the total rock composition. Where calcite is present there are suggestions that it may have been partially corroded and in core plug 77 (1781.98m) it is possible that a significant amount of clear spar has been dissolved. EDS analysis of the calcite from two samples indicates minimal chemical variation with an average composition of 94.6 mole% $CaCO_3$, 1.4 mole% $MgCO_3$, 1.0 mole % $MnCO_3$ and 3.0 mole % $FeCO_3$. The Fe and Mn content indicate that the calcite is slightly ferroan and therefore probably precipitated in the burial diagenetic zone where groundwaters are not oxygenated. There is nothing obvious to explain the distribution of the calcite cement but the Ca might have been sourced from plagioclase feldspars. Typically plagioclase is absent from those samples with high percentages of calcite in both Casino-4 and Casino-3. This either indicates the plagioclase was preferentially replaced by calcite, or that it was dissolved and this liberated Ca. The source of CO_2 for these cements could be related to Pleistocene volcanism, decarboxylation prior to hydrocarbon migration and/or the partial dissolution of earlier siderite cements.

Comparison of the calcite chemistry at Casino-4 with results from Watson *et al* (2004) shows a very similar composition to calcite cements from the Waarre Formation in Caroline-1. However, the crystal habit and textural relationships at Casino-4 are not consistent with the descriptions by Watson *et al* (2004) for Caroline-1, except that the calcite did form after quartz overgrowths. These authors attributed the formation of late diagenetic carbonates in the Otway Basin to CO_2 derived from Pleistocene to Recent igneous activity. If there was further igneous activity after the calcite precipitated and this injected abundant CO_2 into Unit A then fluids could have become weakly acidic causing calcite and siderite dissolution. As carbonate dissolution progressed the pore fluids would have become buffered by the carbonate until pH became alkaline again and another phase of carbonate could precipitate.

Thin section staining revealed that after the phase of calcite cement, minor ferroan calcite precipitated. However, where both staining and XRD results are available (core plug 68, 1779.3m), the XRD confirmed that this final carbonate is dolomite, rather than ferroan calcite. Dolomite spar is typically blocky and rarely has curved crystal boundaries typical of saddle dolomite. Intergranular and dissolution pores are both filled with dolomite, grains are replaced by dolomite and the spar has euhedral terminations indicating that it was not influenced by dissolution. Dolomite does occur in the same samples that have significant calcite cements but it tends to be a minor component (~5%). EDS analyses of dolomite spar from Casino-3 (MSCT 13, depth 2061.5m) indicated that there are trace amounts of Fe in the dolomite. This tendency towards a ferroan composition is consistent with late diagenetic burial cement. Mg and Fe could both have been sourced from earlier siderite cements and/or chloritic clays associated with volcanic lithics. The origin of CO_2 in the dolomite might also have multiple sources including a late phase of CO_2 introduced by igneous activity. However, the fact that this is saddle dolomite might favour a connection with hydrocarbons. When sulphate activity is lowered by reducing organic matter and pore waters are alkaline then conditions may favour dolomite precipitation. Dolomite could be neomorphically replacing the earlier calcite cement.

All samples in Unit A have evidence of minor mechanical compaction resulting in tangential and rare concavo-convex grain contacts. Loss of porosity due to compaction is weakly depth related (Fig. 27a) but it does not increase with depth, it decreases. Therefore compaction is not simply a function of depth of burial because it should increase in deeper samples. Results from Casino-3 where Unit A is buried more deeply (Fig. 27b) indicate no real change in the amount of compaction compared to Casino-4. There are probably two factors that controlled the degree of mechanical compaction. Firstly, it has been demonstrated that lithics (in particular metamorphic lithics many of which are ductile) increase in abundance from the base of Unit A at Casino-4 up to approximately 1767m where there is a decline. A weak correlation between compaction and the number of lithics (Fig. 28a) is consistent with the depth trend. As the number of metamorphic lithics increased there was an increase in mechanical compaction. The second factor which probably influenced compaction was the timing of carbonate cements. Siderite is considered an early cement in Unit A, especially where it forms circumgranular rims, therefore siderite could have limited early compaction. Those samples with higher percentages of siderite have been less influenced by compaction loss (Fig. 28b). Carbonate cements of calcite and dolomite that have been interpreted as late diagenetic had no influence on compaction loss (Fig. 28c). Samples with high percentages of carbonate cement have exactly the same amount of compaction loss as samples which lack this cement. This observation confirms the late diagenetic character of both calcite and dolomite cements in Unit A at the Casino Field.

