OPEN FILE PROGRESS REPORT ON INVESTIGATION OF THE SOUTHEASTERN MAIN KAROO BASIN THROUGH CIMERA-KARIN BOREHOLE KWV-1 NEAR WILLOWVALE IN THE EASTERN CAPE PROVINCE

by M.O. de Kock, N.J. Beukes, H.S. van Niekerk, D. Cole, K. Robey, A. Birch, and A.E. Götz

ABSTRACT

CIMERA-KARIN drilled a deep borehole (KWV-1) near Willowvale in the Eastern Cape Province in order to explore the geology and, in particular, the shale gas potential in the south-eastern part of the Main Karoo Basin. What follows is an open file report to the community and all other interested parties on the initial results from the borehole. The borehole was drilled in an area with known abundant intrusive dolerites in order to compare results with the first hole that CIMERA-KARIN drilled near Ceres in the Tankwa Karoo in a dolerite-free area.

Borehole KWV-1 intersected a much thicker stratigraphic succession before reaching the Whitehill Formation target than what was expected. The formation was intersected at a depth of 2294.89 m, that is, some 600 m deeper than the earlier predicted depth of 1700 m. The borehole was collared in grey mudstone and sandstone of the Balfour Formation of the Beaufort Group and stopped at a depth of 2353 m after intersecting 14.7 m of Dwyka diamictite below the contact with the Prince Albert Formation. An interesting aspect of the stratigraphic succession in the area is that the Pluto's Vale sandstone member of the Ripon Formation is much thicker than what it is in its type area at the Ecca Pass near Grahamstown. Tuff beds are also very poorly developed and scarce in the succession that is correlated with the Collingham Formation. The Whitehill Formation has a thickness of 13.05 m and is intruded by a 18.76 m-thick dolerite sill. Several dolerite sills were intersected, with the thickest one 149 m thick and composed of several intrusions. The borehole was essentially dry, yielding very little groundwater.

Nine one-meter length samples of carbonaceous mudstones were collected for quantifying natural gas content. Six of these came from shale in the Ripon Formation and three from the Whitehill Formation. Except for one or two samples from the Ripon Formation, all of these samples yielded no free gas and/or residual gas. RockEval analyses of the samples indicated a high maturity, but with organic carbon contents of 0.22 to 6.27 wt %. The shale gas potential of this part of the Main Karoo Basin can thus be considered to be essentially zero.

INTRODUCTION

The Karoo Research Initiative (KARIN) is an academic study of the geology of the Karoo Supergroup, with special reference to its shale gas potential, by geoscientists from six of South Africa's leading universities, Keele University in the United Kingdom, and the Council for Geosciences (CGS) of South Africa. KARIN is incorporated under the DST-NRF Centre of Excellence for Integrated Mineral and Energy Resource Analysis (CIMERA). The principal aim of KARIN is to investigate the southern part of the Main Karoo Basin through the extraction of deep drill cores. The first of these boreholes (KZF-01) in the Tankwa Karoo near Ceres in the Western Cape Province was successfully completed to a final depth of 671 m in August 2015, and was reported on earlier (De Kock et al., 2015). This report deals with the second borehole (KWV-1) that was drilled near

Willowvale in the Eastern Cape Province (Fig. 1). Drilling commenced on 2 September 2015 and was completed at a final depth of 2353.48 m on 11 December, 2015.

Wireline geophysical logging and sampling of groundwater in the borehole took place in the second half of January, 2016.

The Karoo succession of rocks (i.e., Karoo Supergroup; Fig. 1) was deposited some 300 to 183 million years ago in the area, now represented by the southern part of the African continent (Catuneanu et al., 2005; Johnson et al., 1996). The sedimentary succession attains a maximum cumulative thickness of 12 km along the southern margin of the Main Karoo Basin, a large erosional remnant of the Karoo Supergroup that now covers approximately two-thirds of South Africa. Here the basin is bounded in the south by the Cape Fold Belt, a narrow zone of crustal shortening and thickening, now represented by the Cape Folded Mountain Belt, which developed in response to Late Paleozoic and Mesozoic subduction along this margin of Gondwanaland (Hansma et al., 2016; Tankard et al., 2009). The fill of the Main Karoo Basin thins dramatically northwards, to produce a highly asymmetrical basin. The palaeo-environmental settings of the basin fill reflect changing climatic conditions as Gondwanaland drifted from high latitudes towards the equator (Johnson et al., 1996; Tankard et al., 2009). Sedimentary fill is glacial at the base (the Dwyka Group) before it transitions through carbonaceous marine conditions, including deep water submarine fans in the south of the basin, into fluvial-deltaic conditions (the Ecca Group). Terrestrial fluvio-lacustrine strata of the Beaufort Group follow, and ultimately the sedimentary basin fill became dominated by fluvial and aeolian sandstones (the Molteno, Elliot and Clarens formations of the Stormberg Group) deposited in an increasingly arid climate (Smith, 1990, 1993). Sedimentation in the basin was terminated at ca. 183 Ma ago with the emplacement and extrusion of the Karoo large igneous province (LIP), which includes the outpouring of at least 1400 m of basaltic lavas (the Drakensberg Group) from a large feeder network of dolerite sills and dykes (Jourdan et al., 2005; Svensen et al., 2012). The Karoo Supergroup and, in particular, the Ecca Group, contain all

