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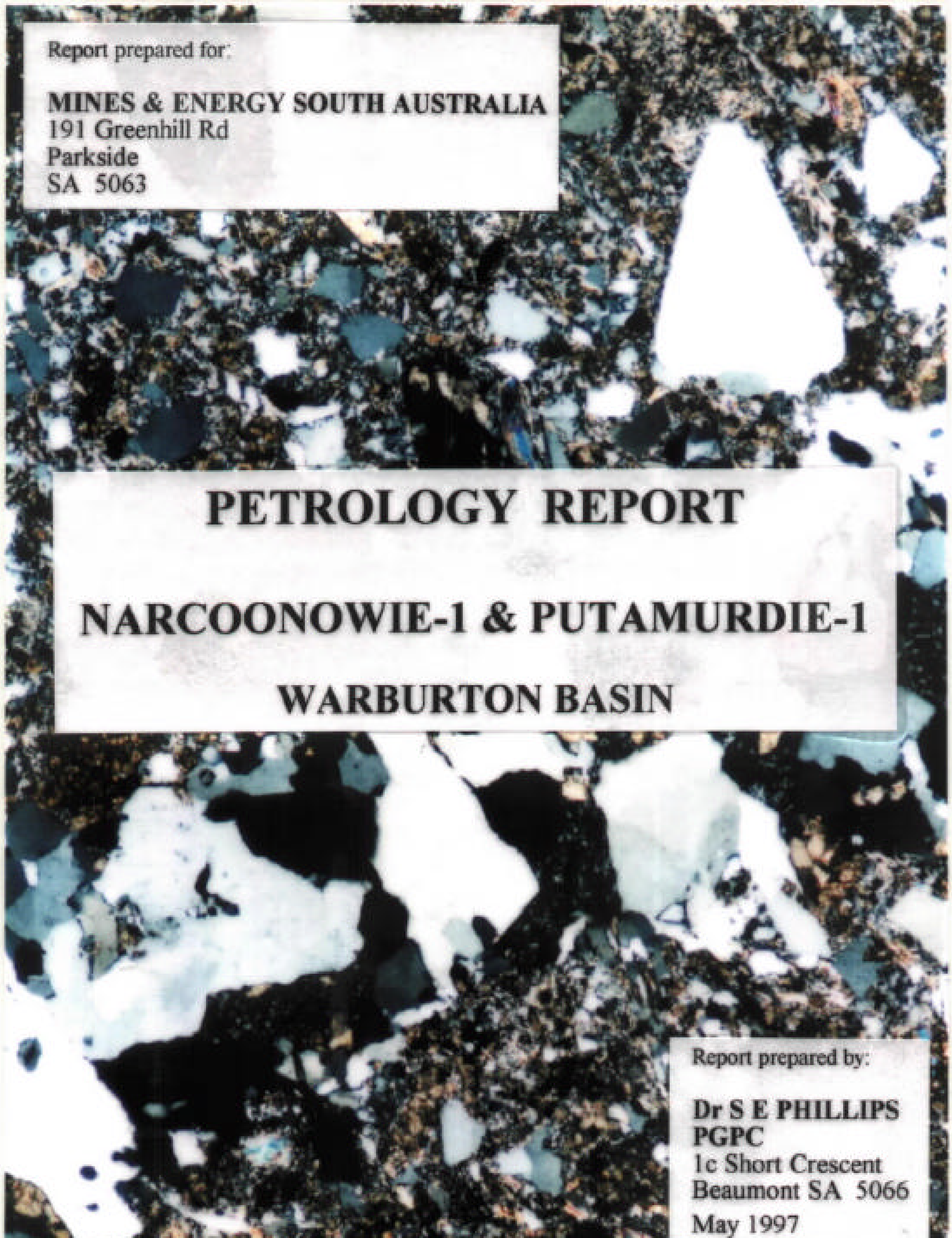

Report prepared for:

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PETROLOGY REPORT

NARCOONOWIE-1 & PUTAMURDIE-1

WARBURTON BASIN

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Front cover:
A fracture filled with polycrystalline quartz, kaolin and minor carbonate spar cross cuts the orientation of bedding/foliation in this greywacke. Thin section photomicrograph of Narcoonowie-1, core 1, depth 6110 ft. Crossed nicols. Horizontal field of view 3.37mm.

1. INTRODUCTION

Mines & Energy South Australia (MESA) submitted four thin sections to PGPC for detailed petrological description. Samples were taken from the ?basement and overlying alteration zones in the wells Narcoonowie-1 and Putamurdie-1 which were drilled in the Warburton Basin. Basement is comprised of sediments of Cambrian to Ordovician age and at Narcoonowie-1 has been described by Gatehouse (1986) as sandstone from the Dullingari Group. Recent drilling in the Cooper Basin has been hampered by difficulties identifying basement in the underlying Warburton Basin. MESA recognised an extensive zone of alteration above basement which has probably contributed to this drilling difficulty. The purpose of this petrology study was to document the nature of the weathering/ diagenetic alteration of basement and suggest possible mechanisms causing the alteration.

After an initial examination of the thin sections provided by MESA it was recommended that X-ray diffraction would assist with the identification of the clay and carbonate minerals present. The cores were sampled by MESA close to the depths of the thin sections for this purpose. Copies of the wireline logs over the relevant depth intervals and a copy of the most recent stratigraphic subdivision of the Warburton Basin were supplied. The samples examined and services provided by PGPC are listed below in Table 1.

TABLE 1 SAMPLES & SERVICES

Well	Depth (ft)	Thin section description	Photomicrograph	XRD
Narcoonowie-1	6545.5	*	*	-
Narcoonowie-1	6543	-	-	*
Narcoonowie-1	6110	*	*	-
Narcoonowie-1	6113	-	-	*
Putamurdie-1	6160	*	*	-
Putamurdie-1	6163	-	-	*
Putamurdie-1	6078	*	*	*

2. METHODS

Thin section description
Thin sections were systematically scanned to determine lithology, composition, porosity and textural relationships. All percentages given in thin section descriptions are visual estimates, not point counts.

X-ray diffraction (XRD)
To determine bulk mineralogy by XRD, samples were ground in a Siebtechnick mill and back mounted into aluminium holders. 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.

3. PETROLOGY

3.1 Narcoonowie-1, core 2, depth 6545.5ft

Thin section description

Rock classification: Subgreywacke

Texture:
This moderately sorted, texturally immature and mineralogically submature sediment has an average grain size of medium sand (0.33mm). Weakly defined bedding or foliation is apparent from the alignment of micas and elongate grains. Two fractures which are up to 0.10mm in width cross cut the grain alignment and are healed with kaolin and carbonate. Along the margin of one side of the thin section there is an elongate carbonate cemented zone which may also represent a healed fracture. The contact between the sandstone and the carbonate cement has an iron staining. Texturally the subgreywacke is matrix supported with rare point and tangential grain contacts. Framework grains are typically subangular with low sphericity and range in diameter from approximately 0.05mm (coarse silt) to 0.75mm (coarse sand).

Porosity:
Porosity is dominated by micropores associated with the grain replacing kaolin. There are isolated secondary grain size pores which could be attributed to either dissolution or plucking during thin section preparation.

Visual Estimate of Composition		%
Framework grains	Quartz	40
	Feldspars	tr
	Lithics	6
	Mica	9
	Accessory minerals	tr
Matrix	Clay	20
Authigenic minerals and cements	Kaolin	5
	Carbonate	10
	Illite	6
	Pyrite	tr
Porosity	Micropores	2
	Dissolution	1

Framework grains:
Monocrystalline and minor polycrystalline quartz is the dominant type of framework grain. Monocrystalline grains are characterised by slightly undulose extinction, scattered vacuoles and rare mineral inclusions of apatite, muscovite and rutile needles. Polycrystalline quartz has undulose extinction and straight crystal boundaries. Remnants of feldspars are evident where there is incomplete kaolin replacement. Other grains completely replaced by illite were probably feldspars (Fig. 1). Lithics consist of altered quartzite, schist, shale and siltstone. Partial replacement by illite and deformation of the ductile lithologies makes these lithics difficult to distinguish from the matrix. Muscovite flakes are typically straight and relatively fresh. There are examples which are up to 0.75mm in length and others which are bent. Accessory minerals are represented by well rounded silt size zircon and sphene, and sand size tourmaline.