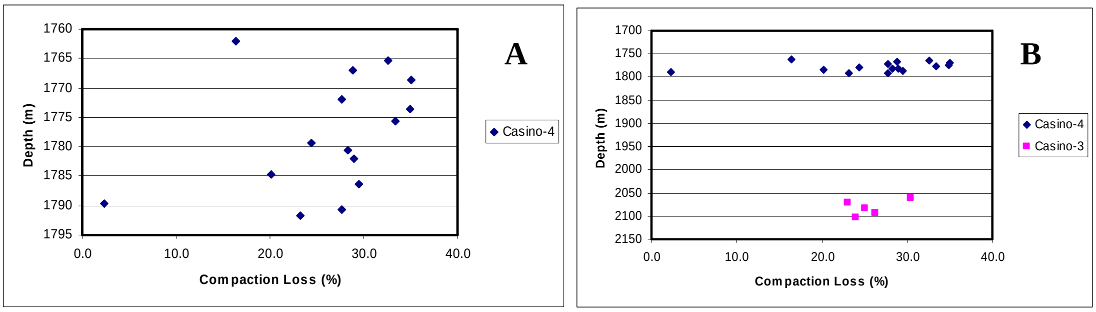


Figure 27 Relationship between porosity loss due to compaction and depth of burial in Unit A of the Waarre Formation. **A** for Casino-4, and **B** comparing Casino-4 and more deeply buried sediment from Casino-3. Compaction loss was calculated using the method of Lundegard (1992).

