Earth Stewardship Science Research Institute

Shale gas characteristics of Permian black shales in the Ecca Group, near Jansenville, Eastern Cape, South Africa

***Claire Geel*[1,2], *Peter Booth*[1], *Maarten de Wit*[1] , *Hans-Martin Schulz*[2]**

1. Department of Geoscience, NMMU and AEON, 2. GFZ, German Research Center for Geoscience

Abstract

This poster reports on the geochemical and petro-physical properties of shales from the Prince Albert, Whitehill and Collingham Formations of the Lower Karoo Supergroup, near Jansenville in the Eastern Cape. Results are based on two boreholes (SFT 1 and SFT 2) sited on a southerly dipping limb of a shallowly plunging syncline. Lithological, sedimentological, structural, geochemical and petro-physical analyses provide detail of the characteristics of these rocks which have become the focus of interest for potential shale gas.

Petrographic, XRF, XRD and SEM analyses from black shales of the Whitehill Formation, show that these rocks are composed of quartz, illite, muscovite and chlorite, with lesser plagioclase and accessary pyrite. The Collingham Formation rocks have the largest proportion of quartz content which gives this formation a higher brittleness factor than that of the Prince Albert and Whitehill Formations. Mercury porosimetry analyses yield average meso- and macro porosity in black shales of the Whitehill Formation (0.83%), confirming that these sediments are tightly packed. Thin layers of dolomite within the shales have porosities of 2.9%, and pores measuring 1.5µm wide.

Total organic carbon content (TOC) and Rock Eval pyrolysis data show that black shales of the Whitehill Formation are high in organic carbon and have an average TOC value of 4.5 wt%. The TOC of shales in the Collingham and Prince Albert Formations is <1 wt%. XRF and (^{13}C and ^{15}N) light stable isotope analyses suggest that the Prince Albert and Whitehill Formations were deposited under anoxic conditions, sourced by a mix of marine and terrestrial organic matter, whereas the Collingham Formation was deposited under more oxidizing conditions.

High maximum temperature values (Tmax average: 528), low overall hydrogen and oxygen index values and high reflectance measurements on bitumen (BR_o= 4%) characterise these sediments as over-mature. As a consequence pyrolyses and thermovapourization data display few hydrocarbon yields.

The main characteristics of black shales in the study area indicate that their over-maturity with respect to hosting gas deposits is attributed to tectono-metamorphic overprinting during the Cape Orogeny. Rocks of the lower Karoo Supergroup outcropping within the area of the Cape Fold Belt therefore have limited potential for hosting gas deposits.

Figure 1: Black shale core drilled from SFT 2 (Whitehill Formation)

Figure 2: Drilling of SFT 1 at angle of 50°

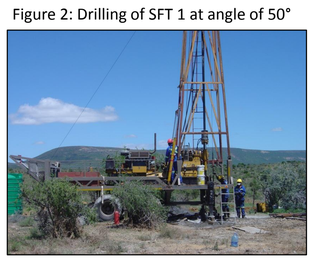

Figure 3: Drilling of SFT 2 (vertical hole)