Matrix:
Anhedral laths of illite and muscovite are aligned tangentially to grain surfaces to form the matrix. The presence of muscovite may indicate partial recrystallisation.

Authigenic minerals and cements:
Feldspars are in various stages of replacement by kaolin booklets. The booklets are up to 15 microns in diameter and there are examples of straight edged vermiform kaolin. Anhedral dusty microspar and micrite has partially replaced grains and the illitic matrix. Iron staining in the micrite may indicate the presence of siderite. Carbonate also occurs as clear and dusty anhedral to subhedral spar which has precipitated in the kaolin. On the edge of the thin section the carbonate spar includes subhedral scalenohedra typical of siderite. These crystals are up to 0.10mm in length. Anhedral laths of illite have selectively replaced grains. Isolated patches of blocky opaque material which replace both matrix and framework grains are comprised of pyrite.

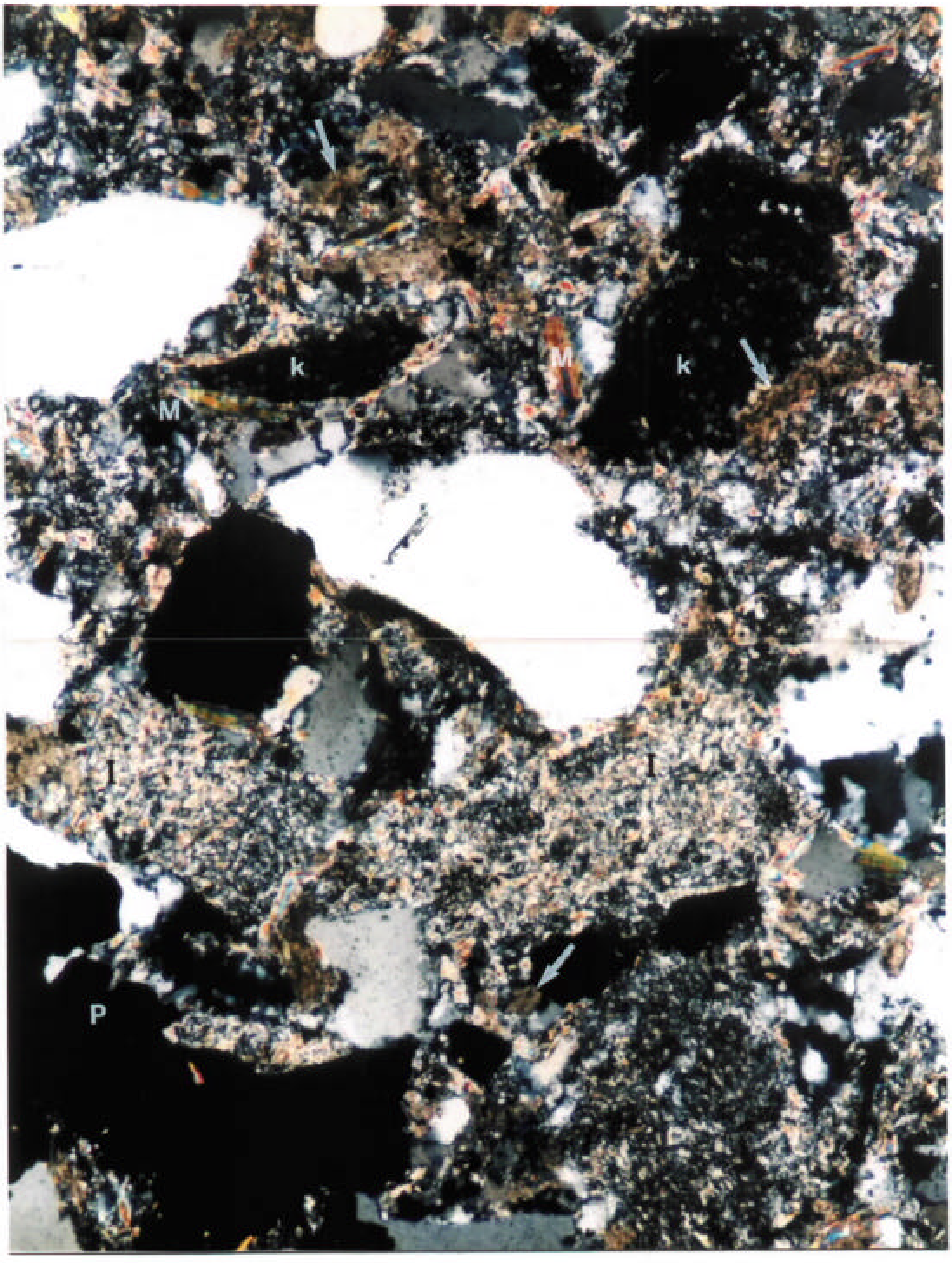

Figure 1

General field of view illustrating grains (probably feldspars) replaced by kaolin (k) and illite (I). The latter are difficult to distinguish from the illitic matrix. Minor carbonate spar and dusty micrite (arrows), pyrite (P) and muscovite flakes (M) are apparent. Thin section photomicrograph of Narcoonowie-1, core 2, depth 6545.5ft. Crossed nicols. Horizontal field of view 1.35mm.

3.2 Narcoonowie-1, core 1, depth 6110 ft

Thin section description

Rock classification: Greywacke

Texture:
The sample is a fine to medium grained, poorly sorted, mineralogically submature and texturally immature greywacke. Alignment of elongate grains could be attributed to the presence of either weakly defined bedding or foliation formed during low grade metamorphism. One prominent fracture (front cover) cross cuts the thin section at right angles to the bedding/foliation. The fracture is up to 1.5mm in width and has been healed with polycrystalline quartz, kaolin and carbonate. The carbonate appears to be the final phase of cement since it replaces kaolin and heals minute fractures (0.03mm width) within the quartz. Texturally the greywacke is matrix supported with minor point and tangential grain contacts. Framework grains are angular to subangular with low sphericity. They range in diameter from approximately 0.06mm (coarse silt) to 1.3mm (very coarse sand).

Porosity:
Porosity is essentially occluded by the abundant matrix in this greywacke. There are traces of microporosity associated with patches of kaolin and rare examples of secondary grain size pores. The latter are attributed to the dissolution of labile grains.

Visual Estimate of Composition		%
Framework grains	Quartz	33
	Feldspar	tr
	Lithics	7
	Mica	4
	Accessory minerals	1
Matrix	Clay	20
	Organic matter	tr
Authigenic minerals and cements	Kaolin	10
	Carbonate	15
	Illite	7
	Pyrite	tr
	Quartz	2
Porosity	Micropores	tr
	Dissolution	tr

Framework grains:
In the greywacke quartz is dominantly monocrystalline with straight to slightly undulose extinction, scattered vacuoles and rare mineral inclusions of muscovite and rutile needles. Isolated grains of polycrystalline quartz have undulose extinction and straight crystal boundaries. Remnants of feldspars which lack twinning occur within grain size patches of illite. Lithics of shale, siltstone, quartzite and schist are evident. Muscovite flakes range from fresh to highly altered, are typically straight and up to 0.9mm in length. Accessory minerals of silt size anhedral tourmaline, sphene, rutile, ?epidote and zircon are apparent. Rare reaction rims (?hydrocarbon envelopes) have formed around the radioactive minerals.

Matrix:
Illitic laths and minute highly altered mica flakes are aligned tangentially to grain surfaces. This illitic material is thought to represent the matrix which may have undergone minor recrystallisation. Silt size quartz is also apparent in the matrix. Angular elongate opaque fragments could represent carbonaceous material.