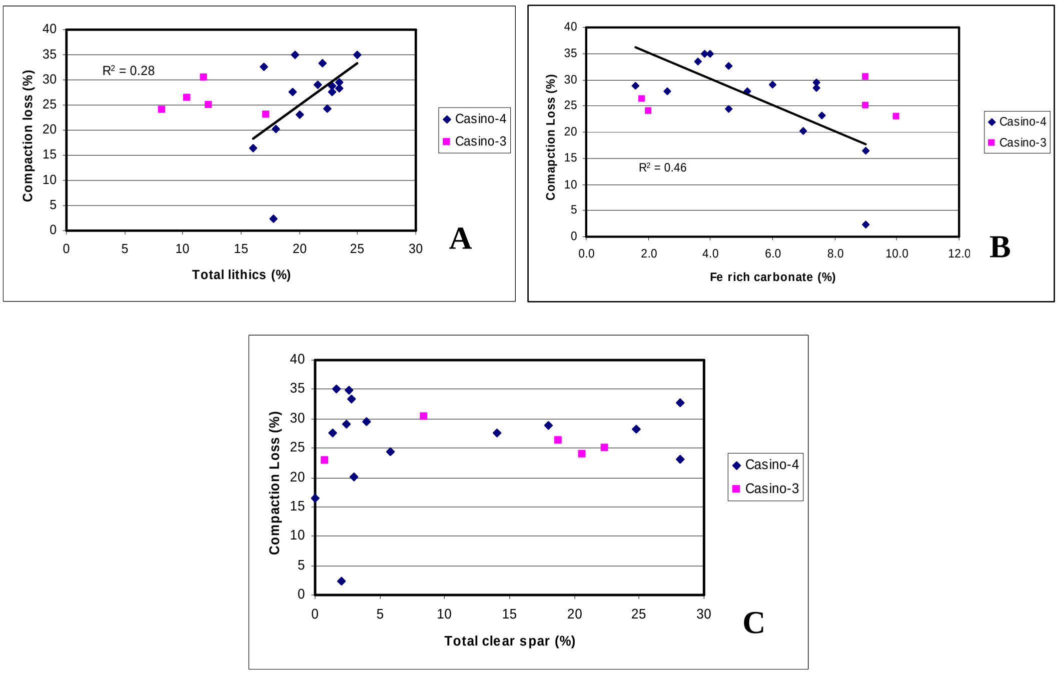


Figure 28. Possible factors controlling compaction loss in Waarre Unit A. **A** relationship with the total number of lithics, **B** the early siderite cements and **C** late diagenetic calcite and dolomite cements. R^2 values are only for data from Casino-4.

The paragenetic sequence recognised in Casino-4 for Unit A is summarised in Figure 29. A high percentage of this diagenetic alteration was early, either related to depositional environments or meteoric phreatic and mixing zones soon after burial. The elements required for precipitation of most authigenic minerals could have been derived from detrital feldspars and lithics. Controls on the distribution of late diagenetic carbonate cements are poorly understood. Concentration of calcite might be related to a number of factors including bedding, localised permeability barriers, localised source of Ca and proximity to faults (if the CO_2 was mantle derived). There appear to be two phases of dissolution, the earlier of which was probably caused by meteoric flushing and the later event might reflect high CO_2 in the reservoir. Differences between these observations and results from Casino-2 and -3 are not considered significant. Minor amounts of pore filling barite in Casino-3 were probably related to the drilling mud.

Event	Diagenetic Stage Early Late Cretaceous	Middle	Late Pleistocene/Recent
glauconite	---		
pyrite	--- ----		
siderite	- - - - - - -		
dissolution & oxidation	- - - -		-----
kaolin	---		
quartz overgrowths	---		
feldspar overgrowths	---		
illite	---		
mechanical compaction	---------		
CO_2 from igneous activity		?----	?-----
calcite			-----
dolomite			-----
hydrocarbon migration			----

Figure 29 Possible paragenetic sequence for Unit A Waarre Formation in Casino-4.

8.5 Reservoir quality

Unit A in the Waarre Formation at Casino-4 contains intergranular pores (average 3.1%), secondary dissolution pores (average 9.1%), minor fracturing (average 0.2%) in selected samples and micropores (average 0.7%). Dissolution pores include grain size pores, intragranular pores within lithics, honeycomb pores associated with corroded feldspars and partial corrosion of calcite and siderite cements. Micropores have been estimated from the percentage of kaolin and glaucony in each sample. Grain fracturing was initially thought to be an artifact of sampling and thin section preparation. However, where quartz grains and chert are fractured in the middle of a core plug the fracturing is probably real. Corroded feldspars tend to display the most fracturing. It is clear from Figure 30 that dissolution pores are dominant throughout Unit A in Casino-4. This observation is consistent with results from Casino-3 and Casino-2 but the average percentages of dissolution pores are less in these wells. Casino-3 has an average of 6.6% and Casino-2 has 4.6% secondary porosity. Values in Casino-2 could be underestimated because these results are based on descriptions of crushed sidewall cores.