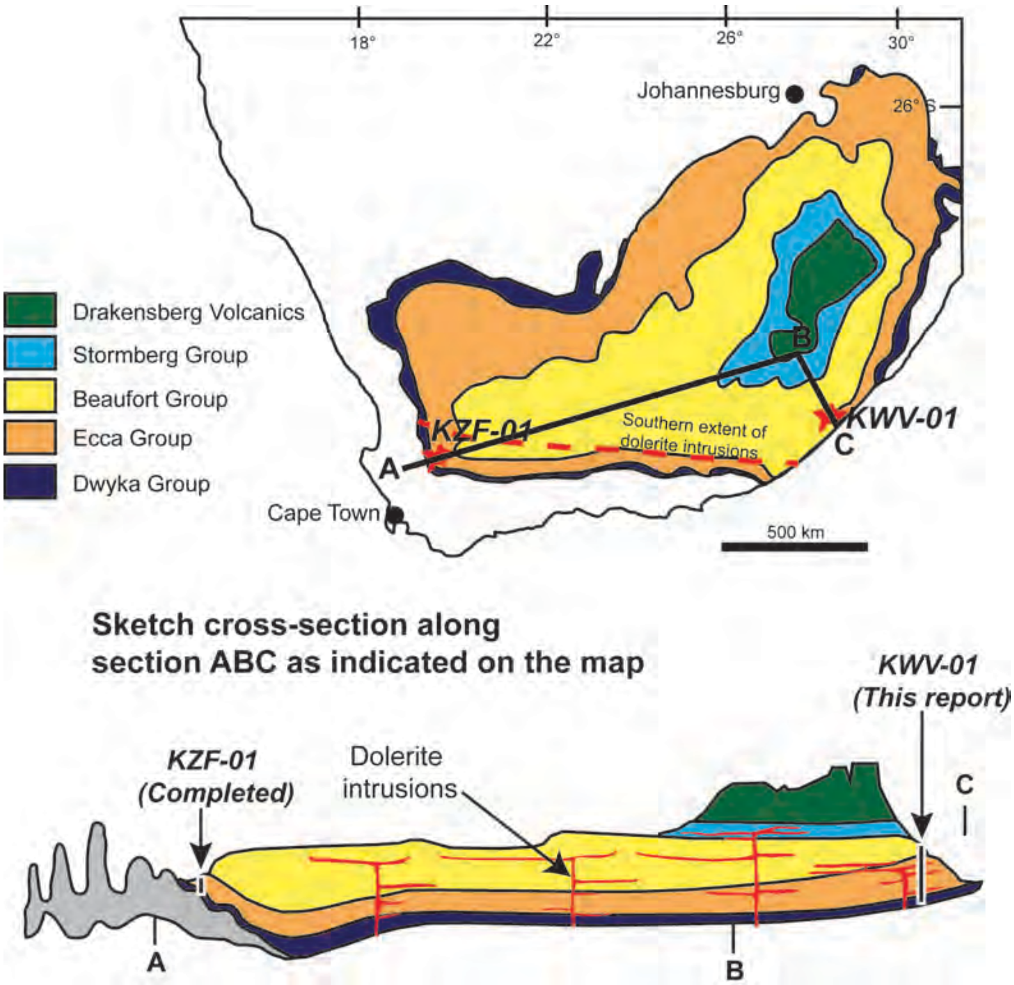

Fig. 1. Simplified geological map and cross section of the Karoo Basin of South Africa and the southern most positions of dolerite intrusions (i.e., the so-called “dolerite line”). The positions of borehole KWV-01 and KZF-01 are indicated.

of the important coal deposits of South Africa (Hancox and Götz, 2014) as well as black carbonaceous shale that are a potential source of shale gas (Geel et al., 2013).

The character of the Ecca Group varies considerably across the basin. It has been divided into several lithostratigraphic units in a number of representative type areas (Johnson, 2009). In the southeastern part of the Main Karoo Basin in the surroundings of the drill site, the Karoo Supergroup is represented, from the base upwards, by the Dwyka Group, the Ecca Group and the lower Balfour Formation of the Beaufort Group, with abundant dolerite sills. Borehole KWV-1 (Fig. 2) was collared in the Balfour Formation and intersected the entire Ecca Group down into the Dwyka Group. The Ecca Group in the area is subdivided from the base upwards into the Prince Albert, Whitehill, Collingham, Ripon, Fort Brown and Waterford formations. The Ripon Formation is, in turn, subdivided, from the base upwards, into the Pluto's Vale (mainly sandstone), Wonderfontein (mainly shale), and Trumpeters (mainly sandstone) members. The carbonaceous Prince Albert and Whitehill formations, in particular, have been identified for their shale gas potential (Decker and Marot, 2012), but this remains largely unquantified.

SCIENTIFIC OBJECTIVES

Drill core from boreholes planned by CIMERA-KARIN will allow for reconstructing the depositional history of the Karoo Basin, and the determination of the physical and petrochemical character of the rock succession. New data will assist in unraveling the deep structure of the basin, and will elucidate the effect and distribution of dolerite intrusions on and within the succession.

