Are spatial mineralogical variations in the Bessie Creek Sandstone, McArthur Basin evidence for variable provenance, diagenesis or hydrothermal alteration?

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AUSTRALIA'S NORTHERN TERRITORY

NORTHERN TERRITORY GEOLOGICAL SURVEY

AGES2017

ANNUAL GEOSCIENCE EXPLORATION SEMINAR

Alice Springs, 28–29 March 2017, Northern Territory

Bessie Creek Sandstone

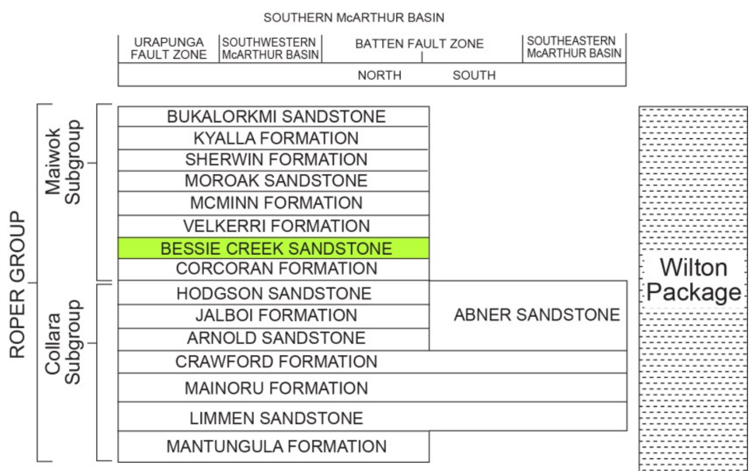
'economic potential…conventional oil/gas reservoir at shallow-moderate depths…. unconventional reservoir for basin-centred gas' (Munson, 2016)

'*quartzarenite*' (MOUNT YOUNG; BAUHINIA DOWNS)

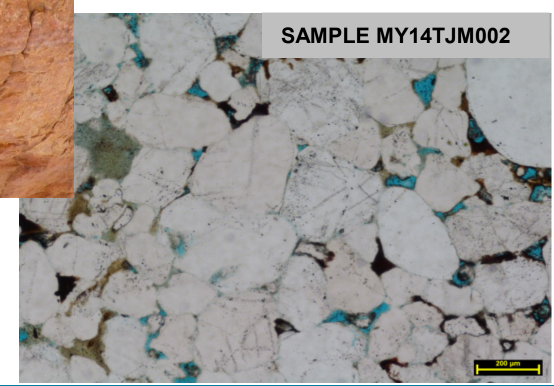
coarser grain size and greater abundance of mud flakes' (Powell et al, 1987)

'*uniform facies...potentially extensive reservoir….'*

'monotonous…' (Abbott et al, 2001)

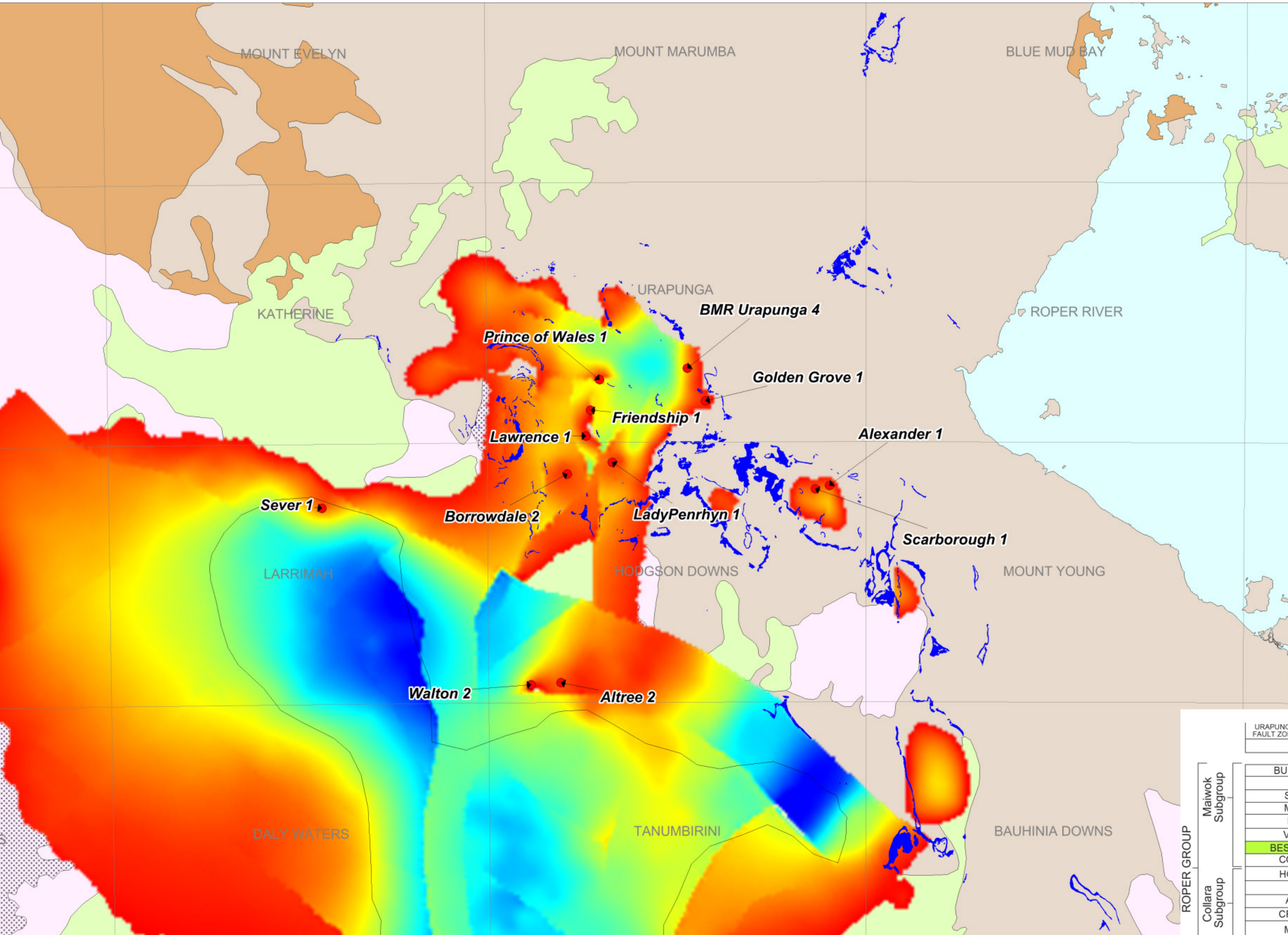


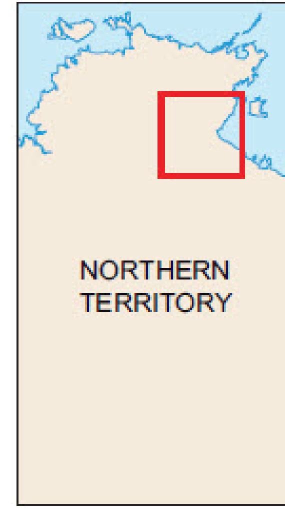
Modified from Ahmad et al (2013)



How uniform is it?