Authigenic minerals and cements:
Kaolin booklets have replaced grains in the greywacke and filled intercrystal pores in the fracture. The booklets are subhedral and approximately 10 to 15 microns in diameter. On the margins of patches of kaolin in the fracture there is a distinct iron staining. Examples of mica flakes partially altered to kaolin are common in the greywacke (Fig. 2). There appear to be two phases of carbonate present. Interlocking blocky crystals of clear spar have partially to completely replaced grain size patches of kaolin in both the greywacke and the fracture. These blocky crystals are subhedral and up to 0.15mm in diameter. Scattered throughout the matrix of the greywacke there are anhedral crystals of microspar which have iron staining. Illite has replaced medium sand size grains which were probably feldspars. Clusters of blocky opaque crystals are composed of pyrite. The quartz which fills the fracture is also polycrystalline with straight crystal boundaries and undulose extinction. Adjacent to patches of kaolin in the fracture/vein the polycrystalline quartz has euhedral terminations.

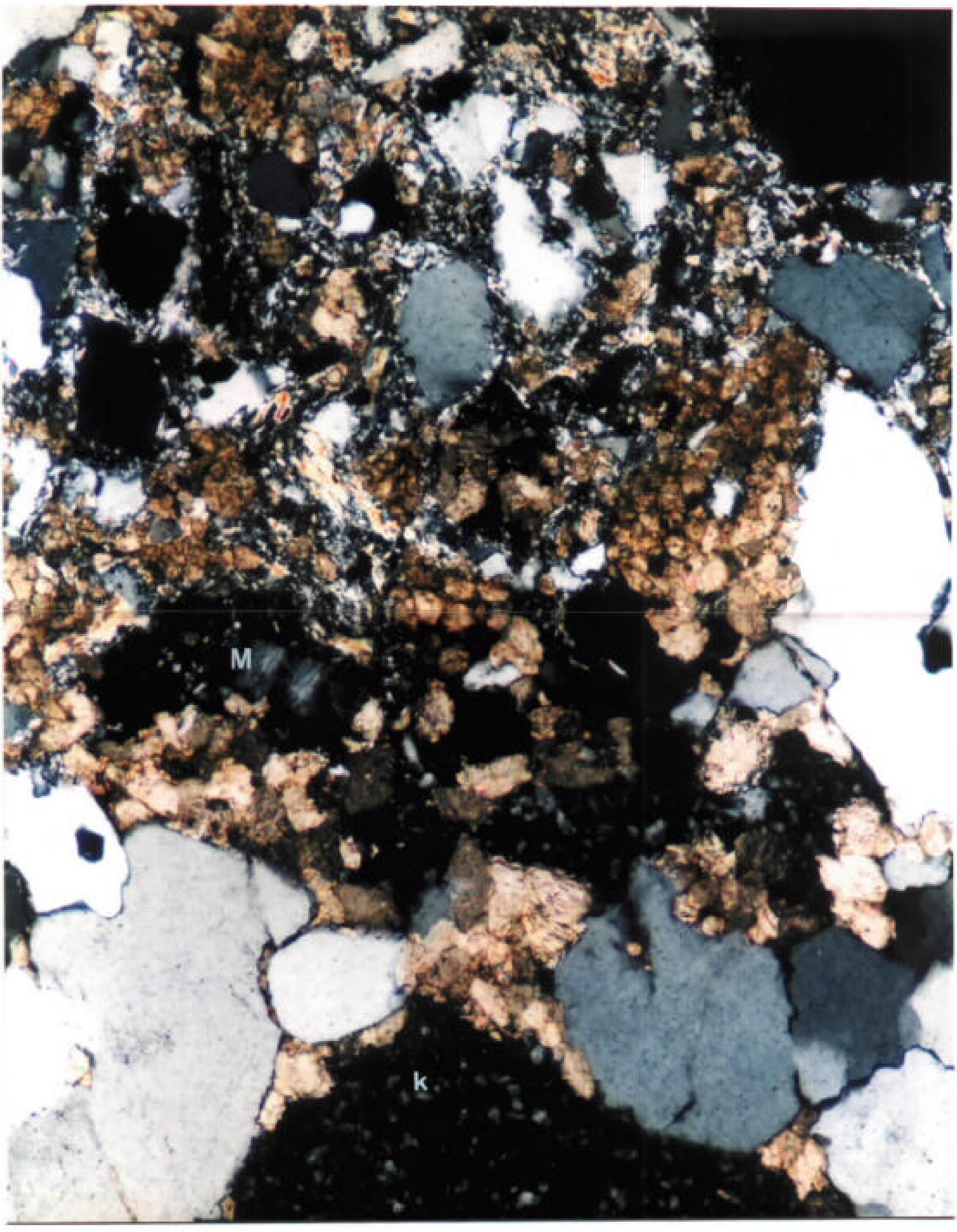

Figure 2
On the edge of the fracture kaolin has replaced a mica (M) which produces much coarser crystals than the kaolin (K) within the fracture. Carbonate spar is slightly more abundant adjacent to the fracture than elsewhere in the greywacke. Note the abundance of illitic matrix in the greywacke. Thin section photomicrograph of Narcoonowie-1, core 1, depth 6110 ft. Crossed nicols. Horizontal field of view 1.35mm.

3.3 Putamurdie-1, core 8, depth 6160 ft

Thin section description

Rock classification: Protoquartzite

Texture:
The sample is a very fine grained, well sorted, mineralogically and texturally submature protoquartzite (Fig. 3). Large elongate and rounded lithics (> 2.3cm) of subgreywacke, greywacke, shale and micaceous siltstone float within the protoquartzite. Alignment of the lithics may indicate the orientation of original bedding. It is possible that the lithics are intraclasts reworked in the sedimentary environment prior to deposition. Texturally the protoquartzite is grain supported with close packing due to tangential and concavo-convex grain contacts. Framework grains were typically subrounded with moderate sphericity prior to recrystallisation. Grains range in diameter from approximately 0.04mm (coarse silt) to 0.25mm (fine sand) with an average near 0.11mm (very fine sand).

Porosity:
There are no pores apparent in either the protoquartzite or the lithics.

Visual Estimate of Composition		%
Framework grains	Quartz	60
	Feldspar	5
	Lithics	10
	Mica	4
	Accessory minerals	tr
Matrix	Clay	6
	Organic matter	tr
Authigenic minerals and cements	Chlorite	9
	Carbonate	5
	Pyrite	tr
Porosity		nd

Framework grains:
Monocrystalline quartz has slightly undulose extinction, scattered vacuoles and rare mineral inclusions of rutile and apatite. The interlocking nature of the quartz grains without any obvious detrital grain boundaries suggests it has been recrystallised. Relatively fresh feldspars which are the same size as quartz grains have pericline, tartan and albite twinning indicating the presence of both K-feldspar and plagioclase. The lithic of micaceous siltstone contains micas which have been altered to chlorite, abundant fresh muscovite, detrital brown clay and stringers of organic matter. The shale lithic contains an even higher percentage of aligned mica flakes than the siltstone. Pockets of sand within the shale could have been deposited as ripples. Quartz grains in the greywacke and subgreywacke are fine sand in size and the matrix is illitic. Muscovite flakes in the protoquartzite are straight and are preserved in various stages of alteration. Biotite has been totally replaced by chlorite. Accessory silt size zircon, tourmaline and opaques are scattered throughout the thin section.

Matrix:
Illitic clay is aligned tangentially to grain surfaces. Extensive replacement of the illite by chlorite is apparent. Stringers of blocky opaque material are probably carbonaceous.

Authigenic minerals and cements:
Pale green chlorite has replaced micas and the matrix clay. It does not form rims on grains nor have a fibrous appearance. The chlorite probably formed in response to low grade metamorphism. Iron staining associated with the grain size patches of carbonate spar

suggest the presence of siderite or ankerite. Rare patches of blocky opaque pyrite has cemented and replaced framework grains.