Specific objectives of the initial phase of the project are:

A) An improved understanding of the stratigraphy (litho- and chrono-stratigraphy) and structure of the southern Karoo Basin
B) Studying of microfossil assemblages towards establishing a biostratigraphic framework for the Ecca Group
C) Studying the total organic carbon content of rocks to gain insights into the thermal evolution of the Main Karoo Basin and the shale gas potential of the Ecca Group and, more specifically, the Whitehill Formation

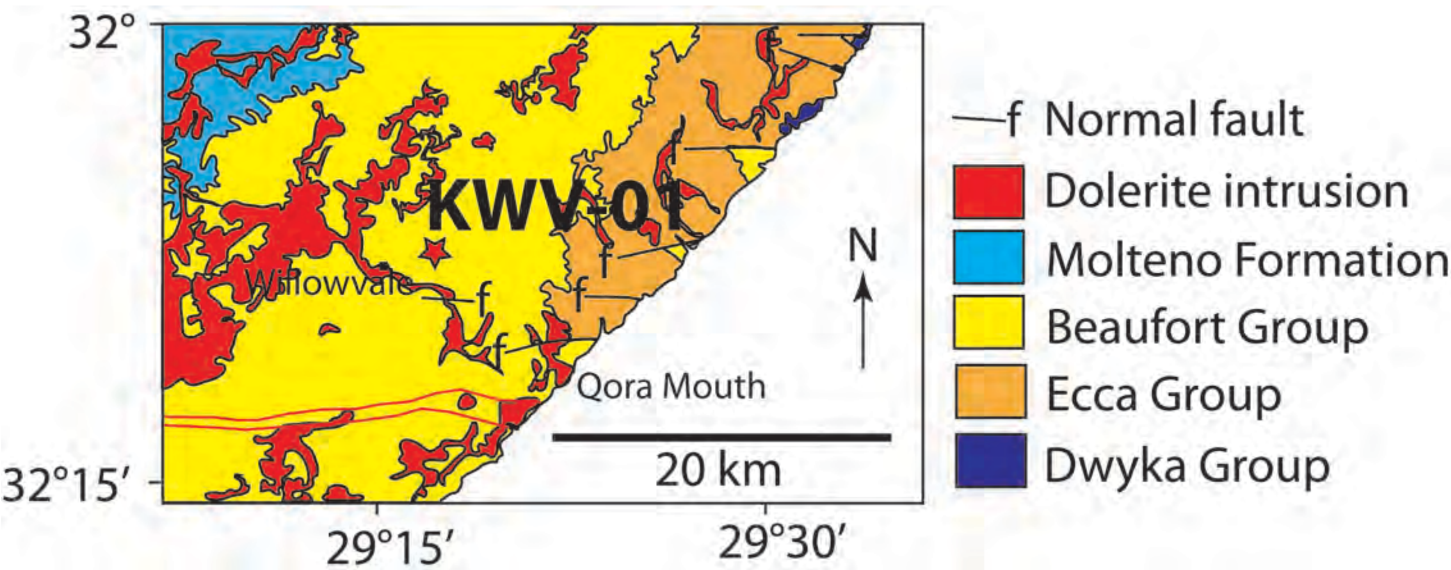

Fig. 2. Regional geology of drill site KWV-01 showing abundant dolerite sill and dyke intrusions. The locality of Willowvale and Qora Mouth are shown for reference relative to the drill site. Map was modified from the 1:250 000 scale 3228 Kei Mouth mapsheet of the Council for Geoscience.

D) Studying the paleomagnetic record towards establishing a magneto-stratigraphic framework for the Karoo Basin

E) Characterization of the hydro-geological conditions and water quality of the deep and shallow aquifer systems in the southern Main Karoo Basin, to analyse the potential risks if there are interactions between the deep and shallow aquifer systems during shale gas exploration and production.

KARIN further generally aims to equip South African postgraduate students with the necessary high-level skills to pursue research, and ultimately careers, in relevant fields. Such capacity building represents a fundamental shift to expand the expertise of South African graduates beyond the traditional national strengths, in the Main Karoo Basin or elsewhere.

DRILLING AND OPERATIONAL STRATEGY

The drill site for borehole KWV-1 (S32 14' 41'' E28 35' 08''; Fig. 1 and Fig. 2) was selected immediately east of Willowvale in a defunct road quarry on the road to Dwesa Nature Reserve (Fig. 3). The locality was selected because of a virtual total lack of information on the detailed stratigraphy of the Karoo succession in the area and also because of abundant dolerite intrusions that allows investigation of the effect of these intrusions on the maturity of organic matter in the sedimentary rocks.

Geoserve Exploration Drilling (Pty) Ltd. was identified as the service provider of choice following a thorough tender process. Drilling was preceded by extensive engagement with the community under leadership of the local tribal chief, setup of a detailed Environmental Management Plan (EMP) by the AGES group of Potchefstroom, and obtaining permission from the Departments of Environmental Affairs, Water and Roads of the Eastern Cape Province. In addition, sampling of surface and shallow groundwater systems was undertaken in the surroundings of the drill site, in conjunction with the CGS and the Institute of Groundwater Studies (IGS) at the University of the Free State. The EMP and drilling progress reports by Geoserve are available on the CIMERA-KARIN website (http://www.cimera.co.za/index.php/karin-feedback) .

