BACKGROUND INFORMATION ON SOEKOR WELLS IN THE KAROO BASIN

A locality map showing the location of the 23 deep wells drilled by SOEKOR in the Karoo Basin in the 1960s/70s is shown in Figure 1. These positions are shown in relation to some key physical/geological features of the Karoo Basin, i.e. the Great Escarpment, the southern limit of dolerite intrusions and the northerly limit of the sub-outcrop of the Cape Supergroup rocks. The information discussed in the sections below was gained from the archives of the Council for Geoscience and the CSIR, with some additional information on well construction from one of the SOEKOR technicians involved in the drilling programme. Two water samples were taken from well SA 1/66 by Prof. van Tonder/Fanie de Lange of the Institute for Groundwater Studies (IGS). Interpretation of some of the well log data has been done by Peter Rosewarne and is indicated as such in the text. Unless otherwise stated it can be assumed that all other information presented below was developed during work by the Karoo Groundwater Expert Group, sponsored by Shell. Further information can be found in the Karoo Groundwater Atlas Volume 2 on the SA Groundwater Division's website.

CONSTRUCTION

The information presented in this section is based on telephonic discussions in 2013 by Chris Esterhuyse of SRK with Andre Els, one of the SOEKOR technicians involved with the drilling programme in the 1960s and 70s. He explained that there were two types of rigs used for the oil exploration drilling. One was an oil rig (as he called it) which drilled larger diameter wells. This type of rig was used at Kareebosch (Murraysburg), Schietfontein (Aberdeen), Addo, Pearston, East London and Williston. A core rig was used for the other wells, which resulted in a smaller diameter well. A typical oil well (larger diameter) would be constructed as follows:

- 0-100 m: Drill 660 mm (26") and ream to 915 mm (36"). Install 760 mm (30") ID steel casing and pressure grout with Portland Cement.
- 600 m (1 500'): Drill 445 mm (17.5") and install 340 mm (13⅜") steel casing. Pressure grout with Portland Cement and install blow-out valve at top of casing.
- 3 000-4 000 m: Drill 311 mm (12¼") and install 245 mm (9⅝") steel casing. Pressure grout, normally with "Type G" cement imported from Holland. Temperature logs were recorded during drilling and that would determine the cement used. Blow-out valve is moved to this casing.
- EOH: Drill 216 mm (8.5") and leave this section of hole open.