Figure 4: Sample of core from SFT 2

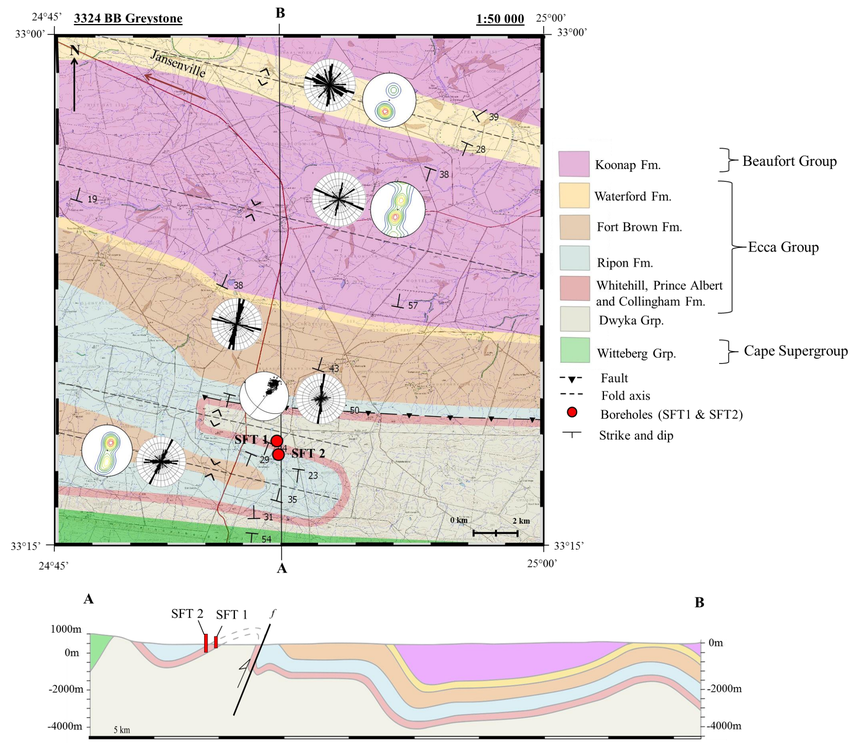

Figure 5: Geological map and cross section (A-B) through the Greystone area. Stereograms on the map are of bedding, plotted as poles to planes, on equal area nets. Joint orientations are shown as rose diagrams which show two dominant strike orientations, viz. N-S and WNW.

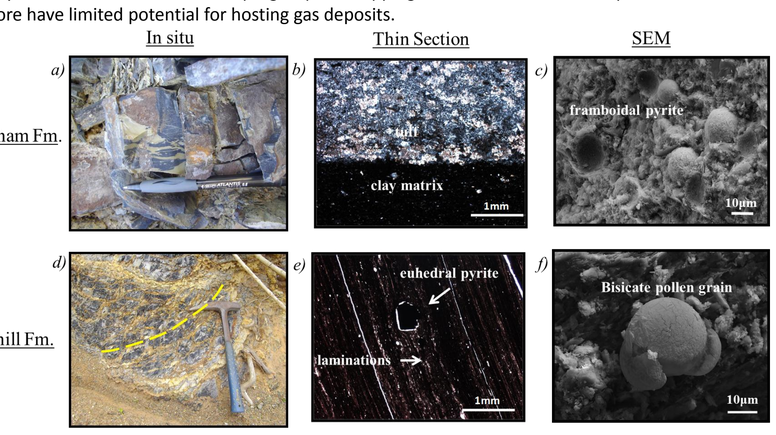

Figure 6: Photographs (first column) showing typical outcrops of the Prince Albert, Whitehill and Collingham Formations in the study area. The second column shows common features of the rocks in thin sections of these formations. The last column shows SEM micrographs of fresh core from borehole SFT 2, where micro-fossils and nature of pyrite grains are clearly visible.

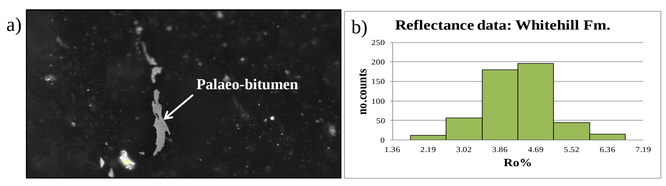

Figure 10: a) Bitumen as seen under reflected light, b) Reflectance data R_o (representative of BR_o) plots as a histogram for the Whitehill Formation (BR_o=4 %).

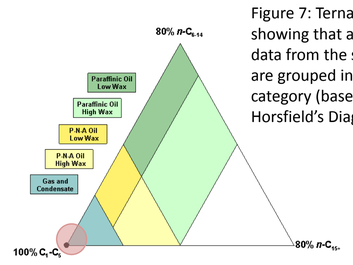

Figure 7: Ternary diagram showing that all pyrolysis data from the study area are grouped in the C1-C5 category (based on Horsfield's Diagram 1989).

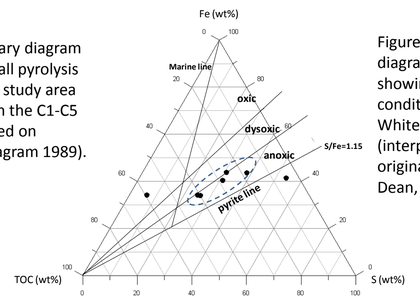

Figure8: Ternary diagram (Fe-TOC-S) showing oxidation conditions in the Whitehill Formation (interpretation based on original by Arthur and Dean, 1989).

