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# Chemical and Lithological Comparison of Katberg and Burgersdorp Formations, South Africa

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**Abstract:** Burgersdorp and Katberg formations are both in the Tarkastad subgroup (upper Beaufort Group) of the Karoo supergroup. These two formations are very important in geological history by virtue of their abundance of terrestrial fossils which have enabled the present-day globally accepted eightfold biostratigraphic subdivision of terrestrial fossils. Katberg formation underlies Burgersdorp formation, although, there have been disputes by several researchers that these two formations are interbedded and this was investigated in the research. The lithological outlay of rocks of both formations as well as their elemental compositions were investigated, their compositions based on thin section and SEM analysis were compared and they revealed that both formations have very similar elemental and mineral compositions. This investigation was carried out on the rocks that outcrop in Whittlesea area, Eastern Cape Province of South Africa.

**Key words:** Katberg formation, Burgersdorp formation, interbedding, SEM, thin sections, terrestrial fossils

## INTRODUCTION

Rocks of the Beaufort Group (Karoo supergroup) covers a large part (approximately 300000 km$^2$) of South Africa's land surface. The upper Beaufort group is known as Tarkastard subgroup while the lower part is known as Adelaide subgroup (Smith, 1990; Rubidge, 1995; Neveling *et al*., 2005). Based on the lithostratigarphic subdivision of the Karoo supergroup, Burgersdorp formation is the younger and overlies Katberg formation (Kent, 1980; Damiani, 2001; McCarthy and Rubridge, 2005; Smith *et al*., 2012). Several researchers have had multiple opinions about these two formations, some have proposed a lateral equivalence of both formations laying emphasis on the fact that they possess an auto cyclic relationship (Stavrakis, 1979; Keyser and Groenewald, 1995; Hancox and Rubidge, 2001). Most studies on these formations have focused on their biostratigaphy and petrography due to their wealth of terrestrial plant and animal fossils which have resulted in the present-day eight-fold biostratigraphic subdivision of the area (Smith, 1990; Groenewald and Kitching, 1995; Rubidge *et al*., 1999; Damiani *et al*., 2000; Neveling *et al*., 2005; Cisneros, 2008). Katberg formation is recognised to be predominantly an arenaceous deposit while Burgersdorp formation is recognised to be predominantly argillaceous (Johnson, 1976; Stavrakis, 1979; Smith, 1990; Neveling *et al*., 2005; Guess, 2012; Kent, 1980). By De-Kock and Kirschvink (2004) classified the strata of these formations as fluvial sediments which consist of alternating mudstone and sandstone units, a characteristic upward-fining is noted in the rock layers with red and purple colours, abundant fossils, desiccation cracks and palaeosol horizons which all suggest that the sediments accumulated in a semiarid environment (Stavrakis, 1980; Smith, 1990; Groenewald, 1996; Hancox and Rubidge, 2001; Damiani, 2001).

Maps can generally be described as a visual representation of an area which shows relationship between spatial features, a geological map shows the distribution of rock units and structures over a specific area or region on a plane surface (e.g., paper) (Richard *et al*., 1999; Njue, 2010; McKay and Harris, 2016). Geological mapping is of utmost importance as maps area are detailed two-dimensional representation of a three dimensional spatial location, they also display relationship between lithologies and the chronostratigraphy of rock units.

**Geological setting and location of the study area:** The study area (Katberg and Burgersdorp formations) is located in Whittlesea which is about 37 km South of Queenstown, Eastern Cape Province, South Africa. The strata are still near horizontal, although, they have been intruded by dolerite dikes and sills which are indicators of groundwater potential of the area. Rocks that were in contact with the basalt intrusion have been slightly metamorphosed into zeolites. In this area the dominant lithology is sandstone which indicates a change in sedimentation during the Triassic Period in South Africa, these sandstone deposits are assumed to be as a result of the eroded landscape due to the fact that plant species

