A South African perspective on shale gas hydraulic fracturing

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Abstract

During the period 1965 to 1975, Soekor explored for oil and gas in the Karoo, a pristine semi-desert area in South Africa. Gas was found in the tight shale formations of the Ecca Group of the Karoo Supergroup, 2500 and 4000 m below the surface. This deposit may be as large as 485Tcf. Companies have applied for exploration licences, but a moratorium was placed on any activities. The biggest issue of concern, apart from environmental negatives, is the shortage of water resources. What also differs from other places in the world is the presence of dolerite dykes and sills in these formations. This paper will deal with the availability of water, how to deal with the dolerite, the potential visual impact on surface, possible pollution of the very valuable drinking water, and other unknowns.

Keywords: hydro-fracturing, fracking, Karoo, shale gas exploitation

Introduction

South Africa is a country blessed with minerals, but without oil and conventional gas resources. During the period 1965 to 1975, Soekor explored for oil and gas in the Karoo, a pristine semi-desert area in South Africa. Gas was found in the tight shale formations of the Ecca Group, 2500 and 4000 m below the surface. This deposit may be as large as 485Tcf, and it is at least 32 Tcf, which would make it the fifth largest deposit in the world (Kuuskraa et al. 2011). Currently the only gas exploitation project in South Africa is the Mossgas project, which was planned on a reserve of only 3 Tcf.

Carbon-rich units of the Ecca Group of the Karoo Supergroup are the target zones for shale gas exploration, principally the Whitehill and Collingham Formations. These units need to be encountered where pressure and temperature conditions are favorable for gas generation. The depth and thickness of the target zones is relatively well known, being informed by geophysical exploration and drilling of 24 deep wells by Soekor in the 1960s and 1970s (Roswell and de Swardt, 1976). The basal Prince Albert Formation and the upper Waterford and Fort Brown Formations are also of interest.

Little is known about the prevalence and orientation of dolerite at depths greater than that typically reached by boreholes. The Karoo represents an erosion surface from which thousands of metres of sediment have been eroded and removed. By extension, it is understood that the dolerite at depth has a similar character and morphology to that currently seen at surface.

Much of the area of the Republic of South Africa comprises rocks of the Karoo Supergroup. This geological unit has been described by Truswell (1977), Catuneanu et al. (2005), and others. As far as is known, South Africa is the only known instance where shale gas targets have been intruded by dolerite. This makes our situation unique; and the ready extrapolation of knowledge from elsewhere in the world to the South African situation should be done with caution.

Well Pad Density

One issue for residents and visitors to the Karoo region will be the density of well pads in the area, and the visibility thereof. Regulatory bodies in the USA allow a maximum density of 1 well pad per 260 ha. In recent shale gas operations in Canada, multi-well pads are about 5 km apart. A similar spacing would be pursued by companies in South Africa if hydrocarbons are discovered and developed in the Karoo. According to Mr Jan-Willem Eggink, (Upstream General Manager, Shell SA), these sites will be typically 4 - 5 km apart, therefor 25 km^2 per well pad.

Only a limited part of the Karoo will be accessible for shale gas drilling, due to exclusions, e.g., topographical constraints, SKA, SALT, townships and nature parks. The estimate is that some 28% are accessible, but companies cannot develop the entire 28%, since they need to find the sweetspots in these areas. In the U.S., this comprises 15-30% of an area. So, in reality, only 5-10% of the total area may be commercially attractive.

Hydrocarbon Exploration

Exploration of the Karoo Basin for oil was undertaken in the 1960's, with some reserves of gas being detected (Roswell and de Swardt, 1976). Gas flowed from well Cranemere 1/68 from a depth of 3 600 m at a rate of 1.8 million cubic feet per day for a short period. However, the resources were considered unviable at the time and no further exploration has been undertaken in the past 40 years.

Geological units with a total organic carbon of 3 - 12% are being targeted for shale gas exploration and there are currently a number of companies that have exploration rights to investigate natural gas resources in Karoo type formations (Figure 1). The Whitehill formation (0.5-14.7% carbon and a thickness of 1-72 m) and the Prince Albert formation (0.35-12.4% carbon and a thickness of 30 – 420 m) in the Karoo, obtained from the Soekor data, compares favourably to the Marcellus shale (0.3-20% carbon and a thickness of 12 - 270 m) and the Barnett shale (0.5-13%carbon and a thickness of 15 - 300 m) in the USA,. The depth of burial also controls the potential for methane generation. Oil is generated at temperatures and pressures found between 1.5 and 5 km, while gas is generated between 3 – 6 km. Dry gas – including methane – occurs at depths greater than 5 km.