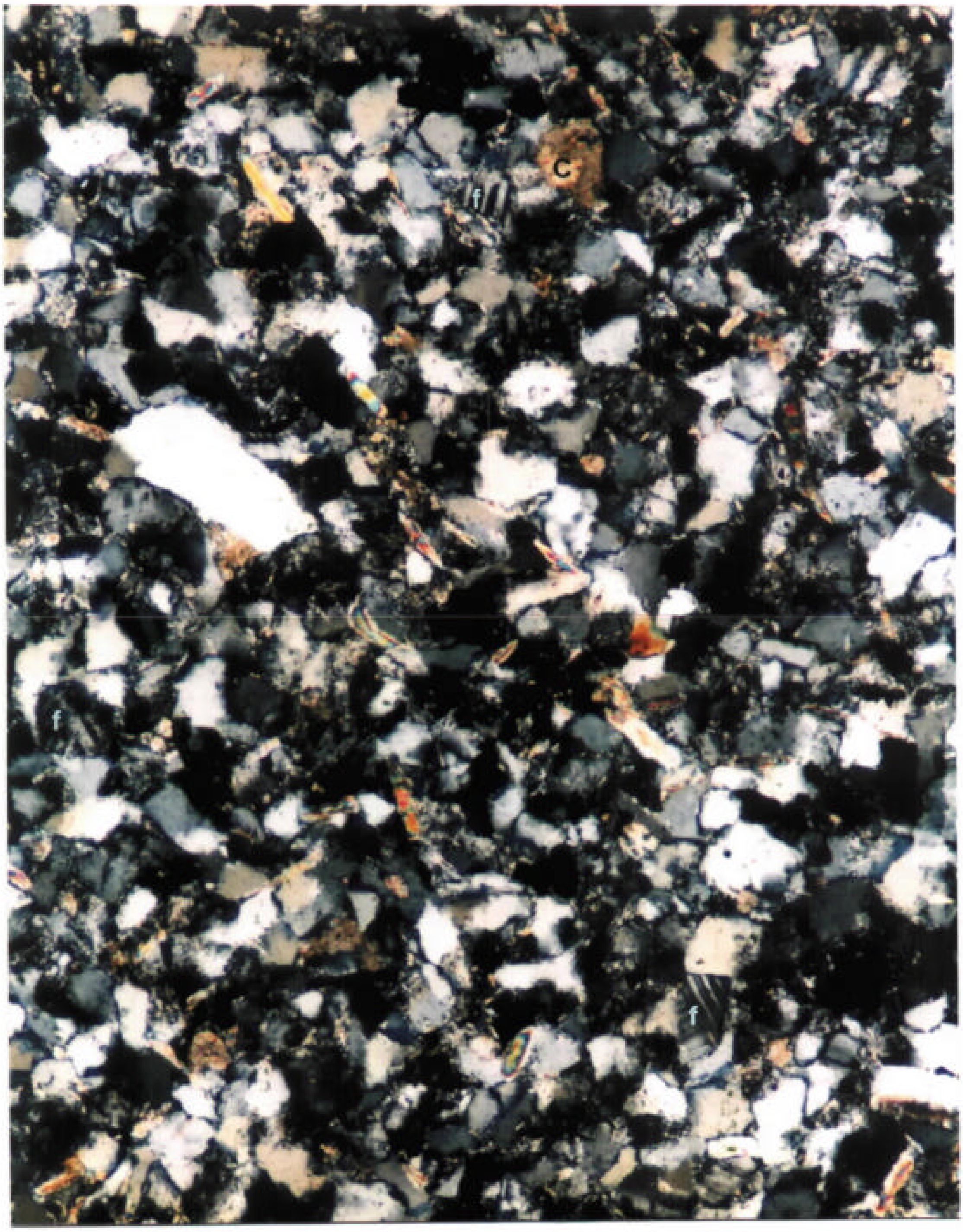

Figure 3

The well sorted, very fine grained nature of this protoquartzite is apparent in this general field of view. Note the feldspars (f), muscovite and grain replacing carbonate (c). Thin section photomicrograph of Putamurdie-1, core 8, depth 6160 ft. Crossed nicols. Horizontal field of view 1.35 mm.

3.4 Putamurdie-1, core 7, depth 6078 ft

Thin section description

Rock classification: Protoquartzite

Texture:
This fine grained, moderately sorted protoquartzite is mineralogically submature and texturally immature. There are numerous thin fractures and channels cross cutting the section at various angles. These fractures are either open or healed. Channels are filled with illitic clay and have Y shaped branching (Fig. 4). The terminations of these branches are tapered and the channels are crenulated which suggests deformation after the channels formed. Fractures healed with quartz are straight, do not branch and are aligned parallel to each other. The open fracture is 0.10mm in diameter, whilst channels filled with illitic clay are up to 0.15mm in diameter and the quartz healed fractures are approximately 0.25mm in diameter. Texturally this sample is grain supported with close packing due to tangential and concavo-convex grain contacts. Grains range in diameter from approximately 0.06mm (coarse silt) to 0.45mm (medium sand) with an average near 0.19mm (fine sand). Prior to metamorphism grains were probably subangular with moderate sphericity.

Porosity:
The open fracture has preserved both porosity and permeability in a restricted zone. The only other evidence of porosity preservation occurs in the centre of illitic channels where there are elongate pores.

Visual Estimate of Composition		%
Framework grains	Quartz	56
	Feldspar	tr
	Lithics	tr
	Mica	3
	Accessory minerals	2
Matrix	Clay	12
Authigenic minerals and cements	Kaolin	8
	Carbonate	5
	Illite	10
	Quartz	1
	Sphene	1
Porosity	Fractures/channels	1

Framework grains:
Monocrystalline quartz with undulose extinction and scattered vacuoles is the dominant framework grain. There are examples which contain inclusions of apatite and rutile needles. Fresh feldspar with albite twinning is very rare. Quartzite lithics are also rare. Muscovite flakes are typically partially altered to illite and are up to 0.25mm in length. Silt size rounded zircon, rutile and anhedral tourmaline are concentrated in poorly defined layers which could outline the original bedding. Anhedral sphene is scattered throughout the thin section.

Matrix:
Illitic laths and minute micas are trapped between quartz grains. The tangential alignment of the laths suggests they were originally detrital but have probably been recrystallised. Illitic clay which fills the channels is aligned tangentially to the edge of the structure and there are zones with brown staining.

Authigenic minerals and cements:
Subhedral kaolin booklets which are commonly less than 10 microns in diameter have selectively replaced grains. Rarely this kaolin is vermiform with ragged edges and there are traces of illite associated with the kaolin. Isolated patches of kaolin contain booklets which are 25 microns in diameter. This coarser kaolin occurs in medium sand size patches rather than the fine sand size noted elsewhere. Clumps of dusty anhedral carbonate microspar concentrate along grain margins. The carbonate has probably precipitated in the detrital clay. Minute illite laths with random orientation occur as grain size patches, probably as an alteration product of feldspars and lithics. Authigenic quartz which has healed fractures is polycrystalline, it has straight crystal boundaries and scattered vacuoles. Elongate and blocky subhedral crystals of sphene attached to anhedral detrital grains are authigenic.