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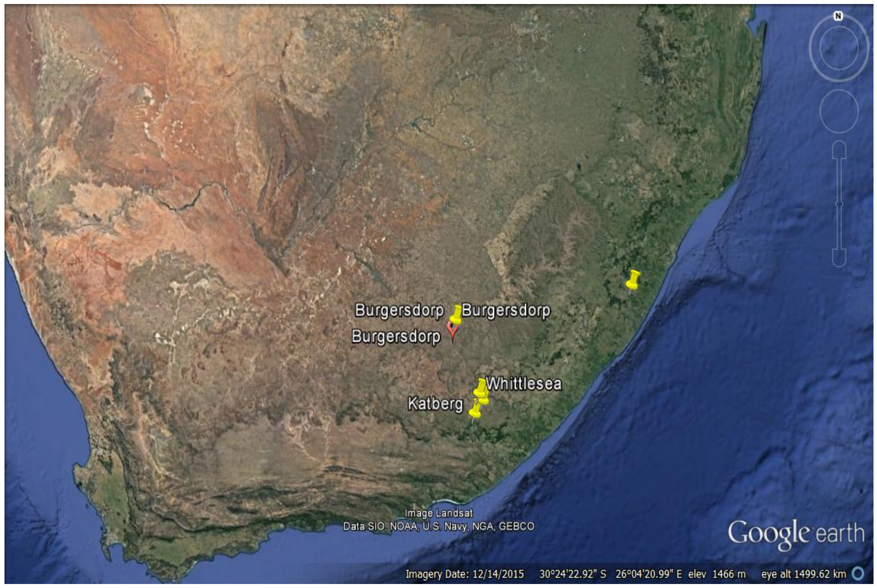


Fig. 1: Google Earth map showing the location of the study area which is located around latitudes: 31.37-32.07° and longitudes: 26.51-28.09°

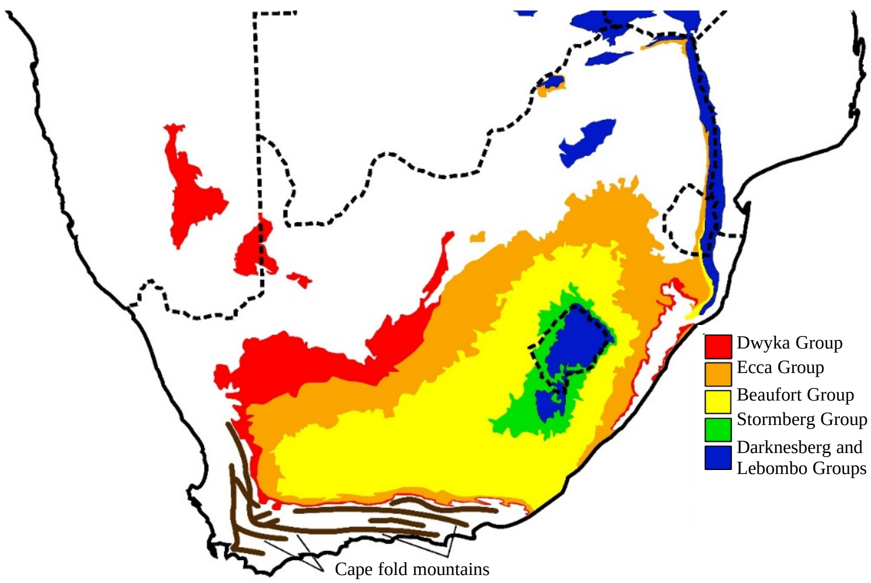


Fig. 2: Distribution of rock sequences of the Karoo supergroup (Bordy *et al*., 2009; Hancox and Rubidge, 2001)

became extinct during the ending of the Permian mass extinction. The mudstones and shales are as a result of recovery of vegetation at a later stage. Fossils of Lystrosaurus and Cynognathus as well as burrow pits have been discovered in both the Katberg and Burgersdorp formations which is an indication of a similarity between the two formations (Fig. 1).