Geohydrology

Karoo aquifers are secondary in character, and owe their storage and transmission capabilities to weathering, fracturing, faulting and the intrusion of dolerite bodies. These secondary aquifers are both heterogeneous and anisotropic, resulting in properties varying significantly over short distances. A dual porosity model is considered appropriate for these systems, where most groundwater is stored in the matrix and the transmission of groundwater takes place in secondary openings such as joints and fractures.

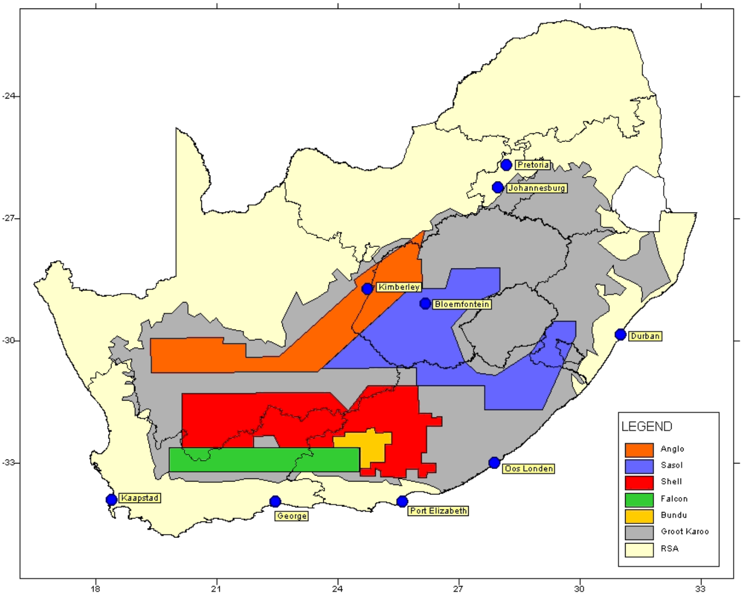

Figure1 *Regional map of South Africa showing the exploration rights and companies associated with these permits (drawn by E. Lukas).*

Possible Sources of Water

The provision of sufficient water for fracking is a key consideration (as the fracking process requires nearly 20 000 m^3 per borehole), and a number of possible sources of water exist:

- Development of local groundwater supplies – this includes exploiting the 4000 breccia plugs in the western Karoo, and the hydraulic fracturing of the aquifers of the Karoo.
- Transporting in surface water from elsewhere – either by road, rail, pipeline or a combination thereof. This will put an additional burden on the roads and infrastructure.
- Piping seawater or desalinated seawater from the coast – this will only be feasible if the water is purified and pipes across the escarp, which will be very costly.
- Water from the Orange River – the excess water is already been allocated to previously disadvantaged farmers.

However, transporting either freshwater or seawater clearly has a number of limitations and must be subject to proper study. Much of the Karoo experiences rainfall ranging between 200mm/a to 400mm/a. Vegetation in the Karoo reflects the low rainfall of the region, and together with characteristic dry river beds and infrequent occurrence of dams, a visual image is created of a region without water.

However, metres below the surface lie under-utilised aquifers. Systematic exploration and research indicates the harvest potential of these aquifers range from 5 000 $m^3/km^2/a$ to more than 25 000$m^3/km^2/a$ (Baron et al., 1998). Karoo groundwater resources are widely used for town water supply, irrigation and stock watering.

It is noteworthy that hydrogeological investigations of Karoo aquifers are generally restricted to the upper 100 m. Modern water drilling equipment has increased the depth of drilling to 150 m, but few boreholes are drilled deeper than 300 m. Data extracted from the National Groundwater Data Base in 2008 and presented by Golder (2011) indicated only 4% of the 2 323 boreholes were drilled deeper than 100 m. Woodford and Chevallier (2002) reported similar findings from analysing 67 borehole logs totalling 13 799 m (at an average depth of 206 m) in the vicinity of Victoria West. They found that 73% of all water interceptions occurred within 80 m of the surface.

Kent (1949) assessed thermal springs in South Africa and reported 12 of the 74 thermal springs are associated with rocks of the Karoo Supergroup. Of these, 8 are located in the target areas for shale gas and are classified as warm springs. Most rise alongside dolerite dykes from depths of about 600 to 1 300 m. While the thermal springs are of relatively shallow origin, they do suggest that groundwater at greater depths is more saline than that in the upper 150 m.

Given that unconventional shale gas exploration will target geological formations between 3 000 and 5 000 m below ground, a significant barrier exists between the aquifers of the Karoo and the target zones for shale gas. Given the low permeabilities reported by Roswell and De Swardt (1976), and the accepted thickness of aquifers in the Karoo, it is conceptually difficult to accept any connection between the two bodies. However, the integrity of this barrier could be compromised by leaking casings. The rehabilitation of the the wells, and the monitoring thereof afterwards, are thus of vital importance for the protection of the groundwater resources.

