

## THERMAL MODEL THEORIES

*Active aquifer* – one possibility is of the presence of an active aquifer system that has flushed the area post thermal maturity. This aquifer would have had to carry cold dense water from the outer basin through the Jarver-1 area cooling the strata and reducing the heat flow. This may be backed up by the presence of cementing in the Paaratte formation possibly caused from cooling and precipitation of siliceous cement from the aquifer fluids. Cold water may be flowing through as a result of dewatering of the outer basin. Alternatively the cold water may flow from higher up the sequence into the outer basin although there are several major faults and barriers to pass before reaching the Jarver-1 location.

*Rapid subsidence & deposition theory* – rapid subsidence (as seen in the Strahan sub basin at Cape Sorell-1 location) could possibly lead to the thermal lag as sediments are rapidly deposited faster than the isotherms are able to penetrate the strata. Although if this were likely, it would be expected to be seen at the Cape Sorell-1 location, which it is not. Rock typing of the Flaxmans Formation (appendix 4) suggests that the sediments were deposited in a deltaic environment where low energy fine grained sand and silt was interbedded with muds. The presence of mud suggests a quiet environment at time of deposition with little chance to rework the sediments. This may be one indicator to possible rapid subsidence.

*Inversion/subsidence theory* – another theory is that once deposited on the rift margin and heated, the strata was then exposed to a period of inversion & erosion. Although several erosive events have been observed to have occurred throughout geological time along this margin, it is not known if this was sufficient in elevation and duration to cool the strata enough. Following this period of inversion, a period of rapid subsidence would be required to bury the strata at a pace where the isotherms again would not be able to penetrate the strata at a rate to preserve the low geothermal gradient. The lack of structure at time of charge and late structuring suggests that this model is unlikely to be correct.

*Depth to Basement over time* – As previously noted, the primary heat pulse occurred within the Cretaceous with little to no regional heat pulses since. The surrounding wells have a relatively thick Wangerrip Group deposited over the Cretaceous sediment pile forming a potential thermal cap (Enclosure 1, figure 29). The area around Jarver-1 has a thin Wangerrip Group leaving it exposed to increased thermal decay over this period of time resulting in the lower temperatures seen at present day.

*Basement type* – it is possible that the underlying basement type may be resulting in high heat flows in certain areas and not in others. Clam, Whelk, and Cape Sorell have all higher heat flows recorded than Jarver. Clam encountered a Phyllite Basement while Whelk has an underlying basalt basement. Higher heat flows are likely to occur in granitic basement regimes. Jarver has one possible granitic side wall core sample taken at the base of the well in an interpreted conglomerate. This may indicate a reworking of a granitic basement nearby that is not present at the Jarver location. With the sparse well spacing, local variations may not be apparent on a regional scale. The low heat flow recorded at Jarver can not be extended far from the Jarver location due to it being the anomaly compared to the regional wells.

# Otway / Sorell Basin Elements

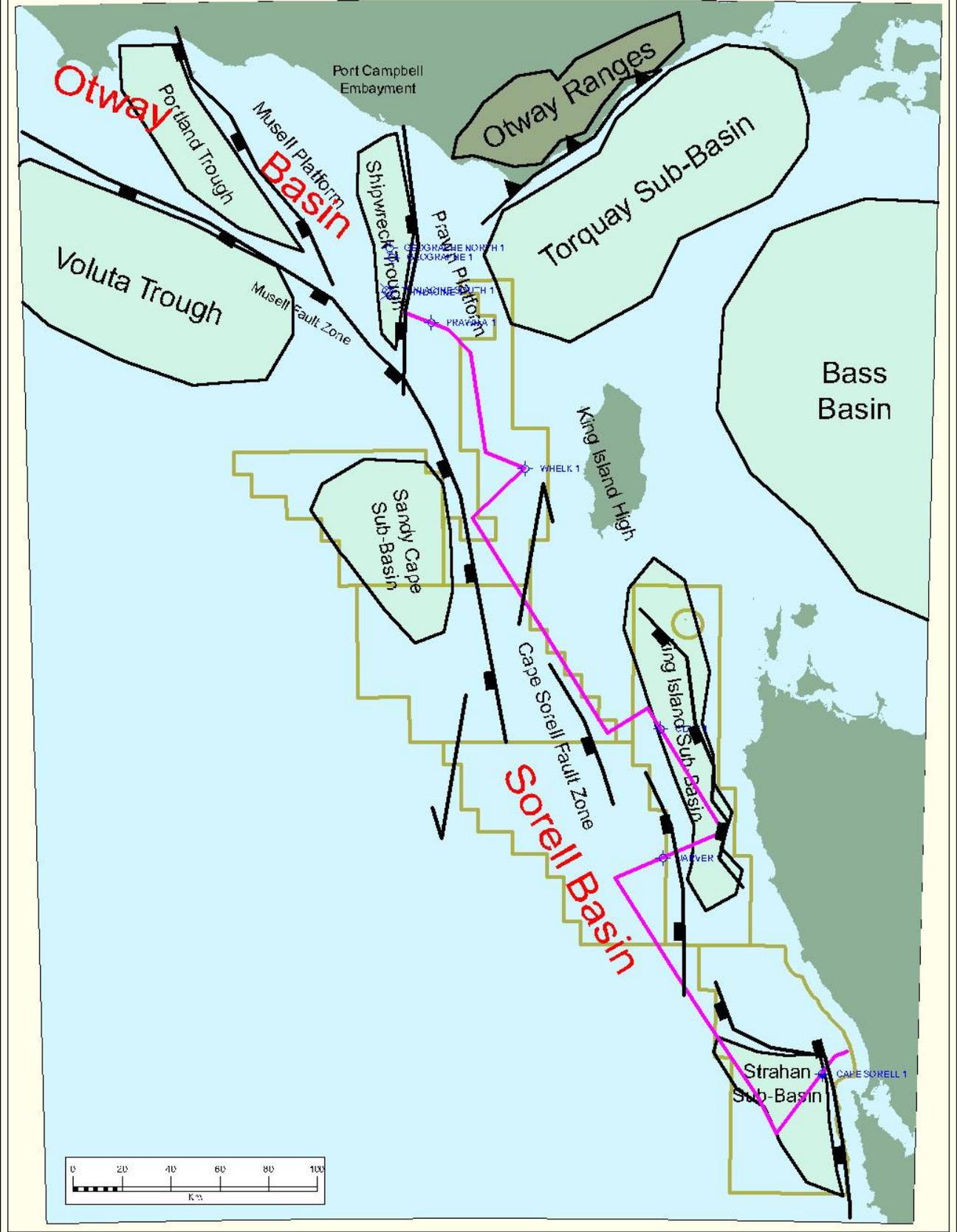


Figure 29 – Structural elements map showing the seismic traverse location (Enclosure 1)

## CONCLUSION

The anomalously low BHT recorded in Jarver-1 lead to the re-modelling of the geothermal gradient & heat flow at the Jarver-1 location. This geothermal model was then used to re-model the surrounding area using seismic interpretation to create pseudo wells with interpreted lithological columns for specific locations. The results from modelling indicate that the interpreted source pod is less mature and less extensive than pre-drill models. This assumes that the seismic amplitudes that are being interpreted as source rock is in fact source rock.

If the source pod does exist in the area, a risk remains for future exploration of timing of expulsion and presence of trap over time. The primary phase of hydrocarbon expulsion was in the late Cretaceous. This requires the presence of a structure at this time, and the preservation of that structure through to present day. Although some of the pseudo wells modelled indicated expulsion of hydrocarbons through to present day the risk remains that the anomalies mapped as hydrocarbons lie at the top of the Eumeralla formation which in many cases has not yet entered the expulsion window. Many models predict possible expulsion from the base of the Eumeralla formation, but not the top. Unfortunately, due to the lack of seismic amplitudes at the base, the base has little interpreted, or reduced source potential.

\*a note on pseudo well names. The name was attributed to the pseudo well when it was 1<sup>st</sup> modelled by model number and year, i.e. the 5<sup>th</sup> model run in the year 2004 would be attributed the pseudo well name Psw\_045, and the 16<sup>th</sup> pseudo well modelled in 2005 would be named PsW\_0516. When a pseudo well was re-modelled, the old pseudo well integers become the suffix, and the current model & year become the new well name, i.e. pseudo well PsW\_045 that was the 5<sup>th</sup> pseudo well re-modelled in 2008 would become PsW\_085\_045.

## **Jarver-1 Clay Mineralogy by XRD Analysis, 1980 – 3054m KB**

Claire Behan, Nick Lemon, July 2008

### **Introduction**

The bottom hole temperature determined for Jarver 1 was 74<sup>0</sup>C at a depth of 3062m, a value that was unexpectedly cold. XRD analysis of the clays from ditch cutting samples selected at intervals between 1980 – 3054m was used as one way to add to the understanding of the thermal history of the area.

### **Method**

The cuttings samples from Jarver 1 were collected at 6m intervals, from which 7 were chosen for XRD analysis from 1980m, 1998m, 2016m, 2304m, 2604m, 2904m, and 3054m representing the Timboon Fm, Paaratte Gp, Intra-Paaratte Gp, Belfast Shale and near basement.

The samples were prepared by gently washing off the drilling mud, gentle grinding in a mortar and pestle to liberate the clay, adding water and the sample shaken, from which the suspended clay and other fines were decanted into a vial and allowed to settle. After removing excess water, the clay sample was further ground, the resulting slurry spread onto a glass slide. This process concentrates the clays but does not remove all rushed sand particles, leaving quartz in particular in the sample as a reference peak.

In order to enhance the smectite-illite XRD peaks, the remaining sample was saturated with a strong (1M) MgCl solution, and rinsed several times before a sample was smeared on a glass disk. All slides were sent to the Amdel XRD laboratory for analysis. Scans from 5 to 40 degrees 2 theta at 0.08 degree increments were requested to assess the bulk mineralogy of the samples. Additionally, the MgCl-treated samples were re-analysed after the swelling clays were expanded with glycerol. The resulting scan files were printed and peaks picked by reference to published mineral peak positions (Hardy and Tucker, in Tucker 1988). Percentages of minerals were estimated by comparing peaks heights and using approximate relative ratios between the key peaks of the minerals present.