Lateral extent and well locations





Bessie Creek Sandstone exposure

Depth in metres for modelled surface

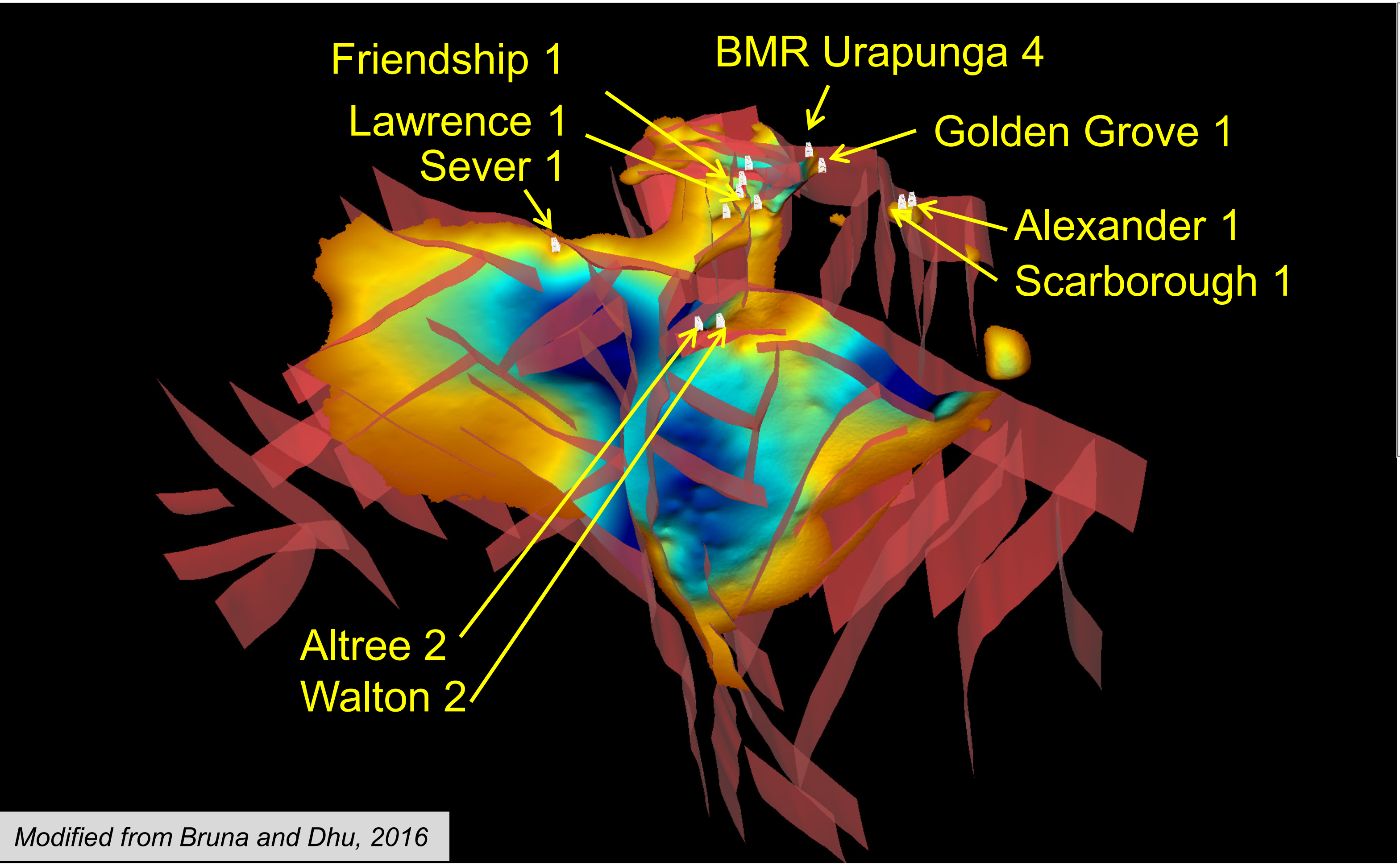
238
-1,000
-2,000
-3,000
-3,270

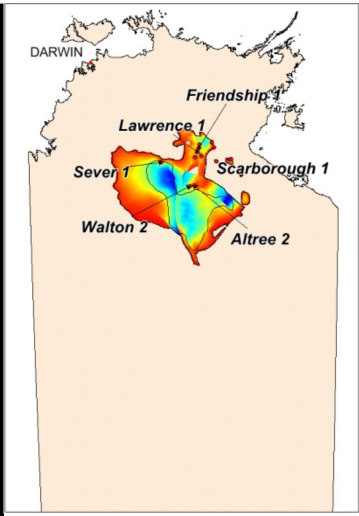
SOUTHERN McARTHUR BASIN

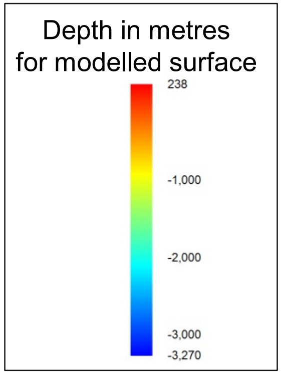
		URAPUNGA FAULT ZONE	SOUTHWESTERN McARTHUR BASIN	BATTEN FAULT ZONE NORTH	BATTEN FAULT ZONE SOUTH	SOUTHEASTERN McARTHUR BASIN
ROPER GROUP	Maiwok Subgroup	BUKALORKMI SANDSTONE				
		KYALLA FORMATION				
		SHERWIN FORMATION				
		MOROAK SANDSTONE				
		MCMINN FORMATION				
		VELKERRI FORMATION				
		BESSIE CREEK SANDSTONE				
	Collara Subgroup	CORCORAN FORMATION				
		HODGSON SANDSTONE			ABNER SANDSTONE	
		JALBOI FORMATION				
		ARNOLD SANDSTONE				
		CRAWFORD FORMATION				
		MAINORU FORMATION				
		LIMMEN SANDSTONE				
		MANTUNGULA FORMATION				

Depth to the top of Bessie Creek Sandstone (Bruna and Dhu, 2016)