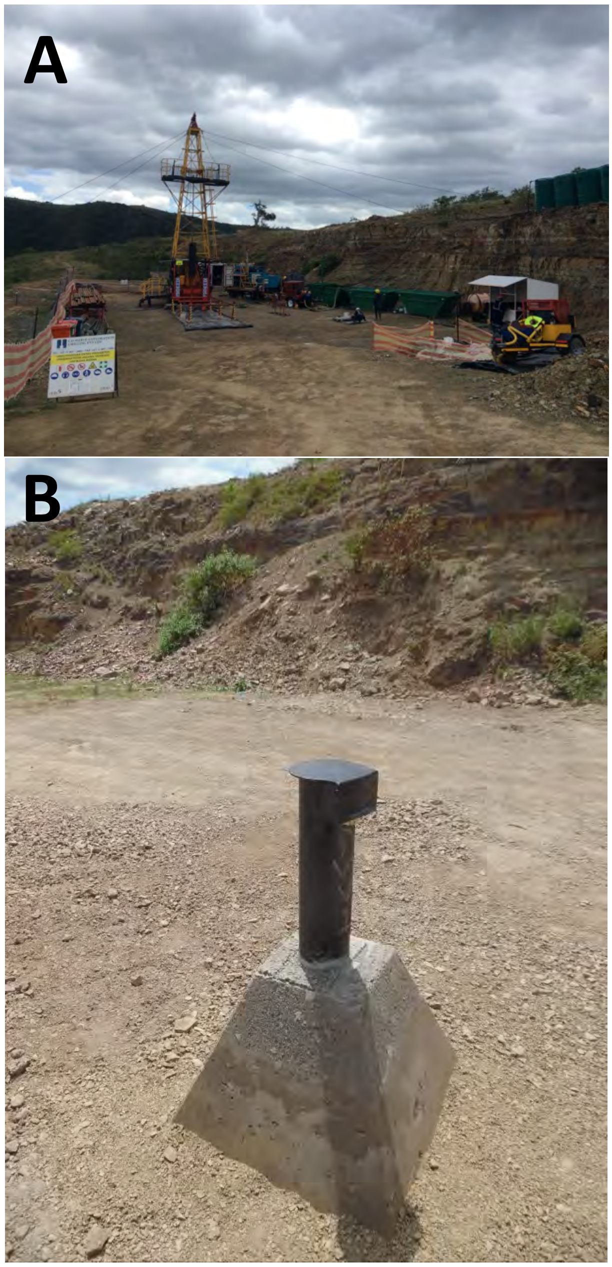

Fig. 3A. Photograph of the drill site in the road quarry near Willowvale. B. Sealed borehole after demobilization at the site.

PQ core was drilled to a depth of 300 m, followed by HQ core to 1000 m and NQ core to the end of the hole at 235239 m. After drilling, the casing was extracted and the borehole sealed with a strong lock. This would allow future sampling of groundwater in the borehole (Fig. 3B).

In general, core recovery from the borehole was excellent. Especially, some of the dolerites drilled very well, often yielding unbroken core pieces for the entire length of the 6 m long core barrels (Fig. 4) Core was logged and photographed on site by the geological manager (Aleck Birch) and Dr Doug Cole of the CGS.

Fig. 4. Six meters of continous HQ core of dolerite.

Core was transported to, and is curated at, the National Core Library of the CGS at Donkerhoek, east of Pretoria.

The borehole was drilled on land belonging to the Cisko Santini tribal community. In return for permission to drill the core on their property, we came to an agreement to build a small community hall for them. The community hall was completed and officially handed over to the the chief of the community on 21 January, 2016 (Fig. 5).

Fig. 5. Prof Beukes handing over the completed Chamemnyango Community Hall to Chief Luks of the Cisko Santini community at Willowvale on behalf of CIMERA-KARIN.

STRATIGRAPHIC SUCCESSION INTERSECTED IN BOREHOLE KWV-1

The various formations of the Ecca Group identified during logging of core are summarized in Fig. 6. Contrary to what was initially predicted, the borehole intersected Whitehill Formation only at a depth of 2276.00 m with 13 cm of Whitehille Formation above dolerite at 1176.13 m-depth, instead of the 1700 m predicted earlier. This increase in depth was mainly due to development of unusually thick Pluto’s Vale greywackes of the Ripon Formation of the Ecca Group in the core. This greywacke unit is in the order of 350 m thick in its type area at Ecca Pass north of Grahamstown (Kingsley, 1977). However, in KWV-1 it reaches a thickness of close to 600m (Fig. 6).