### **Results**

The main mineral present is quartz, despite the attempts to concentrate the clays

Illite-muscovite is the most abundant clay (>50%) in the majority of samples, except 2604m and 2904m (25% & 35% respectively).

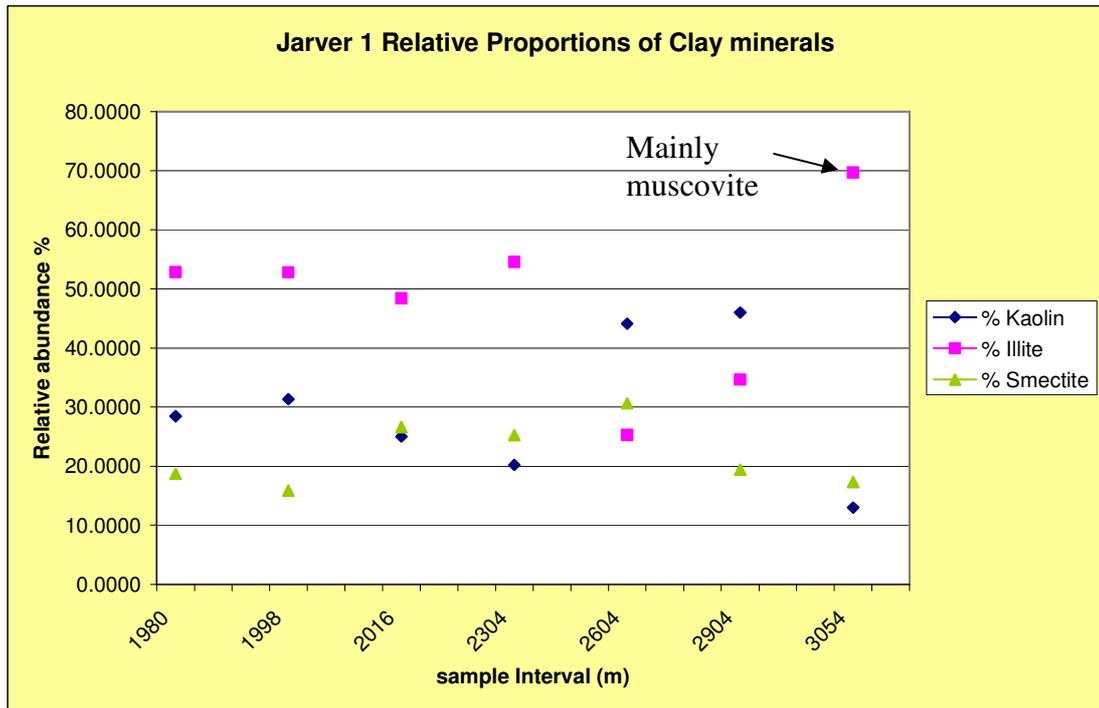
Kaolin occurs in all samples, at approximately 20-32% abundance, except for 2604m and 2904m depths where it is at 44-46%.

Smectite occurs in all samples at 15 – 30% abundance.

Feldspar, in the form of albite and orthoclase is more abundant in the sample at 1998m (Paaratte Gp sandstone) but occurs in all samples.

Siderite is present in all samples, decreasing in proportion with depth.

The near basement sample has 70% illite-muscovite, with less than 18% smectite and 13% kaolin, a markedly different distribution to the Cretaceous samples. Thin section petrology at this depth shows the key mineral is muscovite, not illite.

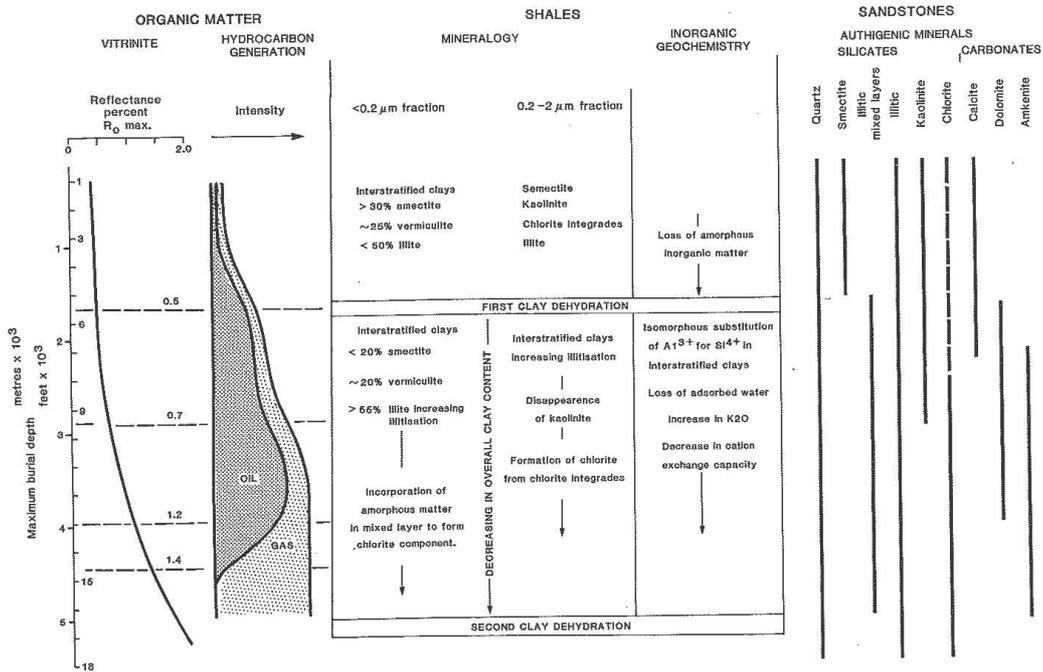


## Interpretation of results

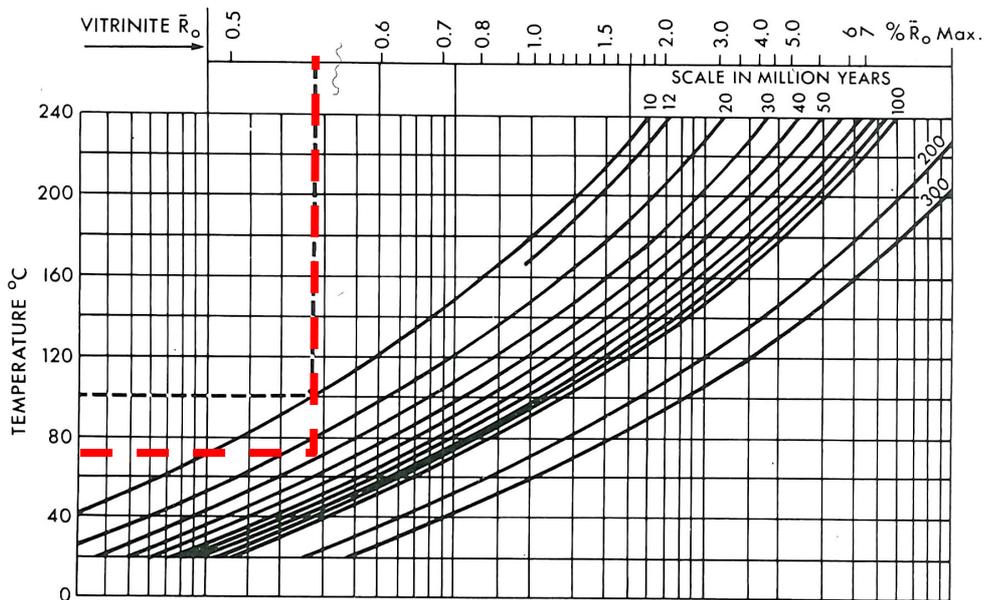
The occurrence and relative proportions of clay minerals in these samples can be used as an indication only of maximum burial depth. Comparing Jarver 1 results to Foscolos (1990) paper on of clay catagenesis and organic matter diagenesis, (Fig 1) the relatively high illite / low smectite abundance, and continued kaolin presence places the Jarver 1 clays at, or just below the First Clay Dehydration demarcation and on the boundary of the early phase of hydrocarbon generation.

The higher proportion of kaolin in the 2604m and 2904m samples can be attributed to feldspar dissolution and precipitation as kaolin pore-filling cements adding to the total. The illite concentration at 3054m is misleading as much of that is in fact muscovite, included in the sediment at the time of deposition and not a function of smectite conversion.

As the bulk mineralogy is somewhat equivocal in this well, more information can be gleaned from the nature of the smectite itself, the degree of illite interlayers indicated by the peak position and the amount of swelling character remaining as determined by the shift in the peak position during glycerol treatment. This is addressed in the discussion section below.

