Energy & Geoscience Institute
AT THE UNIVERSITY OF UTAH

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IN DEVELOPMENT

Reservoir Characterization of the Karoo Basin, South Africa

Regional Geological Characterization & Unconventional Reservoir Evaluation

Principal Investigator:

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CORE through PORE™

Investment per Sponsor
$80k USD

Duration
24 months

Project I 01242

VALUE

- The integration of three key technical areas to establish an unparalleled understanding of shale resources in South Africa's Karoo Basin.
- **Core through Pore™ Integrated Petrological Workflow** for cutting-edge interpretation of composition, texture, fabric, porosity, permeability, micro-tectonics, micro-facies/depositional evolution and diagenetic history.
- **Geophysical & Petrophysical Data:** integrated within the gross tectonic structural framework, taking into account the correlation of available gravity and magnetic data within the fundamental sequence stratigraphic framework of the basin.
- **Organic Petrology:** Evaluation of key samples using rock-Eval, TOC, and biomarkers with the integration of inorganic (petrological) analyses and regional (geophysical/petrophysical) data.

KEY DELIVERABLES

1. Comprehensive petrological analyses using the Core through PoreTM integrated analytical approach using optical microscopy, XRD, XRF, QEMSCAN®, SEM, FIB-SEM and TEM/STEM.
2. Geochemical and petrological databases and charts (Excel).
3. Integrated assessment of analysis with available well log and magnetic data.
4. Delivered on ArcGIS platform with GIS catalog delivered in Excel format.
5. Analog table in Excel format containing key shale parameters and potential analogous North American reservoirs.
6. Documentation from interim and final project presentations.

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Rationale & Significance

Recent estimates of unconventional resources in the Karoo Basin, suggest recoverable shale gas in-place varying significantly, from ~30 Tcf to ~500 Tcf (i.e. Decker and Marot, 2012). Potentially large gas reserves; coupled with the present energy shortfall in South Africa, has led to shale gas becoming an attractive new energy prospect, with much of the renewed exploration focus falling on the Karoo Basin shales.

The project is designed to evaluate the gas potential of key carbonaceous shales within the Ecca and Dwyka Groups of the Karoo Basin; with integrated results used to define and evaluate the fundamental factors important to shale hydrocarbon potential in the Karoo Basin. A subsequent comparison of key parameters and results to analogous basins in North America will be used to identify areas with the greatest potential to viably host and produce shale gas within the Karoo.