Modelled extent of subsurface Bessie Creek Sandstone

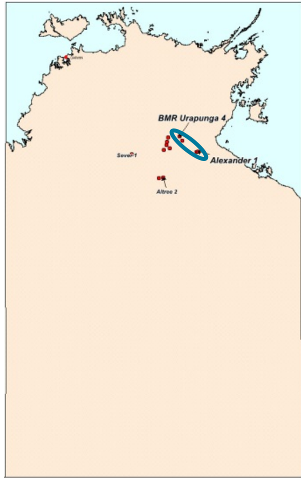


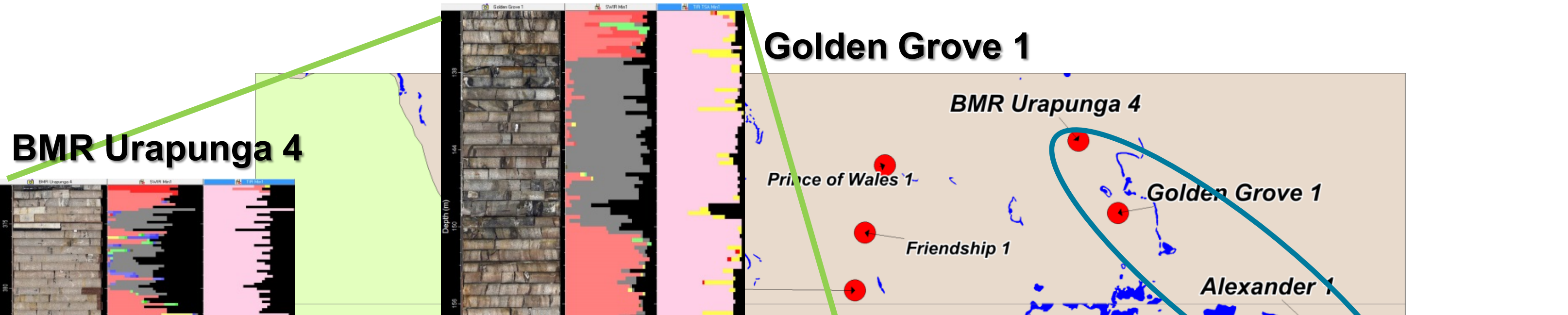
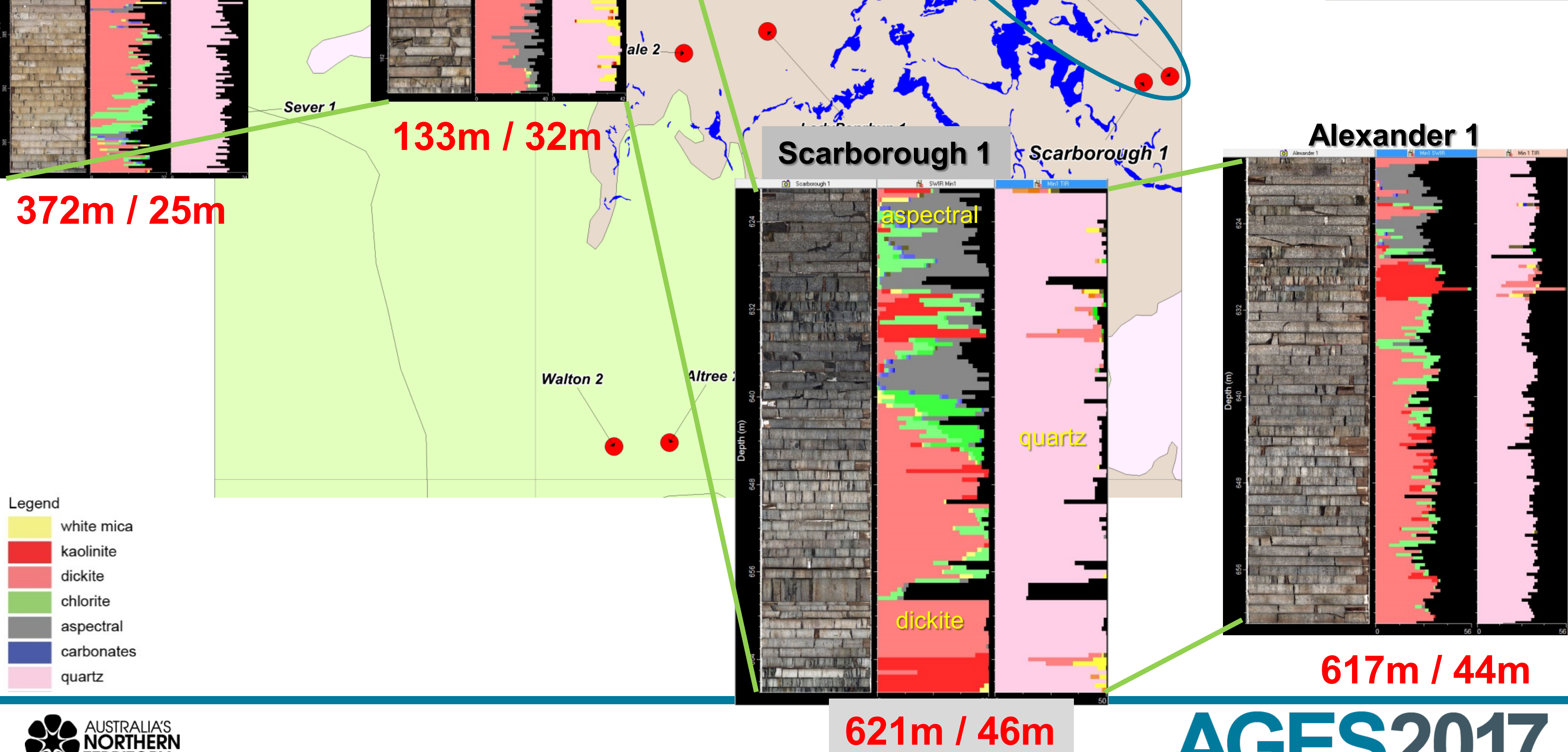




Depth (from surface) to the top of Bessie Creek Sandstone

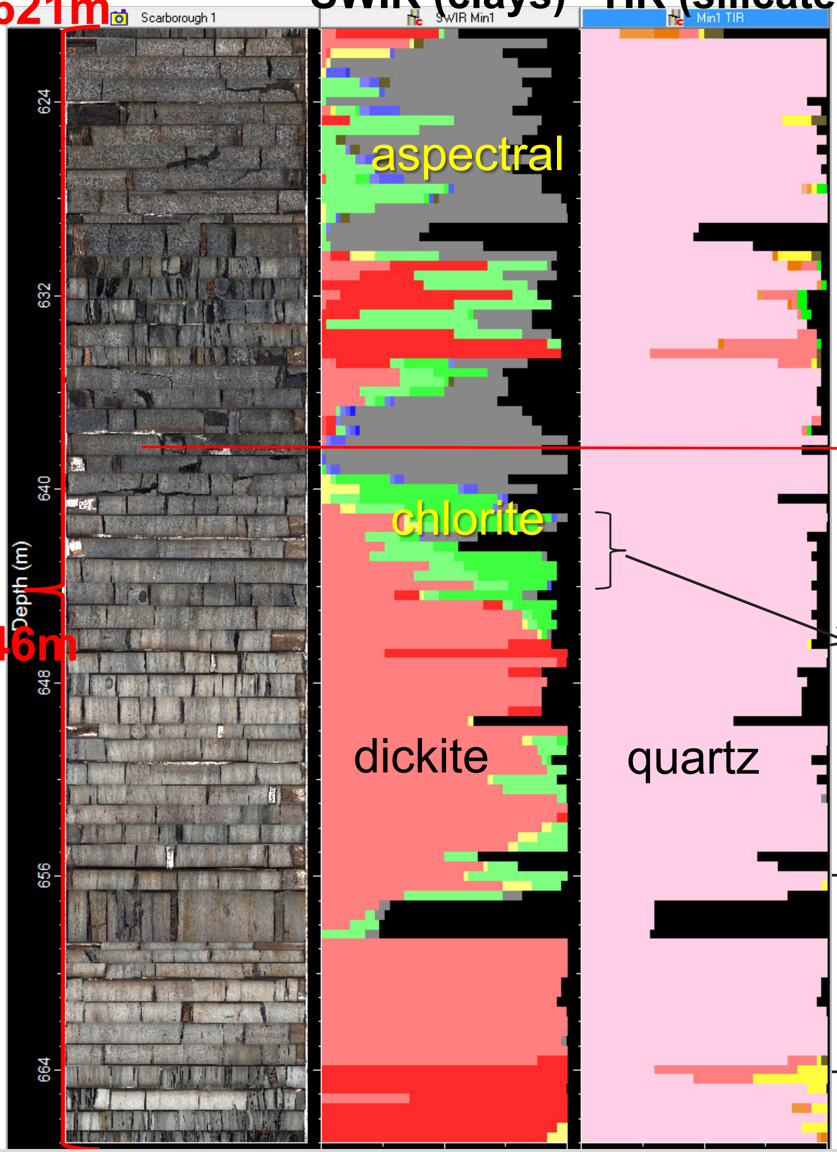
Eastern area – comparing mineralogy between wells

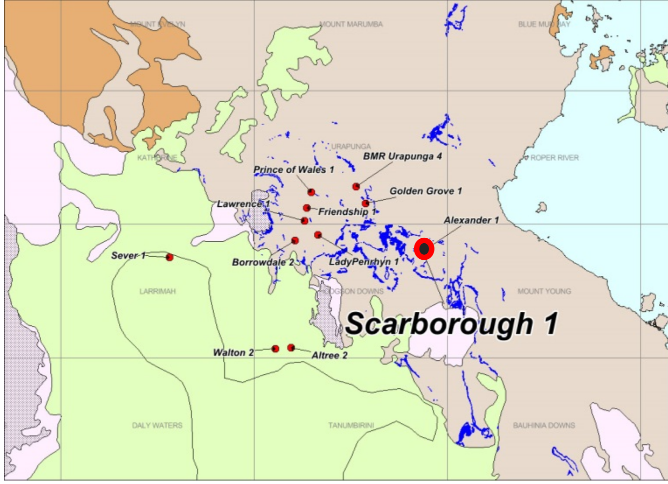


Scarborough 1 – kaolin group

SWIR (clays) TIR (silicates)