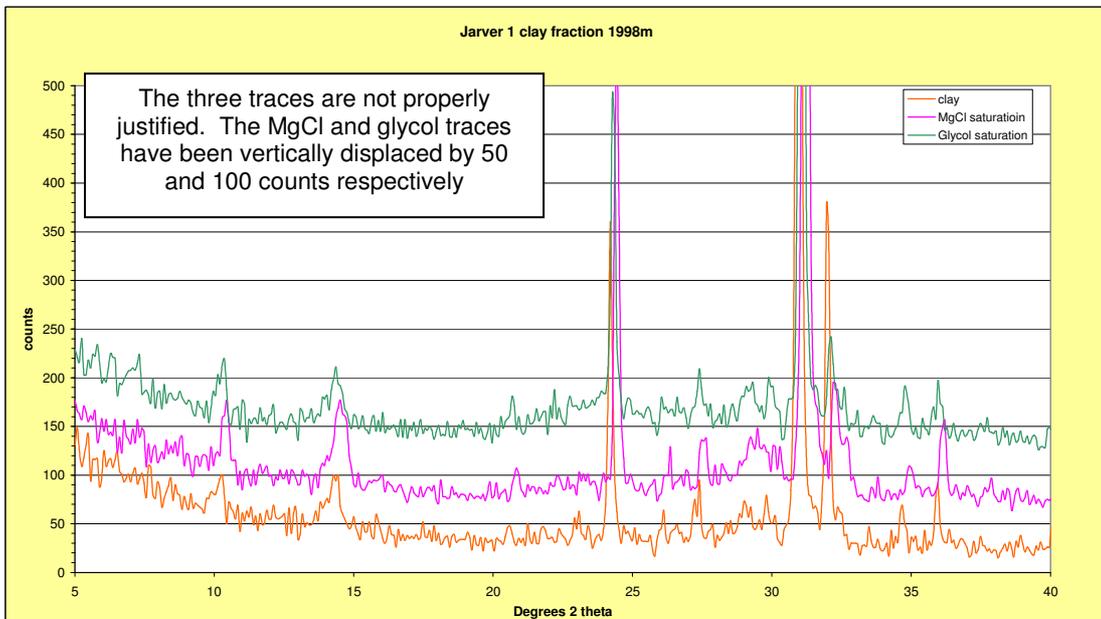
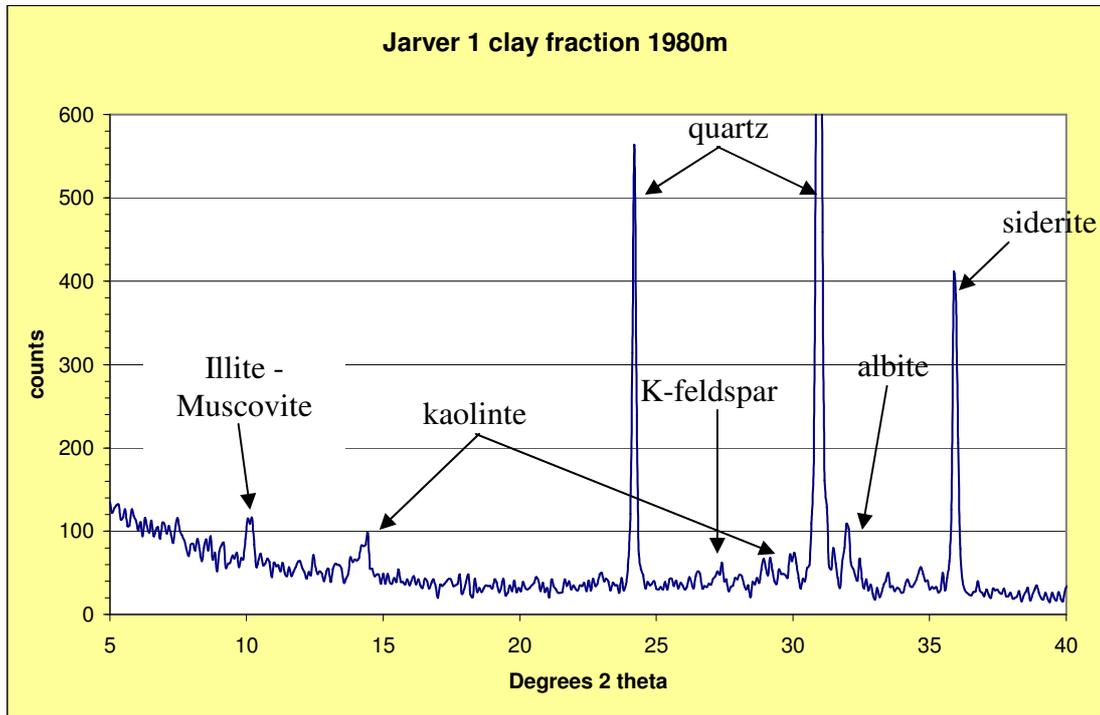


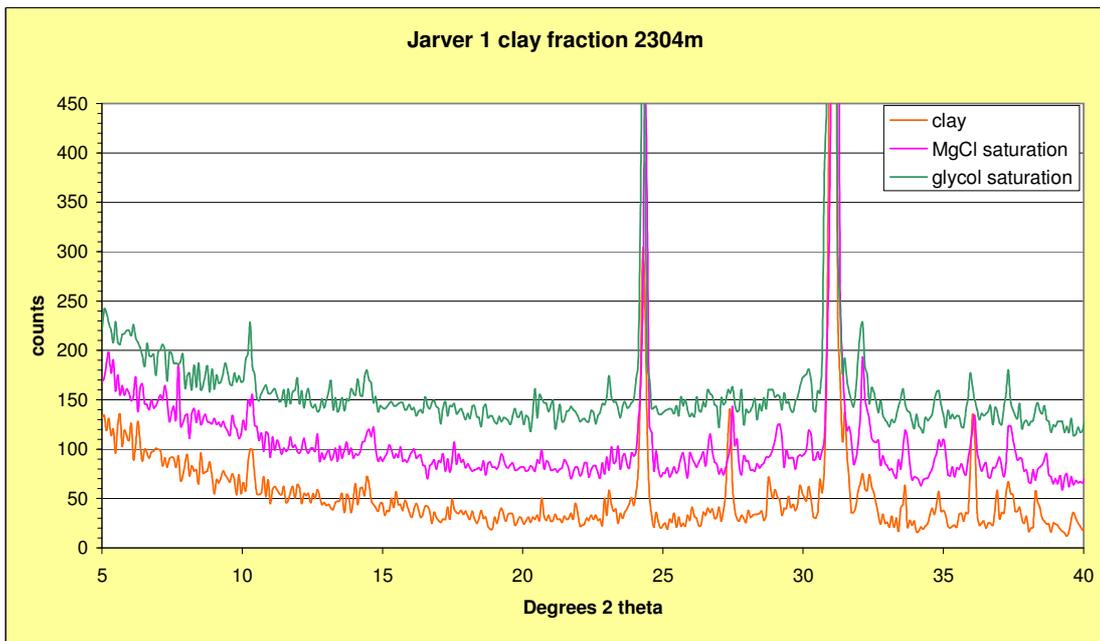
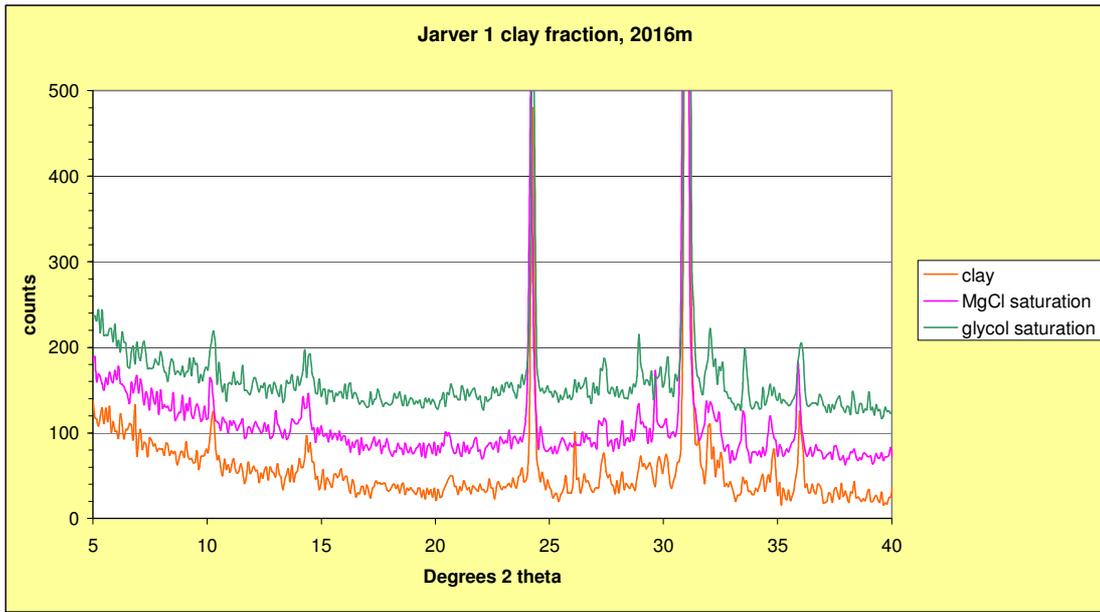
**Figure 1.** from Foscolos, A.E. 1979. - Relationship between diagenesis (catagenesis) of shales and the occurrence of authigenic minerals in sandstones