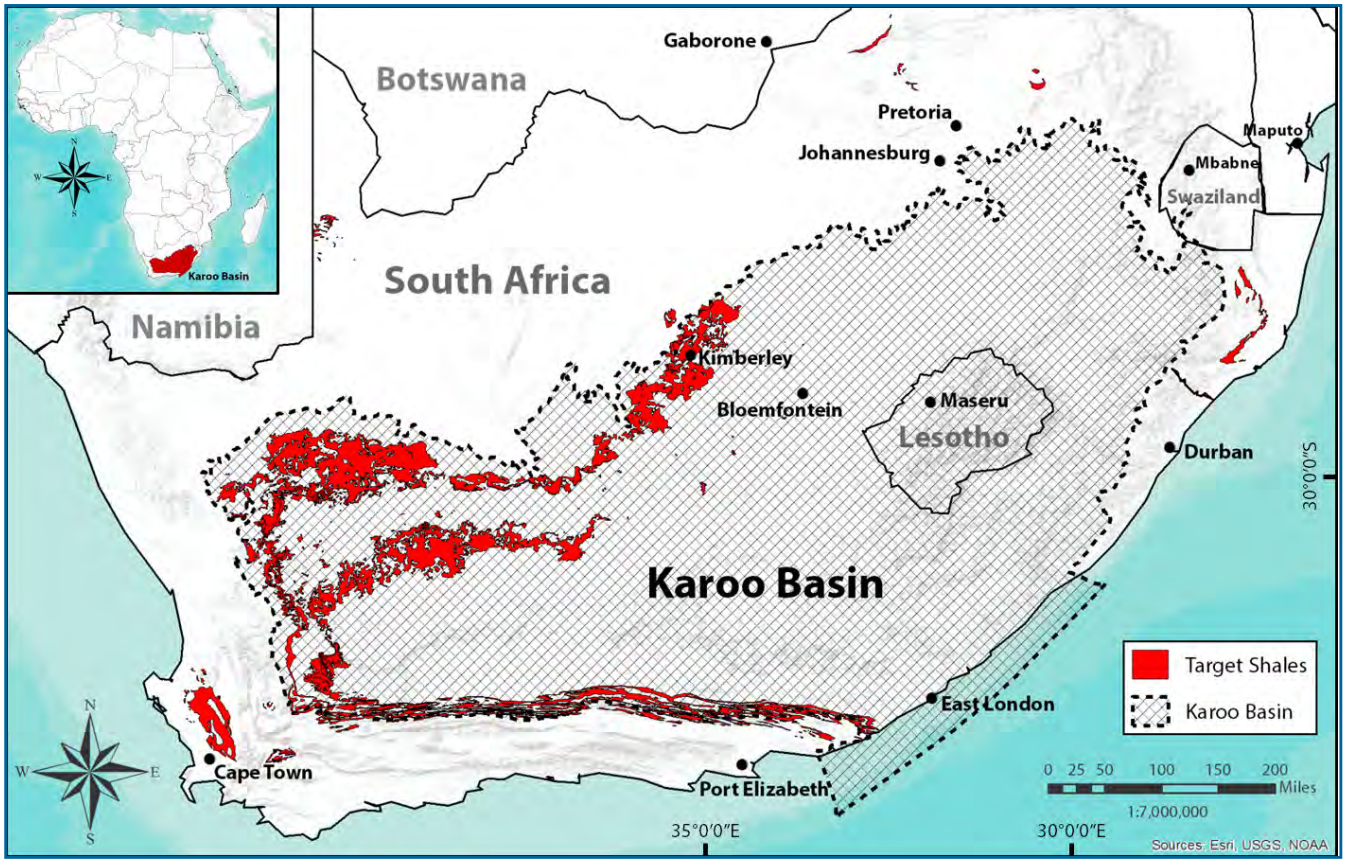

Figure 1 Position of the Karoo Basin and target shales.

Overview

The Karoo Basin, South Africa (Figures 1, 4, 6) covers an estimated 600,000 km^2 of the country's land surface, encompassing sedimentation from approximately 280 Ma to 180 Ma. The basin, host to a significant proportion of South Africa's coal reserves (i.e. Waterberg Coalfields), has previously been the target of unsuccessful conventional hydrocarbon exploration in the 1960s and 1970s, with more recent hydrocarbon exploration now focusing on the unconventional reservoir potential of shales. Recent resource estimates (Decker and Marot, 2012) predict variable recoverable shale gas in-place from ~30 Tcf to ~500 Tcf, noting that even conservative estimations indicate a potentially large recoverable resource. However, little information is readily available related to integrated analyses of potentially viable shales across the Karoo Basin. Furthermore, the effects of deformation, shale degassing, fluid migration and the natural fracturing characteristics of target shales (i.e. Ecca Group shales) within the Karoo Basin are poorly understood and integrated.

Geographically, the Southern Karoo Basin hosts the primary unconventional reservoir-/play-targets for shale-gas exploration, with the carbonaceous shales of the Ecca and Dwyka Groups (Karoo Supergroup) the primary focus of interest. Previous studies noted little lithological variation in the Ecca and Dwyka Groups units along strike from the KwaZulu-Natal Province in the east to the Cape Province in the west, making the Karoo shales an ideal target for geological, petrological and geophysical characterization.