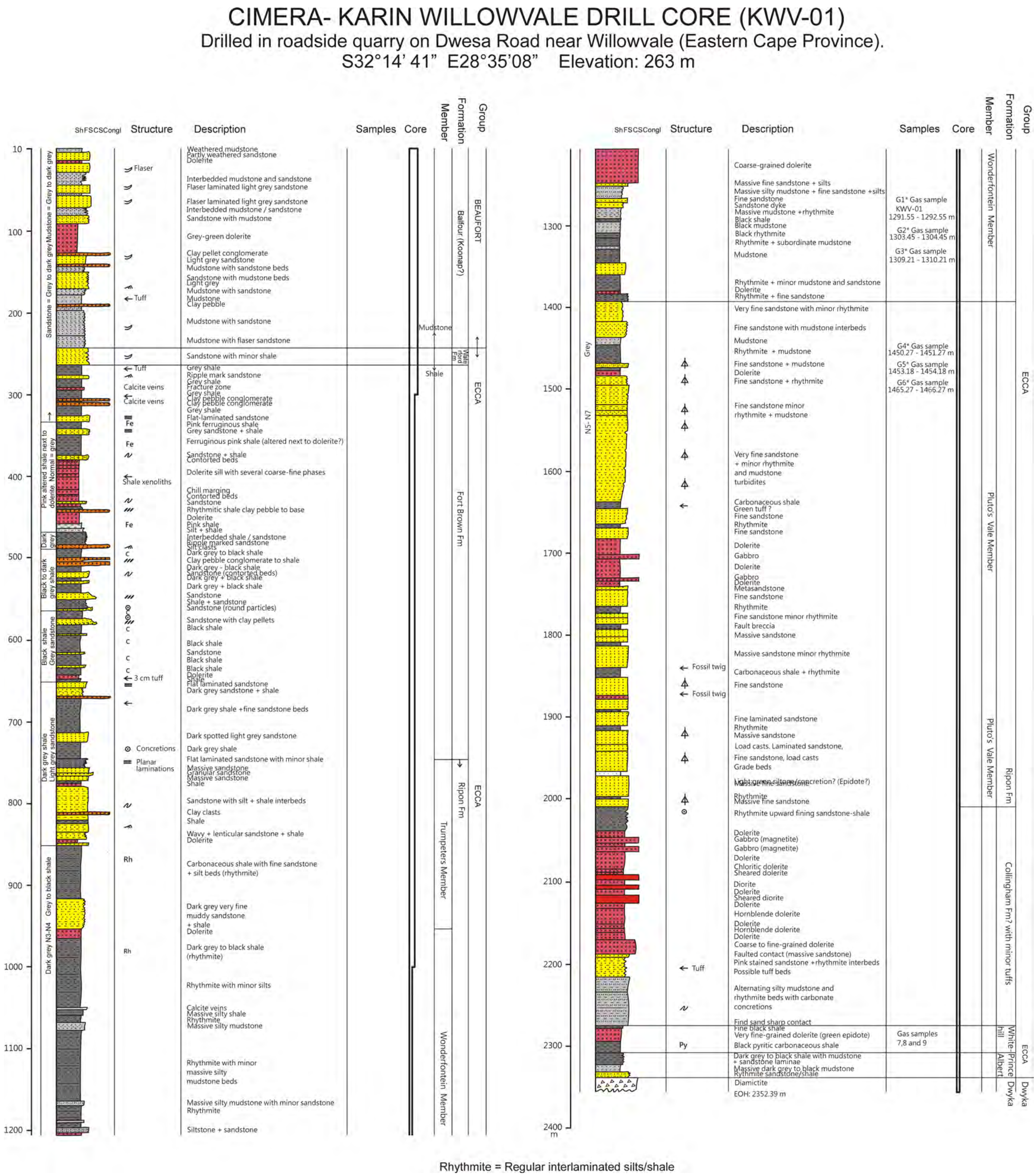

Fig. 6. Simplified graphic log of borehole KWV-1 showing intersected lithologies and their stratigraphic assignment.

Another interesting aspect of the core is that the Collingham Formation, normally defined by an abundance of thin tuff beds, is not clearly defined in the KWV-1 drill core. However, a dark shale-rich unit below the Pluto's Vale Member of the Ripon Formation contains two well defined tuff beds, each about 15 cm thick, and this unit, which is in the order of 100 m thick (excluding a 150 m thick composite coarse dolerite sill intruded into it) is correlated with the Collingham Formation (Fig. 7A).

The Whitehill Formation is only 13.05 m thick, with 13 cm above a 18.76 m-thick dolerite, in the core (Fig. 7B). It is pyritic, dark, highly carbonaceous and finely laminated. A 18.7 m thick, fine-grained dolerite sill is intruded virtually right along its very sharp contact with fine grey siltstone of the overlying Collingham Formation (Fig. 6).

The Prince Albert Formation in the core is composed of very dark grey to grey shale and siltstone and has a thickness of 30.9 m (Fig. 7C). It is in gradational contact with fine diamictite of the underlying Dwyka Formation of which a thickness of 14.7 m was intersected before the borehole was stopped (Fig. 7D).

Higher up in the core, the Pluto's Vale Member contains a prominent carbonaceous black shale unit close to the contact with the overlying shaley Wonderfontein Member. The lowermost shales/rhythmites of this member are also black and carbonaceous. These shales were sampled for gas desorption studies together with samples taken from the Whitehill Formation (Fig. 7E).

The Trumpeters Member forming the top of the Ripon Formation is composed of two prominent fine sandstone-rich units with interbeds of siltstone and fine carbonaceous shale (Fig. 7F). The overlying Fort Brown Formation, representing the top unit of the Ecca Group in the core, is composed of black and dark grey shale with abundant thin, fine sandstone beds that often contain clay-pellet beds along bottom contacts with shale (Fig. 7G). The top of the Ecca Group is represented by a prominent sandstone-dominated unit that is correlated with the Waterford Formation (Fig. 6)(Rubidge et al.,2012).

The upper ~270 m of the core intersected light grey, flat-bedded, fine sandstone with abundant mud flasers, interbedded with grey to dark grey massive mudstone of the Balfour Formation of the Beaufort Group (Fig. 7H). Clay-pellet conglomerates are present in some of the sandstone beds. The rocks also often have a pinkish colour.