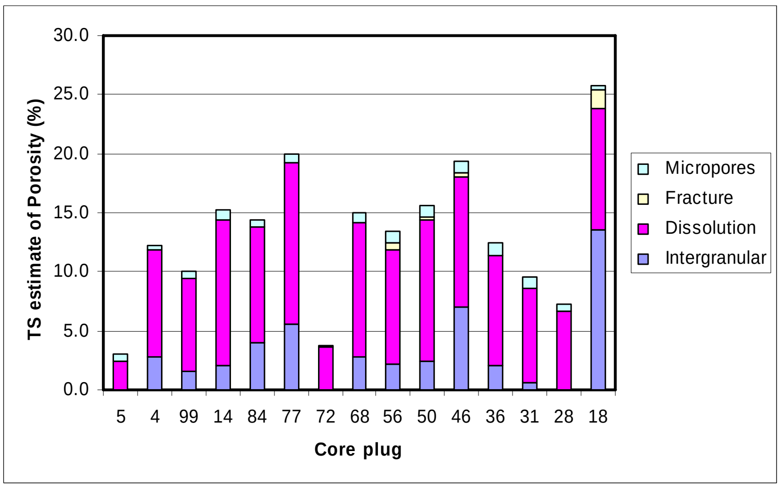


Figure 30 Pore types in each sample from Unit A at Casino-4.

Within the petrology data set from Casino-4 there is a strong correlation (r^2=0.91) between routine core analysis results for porosity and permeability (Fig. 31). Data from Casino-3 also lies on the same trend. This strong correlation would tend to suggest that both porosity and permeability were controlled by the same factor(s) in Unit A.

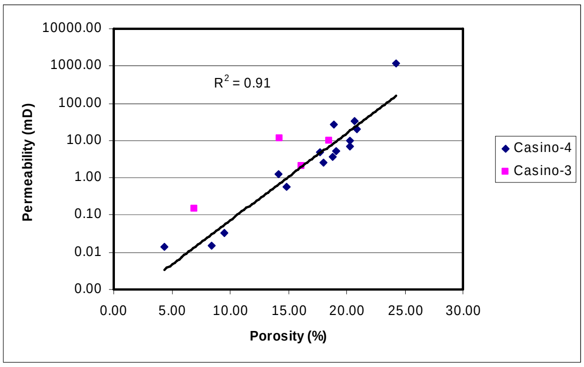


Figure 31 Cross plot of routine core analysis results for petrology samples from Unit A. Note: r^2 value only relates to Casino-4 data.

Porosity can be a function of depth and rock composition, whilst permeability is typically controlled by porosity and rock composition. A series of univariate analyses were performed to assess the influence of these various parameters on reservoir quality. There would appear to be no correlation between porosity and grain size, sorting, lithic content, compaction and the percentages of quartz and feldspar overgrowths. It has already been demonstrated that porosity loss due to compaction was not depth related but may have been controlled by the abundance of early siderite cements and the percentage of metamorphic lithics (Fig. 28). In Casino-3 it was found that intergranular pores were better preserved where overgrowths had developed to provide a rigid framework to the rock.

Precipitation of authigenic minerals in pores is an obvious control of porosity. In Casino-4 the most abundant authigenic minerals are carbonates and there is a strong correlation (r^2=0.70) between pore filling carbonate as determined from thin section descriptions and core porosity values (Fig. 32a). Porosity is limited by the amount of carbonate spar. Results from Casino-3 are also consistent with this trend. Furthermore, it would appear that there is a correlation between dissolution pores and the amount of carbonate in pores (Fig. 32b). There are more dissolution pores and a greater scatter in the number of pores where the percentages of carbonate are low.