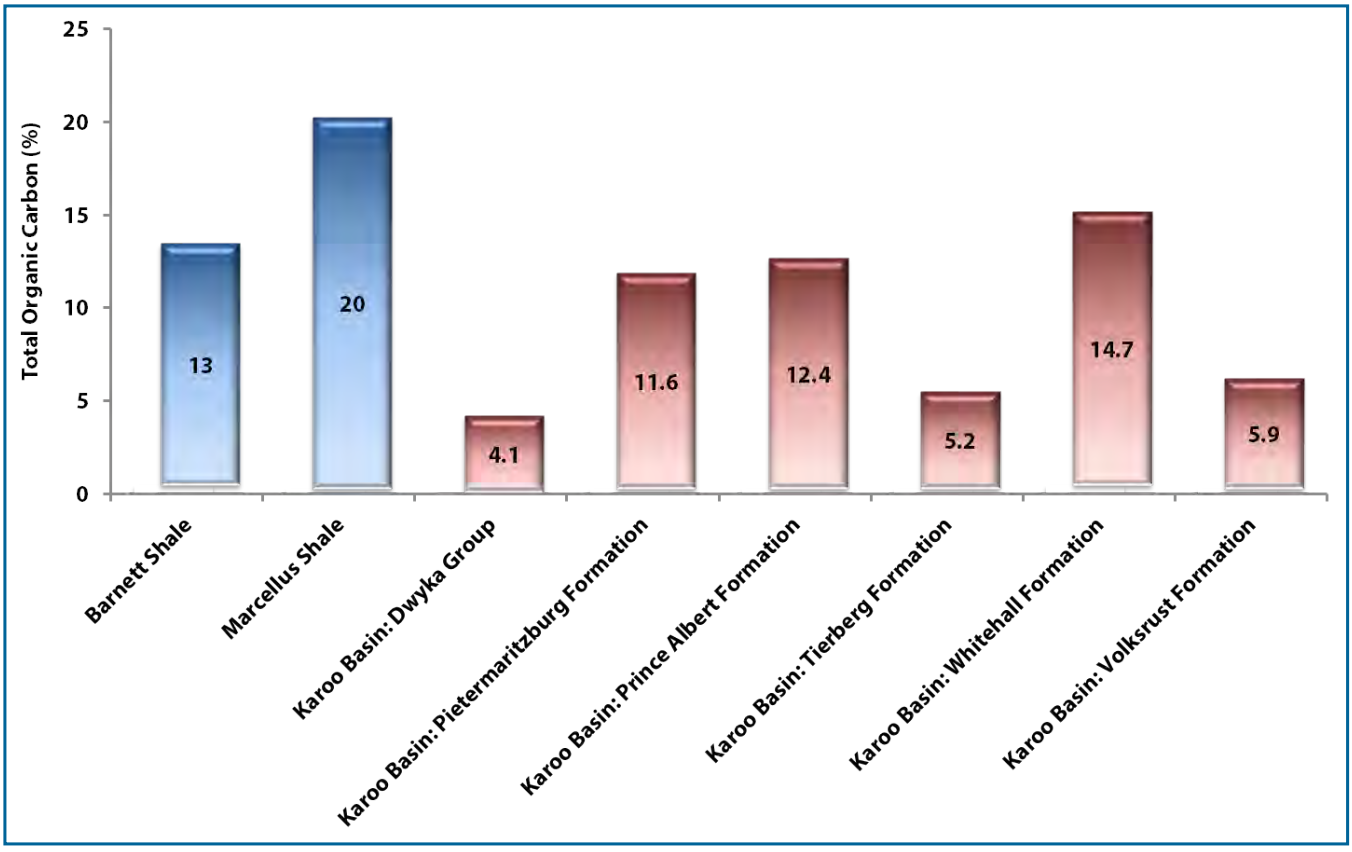

Figure 2 Estimated percentages of total organic carbon (TOC) of notable North American shale plays (blue) compared with potentially viable Karoo Basin shale formations (red). Data from Steyl, G, Van Tonder, G. J, & Chevallier, L. State of the Art: Fracking for Shale Gas Exploration in South-Africa and the Impact on Water Resources. In Commission W.R., 96. Pretoria 2012.