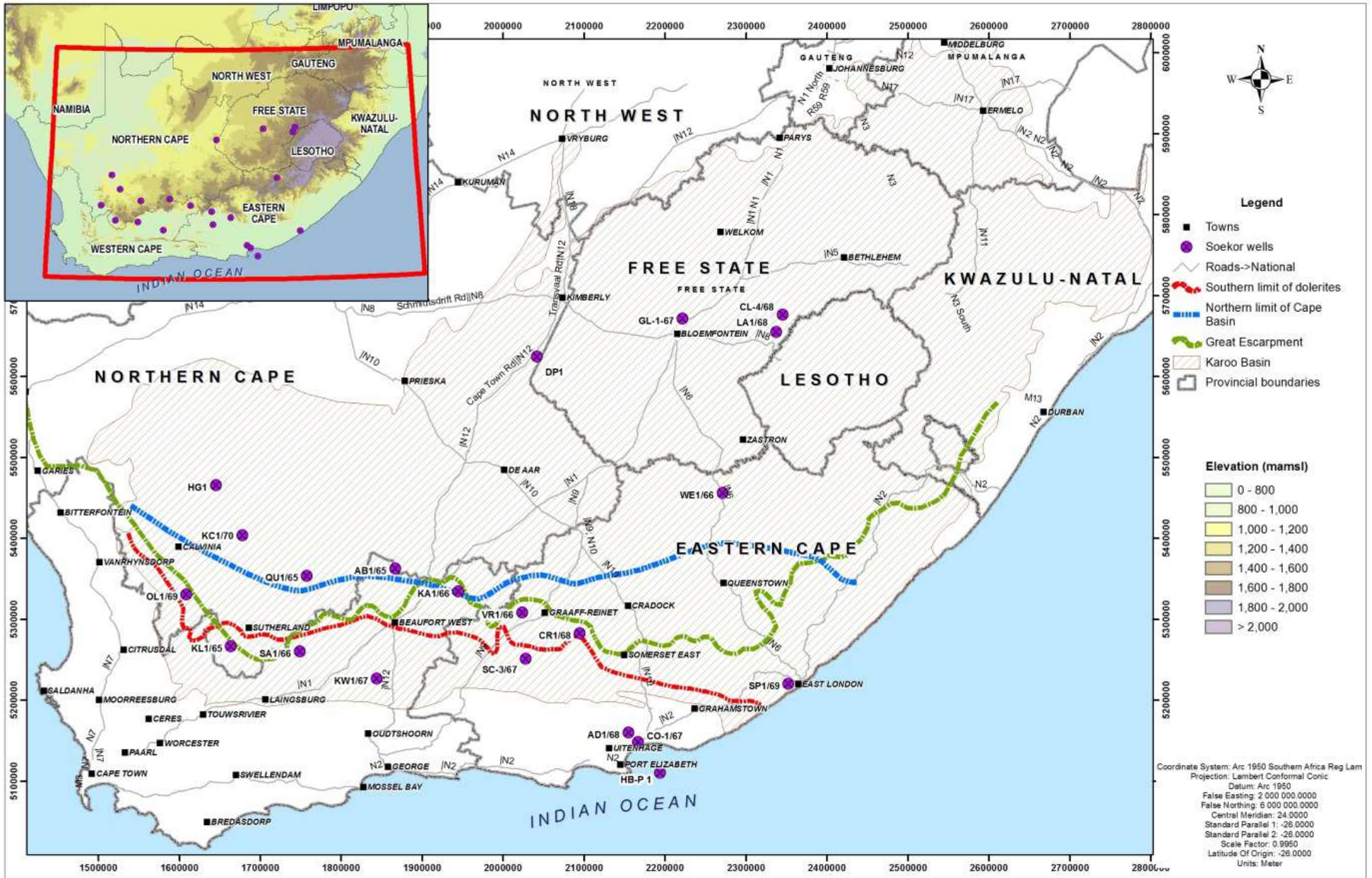
At the Aberdeen (Schietfontein) borehole, mud-loss occurred in the 216 mm section of the borehole and they had to install 178 mm (7.5") casing past this fracture zone to 4 877 m (16 000') depth. This casing was telescoped and grouted with 'Type G' cement (Not sure at what depth the top of this casing is, but it overlapped the larger casing "a few hundred foot". The bottom end of this well (16 000' – 21 000') is 165 mm (6.5") diameter.

Although Els did not work permanently on core rigs, he relieved core rig personnel from time to time (e.g. at Merweville). Thus his knowledge of the core rigs is not as detailed as the oil rigs, but he remembers that casing (127 mm ID) was installed to approximately 1 200 m (4 000') in these wells. Also there was only one casing string installed, with a short piece of surface casing (maximum 9 m) on top.

Some of the wells appear to have been fitted with 'taps'/valves at surface, presumably only those that showed artesian flow? This was how Prof. van Tonder obtained water samples from well SA 1/66 and

there was press coverage of him setting alight the gas escaping from this valve (not a recommended practice from a safety point of view!).

At well closure (most wells), a packer was installed *c*.30 m below surface and the section above this packer was filled with concrete (Portland Cement). The core rig drilled wells have a final diameter of 120 mm (4¾") and the nominal casing diameter is 127 mm (5"). These wells were also sealed as described above. However, it must be noted there that there is no site-specific information on well closure and the actual dimensions, composition and integrity of any such plugs is unknown. Attempting to open any such wells/plugs could be a dangerous undertaking and will require, *inter alia,* a hazard management assessment and should only be carried out by suitably experienced/qualified personnel after careful assessment of the risks and mitigation measures.



Data Source/Notes DWA (2013) Council for Geoscience (2013)	Project SOEKOR WELL POINTS	For proper clarity this drawing must be printed at A3 paper size	Scale 1:4 200 000	Compiled by GOES	Date 2014/09/23
	Title LOCALITY MAP			Reviewed by ROSW	Date 2014/09/23
				Project No	Fig No 1-1

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Revision: A Date: 23 09 2014

WELL LOGS

Copies of the original SOEKOR well logs have been obtained from the CGS and data pertaining to groundwater, where noted on the logs, has been extracted and a spreadsheet summary of such data is attached. It should be borne in mind that some of the wells were initially drilled in the 1940s and then deepened by SOEKOR in their later drilling programme. According to information contained in Blignaut *et al* 1953[1] some wells were sited on fold axes/domes (wells below Great Escarpment), i.e. on structures that could be favourable for oil occurrence but which would be avoided for shale gas wells because of the likelihood of fracturing.