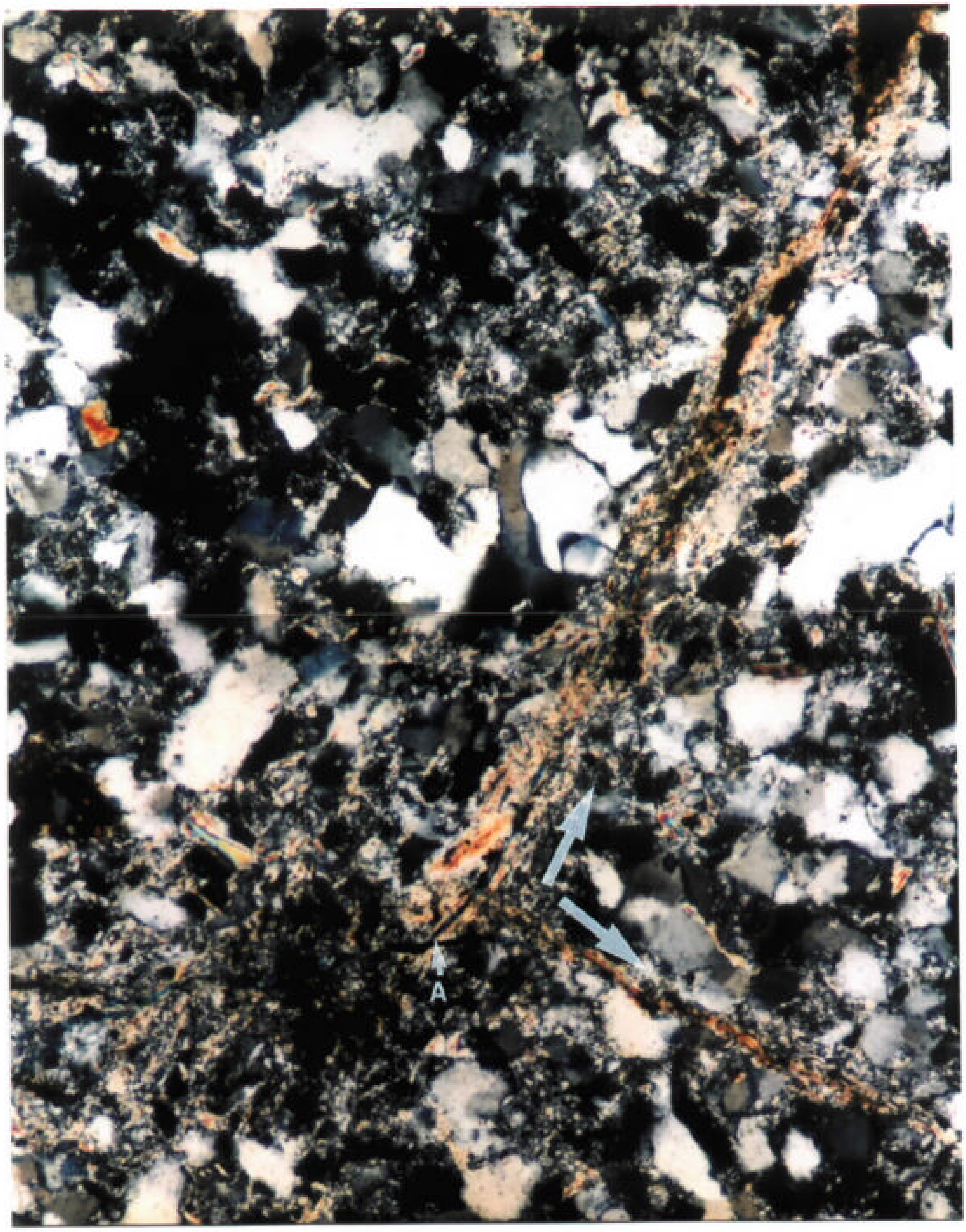

Figure 4

Branching in the illitic clay filled channel is indicated by arrows. Note that the centre of the channel is not completely filled with illite (A). The protoquartzite is fine grained and moderately well sorted. Thin section photomicrograph of Putamurdie-1, core 7, depth 6078 ft . Crossed nicols. Horizontal field of view 1.35mm.

4. X-RAY DIFFRACTION RESULTS

All the XRD results are summarised in the tables below and the XRD traces are presented in Appendix A. The most obvious trend from the XRD results is the increase in abundance of kaolinite in the clay fraction of samples taken from the alteration zone. Furthermore, kaolinite in the alteration zone has a better ordered crystal structure than the basement kaolinite. Illite is the next most abundant clay mineral, but there does not appear to be any trend in the proportion of illite from these XRD results. Feldspars (albite and microcline) are only identified in the basement sample from Putamurdie-1 (6163 ft). The change in carbonate composition from siderite in the basement to siderite plus dolomite in the alteration zone at Narcoonowie-1 may be related to the processes responsible for the alteration of basement. Trace amounts of interstratified or mixed layer clay typically include a smectite component and could be chlorite-smectite in composition. This is suggested by the broad nature of chlorite peaks and the d spacing of the superlattice which ranges from approximately 22 to 25 Angstroms.

TABLE 2. BULK XRD MINERALOGY

Well	Depth (ft)	Chlor	I/M	Kaol	Qtz	Alb	Micr	Sid	Dolo	Pyr
			Strongest peak height in counts							
Narcoonowie-1										
	6543	?tr	1415	-	4711	-	-	1004	-	-
	6113	?tr	807	760	8250	-	-	366	541	60
Putamurdie-1										
	6163	416	813	608	7795	990	1123	-	-	-
	6078	-	427	460	10444	150	-	-	-	-

TABLE 3. CLAY XRD MINERALOGY

Well	Depth (ft)	Inter	Chlor	Illite	Kaol	Qtz	Alb	Micr	Sid	Dolo
			Strongest peak height in counts							
Narcoonowie-1										
	6543	366	-	2197	155	2838	-	-	-	-
	6113	373	275	1815	4156	2366	-	-	356	379
Putamurdie-1										
	6163	375	375	1309	622	2848	597	361	-	-
	6078	431	386	1466	3356	2003	-	-	-	-

Inter = interstratified or mixed layer clay, Chlor = chlorite, I/M = illite/muscovite, Kaol = kaolinite, Qtz = quartz, Alb = albite, Micr = microcline, Sid = siderite, Dolo = dolomite and Pyr = pyrite.

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.

5. DISCUSSION

Samples from basement and the overlying alteration zone at Narcoonowie-1 and Putamurdie-1 are different in the type and degree of mineralogical alteration (Table 4). A major factor controlling these variations is the lithological difference in the basement rocks at each location. A number of processes have been responsible for the alteration of basement and these include, weathering possibly in a soil profile, flushing by meteoric waters after burial and fracturing with associated migration of fluids and gases. The diagenetic sequence for each well and possible mechanisms responsible for this alteration are described below.

TABLE 4 SUMMARY OF LITHOLOGY, TEXTURE & MINERALOGY

Well	**Narcoonowie-1**		**Putamurdie-1**	
Core	2	1	8	7
Depth (ft)	6545.5	6110	6160	6078
Lithology	subgreywacke	greywacke	protoquartzite	protoquartzite
Grain size (mm)	medium 0.33	fine-medium -	very fine 0.11	fine 0.19
Sorting	moderate	poor	well	moderate
Roundness	SA	A-SA	SR	SA
Structures	?bedding/foliation healed fractures	?bedding/foliation healed fracture	bedding intraclasts	open & healed fractures + channels ?bedding
Framework grains				
Quartz	40	33	60	56
Feldspar	tr	tr	5	tr
Lithics	6	7	10	tr
Mica	9	4	4	3
Accessory	tr	1	tr	2
Matrix				
Clay	20	20	6	12
Organic matter	-	tr	tr	-
Authigenic minerals				
Kaolin	5	10	-	8
Carbonate	10	15	5	5
Illite	6	7	-	10
Pyrite	tr	tr	tr	-
Quartz	-	2	-	1
Chlorite	-	-	9	-
Sphene	-	-	-	1
Porosity				
Micropores	2	tr	-	-
Dissolution	1	tr	-	-
Fractures	-	-	-	1

Note: All percentages given in Table 4 are visual estimates not point count results.

Narcoonowie-1

The basement sample at 6545.5ft is comprised of a medium grained, moderately sorted subgreywacke which has been diagenetically altered. The degree of alteration is less than the overlying fine to medium grained, poorly sorted greywacke at 6110 ft. The type of alteration is similar in both samples and has probably resulted from flushing by meteoric waters soon after burial and the migration of gases/fluids up fractures.