Sample Acquisition & Logistics

The preliminary selection of target source/reservoir lithologies/areas, in addition to their associated seal/cap lithologies are identified in relation to suitable (i.e. marine and transitional lacustrine) depositional environments and basin dynamics (i.e. deformation characteristics). Carbonaceous shales of the Lower and Upper Ecca Group within the central and southwestern areas of the Karoo Basin are identified as the primary targets, with shales of the Dwyka Group considered a secondary target. Target formations of both groups are as follows:

1. **Ecca Group (marine and lacustrine shales, tight sands, carbonates):**
    a. Pietermaritzburg Formation (KwaZulu-Natal Province)
    b. Prince Albert Formation (Northern and Western Cape Provinces)
    c. (Carbonaceous) Tierberg Formation (Free State and KwaZulu-Natal Provinces?)
    d. Whitehall (source/reservoir) and Collingham (source and/-or cap rock) Formations (Northern and Western Cap Provinces)
    e. Volksrust Formation (Free State and KwaZulu-Natal Provinces)
    f. Vryheid Formation (Free State and KwaZulu-Natal Provinces)

2. **Dwyka Group (shales intermixed with turbidite and deltaic sequences):**
    a. Elandsvlei Formation (Free State and KwaZulu-Natal Provinces?)
    b. Potentially also the Witberg River section Formation (shales)

The evaluation of target shales involves collection of core, cutting samples, outcrop rocks, sediments from archival core, and fieldwork from across several areas of the Karoo Basin (Figures 2 and 3). Samples will preliminary be collected from ground-truthing of multiple shales and existing (archival cores).

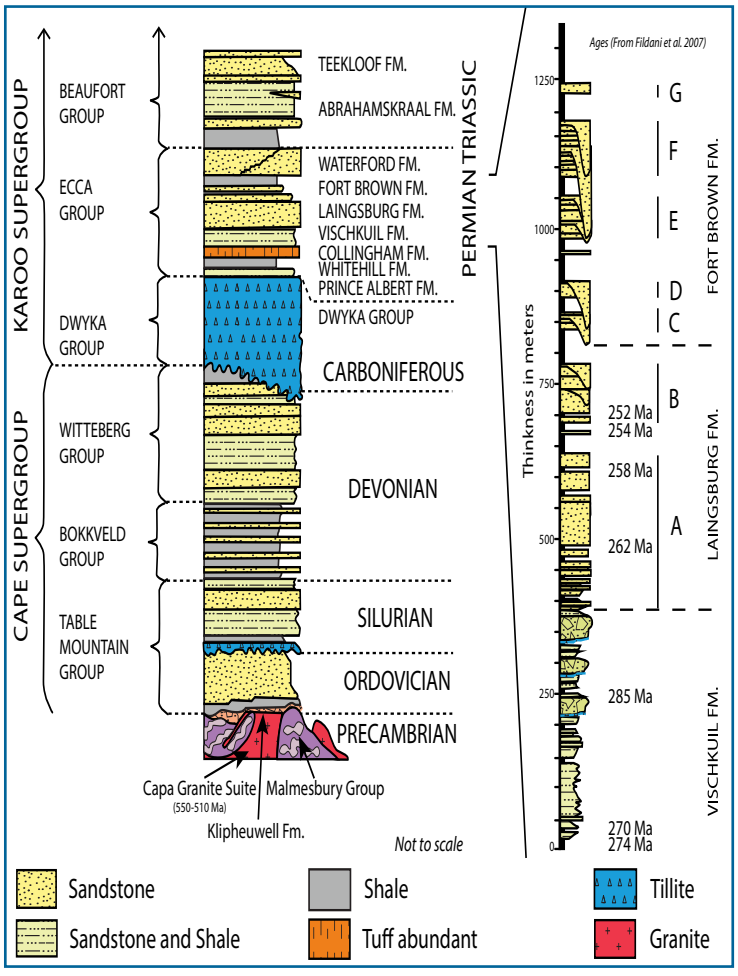

Figure 3 Schematic stratigraphic column for the Karoo and Cape Supergroups. Figure modified from Flint et al, 2011, ages from Fildani et al,. 2007