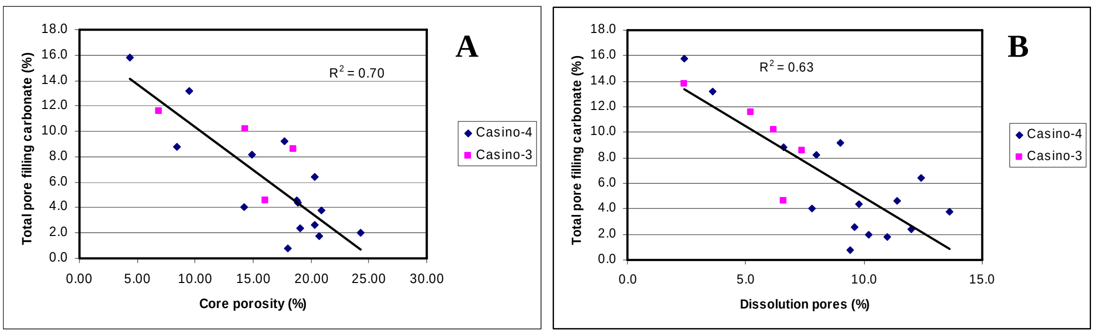


Figure 32. Cross plots of the amount of carbonate occluding pores and estimates of porosity. **A** for core derived porosity and **B** for the percentage of dissolution pores estimated from thin section. Note: r^2 values only relate to Casino-4 data.

The major control of porosity in Casino-4 was the distribution of carbonate cements which occluded intergranular pores. Since intergranular pores are typically interconnected this is the most likely control of permeability. Figure 33a illustrates that there is a moderately strong correlation (r^2=0.72) between permeability and intergranular porosity in Casino-4. Surprisingly there is also a moderate correlation (r^2=0.60) between dissolution pores and permeability (Fig. 33b). Normally dissolution pores are not thought to be interconnected and hence do not represent effective porosity. However, in Unit A these secondary pores do appear to be interconnected. Interconnection of dissolution pores could have resulted from both grain fracturing and via the intergranular pores. The relationship between dissolution pores and intergranular pores (Fig. 34) does show a correlation which might confirm that dissolution pores are connected via the intergranular pores. It is also apparent from Figure 34 that the correlation is strongest after there has been approximately 6% dissolution. This might suggest that at least some of the intergranular pores are secondary in nature and have been reopened by the dissolution of carbonate cement. It is more difficult to assess the impact of grain fracturing because it is restricted to only four samples. However, core plug 18 (depth 1762.1m) which has the highest permeability also has the highest percentage (1.6%) of grain fracturing.

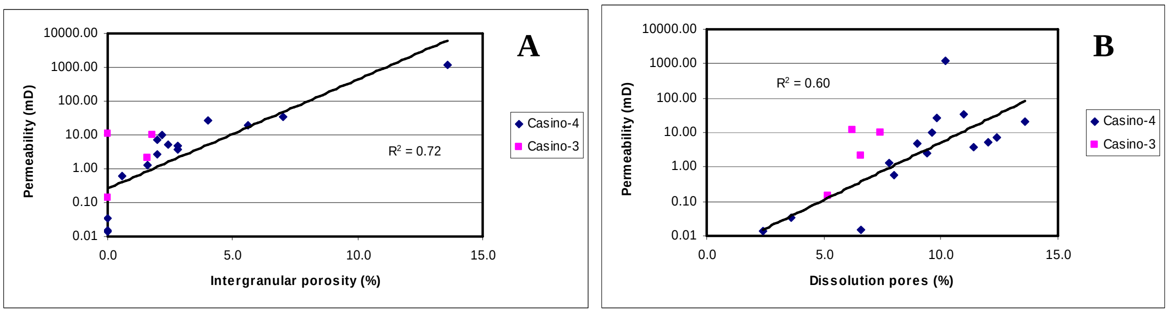


Figure 33. Correlations between permeability and the percentages of (**A**) intergranular pores, and (**B**) dissolution pores determined from thin section.
Note: r^2 values only relate to Casino-4 data.

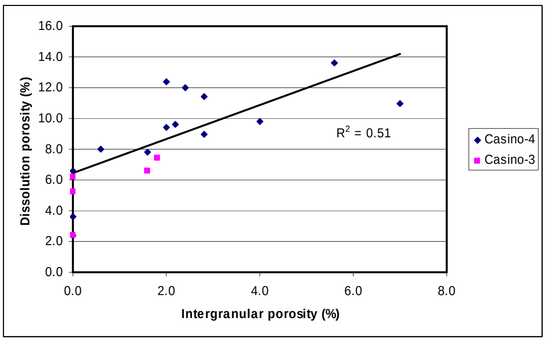


Figure 34 Relationship between dissolution pores and intergranular pores estimated from thin section.
Note: r^2 value only relates to Casino-4 data.