The earliest diagenetic alteration was probably the precipitation of micritic siderite in the detrital clay matrix soon after burial. At this time the pore fluids would have been alkaline, sulphide activity low and carbonate activity high. Iron was probably sourced directly from the detrital clay minerals. Late diagenetic siderite spar probably formed via neomorphism of the micrite, but dolomite would probably have precipitated from carbonate saturated fluids. The latter could be related to the release of CO_2 rich gases derived from basement in a mechanism similar to that suggested for calcite by Schulz-Rojahn (1993) for the Eromanga Basin. Alternatively when vuggy pores developed in Cambrian unnamed dolomites and dolomites of the Kalladeina Formation (Roberts et al, 1990) then groundwaters moving up fractures would have been saturated with dolomite. The dolomite could have precipitated in the Dullingari Group because sulphide activity had been lowered by the action of bacteria reducing organic matter to form the traces of blocky pyrite noted in both the basement and alteration zone. Low sulphide activity and alkaline conditions are essential before dolomite will precipitate.

Flushing by meteoric waters soon after burial, and/or mixing of meteoric and compactional waters later in the diagenetic history, could have been responsible for the extensive alteration of feldspars to illite and kaolinite. Typically neutral to alkaline pore fluids combined with sufficient potassium are required for illite genesis. There are similar proportions of grains altered to illite in both the basement and alteration zone which may suggest this is the result of weathering or early diagenetic alteration. As the pore fluids became more acidic and potassium activity was lowered by illite precipitation these conditions would favour the formation of kaolinite. Kaolinite is more abundant in the alteration zone (10%) and appears to have a better ordered crystal structure based on the XRD results. There are probably three mechanisms by which the kaolinite has formed. Firstly, in the alteration zone there is vermiform kaolinite with a large crystal size. In the Brent Sandstone, Osborne et al (1994) noted that early diagenetic vermiform kaolinite associated with expanded micas precipitated slowly at 25 to 50°C when pore fluids were not supersaturated. The percentage of mica in the basement at Narcoonowie-1 was estimated as 9% and there was no vermiform kaolinite identified, but at 6110 ft there is only 4% mica and vermiform kaolinite is present. This may indicate that micas in the alteration zone at Narcoonowie-1 have been converted to kaolinite. The second possible mechanism of kaolinite formation was via direct replacement of feldspars in both the basement and alteration zone during flushing by meteoric waters. Kaolinite formed via this mechanism occurs as subhedral booklets which range from 10 to 15 microns in diameter concentrating in grain size patches. This is the most common habit of kaolinite in both the basement and alteration zone. Thin fractures in both the basement and alteration zone contain kaolinite which is blocky in habit but was not a direct alteration product of feldspars. This third phase of kaolinite formation could be related to compactional waters released during fracturing of the Warburton Basin. Osborne et al (1994) identified blocky kaolinite which precipitated rapidly from supersaturated pore waters at temperatures of 50-80°C as late diagenetic.

The cement stratigraphy of fractures is complex and may suggest more than one phase of fracturing. Thin fractures in basement are healed with either both kaolinite and carbonate spar (?dolomite), or only carbonate spar (?siderite), and the wider fracture in the alteration zone is filled with polycrystalline quartz, kaolinite and carbonate spar (?dolomite). In the latter example the polycrystalline quartz appears to be the first cement. Silica is soluble when pH is greater than 9 at 25°C. Silica rich compactional waters have probably migrated up the fractures from deeper in the Warburton Basin and precipitation occurred when the pH and/or temperature changed. The siderite filled ?fracture on the edge of the basement sample (6545.5ft) may be related to CO_2 rich gases migrating up the fractures. In fractures where the carbonate spar is associated with kaolinite it appears to have precipitated on the margins and within pores filled with kaolinite. Therefore this phase of carbonate spar which is probably dolomite may postdate the kaolinite. A similar relationship is apparent within the surrounding greywacke where grain replacing kaolinite has been the site for carbonate precipitation. It is possible that fluids/gases migrating up the fractures have altered the surrounding bedrock. Micropores in the kaolinite could have provided sites where fluids accumulated long enough for the carbonate to precipitate. This sequence might suggest at least one phase of fracturing occurred prior to and/or in association with the third type of kaolinite described above. Other phases of fracturing occurred when fluids were silica and/ or carbonate rich. Taylor et al (1991) have described fractures in the Dullingari Group at Lycosa-1 as filled with authigenic siderite, ferroan dolomite, rhodochrosite, ankerite, pyrite, galena, quartz and kaolinite. They were unable to establish a cement stratigraphy because of the differences between individual fractures. The fluids responsible for this mineralisation were interpreted as hydrothermal possibly associated with the intrusion of granites in the Moomba area during the Early Carboniferous.

Putamurdie-1

Basement at Putamurdie-1 consists of relatively fresh, very fine grained, well sorted protoquartzite with granule size metasedimentary intraclasts. Feldspars include both albite and microcline and comprise up to 5% of the total rock composition. Alteration of biotite and detrital clay matrix to chlorite was probably the result of low grade metamorphism. The only diagenetic alteration of the basement rock was the selective replacement of isolated grains by iron stained carbonate spar (?siderite or ankerite) and trace amounts of blocky pyrite. XRD indicates the presence of poorly crystalline kaolinite which is thought to be intermixed with illite in the detrital clay matrix.

The sample from the alteration zone at 6078 ft is a fine grained, moderately sorted protoquartzite which has both open and healed fractures, channels and evidence of bedding. The illite filled channels have Y shaped branching, tapered terminations and are crenulated. The latter indicates these channels were present before any significant mechanical compaction and therefore are very early diagenetic possibly related to roots penetrating the C horizon of a soil profile. In contrast the fractures healed with polycrystalline quartz are straight and have parallel alignment. These fractures may have formed at the same time as late fractures containing authigenic quartz at Narcoonowie-1. Therefore at Putamurdie-1 there is evidence of both early alteration during exposure possibly as a soil profile and late diagenetic alteration associated with fracturing in the Warburton Basin.

When compared to basement an increase in the percentage of illite and kaolinite and a decrease in the proportion of chlorite are the most pronounced changes in the alteration zone at Putamurdie-1. Only trace amounts of feldspar are evident in the alteration zone, presumably the others if present have been converted to kaolinite and illite. The kaolinite occurs as subhedral booklets which are up to 25 microns in diameter and typically occurs as grain size patches. There is no evidence that micas have been altered to kaolinite nor for the introduction of fluids via fractures which resulted in late diagenetic kaolinisation. Kaolinite and illite probably formed as a result of flushing by meteoric waters during early diagenesis and/or weathering. Conversion of chlorite and possibly interstratified chlorite-smectite to illite would be a late diagenetic mechanism for increasing the percentage of illite in the alteration zone. The conversion of smectite to illite occurs at temperatures near 100°C and would have released magnesium, silica and possibly iron. Minor amounts of authigenic sphene have also been identified in the alteration zone. Typically these crystals are attached to detrital grains of sphene which suggests there has been in situ dissolution and recrystallisation. Elsewhere authigenic sphene is commonly associated with volcaniclastic sediments where titanium rich minerals (eg biotite, rutile and ilmenite) have been altered and sphene has replaced grains and filled pores. Morad (1988) showed that sphene could crystallise at temperatures as low as 60°C.

Fractures in the alteration zone at Putamurdie-1 are either open or healed by polycrystalline quartz. Timing of this fracturing is difficult to identify and clearly there have been at least two phases with the open fractures representing the final phase. Mineralogical alteration of the surrounding protoquartzite associated with this fracturing appears to have been minimal.

6. CONCLUSIONS

- At Narcoonowie-1 the alteration zone is identified by a reduction in the number of micas, an increase in the proportion of kaolinite, carbonate and authigenic quartz.
- The alteration zone at Putamurdie-1 is apparent from a loss of feldspars and chlorite, and increases in the percentages of illite and kaolinite.
- An increase in the percentage of kaolinite is the only consistent mineralogical change in the alteration zone of both wells.
- The alteration zone appears to have developed at Narcoonowie-1 due to meteoric flushing and gases/fluids migrating up fractures.
- At Putamurdie-1 the alteration zone is a function of weathering, possibly in a soil and meteoric flushing.