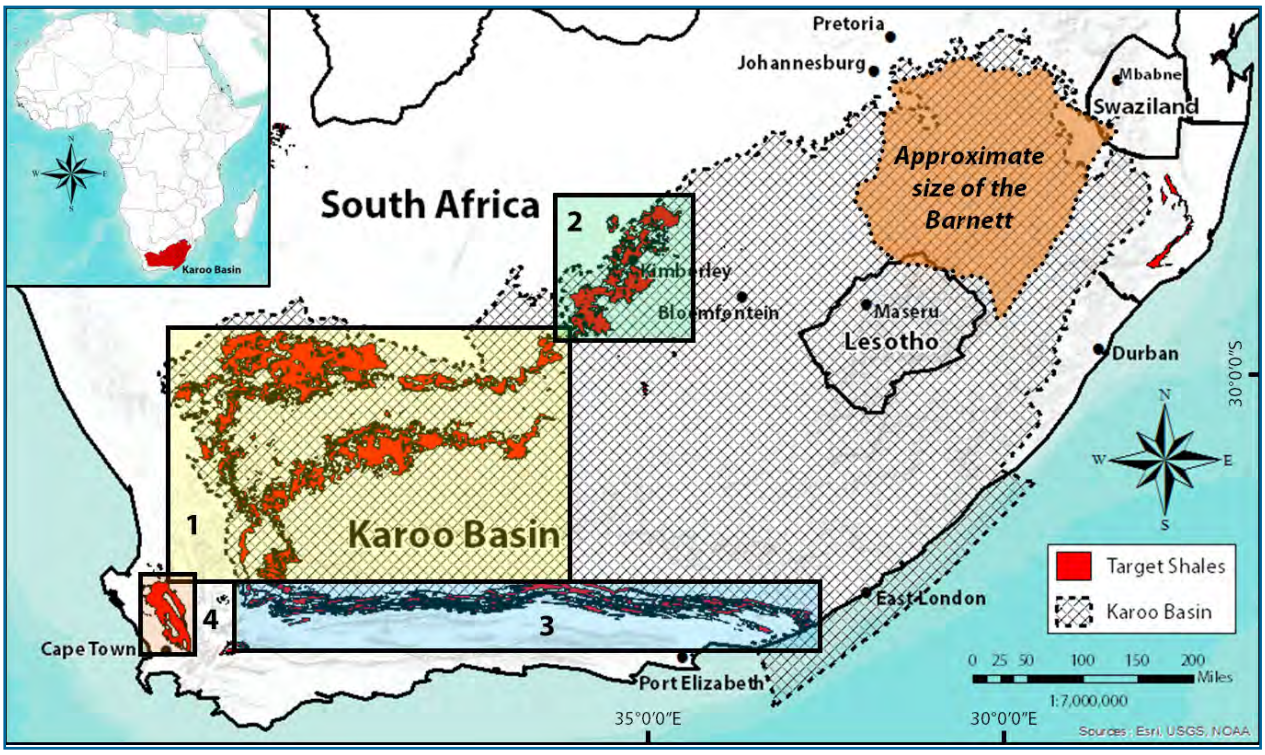

Figure 4 Proposed target areas of unconventional rocks (shales, carbonates and tight sands) within the Karoo Basin. Areas are listed from 1-4 in order of priority. Area 4, outside of the Karoo is noted as being of subordinate interest.

Key Research Areas & Scope of Work

The project is designed to have a strong emphasis on the contextually significant relationships via cutting edge analytical data across multiple sources (i.e. geology, petrophysics and geophysics), collaborators, analytical platforms/tools (i.e. optical microscopy, XRD, XRF, QEMSCAN®, SEM, FIB-SEM etc.), and across multiple scales (i.e. macro- to nano- scales). The ultimate goal is to minimize time and resources currently dedicated to the identification of potential reservoir plays in the Karoo Basin. Improving our ability to locate, trace and supply oil and gas more effectively in South Africa in the future.