'pore-filling bitumen throughout'
bitumen appears to impede silicification'
(Barberis and Ledlie, 1989)

relict oil / water contact 642.7m (Barberis and Ledlie, 1989)

- chlorite is oil-wet (metal cations attract polar compounds in oil)
- dickite is water-wet

XRD: quartz > 80%; dickite 5-10%; chlorite 2%

XRD: kaolinite (35-50%); quartz (25-35%), white mica (25-35%)

Legend
- white mica
- kaolinite
- dickite
- chlorite
- aspectral
- carbonates
- quartz

Dominant mineral match; will not pick up quartz in SWIR

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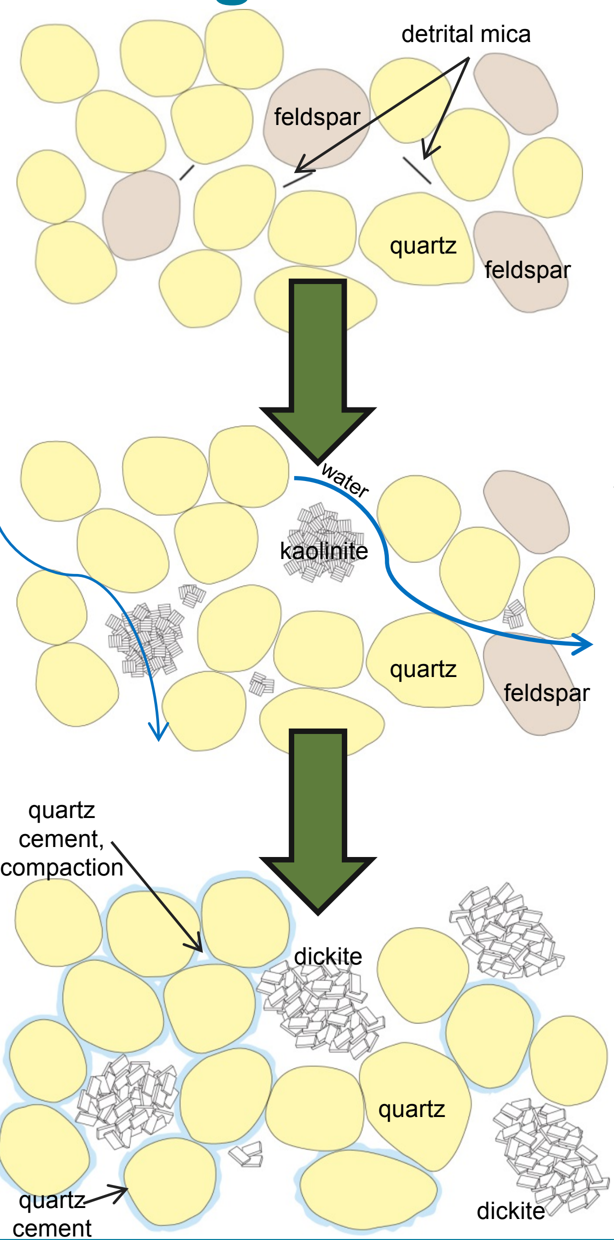
Authigenic kaolinite and dickite formation



Possible source material; quartz, feldspars, detrital white micas

K-feldspar to kaolinite

$2KAlSi_3O_8 + 2H^+ + 9H_2O \rightarrow Al_2Si_2O_5(OH)_4 + 4H_4SiO_4 + 2K^+$

K- Feldspar + (acidic) water → kaolinite. Potassium removed (open system) (Lanson et al, 2002)

High water volumes (‘meteoric water flushing’ tropical environment)

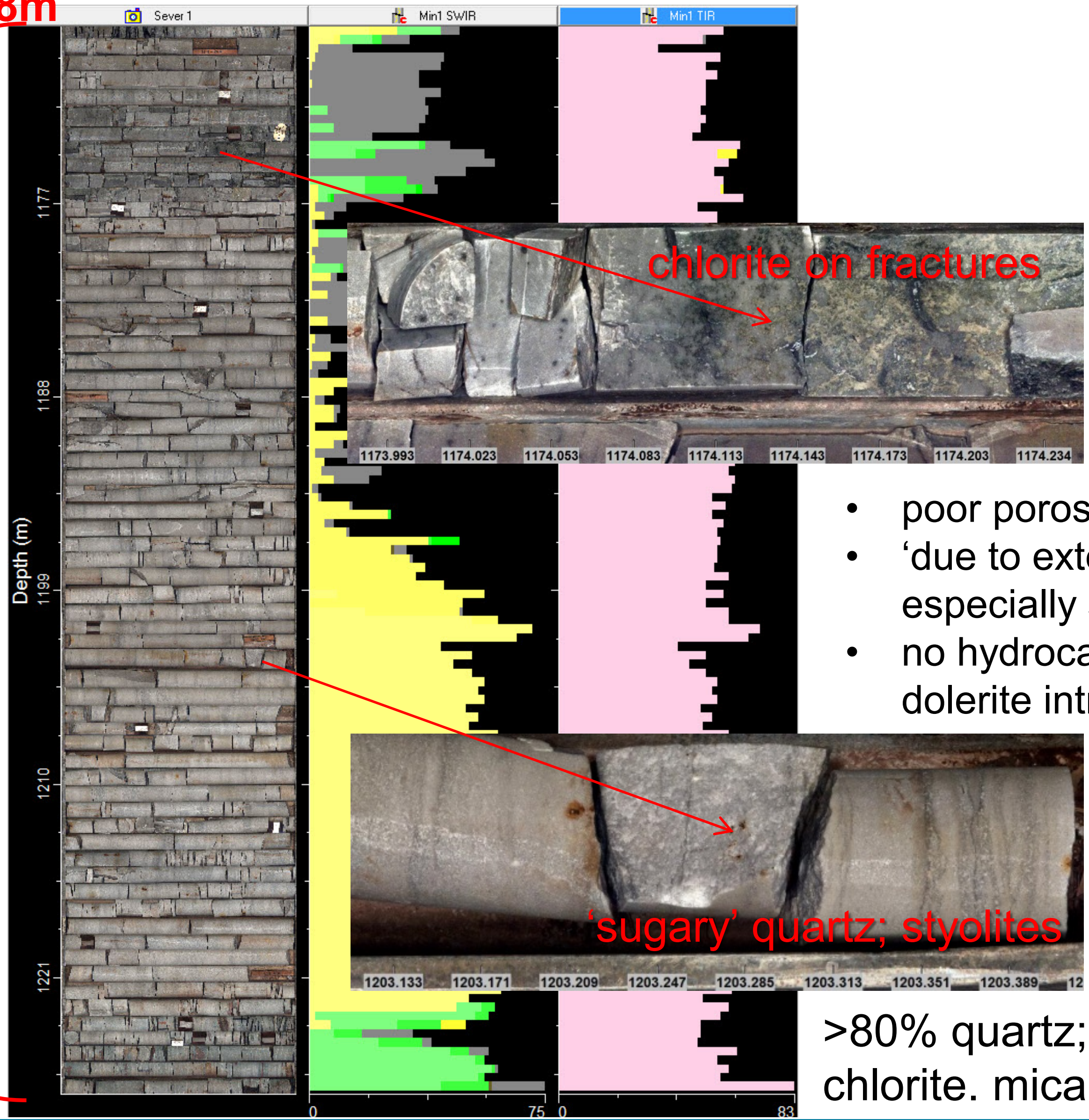
Kaolinite [$Al_2Si_2O_5(OH)_4$] to dickite [$Al_2Si_2O_5(OH)_4$]