9. CONCLUSIONS

1. Unit A in the Waarre Formation at Casino-4 is comprised of fine to coarse grained, very poor to very well sorted, mineralogically immature litharenites, carbonate cemented litharenites and one feldspathic litharenite. Prior to alteration all the sandstones could have been more feldspathic.

2. Sediment provenance was dominated by a metamorphic source which was probably uplifted during the early stages of Waarre deposition but ceased near the top of the sequence. This trend was recognised previously in Casino-3 and elsewhere on the Mussel Platform. The metamorphic terrane was probably the source of K-feldspars, whilst an igneous provenance could have sourced the plagioclase. There has been reworking of sediment within the depositional environment.

3. Deposition may have occurred in a fluvial meteoric to brackish setting. Early diagenetic alteration reflects a meteoric phreatic and then mixing zone as burial progressed. Equant circumgranular cements of siderite formed in the meteoric phreatic zone. Traces of glauconite and framboidal pyrite could reflect the marine influence in the mixing zone which was oxidised when flushed by meteoric waters.

4. Distinct zoning in the early diagenetic siderite indicates the evolution of pore waters from Fe to more Mg rich via up to 7 phases of precipitation. Feldspars and micas were altered to kaolinite possibly as a result of flushing by meteoric waters. Minor quartz and feldspar overgrowths, and grain replacing illite all formed prior to the calcite cement. Late diagenetic slightly ferroan calcite is the dominant authigenic mineral and may be related to CO_2 released during Pleistocene/Recent igneous activity. There was minor dissolution of this cement prior to the final phase of saddle dolomite which could be related to hydrocarbon migration.

5. Reservoir quality was controlled by the distribution of carbonate cements in Unit A. Dissolution pores are dominant and appear to be interconnected possibly via grain fracturing and intergranular pores. At least some of the intergranular pores might be secondary in origin where there has been more than 6% dissolution.

10. GLOSSARY OF TERMS

Framboid
A cluster of pyrite crystals with a spheroidal outline.

Glaucony
A term used to describe green minerals without any genetic connotations. If the green minerals can be identified, a specific mineral name is given.

Glauconite
An Fe-rich dioctahedral illite. The term is also used to refer to a family of Fe-rich dioctahedral clays with varying ratios of expanded (smectite) and non-expanded layers.

Granophyric Texture
A variety of micrographic intergrowth of quartz and alkali feldspar that is either crudely radiate or is less regular than micrographic texture.

Honeycomb Porosity
Secondary porosity produced by the corrosion (etching) of detrital grains.

Micrographic Intergrowth
A regular intergrowth of two minerals.

Microporosity
Porosity directly associated with clay minerals.

Neomorphism
All transformations between a mineral and the same mineral, or another of the same general composition.

Poikilotopic
A sedimentary textural term denoting a single crystal of carbonate enclosing more than one framework grain.

Radiate Texture
Textures in which elongate crystals diverge from a common nucleus.

Porphyritic
A textural term applied to igneous rocks in which there are two distinct grain sizes present.

Spherulitic
The presence of more or less globular masses of generally acicular crystals, having a radial arrangement. spherulites form as a result of devitrification of volcanic glass.

Trachytic
A textural term applied to the groundmasses of volcanic rocks in which there is a subparallel arrangement of microcrystalline, lath shaped feldspars. The term is not restricted in use to rocks of trachyte composition.

Vacuole
Gas or liquid filled inclusion.