Given the claims of excessive water requirements for fracking and the impact on the environment, this volume of water needs to be put in perspective:

- About 5 000 m^3 is required to irrigate 1 ha of crop in the Karoo, thus the volume of water needed to frack one well is equivalent to that used to irrigate 4 ha of land. The key difference in water demand is that the irrigated water is applied over 3 – 4 months while that used by fracking is used over a period of 5 days.
- The average daily water consumption of a Karoo town (e.g. Beaufort West) is 8 500 m^3; thus, the volume of water needed to frack one well is equivalent to that used over 2.5 days by the town. However, the rate of water required for fracking is about half of that of Beaufort West, and is required for a period of 5 days.

Volume of groundwater in the Karoo formations of SA

Van der Voort (2001) determined the porosity values of shallow fractured sedimentary rocks (less than 100 m below surface) from geological cores of different formations in the Karoo and obtained values of between 3 and 15% with an average of 8%. This implies that each cubic meter of rock contains on average of 0.08 m^3 of water (or 80 L). A hectare of land thus contains ≈80 m^3 of water for each 1 m of saturated thickness. If a saturated thickness of 80 m is taken (i.e., from an average water level of 20 m below surface to 100 m), an amount of 6 400 m^3 is stored in 1 ha. The groundwater recharge ranges between 1 – 5 % of the annual rainfall with an average of 3% and for an annual rainfall of 480 mm, the annual recharge will be about 144 m^3 per ha or 2.25% of the total amount of groundwater stored in the first 100 m of the formation.

The porosity of sandstones and of shales can be used as a rough measure of the original thickness of overburden. Maxwell (1964) shows that the porosity of clean quartzitic sandstones decreases as a linear function of increasing burial and also to some extent with increasing age. In areas with a high thermal gradient, the reduction in porosity is more rapid than in those with a low gradient, i.e., it is partly temperature dependent. According to Maxwell's studies, sandstones can be expected to have a porosity of about 10-15% at a depth of 3 000 m and about 5% at 5 000 m. In the sandstones studied by him, the processes chiefly responsible for porosity reduction were compaction and cementation. Unlike the porosity of "clean" sandstones, the porosity of shales decreases very rapidly in the first few hundred meters of burial as interstitial water is expelled and more slowly thereafter. A curve drawn by Maxwell (1964) shows that shale porosity is between 5 and 10% at a depth of about 2 000 m, and 5 percent at slightly over 3 000 m. According to Rumeau and Sourisse (1972), however, shale porosity can be strongly influenced by the age of the sediments (duration of burial).

From a depth of 100 to 3000 m below the surface, the only laboratory porosity estimations are those obtained from the 20 Soekor boreholes drilled in the 1960s: between 0.1 to 8% with an average of 2.5%. It is thus expected that the Karoo formation contains water at depth but that the quality of the water is not good (for domestic purposes). The permeability (hydraulic conductivity) is extremely low (less than 10-11 m/d) and hydraulic fracturing is thus required for the water to flow freely from the rock. The shale gas exploration companies can thus use hydro-fracturing in the shallower Karoo formations to increase the permeability of the rock and the deeper groundwater (e.g. from 300 – 700 m) could be used as the water for the fracking of the shale gas formations.

If the companies are going to use deep groundwater to satisfy their need for fracking, the question will be what the impact of such operations will be on the shallower fresh groundwater aquifer. From practical experience in the Karoo (e.g. Mooikraal Underground Coal Colliery), we know that a shallow water table still exists above mined out underground collieries that are deeper than 100 m below the surface. During the fracking process for water at shallow depths, no harmful chemicals will be used (only water and sand), which will make it a safe, feasible option.

Proper detailed investigation is required to assess the viability of supplying water for fracking in the Karoo. Appropriate exploration, testing, and management of groundwater resources will be required if groundwater resources are to be used. Targets for exploration include dolerite contact zones, breccia plugs, and localised fracture zones.

It is advised to drill a few test well fields in order to determine if it is viable to extract enough water from the Karoo aquifers without depleting them. If successful, this will put a lot of people at ease, as potable groundwater is the lifeline of the Karoo.The key to the successful and sustainable use of any resource – including groundwater – is proper development and management. In Texas, dirt dams are built long before the fracking process starts in a Barnett shale area, and water is pumped at a low tempo into these dams, ensuring enough water at the time of developement.

Positives and negatives regarding fracking in the Karoo

Positives:

In a country that is a net importer of energy, shale gas can improve the deficit if the reserves are proven to be substantial. Techniques have improved a lot in the last few years. More casings are used down the hole, more environmental friendly chemicals are used and modern treatment facilities are built to remove the salts from the flow-back water. All operations are done on geomembranes and flow-back water is typically used to frack new wells.