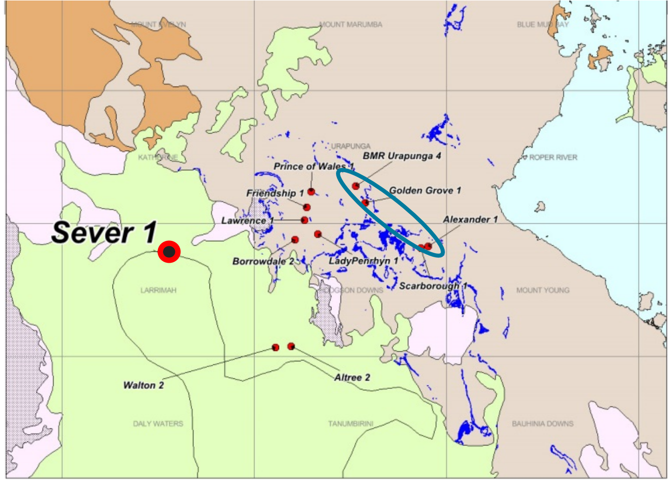
Dickite – high temperature kaolin polymorph (more ordered crystals)

Increasing burial depth; kaolinite is gradually transformed to dickite [3.0-4.5km; 90-130°C; Worden and Morad (2003)]

Hydrocarbon emplacement may slow or inhibit kaolinite-dickite reaction (Beaufort et al, 1998)

Sever 1 – illite (white mica)

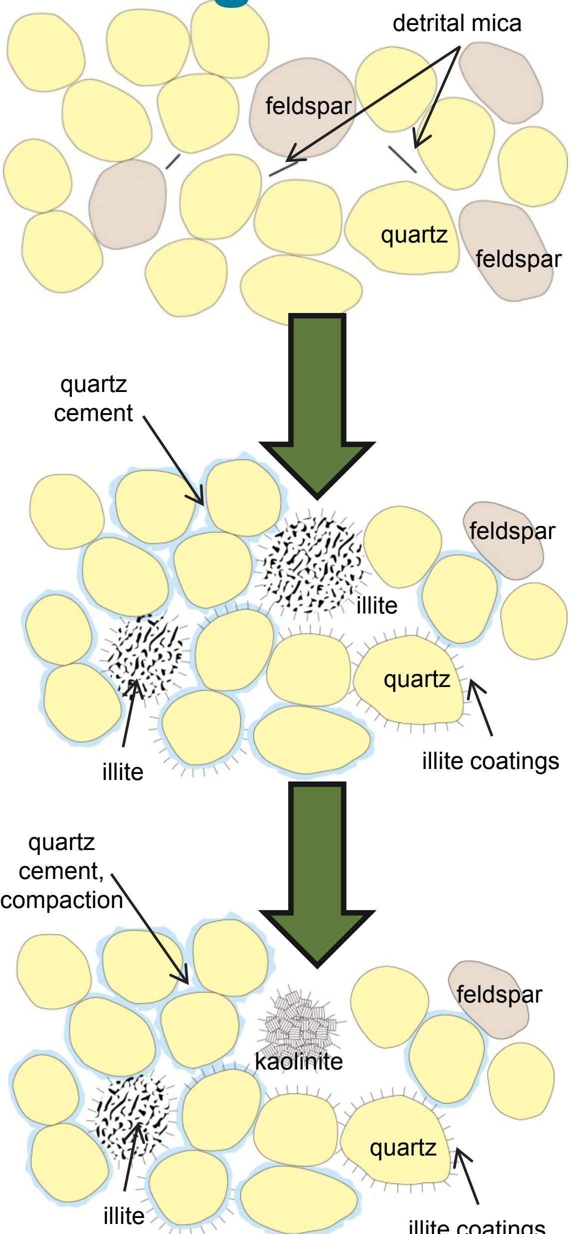




- poor porosity, extremely low permeability
- 'due to extensive diagenetic effects, especially silicification'
- no hydrocarbon shows, overmature from dolerite intrusion (Lanigan & Torkington, 1990)

>80% quartz; <2% white mica; <2% chlorite. mica> chlorite (XRD n=2)

Authigenic illite (white mica) formation



Possible source material; quartz, feldspars, detrital white micas

Authigenic illite from K-feldspar

$3KAlSi_3O_8 + H_2O + 2H^+ \rightarrow KAl_3Si_3O_{10}(OH)_2 + 6SiO_2 + 2K^+$

K-Feldspar + water → illite +quartz (cement)

K-feldspar + influx of acid-bearing formation water

(Worden and Morad, 2003)

'closed' system	quartz cement and K+ remain in system
'closed' due to:	reduced porosity / quartz cementation (?)
	burial compaction reduces meteoric water flow

Authigenic illite from K-feldspar and kaolinite:

$KAlSi_3O_8 + Al_2Si_2O_5(OH)_4 \rightarrow KAl_3Si_3O_{10}(OH)_2 + 2SiO_2 + H_2O$

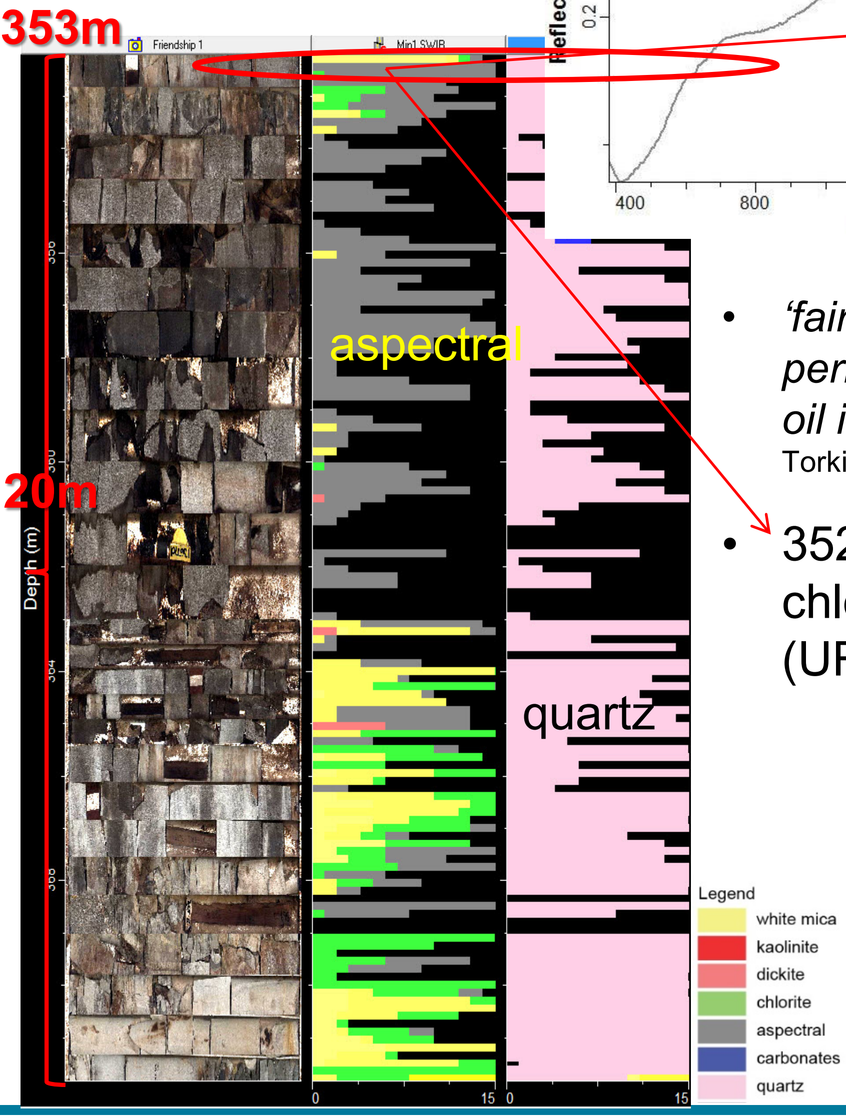
K-Feldspar + kaolinite →illite + quartz (cement)