Project research is proposed to focus on the integration of three key technical areas; with the aim of establishing an unparalleled understanding of shale resources in South Africa's Karoo Basin, allowing sponsors to make well informed exploration decisions:

1. **Core through Pore™ Integrated Petrological Workflow.** Identification, quantification and correlation of unconventional samples (encompassing shales, tight sands and carbonates) from micro- to nano-scales. Analytical techniques include: optical microscopy (petrographic thin section analyses), automated mineralogy (QEMSCAN®), XRD, XRF, Ar-ion milling, SEM (including high-resolution composite imaging; Figure 4), FIB-SEM, in addition to the integration of novel high-resolution techniques (i.e. TEM/STEM). The integration of petrological analyses allows cutting-edge interpretation of composition, texture, fabric, porosity, permeability, micro-tectonics, micro-facies/depositional evolution and diagenetic history.

2. **Geophysical & Petrophysical Data:** Evaluation and integration of available petrophysical and Geophysical data including well log data (i.e. (Delta Log-R measurements, fluid saturations, density, TOC content, net/gross thicknesses and mechanical properties etc.) is proposed to be carried out within the gross tectonic structural framework, taking into account the correlation of available gravity and magnetic data within the fundamental sequence stratigraphic framework of the basin.
3. **Organic Petrology:** Evaluation of key samples using rock-Eval, TOC, and biomarkers with the integration of inorganic (petrological) analyses and regional (geophysical/petrophysical) data.

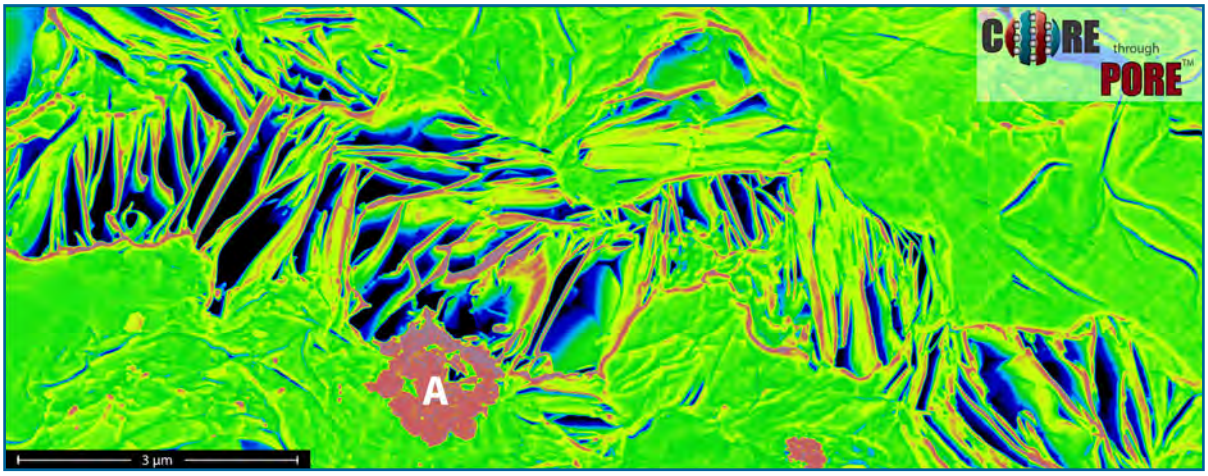

Figure 5 High-resolution, enhanced-color scanning electron microscope (SEM) image of analogous shale to the Karoo Basin. Image shows intraparticle (kaolinite) porosity. As a scale reference, the prominent pyrite grain in the image, marked 'A' indicates the typical size of a single human red blood cell.

Project Deliverables

Project deliverables will focus on the critical assessment of potential shales in key areas of the basin, using available literature, geological modeling and new analyses of samples, including:

1. **Basic Deliverables:**
   a. Key areas of project delivered using ArcGIS (*versions 9.3 and 10.2*) with GIS catalog delivered in Excel format.
   b. Excel delivery of all tables (*including all numerical analytical results*)
   c. Complete bibliography.
   d. PDF documents from final presentation.
   e. Geochemical and petrological databases and charts (Excel).
2. **Advanced Deliverables:**
   a. Comprehensive petrological analyses using the 'Core through Pore™' integrated analytical approach using optical microscopy, XRD, XRF, QEMSCAN®, SEM, FIB-SEM and TEM/STEM.
   b. Integration and assessment of analysis with available well log and magnetic data.
   c. Analog table in Excel format containing key shale parameters and potential analogous North American reservoirs.