GROUNDWATER

Shallow Aquifer Systems

Similar to the KZF-1 borehole, a hydrocensus of the available boreholes in a 10 km radius of the drill site was completed by the Council for Geoscience in order to establish the baseline shallow aquifer conditions in the study area. From the Department of Water and Sanitation's National Groundwater Archive (NGA) dataset, there are 151 groundwater points (75 boreholes and 76 springs) in the study area (Fig. 8). During the hydrocensus, 87% of the borehole sites identified by the NGA database were visited by the project team and only 23 groundwater sites were found. The remaining 42 NGA sites are either removed, vandalised, or incorrect information was provided in the NGA database. In addition, only groundwater samples were collected, because none of the sampled borehole constructions allowed for static water level measurements or slug tests to be performed. In total, only 6 groundwater samples were collected in the study area, as well as 2 river samples and the drilling water (sourced also from the Shixi River) (Table 1).

The same sampling protocol was followed as given in the KZF-1 hydrocensus and the laboratory is at present analysing the samples. A detailed discussion will follow after results are available. However, it can be noted that the groundwater and surface water are of a good quality, based on the pH and EC measurements, and that surface water is the main source of domestic water supply in the area.

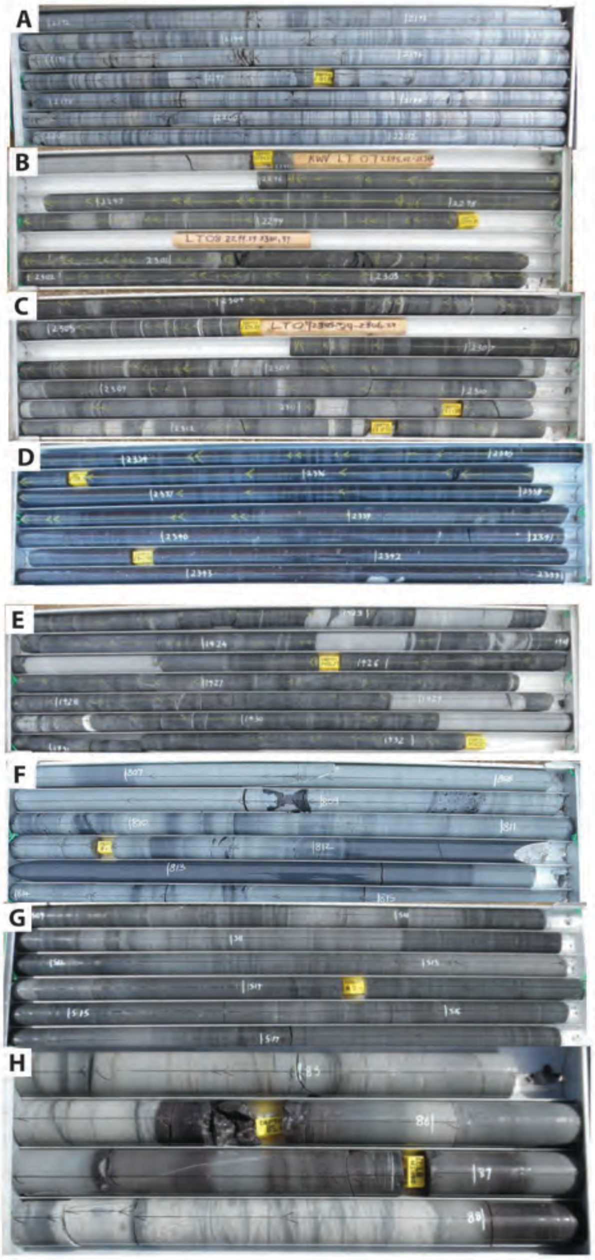

Fig. 7A. The Collingham Formation. B. The Whitehill Formation with samples removed for gas desorbtion studies. C. The contact between the Whitehill Formation and the Prince Albert Formation. D. The contact between the Prince Albert Formation and the Dwyka Group. E. Carbonacous shale of the Wonderfontein Member of the Ripon Formation. F. The Trumpeters Member (Ripon Formation). G. The Fort Brown Formation. H. The Balfour Formation.

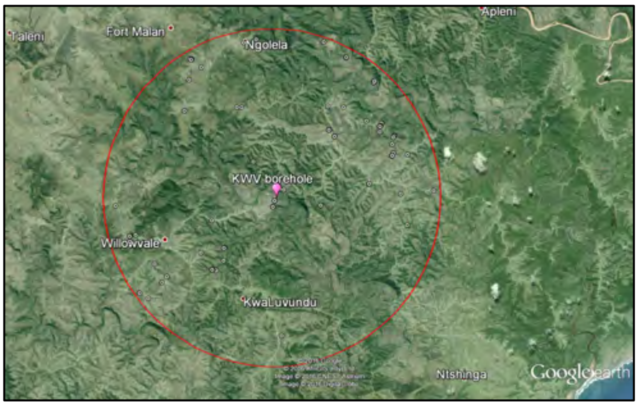

Fig. 8. KWV-1 borehole location and the NGA borehole positions (*n* = 75) within a 10 km radius of the deep borehole superimposed on a Google Earth image.