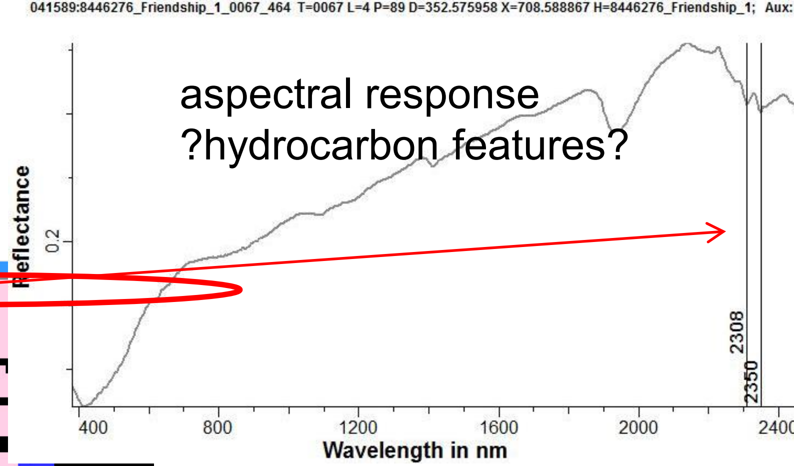
(Lanson et al, 2002)

Dickite is less susceptible to illitisation than kaolinite

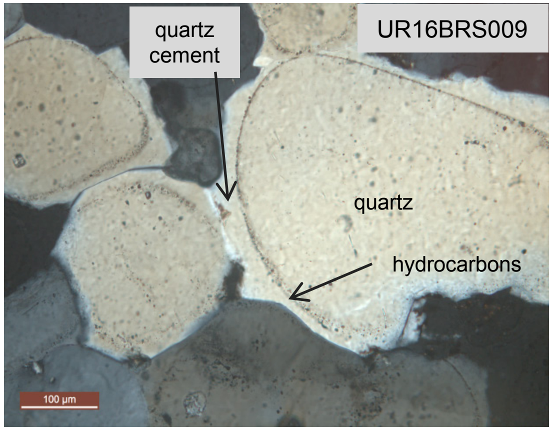
(Worden and Morad, 2003)

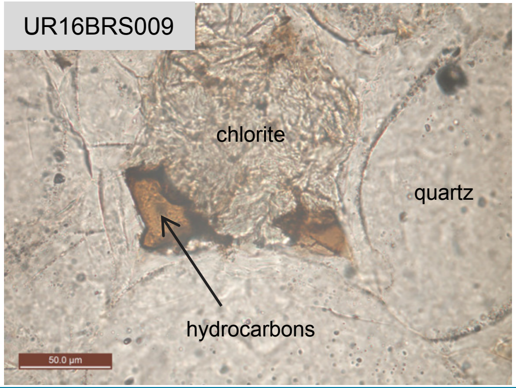
Friendship 1 hydrocarbons

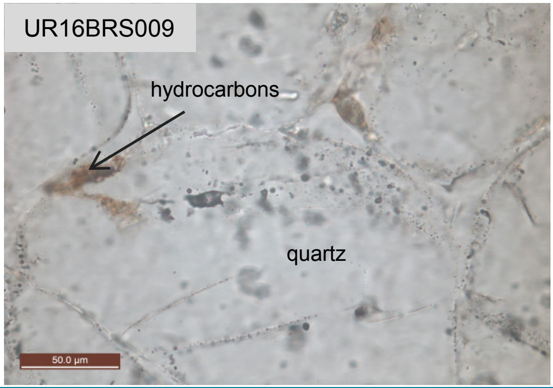




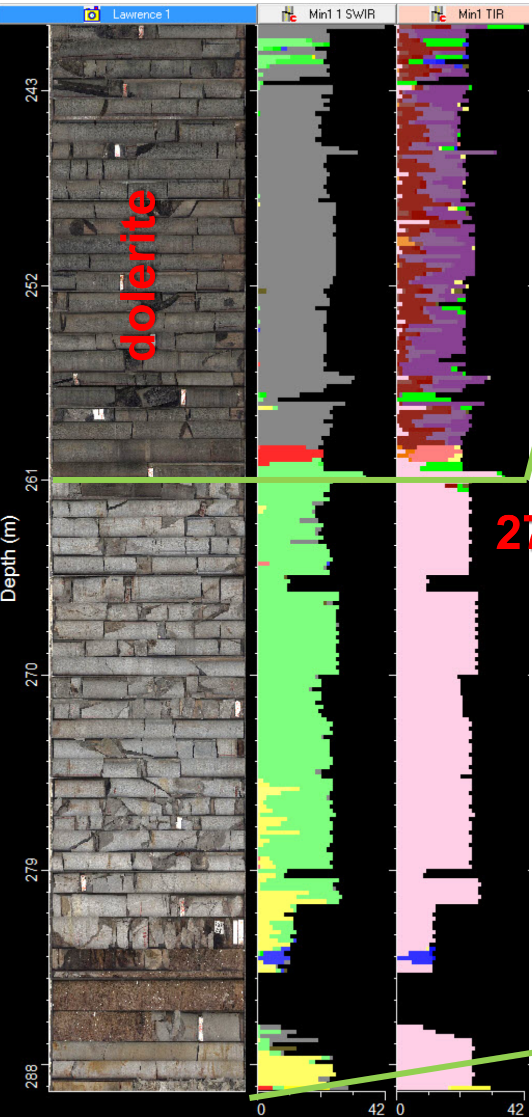
- *'fair oil shows… porosity and permeability preserved when oil is present'* (Ledlie and Torkington, 1988).
- 352.58m: quartz >80%; chlorite <2% (UR16BRS009)