Some key points arising from scrutiny of these logs are:

- Porosity of sandstones mostly *c*.0.5 per cent, but some >20 per cent;
- Numerous water strikes in wells below Great Escarpment to >4 000 m;
- Only 'flowing' water strikes observable, from the Ecca/Dwyka groups and Cape Supergroup (Table Mountain Group?); none in wells above the Great Escarpment;
- Artesian flows at surface of 1 to 3 L/s;
- Pressure heads of, e.g.:
    - 700 m at 674 m depth
    - 3 307 m at 3 215 m depth
- Water temperatures of 46 to 77ºC.

It is interpreted by Rosewarne that groundwater strikes were mainly noted in the wells below the Great Escarpment because these were the only wells to show artesian flow. With the coring drill method used, non-artesian flows would not be noted; only mud losses and fractures. Artesian flows are interpreted by Rosewarne to be as a result of the juxtaposition of the wells between the Cape Fold Belt Mountains to the south and the Great Escarpment to the north, and the presence of groundwater under pressure in the Cape Supergoup rocks underlying the Karoo Supergroup. In some cases the former rocks were penetrated by the wells and groundwater intersections/artesian flows noted. Numerous fractures were also recorded in the Dwyka Group in this area, which is attributed to proximity to the Cape Fold Belt.

There are references to water samples having been taken, e.g. this note from KL 1/65 at a water strike zone between 3 200 and 3 240 m depth – "3 samples water", but no trace has been found of any related chemical analyses. Alan Woodford (pers comm, 2013) reported that he left behind a box of SOEKOR data in the Cape Town office of the DWA when he left in 1998.

An example of the log of a well from below the Great Escarpment, VR 1/66, is shown in Table 1 and Figure below.

[1] Haughton, S.S., Blignaut, J.J.G, Rossouw, P.J., Spies, J.J. & Zagt, S. (1953): Resultate van die ondersoek in verband met die moontlike voorkoms van olie in Karoogesteentes in dele van die Unie van Suid-Africa, Mem. Geol. Opn. S. Afr., 45, 122p.

Well	Logs	Description		Comment
Vrede 1/66	master log	0- 3,837.7m	CSIR/CoG	
		fracturing @ 323.1m		
		Fracturing and Jointing @ 378m		
		434.3 - 481.6m occasional fracturing / methane recorded		
		653.8m Artesian Flow 0.6L/s		
		652.3 - 665.7m fracturing		
		673.6m Artesian Flow 1.0L/s @ 6867 kPa / 789.4m and 0.9L/s		Pressure head = 700 m therefore artesian head is c.26 m
		1,374.6m fracturing		
		1,475.2m jointing and fracturing		
		1,10.6m fissure and vertical jointing		
		1,920.2 - 1,932.7m Artesian Flow and Gas		Assumed that the individual flows are sealed off (grouted) i.e. each flow recorded is a new interception?
		2,194.6 - 2,206.5m Artesian Flow 0.5L/s		
		2,468.9m Artesian Flow 0.5 L/s		
		2,743.2m Artesian Flow 0.5 L/s		
		2,877.3m Massive Vertical, sub-vertical joints		
		3,020.7m Artesian Flow 0.5L/s sub vertical fracturing		
		3,090.7 - 3,121.2m no returns on drilling water		
		Water strike at c.3 200 m @ 46^{o}C		

Table 1: SUMMARY OF GROUNDWATER-RELATED INFORMATION FROM LOG OF VR 1/66

Project: Karoo Groundwater Atlas Vol. 2 **Page:** 1 of 1

Well No.: VR 1/66 **Drilling Method:** Core **Elevation (mamsl):** c.1046 m

Date Drilled: 1966 **X:** 2023575.08 **Water level:**

Depth: 3505.2 m **Y:** 5308425.82 **Logged By:** Soekor

Water Strike				Depth (m)	Graphic Log	Description	Formation	Group
Pressure (kPa)	TDS (mg/L)/ Temp (°C)	Artesian Flow (L/s)	Water Strikes					
6867		1.0 0.9	W W	0–1200		Interbedded sandstone, shale & siltstone (fracturing at 323 / 378 / 440 / 660) Dolerite Interbedded sandstone, shale & siltstone	Abrahamskraal	Beaufort
		0.5 0.5 0.5 0.5	W W W W	1300–2700		Interbedded sandstone, shale & siltstone (fracturing at 1374 / 1475)		Ecca
				2700–2800		Dark grey shale Black to dark grey shale	Whitehill Prince Albert	
				2800–3300		Diamictite		Dwyka
				3300–3500		Sandstone End of Borehole		Cape Supergroup