Deposition of the Karoo Basin took place between the Triassic and Carboniferous periods. Being the most widely spread stratigraphic unit in Africa, the Karoo supergroup covers about two thirds of Southern Africa's total land area and it extends into Lesotho, Zimbabwe, Zambia, Malawi, Swaziland and Namibia (Fig. 2).

In South Africa, it covers almost the whole of free state and large parts of the Eastern Cape, Northern Cape, Mpumalanga and KwazuluNatal Provinces, respectively (Bhatia, 1983; Hiller and Stavrakis, 1984; Botha and Smith, 2006, 2007; Diskin *et al*., 2010) the rock types that dominate the Karoo are mainly shale, mudstone and sandstone, diamictites found in some area. Most of the Karoo has been intruded by dolerites which have caused minor and major changes in the characteristics of the rocks, the dolerites also serve as a great trap for groundwater. The depositional environments for the Karoo supergroup include glacial, deep marine, shallow marine, deltaic, fluvial, lacustrine and aeolian environments (Hiller and Stavrakis, 1984; Smith *et al*., 1993; Johnson *et al*., 1996; Catuneanu and Elango, 2001).

The Beaufort Group is subdivided into the upper Adelaide and lower Tarkastad subgroups, respectively, it covers approximately 300.000 $km^2$ in South Africa and is known worldwide for its abundance of terrestrial fossils (Smith, 1990; Rubidge *et al*., 1999; Hancox and Rubidge, 2001; Neveling *et al*., 2000, 2005) due to the reciprocal flexural profile of the Karoo Basin, it can be said that the Beaufort Group accumulated in a strongly partitioned foreland basin.

The Katberg formation has an equivalent in the Northern Cape Province which is known as Verkykerskop formation (Hancox and Rubidge, 2001). Both formations are composed of medium to coarse grained sandstone which have been considered to have been uplifted tectonically in the Cape Fold Belt (Cole, 1992; Groenewald, 1996; Smith, 1990).

Based on the King Williams Town geological map, the horizontal beds of Katberg sandstone was seen to overlay the younger Burgersdorp rocks with no evidence that overturning of strata occurred (Stavrakis, 1979). According to Almond, the mudrocks were deposited by suspension that settled in the overbank areas after flooding and inundation events while other fine-grained sediments such as silt were deposited by lakes. Gess, suggests that the beginning of the Triassic Period in South Africa was marked by a change in sedimentation which led to the distinct sandstone dominated lithology of the Katberg formation (Du Plesis, 2008). In order to clarify the arguments about the rock outlay of the Katberg and Burgersdorp formations, this study has used a critical analysis of aerial photographs and topographic maps to identify and map lithologies towards confirming if interbedding occurs while petrographic and scanning electron microscope were used to determine and compare the elemental and mineral composition of both rock formations.

## MATERIALS AND METHODS

**Aerial photographs and topographic maps:** Aerial photos and topographic maps were critically analysed for desktop mapping, several field visits were made in order to confirm results of desktop mapping. Google Earth was also used to confirm lithologies which were difficult to identify on the desktop, the identified lithology were then digitized to create the lithology map of the study area.

Photo Studio 5.5 Software was used to view analyse and digitize aerial photos and the topographic map of the study area. A total of 25 aerial photos and one topographic map covering the study area (block 3226 BD) were uploaded unto the PhotoStudio Software. Each aerial photo was analysed separately, features such as dams, road junctions and farms that could be identified on both the topographic map and aerial were earmarked with a red colour, to recognise specific locations when in the field and also to appropriately position the aerial photos on the topographic maps. Mudstones and shales were grouped together as argillaceous deposits while sandstones were grouped as arenaceous deposits. Most of the Karoo has been intruded by dolerites, therefore, dolerite intrusions (dykes and sills) were also mapped. The arenaceous and argillaceous deposits, dykes and sills were identified and digitized and a specific colour was assigned to each of these features. Arenaceous deposits were digitized in green, argillaceous deposits in grey, dykes and sills in red, while ponds, dams and rivers were digitized in different shades of blue, respectively. The aerial photos and topographic map were later superimposed and digitized with geological and geographical features assigned to separate layers with colour codes. All of these layers were later merged to produce a final map of the study area.