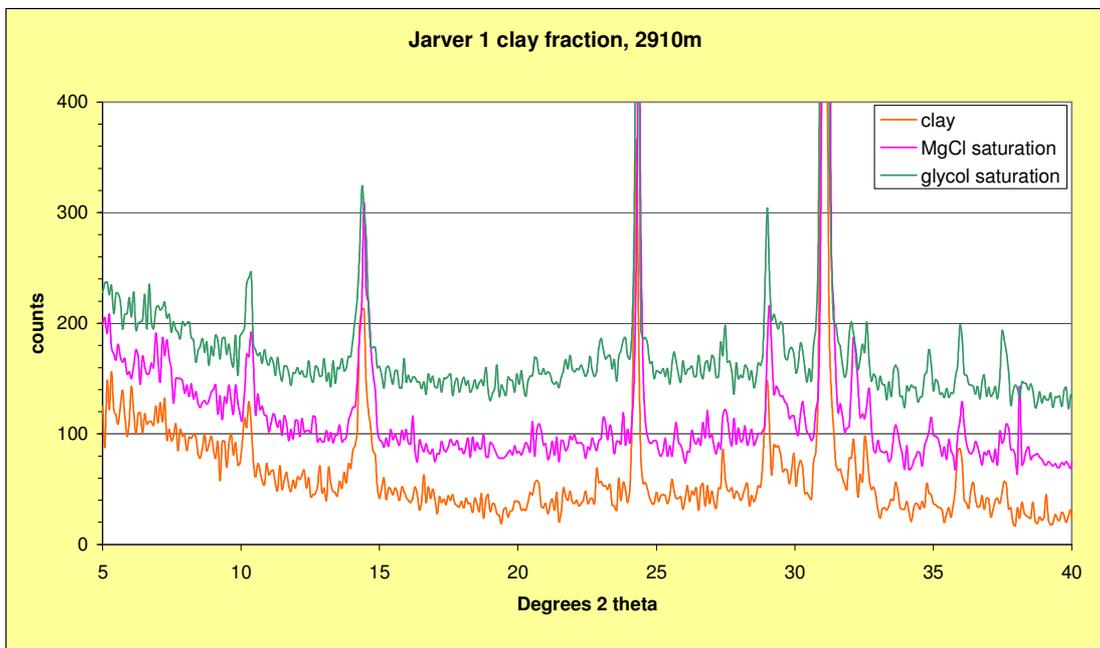
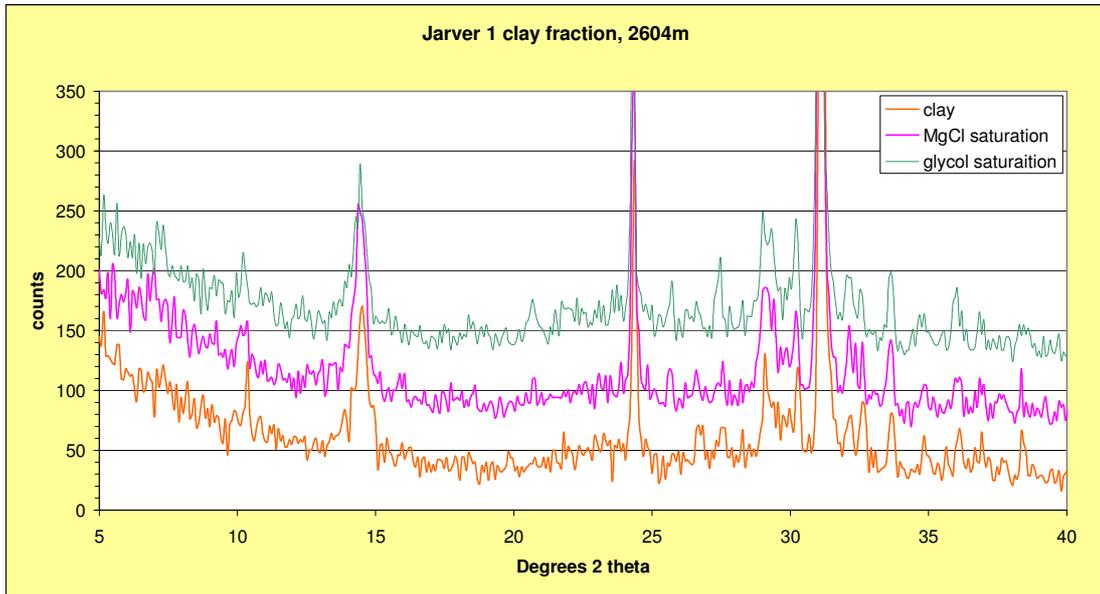


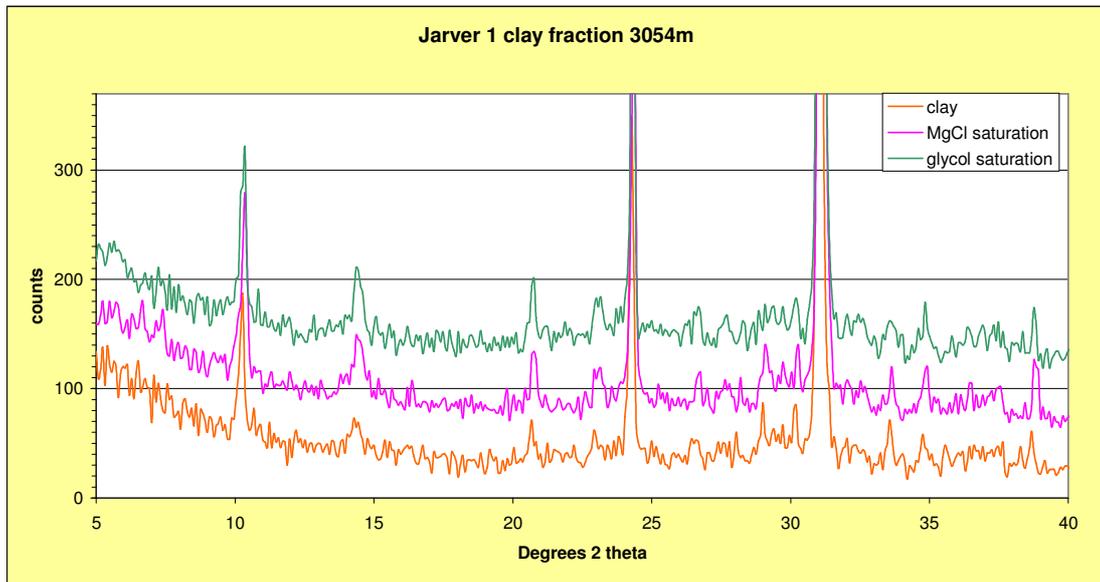
**Figure 2.** Correlation between Temperature, time and level of organic diagenesis (from Bustin, Barnes and Barnes, 1990). The red dashed line shows that the bottom hole temperature in Jarver 1 and the level of diagenesis indicated by the clay mineralogy suggests the sediments should have been exposed to that temperature for 30 million years.

**XRD plots from each sample depth:**









## Discussion

The sample preparation technique was a compromise between a pure clay separate and a whole rock analysis. As it happened, the whole rock components could be seen well but definition of the clays, particularly the smectites, was compromised. Smectites should report around 7 degrees but the peaks here on the traces above are very diffuse. Mg saturation has sharpened the smectite peak a little, although the proportion in each sample is low. The Mg-saturated sample gives the best results for determination of the relative proportions of the various clays in each sample. Well crystallized muscovite produces a sharp peak in exactly the same position (10 degrees) as illite, making interpretation of the relative proportion of muscovite and illite very difficult. Some distinction is afforded the sharpness of the muscovite peak with respect to the broader, more diffuse illite peak and its tendency to be asymmetric towards 9 degrees.

Pure smectite, as indicated by a Mg-saturated peak at  $14\text{\AA}^0$  (7.4 degrees 2 theta) with expansion to  $17\text{\AA}^0$  or  $18\text{\AA}^0$  (5-6 degrees 2 theta), occurs in samples from all the sampled depths in Jarver 1. There is some conversion of smectite to illite in the sample from 2604m (illite-smectite at  $13\text{\AA}^0$  with expansion to  $14\text{\AA}^0$ ). The conversion of some of the smectite to illite is more complete in the near-basement sample at 3054m where a peak at  $10.81\text{\AA}^0$ , very close to the 10 degree illite peak, only expands as far as  $11.67\text{\AA}^0$  upon glycerol treatment.

The sample from 2604m has just entered the first clay dehydration zone at vitrinite reflectance 0.5. The sample from 3054m shows illite conversion and a loss of adsorbed water and swelling capacity, thought to be around a vitrinite reflectance of 0.6. Assuming that clays convert at similar rates as organic matter, a sediment would need to be at a temperature of  $74^{\circ}\text{C}$  for 40 million years to achieve this level of alteration (see Figure 2 above). A similar level of conversion could be achieved in a shorter time if the temperature were raised; for example 15 Ma at  $100^{\circ}\text{C}$ . The degree of clay conversion observed infers that at least the lower half of the succession intersected in Jarver 1 has seen higher temperatures in the past.

## REFERENCES

- Bustin, R.M., Barnes, M.A. and Barnes, W.C., 1990. Determining levels of organic diagenesis in sediments and fossil fuels. In McIlreath, I.A. and Morrow, D.W., 1990. Diagenesis: *Geoscience Canada Reprint Series 4*.
- Foscolos, A.E., 1990. Catagenesis of Argillaceous Sedimentary Rocks; In McIlreath, I.A. and Morrow, D.W., 1990. Diagenesis: *Geoscience Canada Reprint Series 4*.
- Hardy, R and Tucker M.E., 1988. X-ray powder diffraction of sediments. In: Tucker, M.E., 1988. Techniques in Sedimentology, *Blackwell Scientific Publications*.

## Jarver 1 – petrology of selected cuttings and sidewall core samples

### Introduction

Jarver 1, a wildcat well drilled off the west coast of Tasmania, tested an area where the geology was at best inferred from seismic correlations from distant wells. Several cuttings samples and one sidewall core were gently washed to remove drilling mud then prepared as thin sections to gain some insight into the lithologies at the chosen levels, in particular the basement interpreted at the time of drilling. During washing of the samples, well rounded, even slightly polished, red grains were commonly observed at the level thought to be basement. A possible interpretation on this is that the last few samples in the hole are of a basal conglomerate composed of basement lithologies, rather than basement itself.

In addition to the samples chosen for thin section analysis a group of samples were sent for XRD (X-ray diffraction) analysis. The XRD was primarily to look at clay mineralogy to assist with the interpretation of the thermal history of the area but it also assist with lithology determination.

**Table 1.** Samples chosen for thin section and XRD (indicated by colour blocks)

Sample interval	Thin section	X-ray diffraction
2016-22m		
2234-40m		
2304-10m		
2386-94m		
2604-10m		
2910-14m		
3018-24m		
SWC 30		
3054-60m		

### Summary

A few samples were selected from Jarver 1, principally to define the nature of the lithologies intersected at the base of the well. The samples also spanned other intervals where the mudlogs suggested sand might be present. The thin section petrology was done in conjunction with XRD mineralogy that was done to assist with determination of the thermal history of this well (in a separate report).

The intersections at the base of the well were thought, at the time of drilling, to be basement. Subsequent close examination of the cuttings and in particular SWC 30, shows the interval near the Total Depth of the well is a conglomeratic section, probably immediately above basement. The interpretation of coarse sediment comes from rounded red chert grains seen in washed cuttings and rounded grains of chert, fault quartz and meta-sandstone in a muddy matrix seen in thin sections of cuttings and a sidewall sample.

The basement appears to be a metamorphic complex composed of cherty devitrified volcanics, foliated meta-sandstone and meta-siltstone. There is evidence that it is cut by common veins of hydrothermal quartz.