Lithological Log

Client: Shell **Project No.:** 443692

Project Location: Karoo

GROUNDWATER QUALITY

There are no known examples of water quality analyses of samples taken from the SOEKOR wells at the time of drilling. In one log it is noted that water samples were taken but no record has been found of any chemical analyses being carried out. Some information is available on TDS and temperature of groundwater and some logs record 'sodium chloride' in mg/L TDS, although this may refer to the drilling mud. A maximum TDS indicated is *c*.10 000 mg/L at *c*.3 000 m. It is possible that the TDS of any deep groundwater occurring north of the sub-outcrop of the Cape Supergroup rocks could be higher than this.

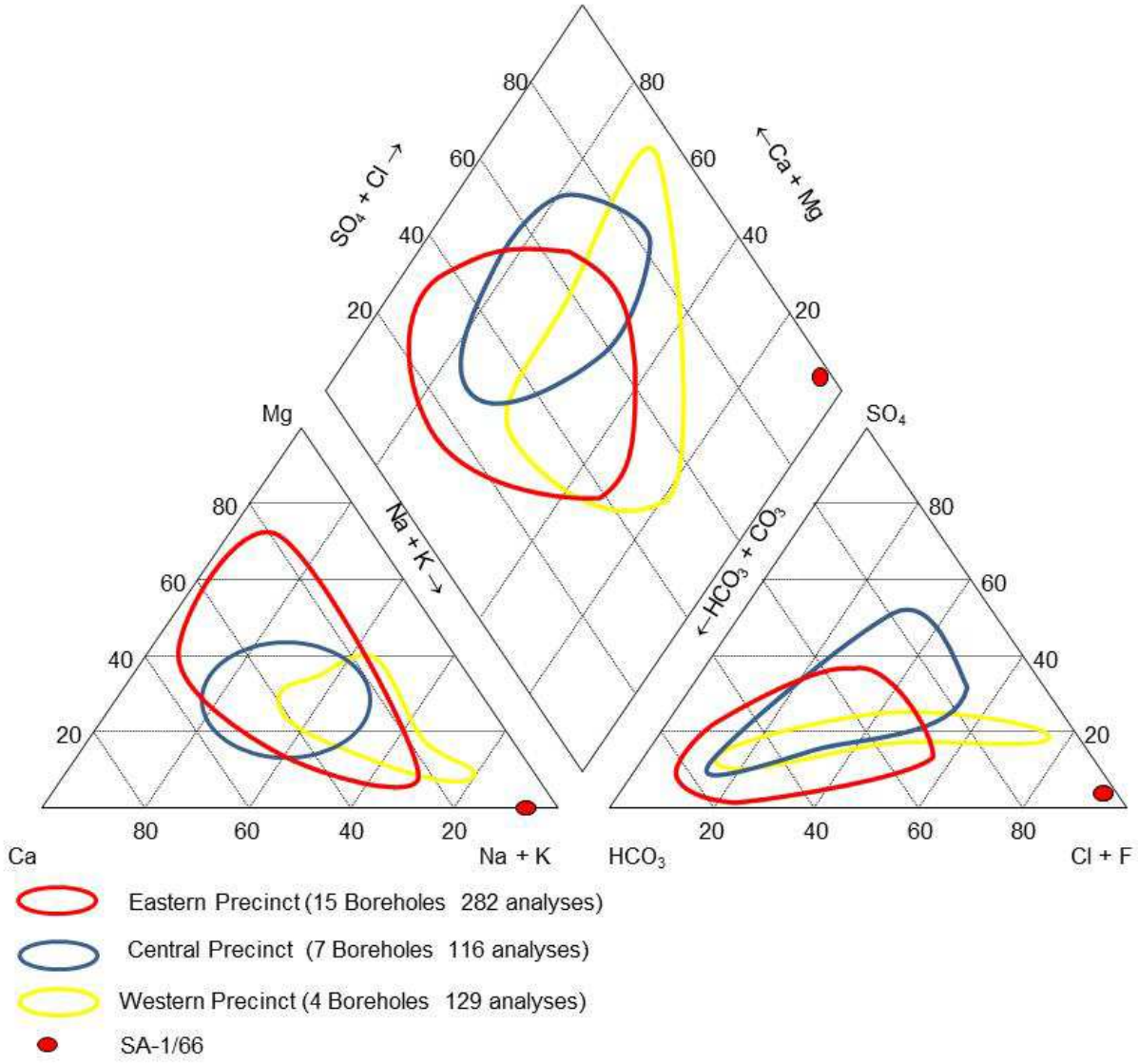
The only chemical analyses available are those from two samples taken in September 2012 and September 2013 by the IGS. These analyses have been plotted on a Piper Diagram (see Figure on next page), with comparison with groundwater quality from the shallow (<300 m) aquifer in the form of the Department of Water and Sanitation's CHART monitoring boreholes (shallow aquifer). The precincts referred to in the Legend are those of the Shell license application areas. It can be seen that the samples plot in a totally different position to the shallow groundwater. The samples also show relatively high concentrations of Br, B Sr and F, unsurprisingly perhaps as these ions are 8th, 9th, 10th and 11th on the list of most common ions in sea water. However, it must be noted that there is no information on the depth at which this water is entering the well and it has lain stagnant for decades.