RECOMMENDATIONS

- Further petrological descriptions of basement rocks and overlying alteration zones in other wells are required to characterise the dominant mechanism responsible for this alteration. It would be important to perform these studies both where the basement is similar to the lithologies identified at Narcoonowie-1 and Putamurdie-1 and where basement is different eg granites at Moomba. This should ensure that the influence of differences in lithology is fully assessed.
- Isotopic analyses of the carbonate cements both in the fractures and adjacent sediments may improve the understanding of possible sources for this alteration. It may also be pertinent to analyse other carbonates from limestones and dolomites in the Warburton Basin.
- It is important to establish the cement stratigraphy of the fractures and this would only be possible by studying more examples. Cathodoluminescence microscopy of the cements will reveal the detail needed to understand the complexities but the mineralogy should be confirmed by XRD, electron microprobe and possibly SEM work.
- To identify the influence of alteration adjacent to fractures it is recommended that a series of thin sections are taken at regular intervals away from fractures containing different mineralogy.

7. GLOSSARY OF TERMS

Boehm lamellae
: Parallel trails of vacuoles in quartz that are thought to form during deformation (metamorphism) of grains.

Framboid
: A cluster of pyrite crystals with a spheroidal outline.

Greywacke
: Sandstone with more than 15% fine clay matrix. Grains of detrital quartz and feldspar occur as phenocrysts and are extremely angular. Variable amounts of lithics, mainly chert, quartzite, slate or phyllite.

Hydrocarbon envelope
: Solid bitumen surrounding a mineral containing radioactive elements. Radiation causes polymerisation of hydrocarbon chains within oil that rims grains.

Microporosity
: Porosity directly associated with clay minerals.

nd
: Abbreviation meaning not detected.

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

Protoquartzite
: Sandstone intermediate between orthoquartzite and subgreywacke.

Subgreywacke
: Similar to a greywacke but has less feldspar and more abundant, better rounded quartz grains.

Vacuole
: Gas or liquid filled inclusion.

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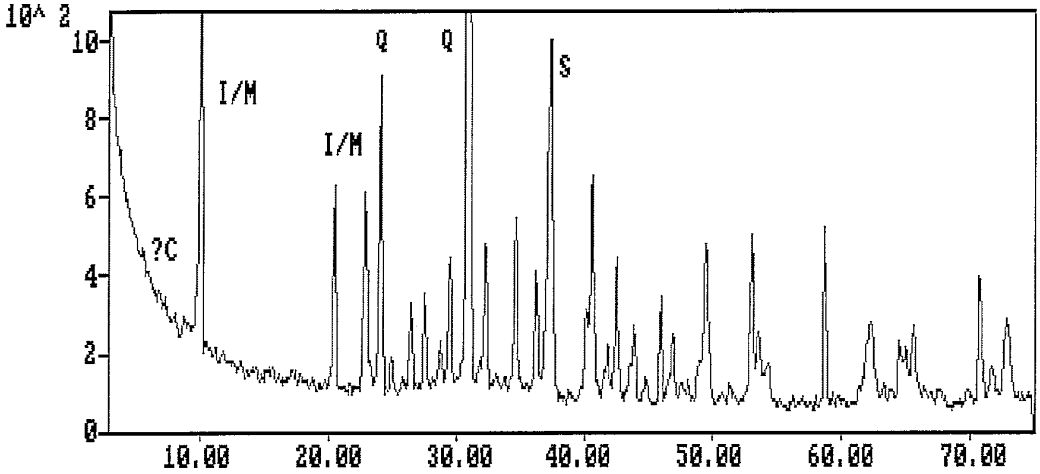
9. APPENDIX A

X-RAY DIFFRACTION TRACES

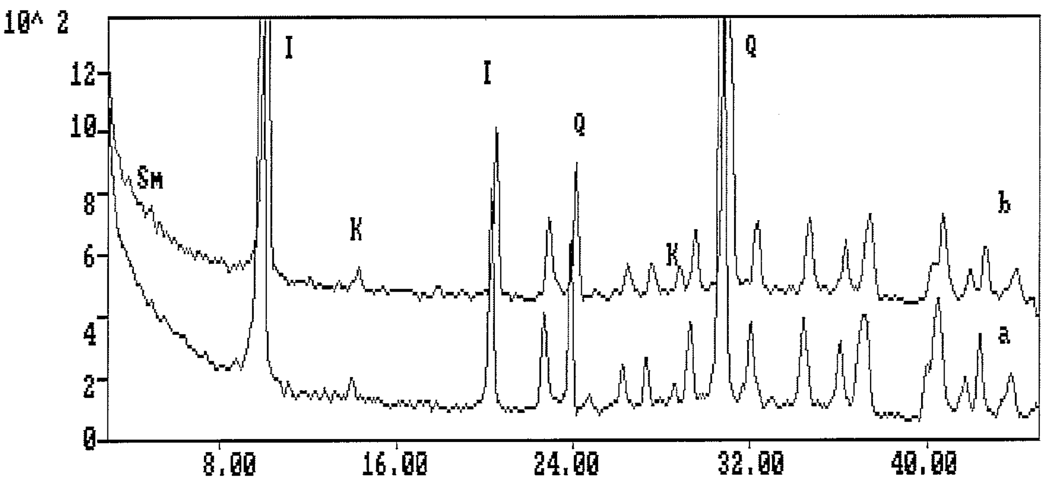
On all the XRD traces only the strongest peak for each mineral identified have been labelled. The horizontal axis is in degrees two theta and the vertical axis in counts of peak intensity. For the clay fraction two XRD traces were run to help with the identification of interstratified minerals. The first trace was saturated with Mg and air dried. The second trace was saturated with Mg and then glycerol prior to air drying. Abbreviations used on all the traces are listed below.

A = albite
C = chlorite
D = dolomite
I = illite
I/M = illite/muscovite
K = kaolinite
M = microcline
S = siderite
Sm = smectite
Q = quartz