Negatives:

There are always risks associated with any mining and one can assume with confidence that the more operations (mining) that is taking place, the higher the risks. The main concerns are the availability of water, the number of trucks on the roads (and can the roads last?), the visible effects that gas extraction will have on the pristine landscape, the effect of the dolerite dykes, and well construction and integrity. Due to the uniqueness of the presence of dolerite dykes and sills in the South African situation, lessons learnt in other parts of the world may not all be applicable to the South African situation; this might result in a different set of rules for the Karoo. The presence of dolerite at that depth is still uncertain, and much debated. Thorough geophysics must be done to determine the sweetspots where dolerite is absent. Dykes could be conduits for polluted water (but also a loss of pressure during fracking, which would cause well abandonment), and such areas must thus be avoided.

Concern has been expressed regarding the mobilisation of radioactive elements such as uranium and other heavy metals during the fracking process and their emergence at the surface with the fracking waters. Studies done on the fine-grained sedimentary rocks of the Karoo Supergroup (and especially on the formations under discussion) indicate that the shale is not enriched with any of the elements of concern (Cole, 2008). These geologic units were deposited under different conditions from that of the shale being targeted for gas exploitation. Further, uranium is mobilised by oxidising groundwater while the groundwater at depth is in a reducing state. Nonetheless, little is known about groundwater quality beyond a depth of 300 m, and heavy metal and radioactive element concentrations at depth are unknown.

Conclusions

Shale gas is an important part of energy production in the USA (and also elsewhere), and could be the same in South Africa. However, there are still a huge number of issues that needs to be resolved before such operations can be allowed in the Karoo. Do we have the gas resources that are being predicted? Will there be enough water in the Karoo or will water have to be transported from somewhere else? Can the Karoo be rehabilitated after such an onslaught of activities? The answers to these questions are still not clear; a huge research effort is still needed. However, the moratorium on exploration will have to be lifted before funding appears to answer these questions and before any final decisions regarding the future of the Karoo are made.

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References

Baron, J, Seward, P and Seymour, A (1998) The groundwater harvest potential map of the Republic of South Africa; Technical report GH 3917, Directorate of Geohydrology, Department of Water Affairs and Forestry, Pretoria.

Catuneanu, O, Wopfner, H, Eriksson, PG, Caincross, B, Rubidge, BS, Smith, RMH, and Hancox, PJ (2005) The Karoo Basin of south-central Africa; J. African Earth Sciences, 43, pp 211 - 253.

Cole, DI (2009) A review of uranium deposits in the Karoo Supergroup of South Africa; Int. Conf. Proc AAPG Conference, Cape Town, South Africa, October 26-29, 2008.

Kent, LE (1949) The thermal waters of the Union of South Africa and South West Africa; Trans. Geol.Soc. SA, 52, pp 231 – 264.

Kuuskraa, V., Stevens, S., Van Leeuwen, T. and Moodhe, K., 2011. World shale gas resources: An initial assessment. Prepared for: United States Energy Information Administration, 2011. World Shale Gas Resources: An Initial Assessment of 14 Regions Outside the United States. Available at: http://www.eia.doe.gov/analysis/studies/worldshalegas.

Maxwell, J.C. (1964). Influence of depth; temperature and geological age on porosity of quartzose sandstone. Bull. Amer. Assoc. Petrol. Geol., 48. 5, pp 697-709.

Roswell, DM and de Swardt, AMJ (1976) Diagenesis in Cape and Karoo sediments, South Africa and it's bearing on their hydrocarbon potential; Trans.Geol.Soc.SA, 79 (1), pp 181 – 245.

Rumeau, 3-L, and Sourisse, C. [1972]. Compaction, diageneseet migration dans les sediments argileux. Bull. Centre. Rech.Pau-S.N.P.A., 6, 2, pp 313-345.

SGEIS (2011) Supplemental Generic Environmental Impact Statement on the oil, gas and solution mining regulatory program; Revised draft, New York State Department of Environmental Conservation, New York.

Truswell, JF (1977) The geological evolution of South Africa; Purnell, Cape Town.

Van der Voort I (2001). Risk based decision tool for managing and protecting groundwater resources PhD Thesis University of the Free State, Bloemfontein (unpublished).

Woodford, AC and Chevallier, L (eds) (2002a) Hydrogeology of the main Karoo Basin current knowledge and future research needs; WRC Report No TT 179/02, Water Research Commission, Pretoria.

Woodford, AC and Chevallier, L (2002b) Regional characterization and mapping of Karoo fractured aquifer system – an integrated approach using geographical information system and digital image; WRC Report No 653/1/02, Water Research Commission, Pretoria.