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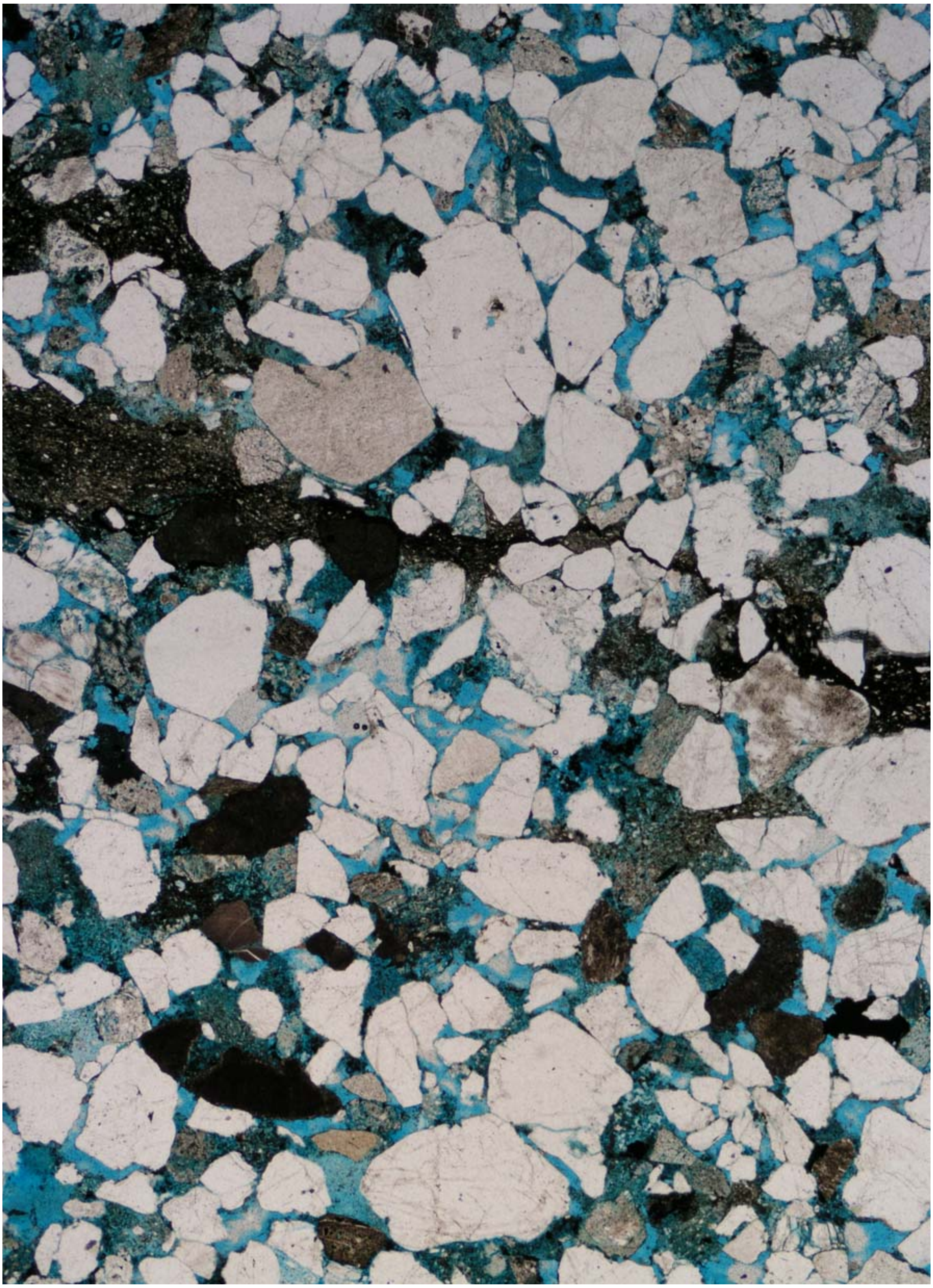

ENCLOSURE I : COMPOSITE LOG

ENCLOSURE II : STRUCTURE MAP

ENCLOSURE III : STRATIGRAPHIC CROSS SECTION

ENCLOSURE IV : LOG INTERPRETATION PLOT