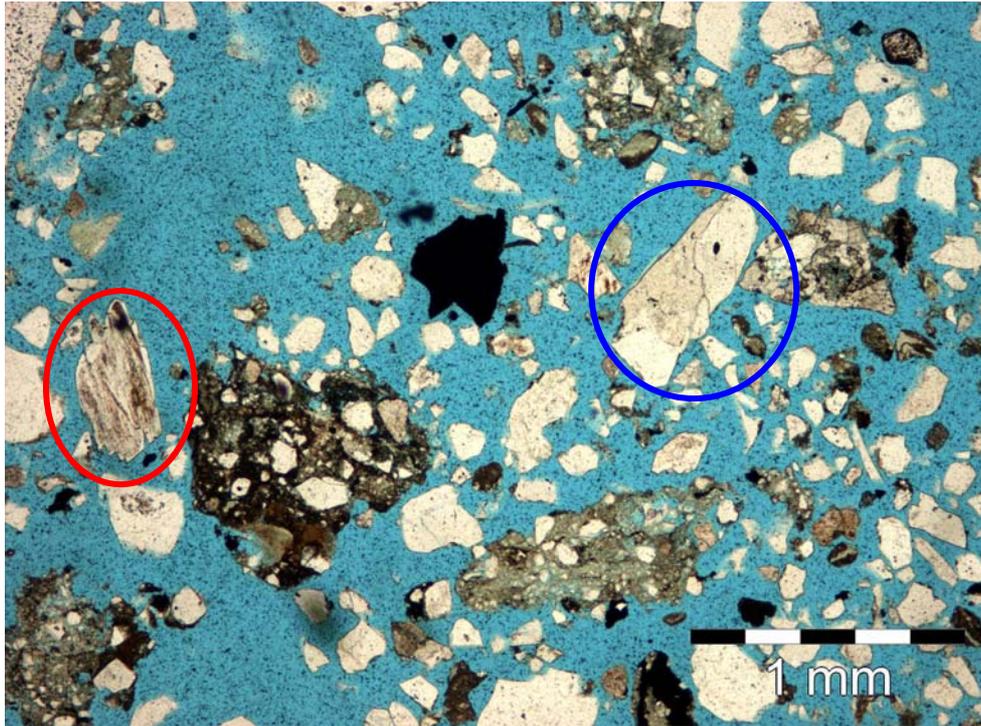
These same basement lithologies appear as lithic fragments in some of the sandstones in the succession above, at least up to 3018 metres. These are accompanied by common quartz grains of metamorphic origin. Above this the sands become more feldspathic with less chert and a change to basaltic fragments. Potassic feldspars are more common than plagioclase in the highest sample included in the thin section suite, that from 2234 – 40m. Quartz grains of igneous origin as opposed to metamorphic origin accompany the potassic feldspars. This indicates a change in provenance from a metamorphic terrain to a granitic terrain from the base to the top of the suite analysed.

## **Thin Section Descriptions**

### **2234-40m, washed cuttings**

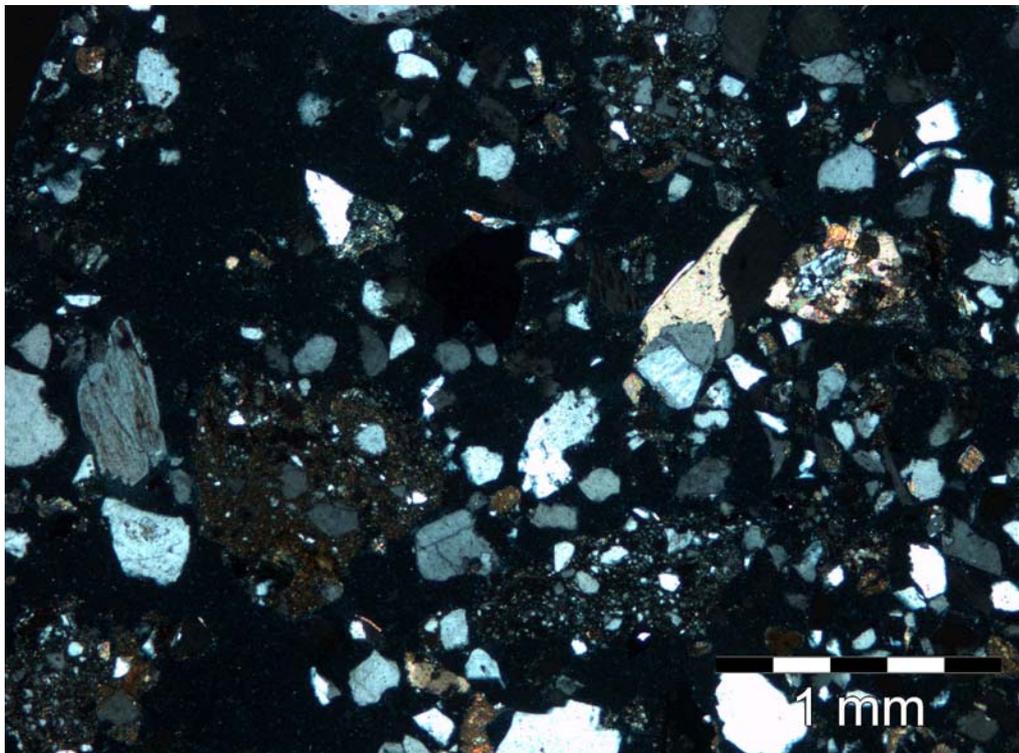
The majority of the cuttings from this interval depict a very fine to medium sand-sized feldsarenite (arkose). The sediment is texturally immature, with poor to moderate sorting and angular to sub-angular grains. Potassic feldspars are also common, often with adularia (low temperature feldspar) overgrowths. Chert is common amongst the siliceous grains. Calcite is the main cement with some early siderite and minor quartz overgrowths. There is likely to still be fair porosity in this interval as much of the sediment disaggregates into single grains. Carbonate cements some clusters of grains but primary pores still occur within these clusters.

Less common amongst the cuttings are grain clusters held by matrix and chips of siltstone.



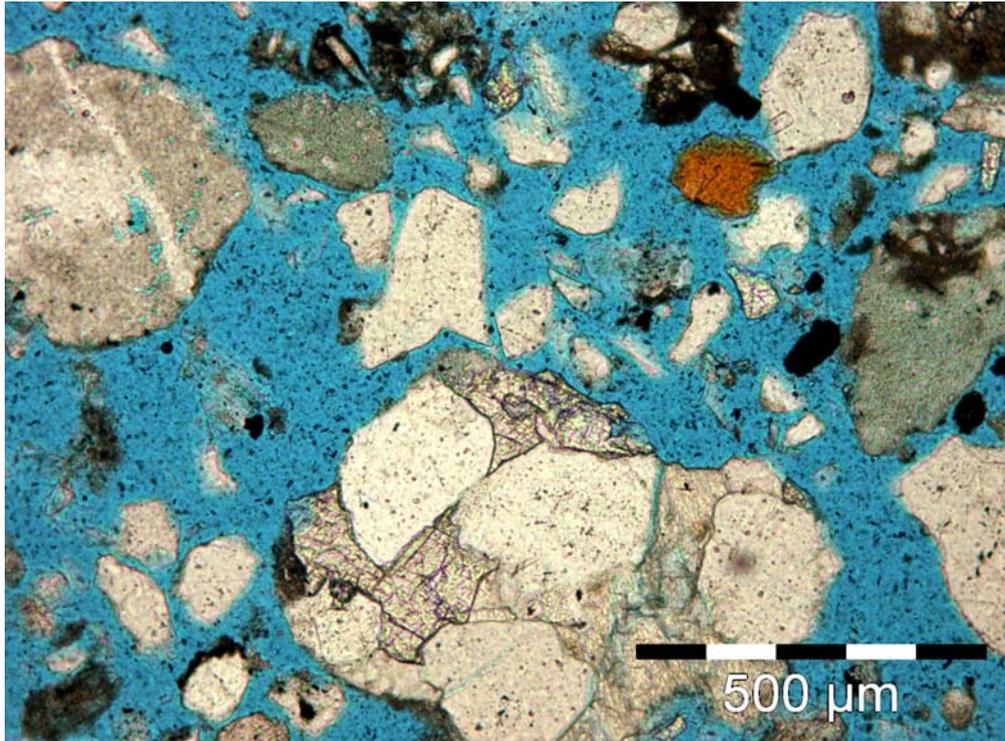
**Figure 1A. Jarver 1, 2234-40m.**

Drill cuttings, single grains and clusters of grains, dispersed in blue resin. A partially altered K feldspar (red circle) has a clear adularia rim. The large dark cluster at left centre is matrix rich. The group of grains in the blue circle has calcite cement.