Willowvale Deep Aquifer Systems

Unlike borehole KZF-1, no artesian water was intersected from a depth of 50 m to 2300 m, with no notable changes in the drilling mud consistency throughout the drilling operation. Attempts were made by Weatherford to collect representative samples of the deep groundwater at depths of 1639 m and 1729 m, but only drilling mud was collected (Fig. 9).

Fig. 9. Collected sample of drilling mud and diesel at a depth of 1639 m in KWV-1.

Discussion and conclusions

This is the first multi-disciplinary investigation into shale gas in South Africa,

Table 1. Sample sites during the KWV-1 hydrocensus

Sample ID	Latitude	Longitude	Elevation (mamsl)	Date	Field pH*	Field EC (mS/m)	Field Temp. (°C)	Additional comments
BH2	-32.248583	28.589417	258	11/11/2015	7.56	135.8	21	Handpump for drinking water supply but abandoned because of white discolouration of water and metallic (iron?) taste of the water
BH3	-32.27048	28.55295	312	5/11/2015	7.32	237.0	26	Production borehole pumped for municipal drinking water supply
BH4	-32.28203	28.5455	345	5/11/2015	7.72	113.1	24	Production borehole pumped intermittently for municipal drinking water supply
BH5(1)	-32.2820	28.54556	342	7/11/2015	7.81	98.7	23	Handpump for drinking water supply but abandoned because too far to fetch water
BH5(2)	-32.2820	28.54556	342	10/11/2015	7.88	98.0	20	Handpump for drinking water supply but abandoned because too far to fetch water
BH10	-32.28236	28.54792	340	7/11/2015	7.44	47.0	22	Handpump used for drinking water supply
BH17	-32.19742	28.52846	520	10/11/2015	6.99	94.5	20	Handpump used for drinking water supply for a school
Qwaninga River	-32.32378	28.54208	265	9/11/2015	8.54	38.7	24	River water used to domestic water supply
Shixi River	-32.239306	28.58900	221	3/11/2015	8.45	43.6	18	This water is extracted by local municipality to use for domestic use. In addition, this water was used for the drilling of KWV-1.
Drilling water	N/A	N/A	N?A	11/11/2015	8.30	44.8	23	Shixi River water that has been in JoJo tanks and used for drilling of KWV-1.

*Water field parameters were measured using an Extech Exstick EC500 which recognised the importance of collecting deeper groundwater data in combination with geological information. A number of lessons were learnt during this project, which need to be considered for future investigations:

- If artesian groundwater is intersected, the driller or hydrogeologist must measure the flow rate four times a day to estimate the flow dynamics;
- If artesian groundwater is intersected, the water must be sampled immediately and the depth noted.
- Flushing of the drilled borehole can cause problems with deep groundwater sampling especially if there is no artesian groundwater to dilute the drilling water and mud.
- If there is any diesel in the sampled water, extreme care must be taken when trying to obtain accurate field measurements.

The lessons learnt from this study are not only applicable to the monitoring of shallow and deep groundwater systems associated with shale gas exploration in the Main Karoo Basin, but also need to be utilised for other developments in South Africa, such as carbon sequestration currently being investigated in Kwa-ZuluNatal or geothermal energy in the Limpopo Province.

INITIAL RESULTS AND FUTURE PLANS

Groundwater

Analysis of groundwater is in progress.

RockEval analyses

Nine samples were selected for residual gas analyses. Small chips of these samples were also sent to the laboratory of Dr Suryenda Dutta at the Indian Institute of Technology, Bombay, Mumbai, India for Rockeval analyses (Table 2).

The samples are interpreted to be overmature, and the T_{max} values are treated with suspicion given the very low S2 values despite very high TOC values of a few of samples.

Table 2. RockEval Pyrolysis results for the Wonderfontein Member ( ) and the Whitehill Formation ( )

Sample	S1 (mg/g)	S2 (mg/g)	Tmax (°C)
KWV1291.27-1292.27	0.07	0.19	481
KWV1303.27-1304.27	0.06	0.28	441
KWV1309.27-1310.27	0.07	0.24	498
KWV1450.27-1451.27	0.06	0.24	427
KWV1453.27-1454.27	0.07	0.29	473
KWV1465.27-1466.27	0.04	0.22	437
KWV2295.02	0.06	0.21	338
KWV2299.39	0.12	0.27	429
KWV2305.39	0.16	0.28	299

Sample	S3 (mg/g)	TOC (%)	HI	OI
KWV1291.27-1292.27	0.08	0.66	29	12
KWV1303.27-1304.27	0.14	0.38	74	37
KWV1309.27-1310.27	0.16	0.74	32	22
KWV1450.27-1451.27	0.12	0.32	75	38
KWV1453.27-1454.27	0.20	0.30	97	67
KWV1465.27-1466.27	0.09	0.22	100	41
KWV2295.02	0.07	2.12	10	3
KWV2299.39	0.23	6.27	4	4
KWV2305.39	0.22	3.04	9	7

Results of the RockEval pyrolysis plotted as hydrogen index versus oxygen index display clear groupings of organic matter characteristics along stratigraphic groups (Fig. 10). Organic matter in the Wonderfontein Member is most consistent with Type II Kerogen.