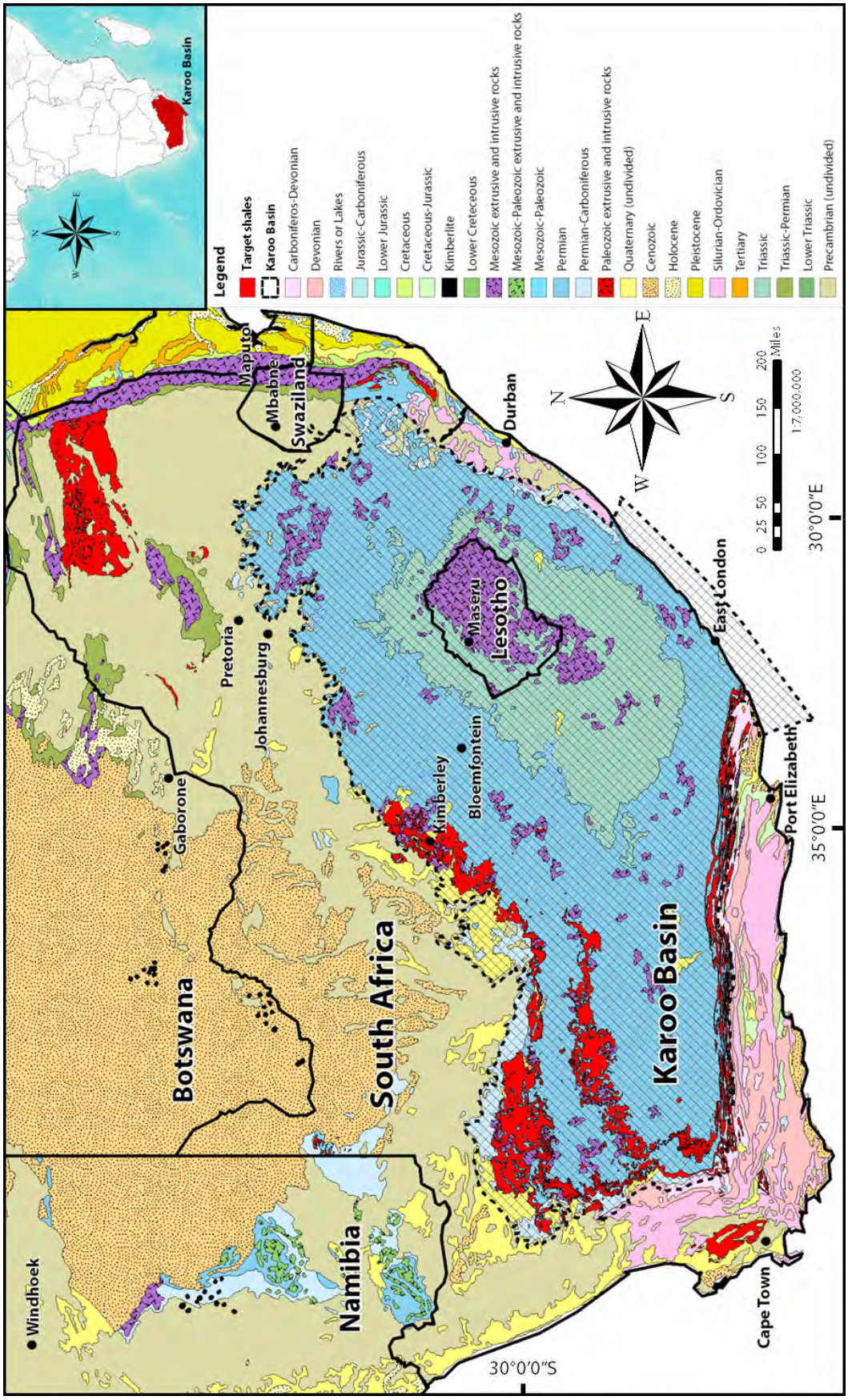

Figure 6 Geological map of South Africa. Target shales for the project are highlighted for reference. Inset map shows position of the Karoo Basin relative to Southern Africa.