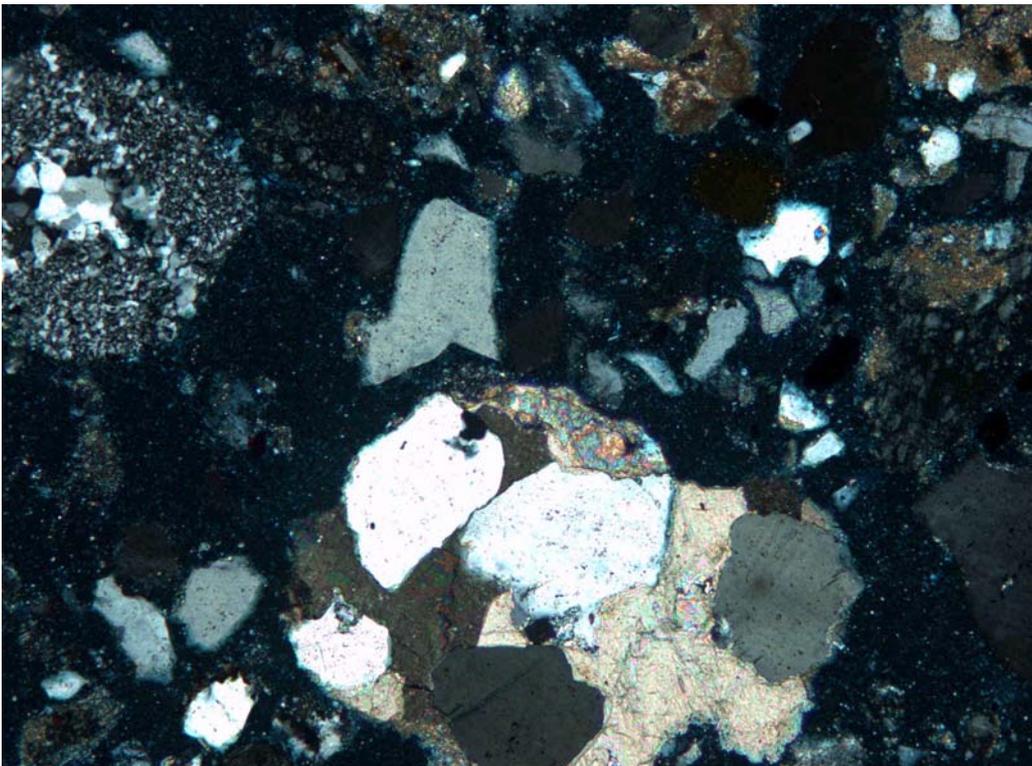
**Figure 1B. Jarver 1, 2234-40m.**

The same field of view as Fig. 1A under crossed polars shows the bright yellows of carbonate cement on some grains and the textured patterns of feldspars over many grains. Most of the clear quartz grains in Fig. 1A show low-strain, indicating an igneous origin.



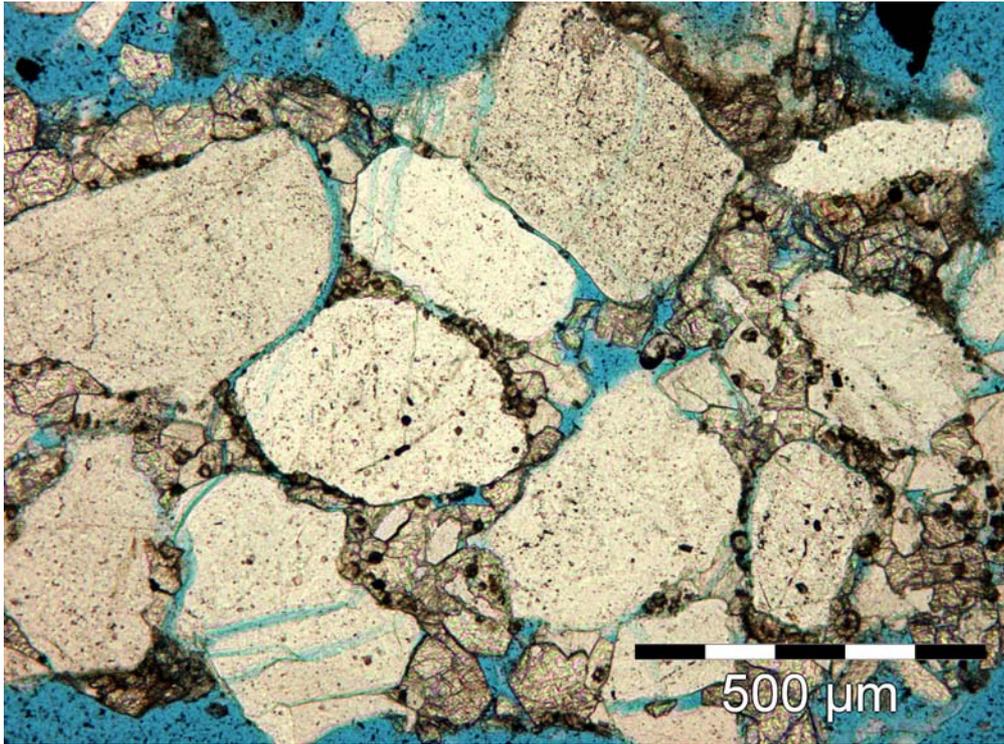
**Figure 2A. Jarver 1, 2234-40m.**

The grain cluster at bottom centre is tightly cemented with calcite.



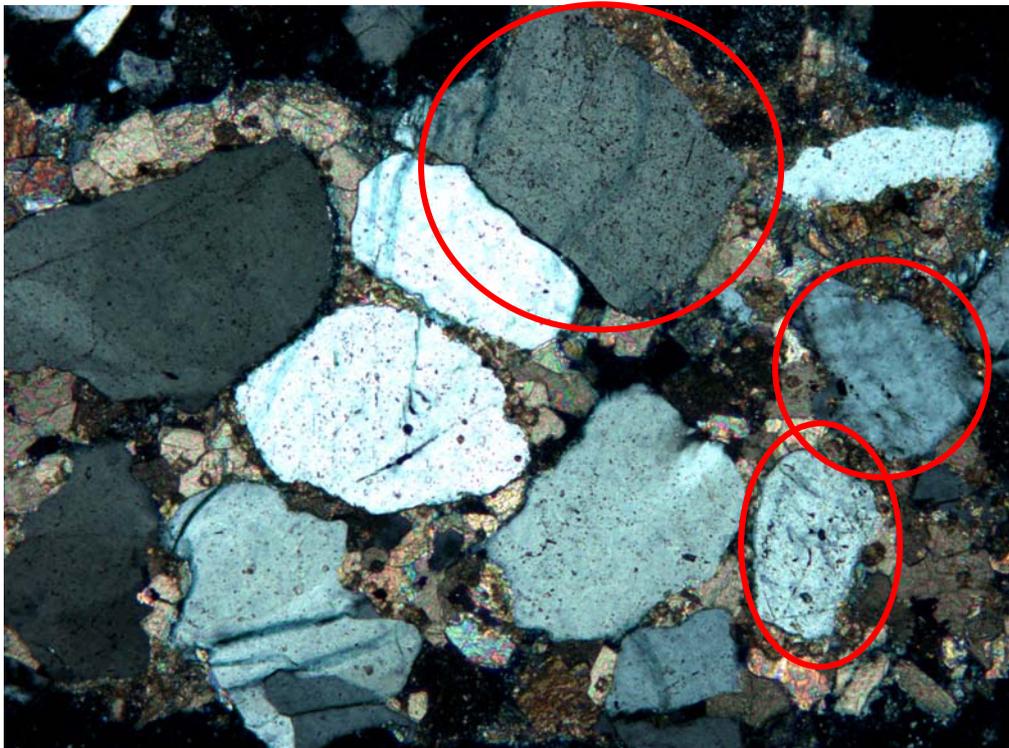
**Figure 2B. Jarver 1, 2234-40m.**

The same field of view as Fig 2A under crossed polars shows the grain at upper left is chert, cut by a chert vein. This is likely to be a devitrified siliceous volcanic grain.



**Figure 3A. Jarver 1, 2234-40m.**

Two stages of carbonate cement this cluster – early, dark, rounded siderite crystals are overlain by larger clear calcite crystals. Primary porosity still remains between the calcite cement



**Figure 3B. Jarver 1, 2234-40m.**

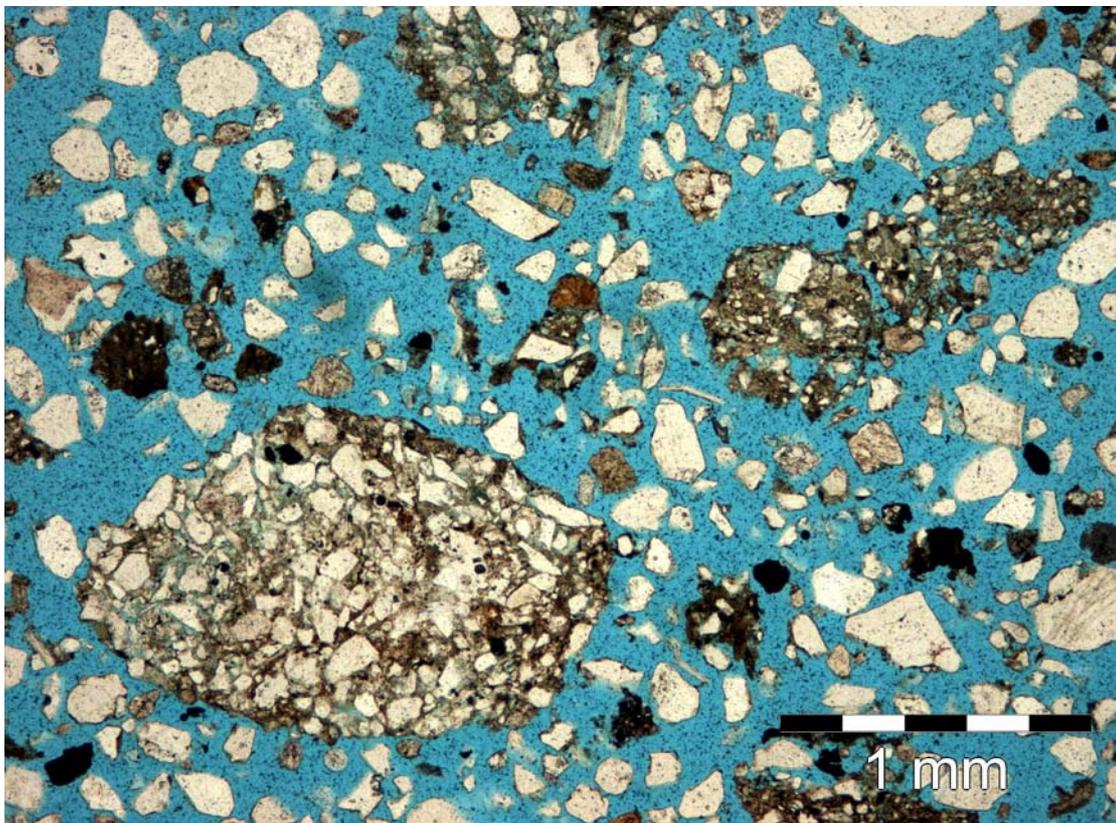
The same field of view as Fig 3A under crossed polars confirms the carbonate mineralogy of the cements. The framework grains circled in red are feldspars. All the quartz grains are low-strain igneous types.