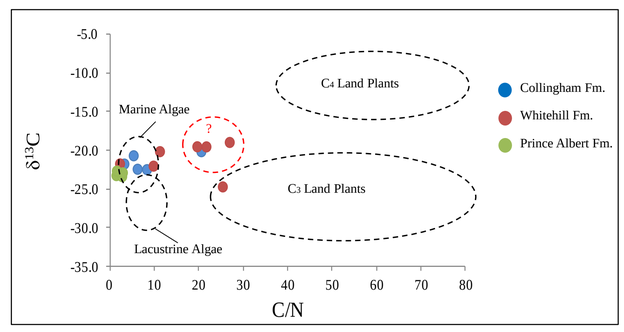

Figure 9: C/N ratios and $\delta^{13}C$‰ values plotted within zones of different organic material sources.

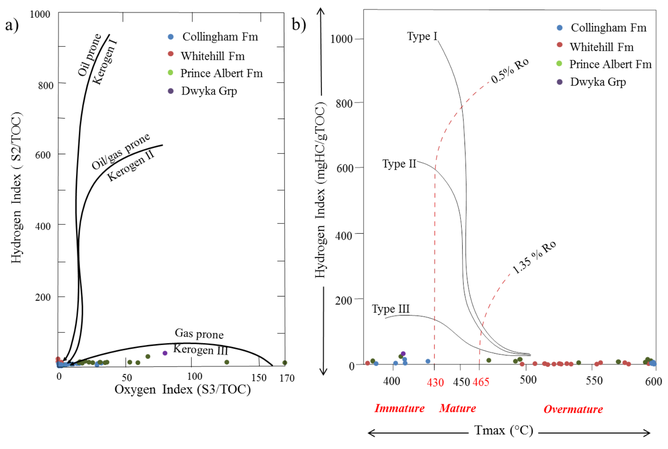

Figure 11: Modified van Krevelen Diagrams showing a) Hydrogen index (HI) vs Oxygen Index (OI); b) Hydrogen index vs Tmax. Note that in (a) all samples of the Prince Albert Formation plot in the Kerogen III field and in (b) samples are predominantly overmature.

Table 1: The Whitehill shale compared with the Barnett and Marcellus shales (data from Bruner and Smosna (2011), Hoelke J (2011) ,Decker and Marot (2012) and Geel, 2014)

Formation	Barnett (Mississippian shale Fort Worth Basin, USA)	Marcellus (Devonian Shale, Appalachian Basin USA)	Whitehill (Permian Shale, South Eastern Karoo Basin, Greystone area, RSA)
Mineral (%)			
Quartz	35-50	10-60	13-55
Clays (illite)	10-50	10-35	5-29
Calcite, dolomite, siderite	0-30	3-50	3-62
Feldspars	7	0-4	0-24
Pyrite	5	5-13	1-16
Phosphate, gypsum	trace	trace	trace
Mica	0	5-30	3-22
Porosity (%)	3-6	3-6	2.90 (including dolomite), 0.83 (excluding dolomite)
Vitrinite reflectance (R_o)	1.2 (max 1.9)	1.6 (max 3.5)	4
Tmax	≥465°C	≥475°C	≥563°C
TOC (%)	2-6	1-10	0.7-8.15
Kerogen type	Type II (minor admixture of type III)	Type II (mixture of type III)	Mixture of type II and type III
Estimated size of shale-gas play	23 310 km²	129 499 km²	155000km² - 183 000km²
Thickness of Formation	107m	15m	~28m
Estimated Potential yield	2.5 bcf-40tcf	50-900tcf	between 32tcf and 485tcf