Research Team

Staff	Expertise/Affiliation
Dr. Bryony Richards (EGI Principal Investigator)	Petrology
Dr. John Hancox (Caracle Creek International Consulting Inc)	Scientific Advisor, Karoo Expert & General Manager of CCIC Africa
Mr. Christopher Kesler (EGI)	ArcGIS Visualization & Interpretation
Ms. Elinda McKenna (EGI)	Sedimentology
Dr. Ian Walton (EGI)	Resource Estimation
	Additional Staff Added as Needed

In addition, scientists and technical staff from EGI and South Africa will participate in the project depending on the areas of expertise as necessary and an advisory team of experts from the sponsoring companies will guide the research as and when deemed necessary and/-or requested.

The project staff are actively seeking collaborative relationships with a number of universities, organizations and individuals to facilitate fieldwork (including the possibility of setting-up state-of-the-art 'field laboratories'), sample acquisition and knowledge.

Project Timeline, Report & Investment

The project is to be carried out over a period of 24 months. A kick-off meeting, in addition to meetings held at the end of the 1st year and the end of the project are anticipated. The need to distribute data as it is obtained is recognized and periodic data uploads will occur over the course of the two years. Project staff will be available for consultation throughout the duration of the project.

The projected investment per sponsor is $80,000 (USD) for the two year duration.

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Research Interests

- Mineralogy and geochemistry
- Radiochemistry (thermo-chronology, stable isotopes)
- Micro to nano-scale mineralogy
- Integrated mineralogy (petrography, microprobe, XRD, QEMSCAN®, SEM, SEM-FIB)
- Characterization of shales using SEM-FIB
- Integration of mineralogy and computing technology
- Microteconics (petrofabrics)

Senior Petrologist Bryony Richards joined EGI in 2012 as a Research Scientist. After earning a B.Sc. Hons at the University of Durham and a Ph.D. in Geology from Royal Holloway College, UK, she subsequently completed postdoctoral research at the University of Johannesburg, South Africa in conjunction with a number of mining companies related to the assessment and development of kimberlites in southern Africa. Professional industry experience includes the evaluation and development of mineral prospects in Africa, with an emphasis on the geochemistry of sedimentary basins, basin/facies analysis, and sediment-hosted mineral deposits. Her work included the interpretation and development of geochemical surveys (soil, rock, and drilling) from reconnaissance and small-scale to full, extensive geochemical programs. She has a recognized background in integrated techniques utilizing mineralogy/petrology, inorganic geochemistry, radiochemistry, and the evaluation and interpretation of complex, multiple technique databases. Her ongoing research includes the evaluation of hydrocarbon potential in various unconventional reservoirs across the world.

At EGI, Bryony's focus is on the development of integrated analytical approaches for the advancement of conventional and unconventional reservoir understanding, exploration, and development as well as understanding to what degree petrofabrics (microtectonics) within shales can reveal greater basin conditions.

Dr. Richards' publications include mineralogical/petrological, geochemical, and radiochemical studies across a diverse range of geological settings related to both academia and industry work, ranging from tectonics and small-volume magmatism, to kimberlites and sediment-hosted copper deposits. Select publications include EGI reports from South America; China, United Kingdom, United States, India and Central Eurasia, focusing on the advancement of shale reservoir characterization using integrated petrological techniques.

Research Experience

- Interpretation of complex databases
- Integrated mineralogical workflow characterization of unconventional reservoir rocks, using macro to nano-scale integrated methods.
- Integrated low-resolution petrological analyses.
- High-resolution (micro- to nano-scale) microscopy for advanced petrological analyses and interpretation including; Ar-ion milling, microprobe, SEM, FIB-SEM and TEM/STEM analyses.
- Integrated imaging techniques including; large composite imaging of SEM analyses, 3D modeling using FIB-SEM and computed tomography.
- Radiochemical techniques including; 40Ar/39Ar thermochronology, U-Pb geochronology and stable Isotopes (δ18O).

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