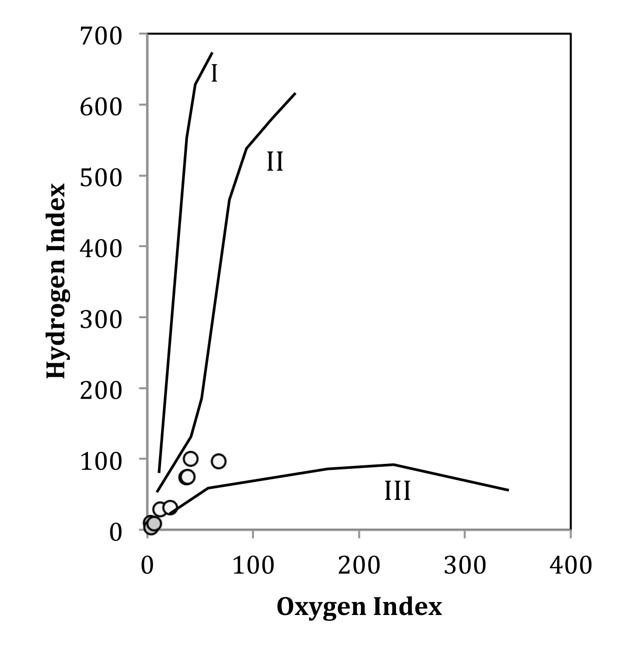

Fig. 10. Hydrogen Index versus Oxygen Index show varying character of organic matter in the Wonderfontein Member ( ) and Whitehill Formation ( ). I, II, and III represent the fields occupied by various kerogen types.

Desorbed and residual gas

Gas is generated during the maturation of organic matter in carbonaceous mudstone. Most of this gas is typically sorbed, or attached to the surface of mudstone particles. Upon a reduction in pressure (e.g., during drilling and core retrieval), some of the gas will desorb from the mudstone and escape via fractures or cleats in the mudstone. This is termed desorbed gas. Gas that remains trapped in the mudstone is referred to as residual gas, and is only released during complete fracturing of the mudstone, which is achieved in the laboratory by milling. The volume of gas that desorbed from mudstones was measured over a period of time.

The highest gas content was in sample LT01 at 1291 m below surface, but this was only 0.22 m^3/t, and the gas content comprised only lost gas and a small initial desorbed volume. All other gas contents were very low or 'too low to measure', essentially nil (Table 3).

Table 3. Desorbed gas contents for the Wonderfontein Member ( ), Pluto's Vale Member ( ) and the Whitehill Formation ( )

Sample	Depth, top of core (m)	Depth, end of core (m)	Max content (m^3/t)	Min content (m^3/t)
LT01	1291.27	1292.27	0.20	0.10
LT02	1303.27	1304.27	0.00	0.00
LT03	1309.27	1310.27	0.03	0.02
LT04	1450.27	1451.27	0.02	0.02
LT05	1453.27	1454.27	0.01	0.01
LT06	1465.27	1466.27	0.05	0.03
LT07	2295.02	tbc	0.01	0.02
LT08	2299.39	tbc	0.00	0.00
LT09	2305.39	tbc	0.00	0.00

PROPOSALS AND SCIENTISTS TAKING PART IN STUDY OF KWV-1

Proposals have been received by the various CIMERA-KARIN scientists (Table 4) to study the retrieved core under the following themes:

1) Stratigraphy, palaeoclimate and basin analysis
2) Magnetostratigraphy and rockmagnetics
3) Petrophysics and geomechanics
4) Karoo sills and dykes
5) Environment and water
6) Geophysics

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We thank the Cisko Santini community for permission to drill on their property. In particular we want to thank Chief Lucks Makuleni for his support and keen interest in the project from start to end. Councillor Nokhanyo Magatya in Willowvale also supported our efforts. We would also like to thank staff of the Departments of Water and

Sanitation, Roads and Public Works and Environmental Affairs of the Eastern Cape Province in East London and Bhisho for their support of the project and permission for the use of water for the drilling process and the road quarry for setting up the drilling camp and drill platform. Special assistance was given by Esmeralda Van Rooyen (Water Affairs), Gerry Pienaar (Environmental Affairs) and Craig McLachlan, Mzi Mafani and Ramona Metune (Roads Department).

The drillers from Geoserve Exploration Drilling (Pty) Ltd. did an incredible job by delivering exceptional cores (Nick Mogridge, Ernst Crous, Jaco). Thanks also to Weatherford and Latona staff for geophyscial logging and on-site and laboratory gas desorption studies, respectively.

Table 4. KARIN scientists

Institution	Scientists
University of Johannesburg	Prof. N.J. Beukes (Director of CIMERA) Prof. M.O. de Kock (South African scientific manager of KARIN) Prof. B. Cairncross, Prof. N. Wagner Dr. H.S. van Niekerk, Dr. C. Vorster Ms L. Bowden
Keele University (UK)	Prof. A.E. Götz (Scientific manager of KARIN)
University of Pretoria	Prof. W. Altermann Prof. J.L. van Rooy Dr N. Lenhardt
University of the Witwatersrand	Prof. L. Latypov Dr. M. Manzi Dr S. Webb Ms S. Scheiber
University of Cape Town	Dr. E. Bordy Ms C. Geel
University of the Freestate	Dr. F.D. Fourie Mr. F. de Lange
Council for Geoscience	Dr. D. Cole Dr. J. Neveling Dr. L. Mare Dr. M. Grobbelaar Dr. L. Chevallier Ms. K. Robey Ms. D. Black

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