WAY FORWARD

The first issue to be tackled, if it is decided to carry out investigations at selected SOEKOR wells, is formulation of a safe procedure to gain access to the wells. According to the information obtained on construction, each well has a *c*.30 m concrete plug in place. A few have valves/taps installed. A hazard assessment and protocol for obtaining safe access to the wells will need to be drawn-up but are not included in this summary (see important cautions in last paragraphs on p2 and p9).

Some ideas for issues that could be investigated by using existing SOEKOR wells, if they are found to be safely accessible and suitable, are:

- Is there any indication that the shallow aquifer has been contaminated by the SOEKOR drilling/wells?
- If so, what processes are dominant?
- If present, how far has contamination spread (however, there is no pre-SOEKOR drilling baseline for comparison)?
- What is the nature of any contamination?
- Can samples of water from deep levels be safely collected for analysis and if so what does this tell us?
- Is methane (and other gases) present in the groundwater and what is its origin?
- Are there any structures associated with these well sites? (some are known to have been purposely sited on folds/'domes')


80
60
40
20
$SO_4 + Cl$
$Ca + Mg$
Mg
SO_4
$Na + K$
$HCO_3 + CO_3$
Ca
$Na + K$
HCO_3
$Cl + F$
Eastern Precinct (15 Boreholes 282 analyses)
Central Precinct (7 Boreholes 116 analyses)
Western Precinct (4 Boreholes 129 analyses)
SA-1/66

Possible activities at selected SOEKOR well sites, if they are found to be safely accessible and suitable, could include:

- Hydrocensus;
- Surface geophysics;
- Installation of shallow exploratory percussion-drilled holes around each well.

In the SOEKOR wells themselves, if they are found to be safely accessible and suitable:

- Downhole camera and geophysical logging;
- Depth sampling of water for detailed chemical analysis (temperature, major ions, trace elements, gases and isotopes);
- Packer testing at depth, to obtain K values and pressures.

However, although the wells are in place and may appear to represent an opportunity for 'free' access to the deeper formations, this needs to be balanced by i) the cost of securing safe access and ii) the risk that expensive downhole probing might ultimately indicate that the wells are unsuitable for robust scientific hydrogeological research purposes. Identifying trial well sites for such initial investigation, if at all, e.g. one below the Great Escarpment and one above, might be a prudent approach.