Sample: **Narcoonowie-1, depth 6543 ft**

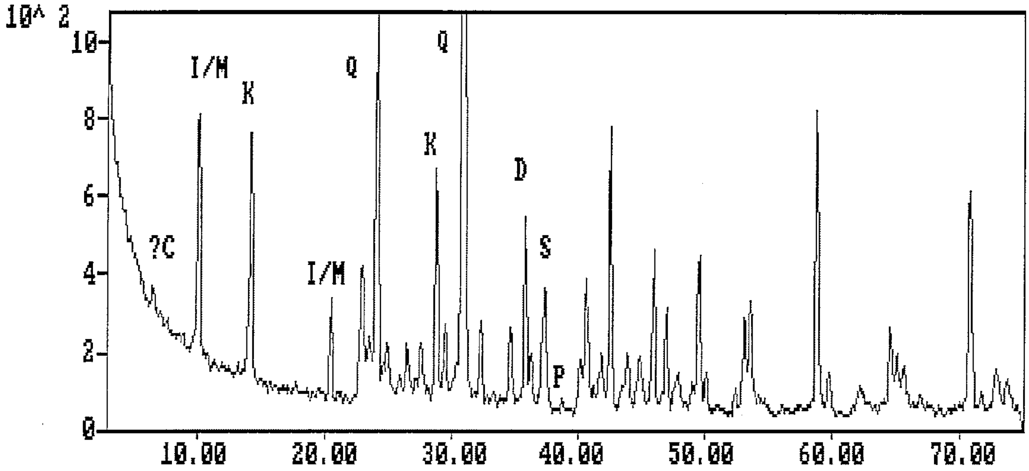


Bulk XRD trace

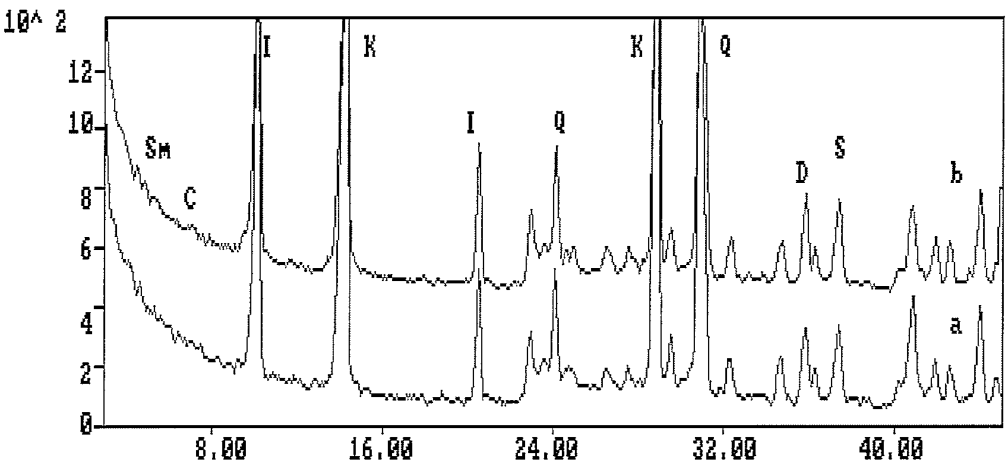


Clay XRD traces. a = Mg only trace and b = Mg + glycerol trace

Sample: **Narcoonowie-1, depth 6113 ft**

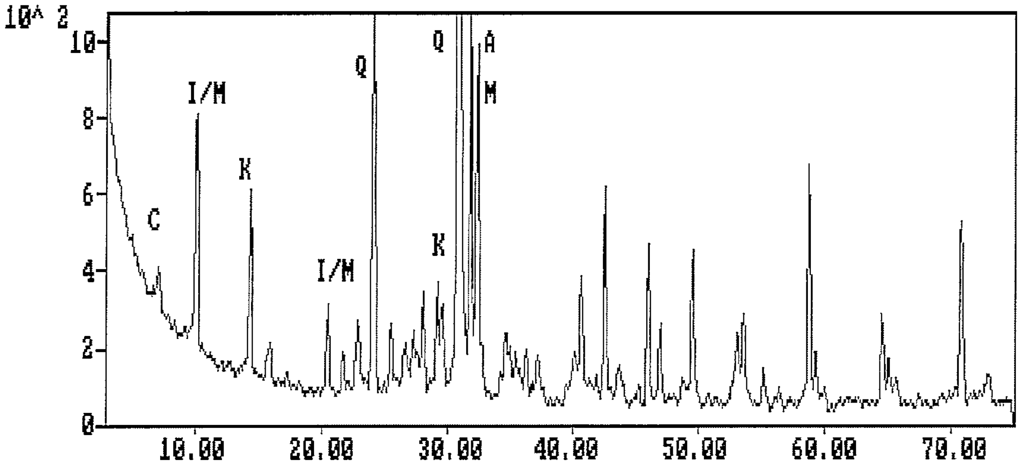


Bulk XRD trace

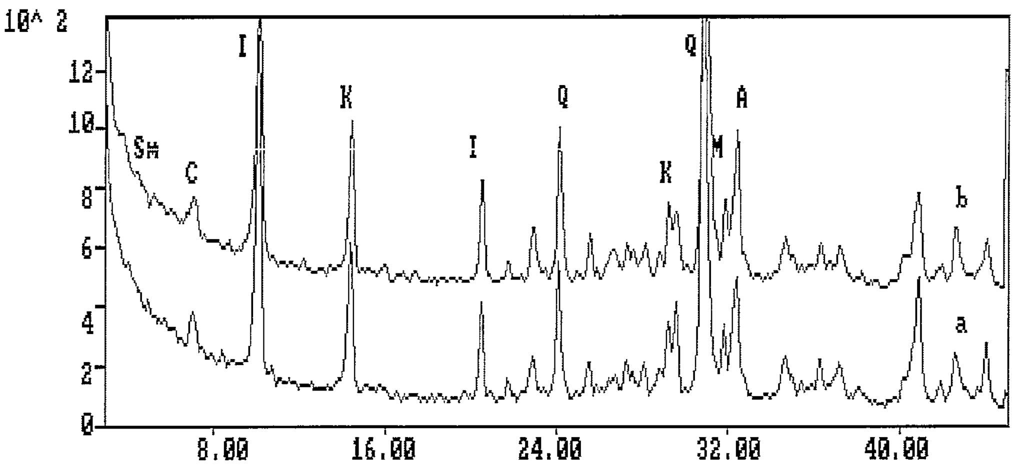


Clay XRD traces. a = Mg only trace and b = Mg + glycerol trace

Sample: **Putamurdie-1, depth 6163 ft**

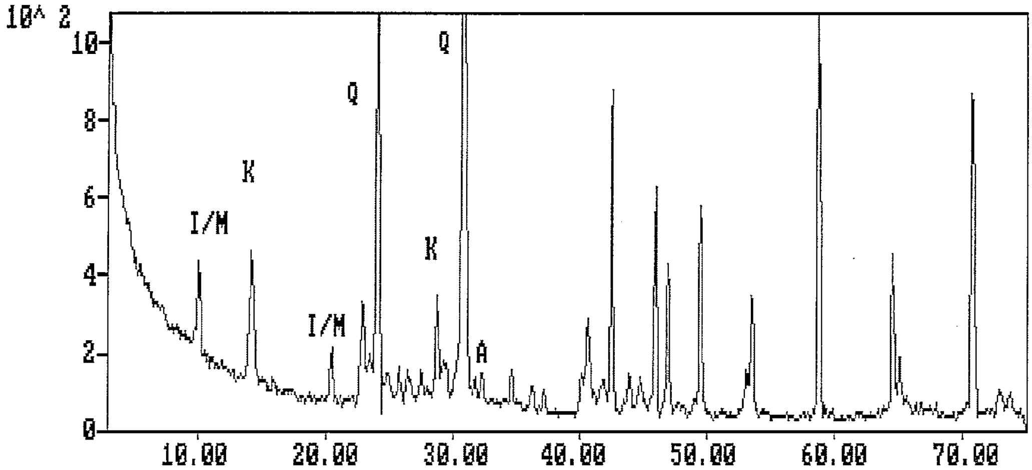


Bulk XRD trace

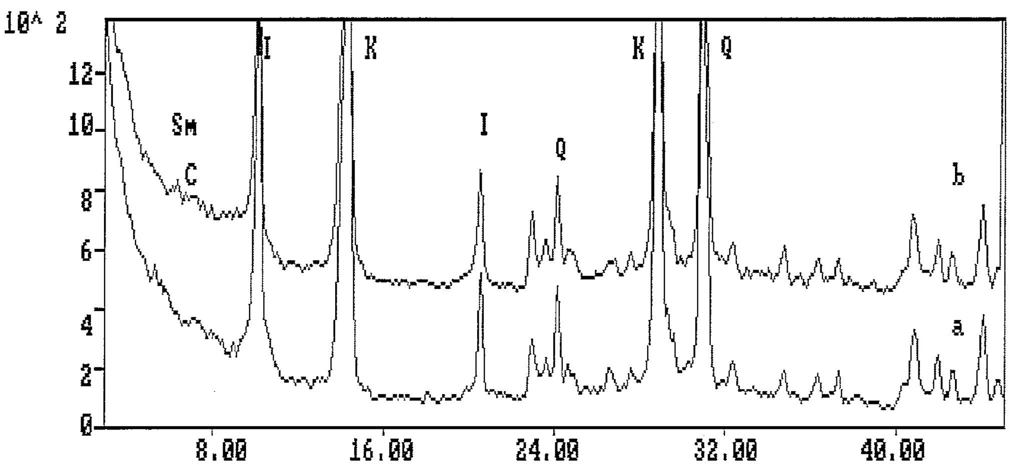


Clay XRD traces. a = Mg only trace and b = Mg + glycerol trace

Sample: **Putamurdie-1, depth 6078 ft**



Bulk XRD trace



Clay XRD traces. a = Mg only trace and b = Mg + glycerol trace