### Jarver 1, 2386 - 94m, washed cuttings

The mixture of cuttings from this interval can be interpreted as a silty very fine to fine grained feldsarenite interbedded with a medium to coarse grained lithic feldsarenite. Most of the quartz grains at this level are highly strained metamorphic types. The lithic grains include basaltic clasts, complete with an ophitic texture of plagioclase laths in a matrix of pyroxene and possible olivine and amphibole, now partly altered to chlorite.

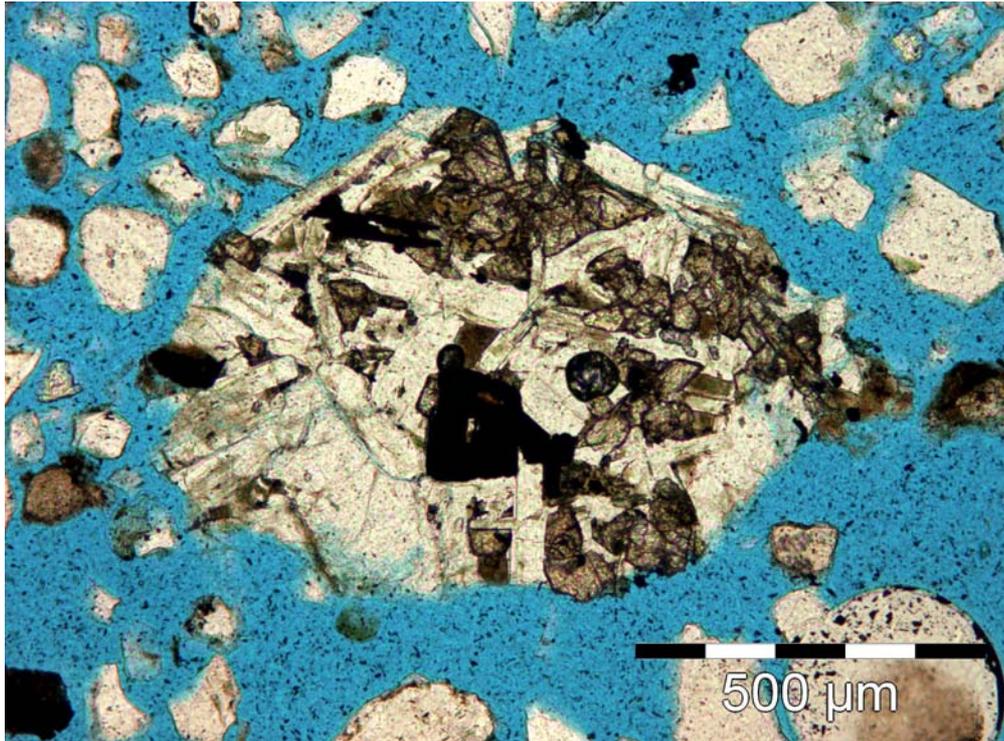
There is little cement as most of the cuttings are individual liberated single grains. There is some carbonate cement and carbonate (calcite?) replacement of feldspar in the coarser sands.

The finer sediments are high in depositional matrix with muscovite flakes and replacive pyrite cement. Glaucony occurs as both a cement and an alteration product of feldspar and mica.



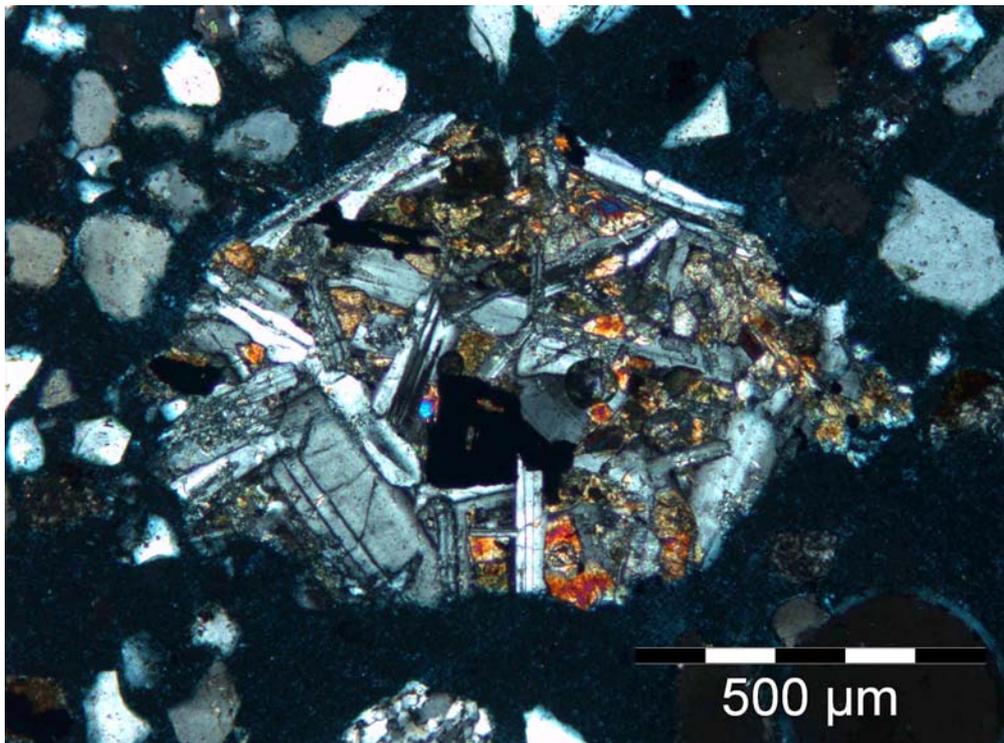
**Figure 4. Jarver 1, 2386 - 94m**

Much of this sample comprises single liberated grains. The large cluster at lower left is a fine sandstone held together by matrix. The two other diffuse groupings are loose grains in drill mud.



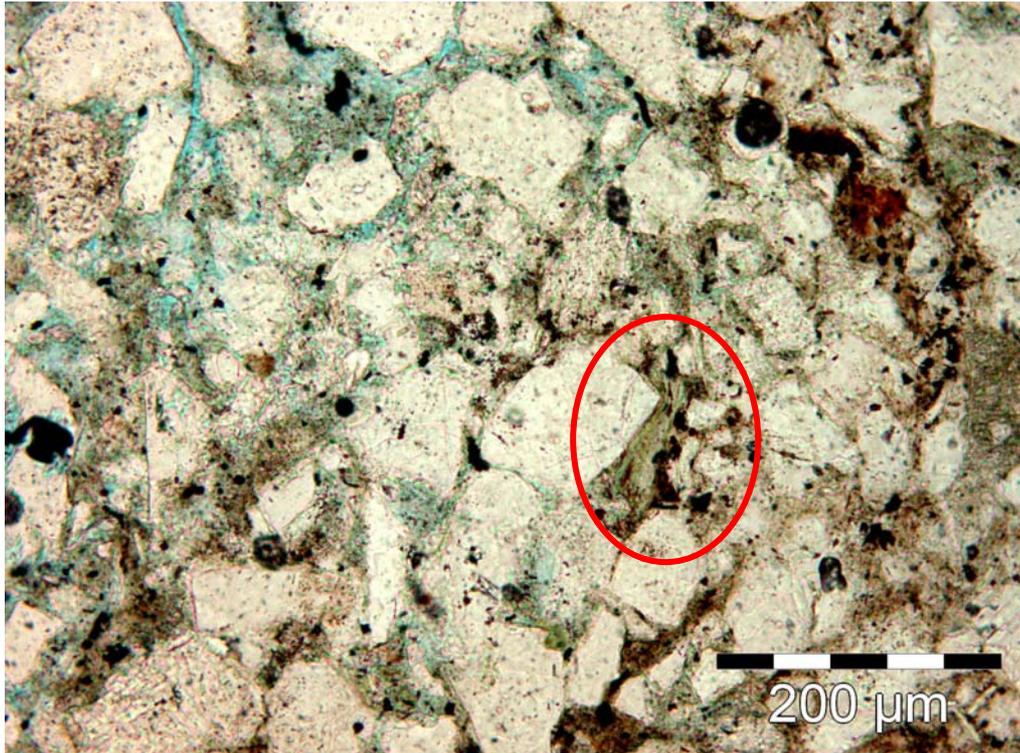
**Figure 5A. Jarver 1, 2386 - 94m**

A basalt rock fragment from one of the coarser interbeds in this interval.



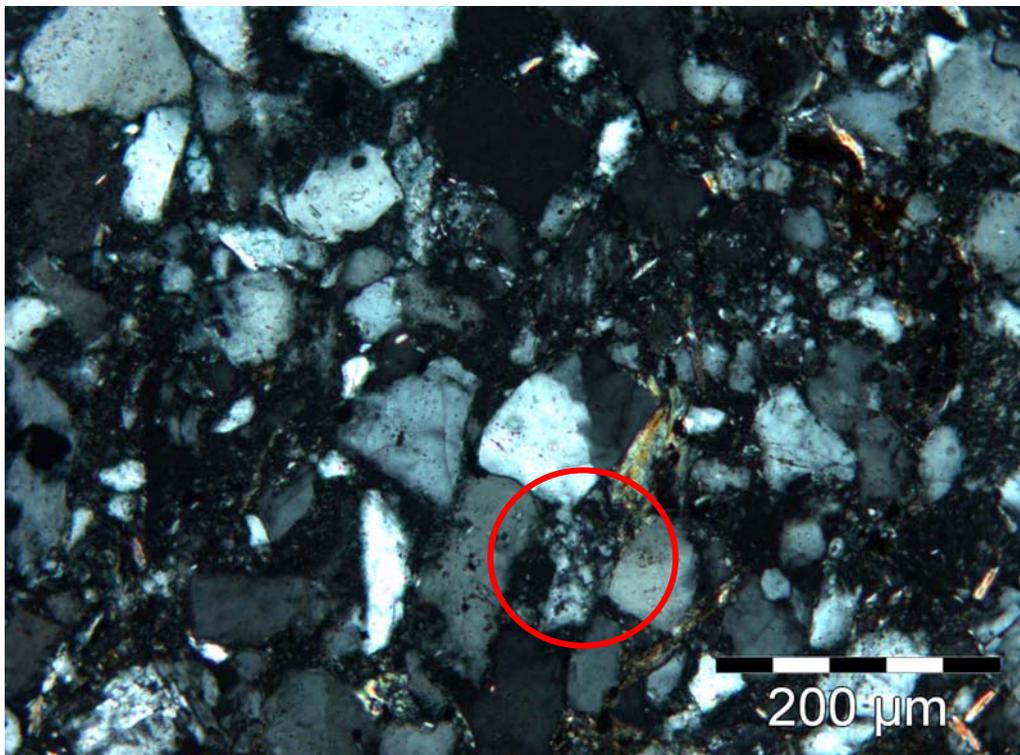
**Figure 5B. Jarver 1, 2386 - 94m**

The same field of view as Fig. 5A under crossed polars shows the distinctive twinned laths of plagioclase surrounded by brightly coloured mafic minerals, pyroxene and possibly olivine. The surrounding single grains are strained metamorphic quartzes.