Peter Rosewarne

Karoo Groundwater Expert Group

November 21 2014

Well	Logs	Description		KGEG Comment
KL 1/65	Master log	0- 3,448.2m (11,313 ft)	CSIR/CoG	
	Well log	548.6m (1800 ft) Fracture Zone	CSIR/CoG	
		Artesian Flow proved below 935.7m (3070ft)		
		983m (3225 ft) 0.15L/s (120 gph) cemented Artesian Flow / Fissure with crystals		Karoo Handbook Table 3.13 (After Kent, 1969) depth of 1006m, TDS 1,390mg/L, pH 8.9
		1,014.7m (3329 ft), 0.08L/s (60 gph) cementation attempted redrilled Artesian Flow reopened 0.15L/s (120 gph)		
		Reaming from 1030.5-1,595.3m (3381-5234ft) , Artesian Flow opened (increased to?) 1.3L/s (1000 gph)		Karoo Handbook Table 3.13 (After Kent, 1969) depths of 2,347+3,184m, Flow 1.2L/s, TDS 10,010mg/L, pH 7.5
		1,633.7m (5360 ft) 70% methane 1.83% ethane		
		1,849m (6078 ft) mud blown 60' above collar, cellar flooded		Would be great if we could get more info on water quality (i.e. at what depth did the TDS change dramatically/ was it a gradual change)
		2,048.6 - 2,065.0m (6721-6775ft) blow-out		
		> 2283 - 2,394.5m (>7490-7856ft) methane present		
		2999m (9840 ft) Artesian Flow opened while drilling		
		3,227.8m (10590 ft) Artesian Flow 1.9L/s (1500 gph) @ 250 psi 172 kPa. 49°C		Pressure head of only 17.5 m - Doesn't make sense
		3,261.4 - 3,346.7m (10700-10980 ft) increased porosity / cavities @ 3,308.6m (10855 ft) / Artesian Flow 3,346.7m (10980 ft)		
		3 215 m artesian flow; 4 561 psi (31 448 kPa) = pressure head of 3 307 m @ c.50^{o}C in TMG		3 water samples taken. Artesian pressure head of c.92 m
		3,369.6m (11055 ft) swamp		Not sure what this means - waterlogging of site due to artesian flow?
	Chromatologs		CoG	
	well sheet data		CoG	
	borehole		CoG	
	Strat log		CoG	
	Progress chart		CoG	
	Composite logs		CoG	

Well	Logs	Description	KGEG Comment
SA 1/66	well logs	2,879.1 - 4,236.7m (9446-13900ft) sheets joined together	
		lithology description	
		Multiple fracturing throughout Tillite 3,142.2 - 3,158m (10309-10361 ft) / 3,198.9 - 3,223.9m (10495-10577ft)	
		Artesian Flow @ 3,206.2m (10519ft) with 3.0 L/s (2400 g/hr). TDS 8 745 ppm.	Karoo Handbook Table 3.13 (After Kent, 1969) has more detailed info on artesian flow with depth (3 flow records up to 3.7L/s, also temperature, TDS and pH records. I think this info plus water chemistry may be 'lost' at DWA - thermal waters was Kent's 'pet project'.
		100 psi pressure (689 kPa) = 70 m pressure head. 46°F. V high gas content	
		Multiple fracturing throughout Tillite 10890-11009/11011-11025 11518-11674/11705-11706/ 11892-11893	100 psi doesn't make sense
		Fracture @ 3,676.8m (12063ft)	
		TDS readings - 3 962 m - 3 465 ppm (NaCl); 3 992 m - 2 890 ppm (NaCl); 4 028-4 148 m - 2 970 ppm (NaCl)	
		1.Chromatologs 2.Composite logs 3.Well logs 4.final log	1. (7169 – 12664 feet) (11 scans) 2. (5 scans) 3.(9446 to 13697 feet) (3 scans) 4.(0 to 13697 feet) (1 scan)

Well	Logs	Description	KGEG Comment
CR 1/68	well logs	900-15282ft 16 sheets	
		lithology and description, gas occurrence, drilling rate	May be use to extract the occurrence of gas?
		3,090.7m (10140ft) cementation attempt	Was this due to an open fissure resulting in mud-loss (i.e. sub-artesian water)?
		3,884.7m (12745ft) no water return Tillite	???
		No mention of water strike	
		1.Chromatologs 2.Well logs	1. 50 to 15282 feet (16 scans) 2. 900 to 1582 feet (16 scans)