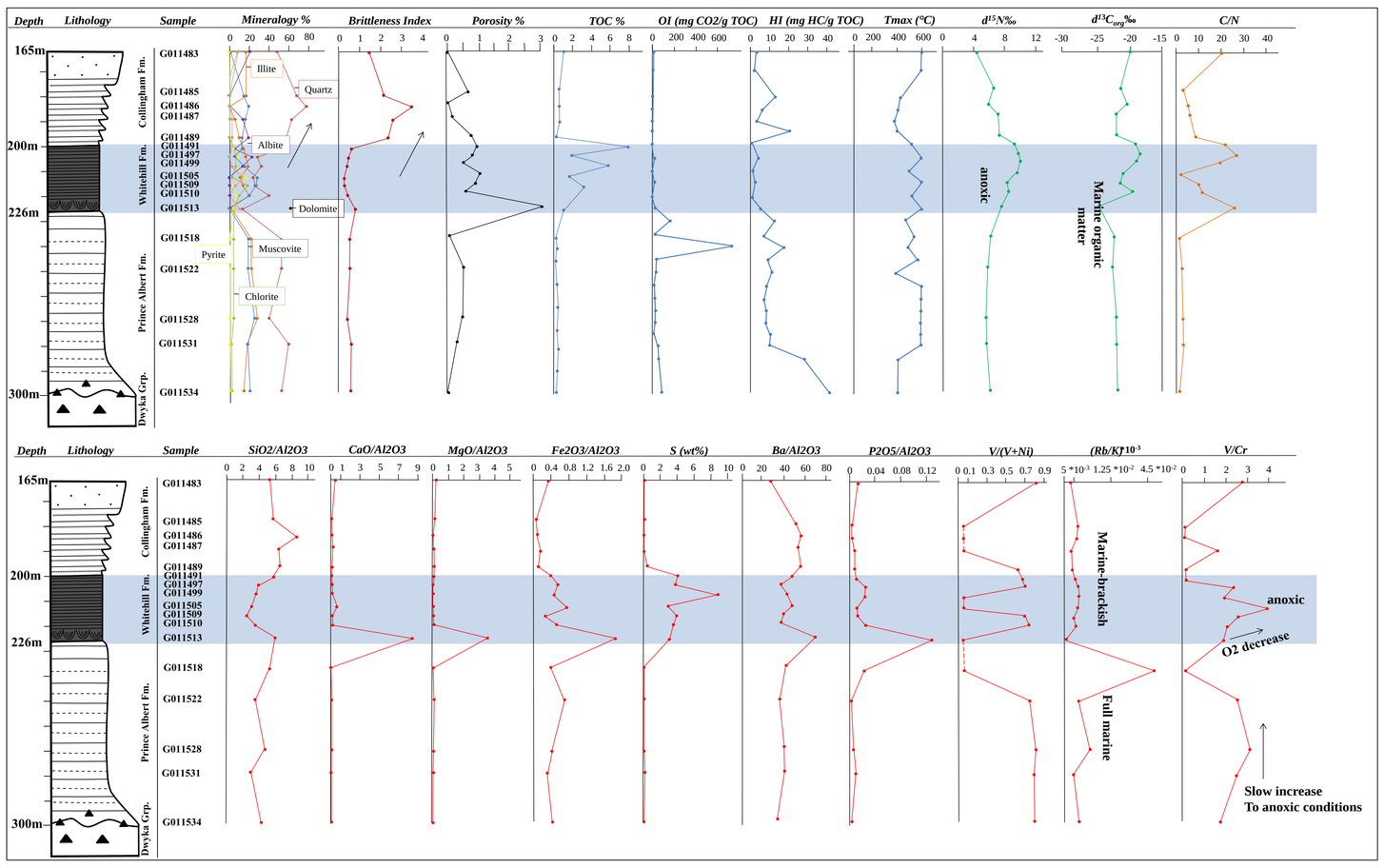

Figure 12: XRF, XRD, TOC, $\delta^{15}N$ and $\delta^{13}C$ stable isotopes, and TOC/Rock Eval data plotted as depth profiles relating to the Prince Albert, Whitehill and Collingham Formations.

CONCLUSION

Lithological, mineralogicial and geochemical characteristics confirm a deltaic depositional model for the lower Ecca Group. This study, moreover, indicates that sediments of the Prince Albert and Whitehill Formations were deposited in an anoxic environment, in contrast to those of the overlying Collingham Formation which formed in oxygenated shallow water conditions. The Whitehill Formation in particular is rich in organic carbon, and thus a favourable stratigraphic unit for retention of gas. The palaeo-environmental setting for the inland sea was likely marine becoming increasingly lacustrine with fresh-brackish conditions prevailing in the Collingham Formation with deposition of mixed (terrestrial and marine) organic matter.

Petro-physical analyses indicate that properties such as brittleness and porosity of the Whitehill Formation, although not as good as the under- and over-lying formations, would facilitate hydraulic fracturing and extraction of gas from these rocks.

Rocks of the Ecca Group, deformed by folding and faulting during the Cape Orogeny, reached temperatures greater than 460° C, which exceed conditions for the dry gas window.

The presence of bitumen and its reflectance values, as well as the very small proportions of hydrocarbons remaining in the shales, prove that rocks in the study area are over-mature, and do not contain any significant quantities of natural gas.

Characteristic properties of the Whitehill Formation as a suitable shale gas host compare favourably with those of currently exploited gas fields in the United States. The Whitehill Formation therefore, in the context of the Karoo Basin, remains an attractive target as a potentially suitable shale gas resource, but only if explored in the region away from the influence of the Cape Fold Belt, as well as taking into account the presence of dolerite intrusions.

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