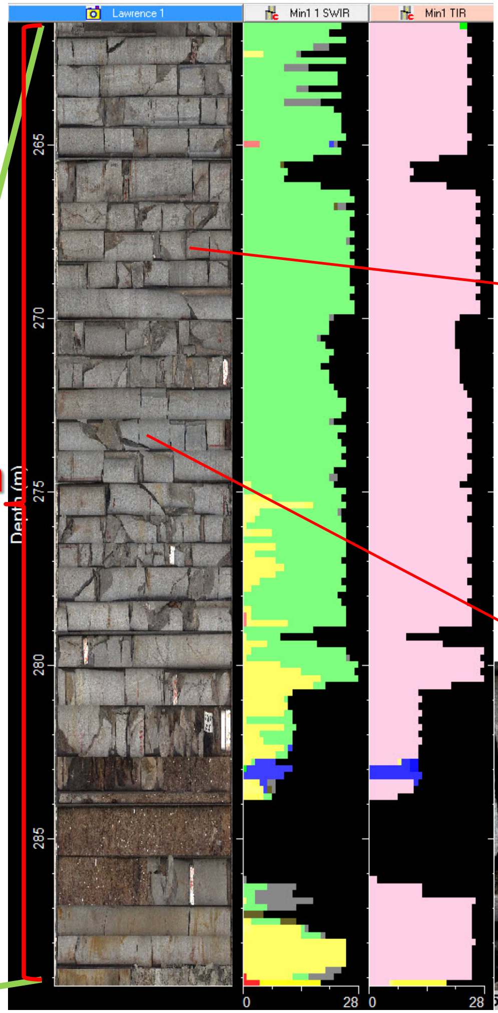


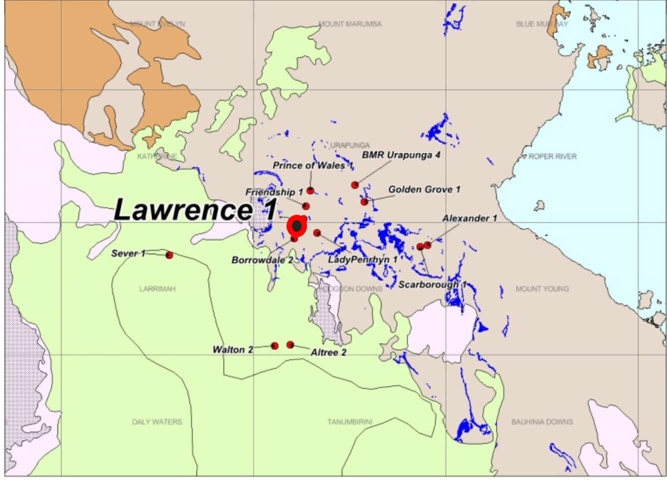




Lawrence 1 – chlorite





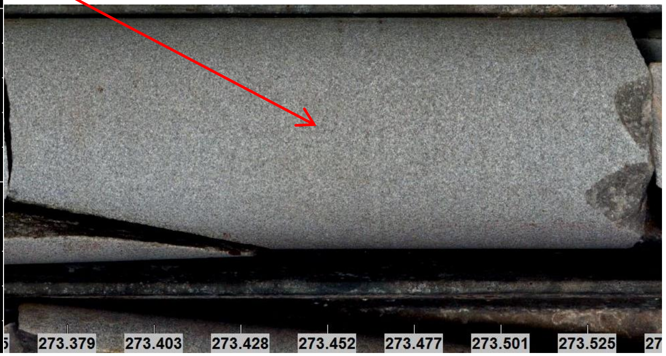


263.37m: quartz > 80%; chlorite (<2%), mica (<2%) chlorite> mica (XRD)

Chlorite could be from:

- Hydrothermal alteration
  - Compositionally immature sediments
  - Berthierine precursor from fluvial discharge

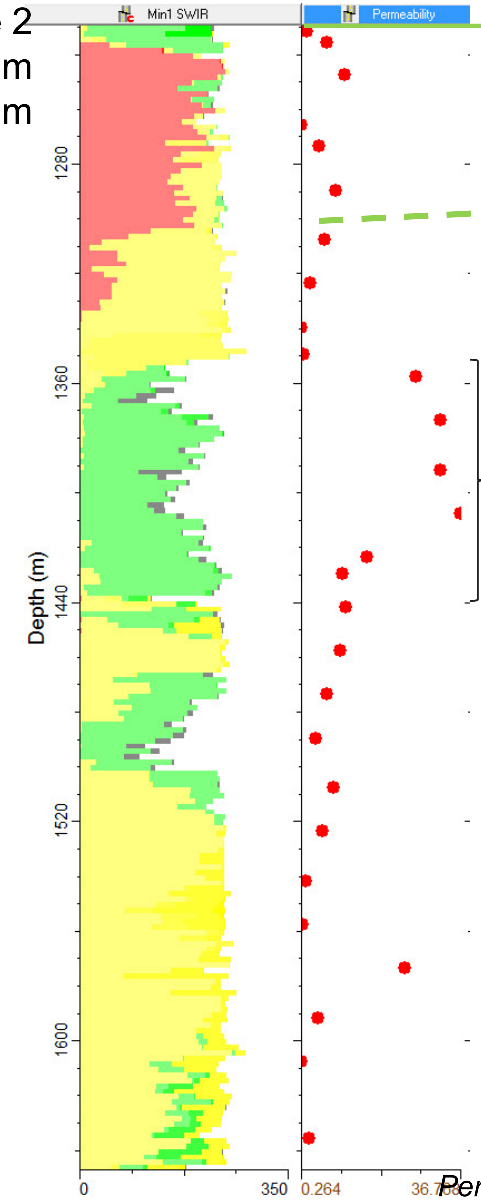
less likely



Legend
- white mica
- kaolinite
- dickite
- chlorite
- aspectral
- carbonates
- quartz

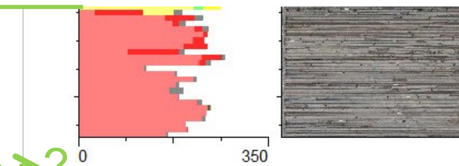
Beetaloo Sub-basin: Altree 2 and Walton 2

Altree 2
Formation Top: 1230m
Thickness: 417m



Higher permeability in upper chlorite zone

Legend
- white mica
- kaolinite
- dickite
- chlorite
- aspectral
- carbonates
- quartz

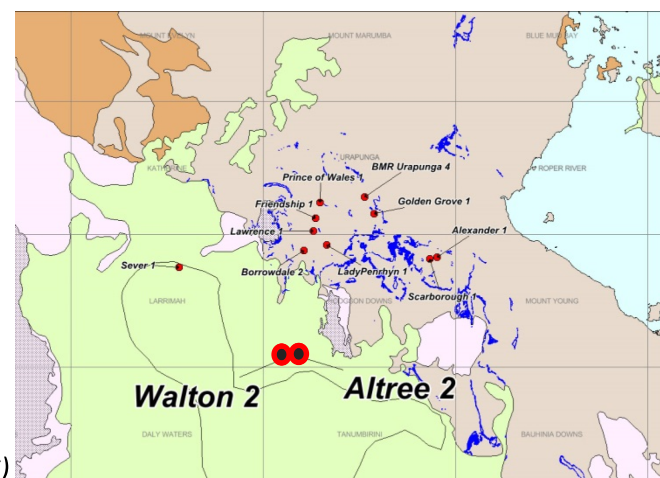


Walton 2
Formation Top: 970m
Thickness: 50+m (?)

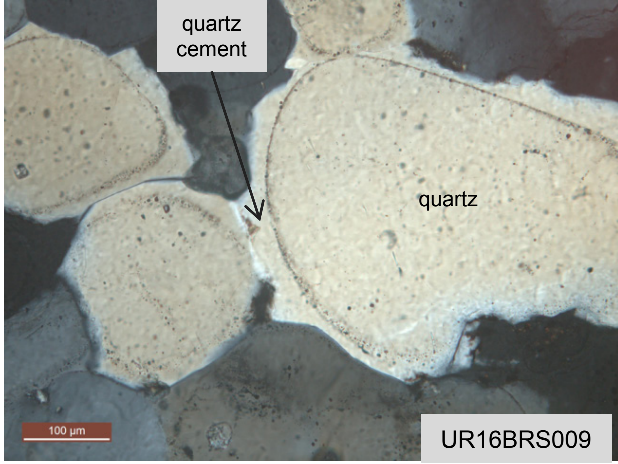
Hole ended in Bessie Creek Sandstone

Similar mineralogy at Formation top

Permeability data from Hallett (2016)



Diagenesis and Provenance



Diagenesis evidence from this study:

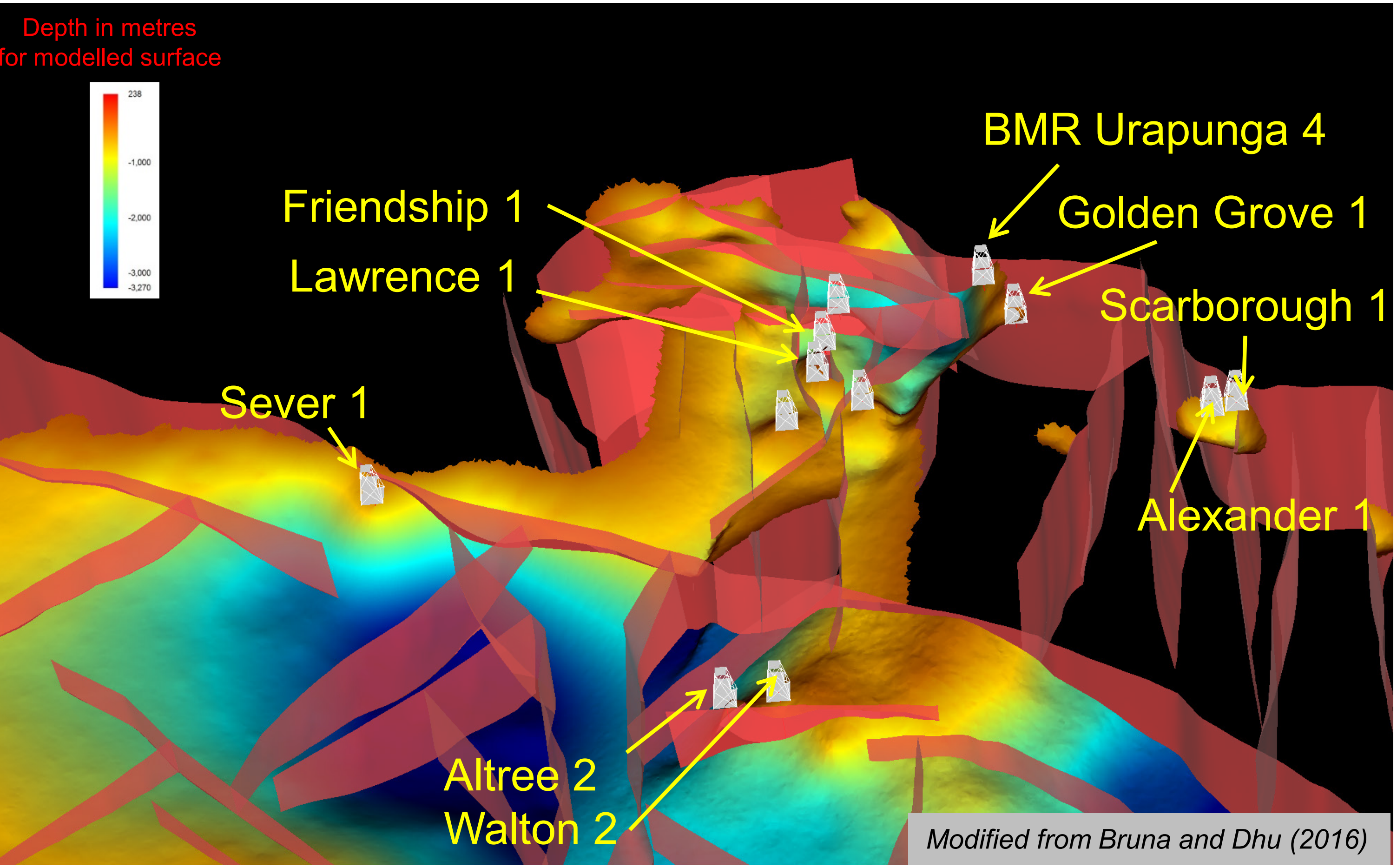
- quartz cement (petrographic evidence)
  - styolites (quartz dissolution; in HyLogger imagery)
  - quartz by-product from illite formation
  - quartz cement precipitating from ascending water during burial
- dickite formation (from kaolinite)
- illite formation (closed system from burial/compaction, smaller pore spaces)
- rare to no feldspars

Provenance:

- Clay mineralogy variations / abundance may be affected by original feldspar abundance, grainsize
  - quartz cementation
  - lack of feldspars

  } does not add evidence about provenance

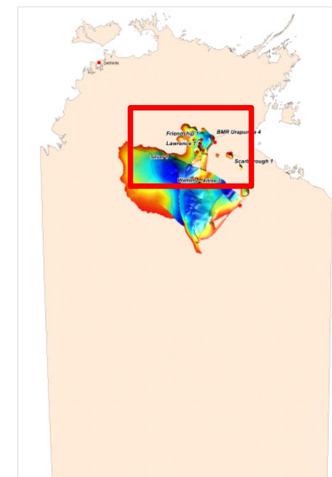
Bessie Creek Sandstone; mineralogy variations summary



Modified from Bruna and Dhu (2016)

Eastern wells

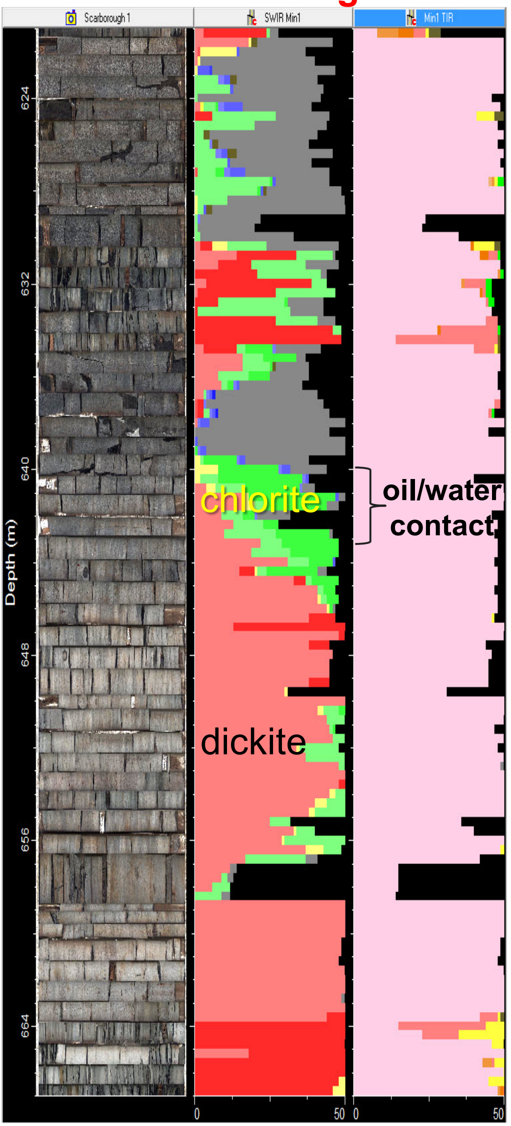
- dickite > kaolinite
- high water flow
- ‘open’ system
- Shallower wells
- 25-46m thickness



Sever 1: white mica (illite); 1168m / 60m thick. Restricted water flow (‘closed system’). NO KAOLINS
Friendship 1: upper aspectral zone has hydrocarbon emplacement before quartz cementation
Lawrence 1: minor chlorite (hydrothermal alteration from dolerite emplacement?)
Altree 2: deep, thick intercept – close to fault boundary?
Walton 2: shallower, unknown thickness (ended in Bessie Creek Sandstone); mineralogy reflects upper zone in Altree 2

Summary

Scarborough 1



- Bessie Creek Sandstone is quartzose, with minor authigenic clays (<2% to 15%)
- Spatial clay variations; kaolin group to east; illite to west
- HyLogger can identify clay variations downhole - eg; oil/water contact (Scarborough 1; see left)
- Friendship 1 petrographic results indicate that hydrocarbon emplacement is early (prior to quartz cementation)
- Chlorite zones may be from hydrothermal fluids resulting from dolerite emplacement (Lawrence 1)

NOT ‘montonous’ and ‘uniform’…. implications for understanding the Bessie Creek Sandstone reservoir potential

Acknowledgements

- HyLogging and TSG are trademarked by CSIRO.
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- Mineral Resources Tasmania prepared the samples and carried out the XRD and petrographic analyses. Funding of this work was through the AuScope NVCL.
- Darren Bowbridge scanned the core.
- Ben Williams and Tania Dhu exported the 3D imagery from Bruna and Dhu (2016).
- Tim Munson / Greg MacDonald / Kathy Johnston did reviewing, editing and drafting.

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