Well	Logs	Description		KGEG Comment
Vrede 1/66	master log	0- 3,837.7m	CSIR/CoG	
		fracturing @ 323.1m		
		Fracturing and Jointing @ 378m		
		434.3 - 481.6m occasional fracturing / methane recorded		
		653.8m Artesian Flow 0.6L/s		
		652.3 - 665.7m fracturing		
		673.6m Artesian Flow 1.0L/s @ 6867 kPa / 789.4m and 0.9L/s		Pressure head = 700 m therefore artesian head is c.26 m
		1,374.6m fracturing		
		1,475.2m jointing and fracturing		
		1,10.6m fissure and vertical jointing		
		1,920.2 - 1,932.7m Artesian Flow and Gas		Assumed that the individual flows are sealed off (grouted) i.e. each flow recorded is a new interception?
		2,194.6 - 2,206.5m Artesian Flow 0.5L/s		
		2,468.9m Artesian Flow 0.5 L/s		
		2,743.2m Artesian Flow 0.5 L/s		
		2,877.3m Massive Vertical, sub-vertical joints		
		3,020.7m Artesian Flow 0.5L/s sub vertical fracturing		
		3,090.7 - 3,121.2m no returns on drilling water		

Well	Logs	Description
WE 1/66	well log	5400-12291 ft brief lithology description with No water strike mentioned
	final log	900- 9000
	includes gamma log; neutron log; density log and caliper log	
	1.Chromatologs 2. master logs 3.well logs 4.final log	1. 0 to 12291 feet (19 scans) 2. 0 to 4500 feet (5 scans) 3. 0 to 12291 feet (14 scans) 4. 0 to 9000 feet (1 scan)

Well	Logs	Description
KD 1/71	well log	0-1771m
		very brief lithology description
		No mention of water strikes

Well	Logs	Description
AB 1/65	well logs	0-2,281.4m (7485ft) 21 sheets
		Lithology with detailed description
		No mention of water strike or fracturing
		4360ft core-loss but no mention why, view other logs
		4540ft core-loss but no mention why
	1.Chromatologs 2. Composite logs 3.well logs 4. master logs 5. sample analysis	1. (1774 to 7570 feet) (9 scans) 2. (0 to 7550 feet) (45 scans) 3. (0 to 7435 feet) (21 scans) 4. (0 to 7583 feet) (9 scans) 5.(1 scan)

Well	Logs	Description	
OL 1/69	Well Log	0-1219.m (4000 ft); Lithology Stratigraphy	CSIR/CoG
		1092.7m (3585 ft) porous crs	
		No mention of water strikes	

Well	Logs	Description
WI 1/72	composite data sheet incl. gamma log; neutron log; density log; sonic log; micro log; electric log and guard log	0-1520m with lithological description; no water strike mentioned

Well	Logs	Description
QU 1/65	well logs	0-1080 ft
		0-720 ft detailed lithology
		No mention of water strike
	1.Chromatologs 2.Composite logs 3.master logs 4.well logs 5.Specific gravity 6. final log 7.radioactivity log 8. lithology 9.Progress charts 10 Geophysical log	1. As above (6574 to 7282 feet) (2 scans) 2. As above (0 to 5100 feet) (30 scans) 3. As above (0 to 8300 feet) (10 scans) 4. 0 to 800 feet (3 scans) 5.graph (1 scan) 6. Gamma ray log; neutron log; rock description (0 to 8300 feet) (1 scan) 7. (4600 to 8300 feet) (1 scan) 8.(1 scan) 9. 3rd and 4th quarters for 1966 10. Gamma ray log; neutron log; guard log; electric log (500 to 740 feet) (1 scan)

Well	Logs	Description	
KA 1/66	well logs	0-222.5m	
		6300-7200ft	
		Min. info on lithology and description, gas occurrence	
		7200-8100ft	
		Min. info on lithology and description	
		1.Sample analysis 2. well logs 3. master log	1. (1 scan) 2. 0 to 8100 feet (9 scans) 3. 0 to 5100 feet (8 scans)

Well	Logs	Description
KC 1/70	Well log	0-1745 m
		very brief lithology description
		No mention of water strikes

Well	Logs	Description	KGEG Comment
SC 3/67	well logs	0-2700ft / 3600-18240ft 20 sheets	Below escarpment would expect artesian water in Dwyka?
		lithology description, drilling rates, gas occurrence	
		4,778 - 4,788.7m (15676-15711ft) symbol to water	What does this mean?
		4,903.6 - 4,930m (16088-16175ft) symbol to water	What does this mean?
		5,020.7 - 5,029.8m (16472-16502ft) m/c water	What does m/c mean?
		Well logs	0 to 18240 feet (11 scans)