**Figure 6A. Jarver 1, 2386 - 94m**

Matrix-rich fine sandstone. The porosity in blue is probably drilling induced, the grain cluster has partially broken apart. The red circle focuses on a mica altered to glaucony. The green cast to the whole image is related to glaucony, as a cement and as alteration of matrix.



**Figure 6B. Jarver 1, 2386 - 94m**

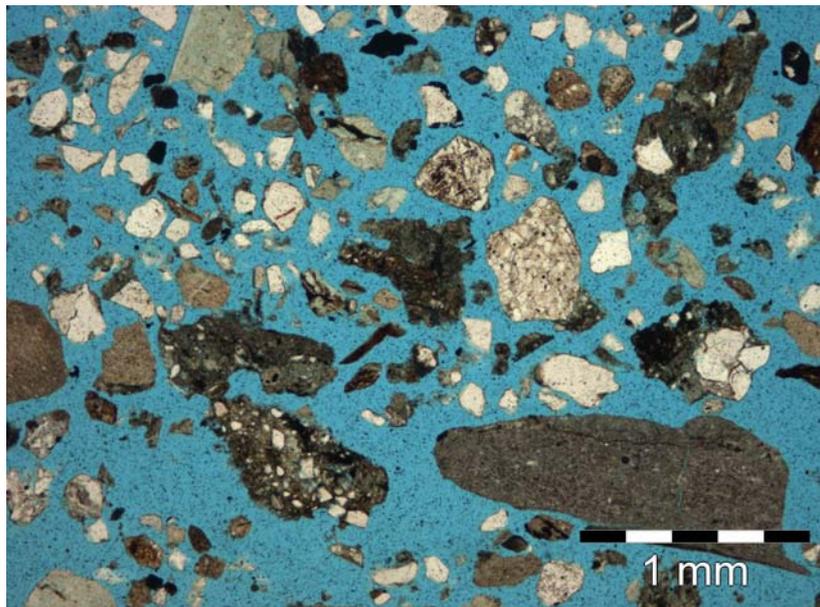
The same field of view as Fig. 6A under crossed polars shows many of the quartz grains have strain shadows, indicating a metamorphic origin. The grey speckled grains like that circled are chert.

### Jarver 1, 3018 – 24m, washed cuttings

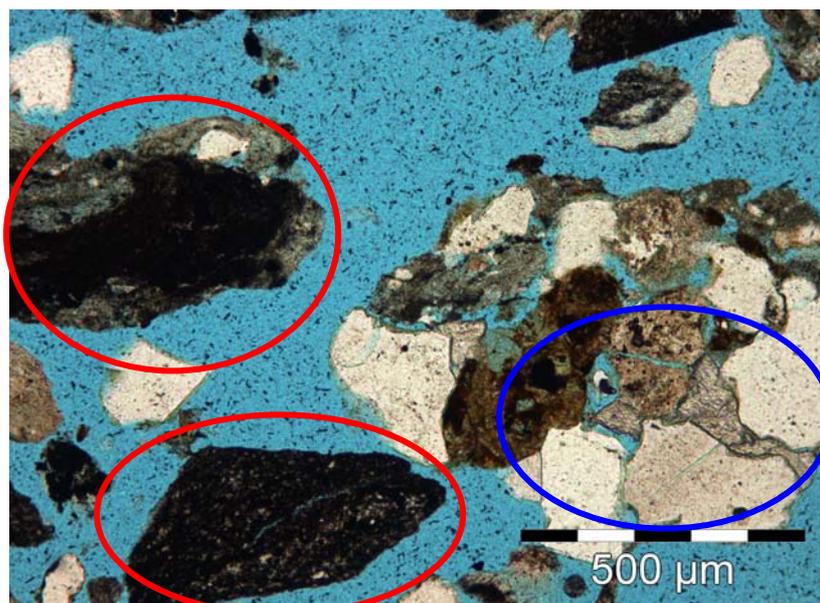
This sample displays a range of lithologies including shale, siltstone and lithic sandstone. There are a number of individual grains including metamorphic quartz, chert and minor feldspar. The lithic component comprises foliated meta-sandstone with muscovite flakes.

The shales are darkened with dispersed organic matter and some have been almost completely replaced by siderite. There is calcite cement in the sandstones and siderite and pyrite cement in the shales.

The chert grains show multiple growth stages, cut by numerous veins of chert. There are possible volcanic textures in the chert.



**Figure 7, Jarver 1, 3018 – 24m.** Mix of lithologies in the cuttings



**Figure 8, Jarver 1, 3018 – 24m.** Siderite cement in shales (red circles) and calcite cement in sandstone (blue circle)

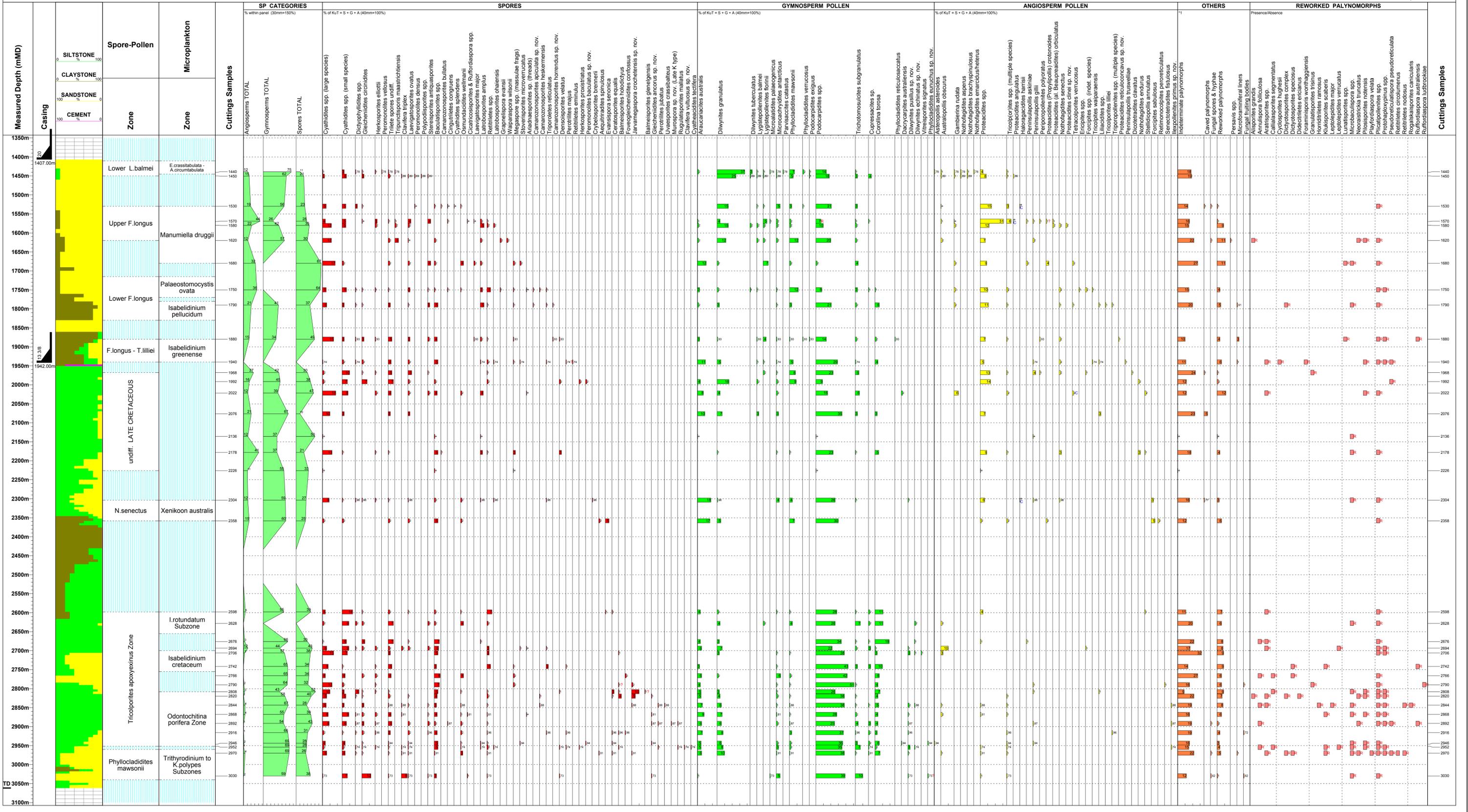
**Well Name : Jarver-1**

Operator : Santos Ltd Spudded : 16 May 2008  
 Well Code : JARVER-1 Completed : 18 June 2008  
 Lat/Long : 41°20' 27.25"S 144°14' 3.19"E  
 Interval : 1350m - 3100m INTERPRETATIVE Spore-Pollen Range Chart  
 Scale : 1:5000 Sample interval 1440 to 3030m  
 Chart date : 21 October 2008 Microscope analysis by Alan D. Partridge

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Attachment to Biostrata Reports 2008/06A



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