**Mapping and field observations:** Geological mapping of the study area was done by several field visits to identify outcrop features and lithologies. Features such as colour, sedimentary structures, lithology and other important information of the area were noted and recorded. Samples were also collected for geochemical analysis and pictures of important features were taken. The topographic map that was used in the desktop study was taken along to the field each time to make it easier to identify features that were marked on it and ensure that the correct study area is being observed at any given time.

**Petrographic analysis:** Samples of sandstones and mudstones were collected from both the Katberg and Burgersdorp formations, respectively. Thin sections of the samples were prepared as described by Hill and Ratkevich. The rock samples were broken down to a size small enough to cut on the tile saw. Then, the sample was cut into a rectangular block with dimensions smaller than a slide, a little coarse grit and water was put on the lap to make a slurry in the middle of the plate. The sample side was ground on the slurry to make it very flat and smooth.

When the rock surface looked as smooth as possible, the lap was cleaned and a medium grit was used to grind, after which it was cleaned again and grinding was done with the fine grit, to make a very smooth and flat rock sample surface. The sample was rinsed clean, placed on the hotplate for a while to dry perfectly. Once, the sample was completely dry, a slide was warmed on the hotplate (100°C). A large drop of mixed epoxy was put on the centre of the slide, the smooth side of the rock sample was carefully set on it and gently pressed for the epoxy to spread evenly. The sample was then set aside in order to cure the epoxy. The thin sections from both formations were then observed and compared for mineral composition using an Olympus CX 31 petrographic microscope.

**Scanning electron microscope and energy dispersive X-ray analyses:** The samples were further prepared for SEM-EDX analysis as described by Pachauri *et al*. (2013). The samples were cut into small pieces and glued to glass slides, after the glue had completely dried, they were then coated with carbon and later taken for viewing under the scanning electron microscope. A SEM machine of model JEOL JSM-6390 LV, equipped with energy dispersive spectrometer was used to determine the elements present in the rock samples and in what amount each was present. This was also used to determine the grain external morphology and rock texture, the images were taken at different magnifications.

## RESULTS AND DISCUSSION

From the final lithology map that was produced in this study, it is evident that Katberg and Burgersdorp formations are interbedded (Fig. 3 and 4). Deposition of sands probably occurred along river channels while flooding occurred from intermittently, frequent periodic flooding must have resulted in the deposition of mudstones and shales including dead plants along the flood plains. These repetitive processes are assumed to have formed the interbedded sandstones, mudstones and shales (Fig. 5) which are well exposed in the study area. The two formations were observed to contain concretions ranging between 0.5-5.0 cm in diameter in some parts. The area with the concretions in Katberg formation exhibited a yellowish-brown colour, this is attributed to an oxidizing environment. In an oxidizing environment, the Iron (Fe) metals present in rocks react with water and oxygen to produce iron oxide which gives rocks a yellowish to red-brownish colouration (Stavrakis, 1979; Oghenekome, 2012).

Depending on the concentration of iron oxide in the rocks, they can be a source of pollution to surface and groundwater around (Du Plessis, 2018). The area with concretions in the Burgersdorp formation (Fig. 6) was similar in colour but was a bit more whitish, the concretions are between 0.2-5.0 cm they were formed as a result of groundwater flow and chemical reactions (Earle *et al*., 2003; Chan *et al*., 2004). The general colour of Katberg sandstone is khaki-green with obvious thick, black laminations which are possibly indicative of the presence of heavy metals (Rubidge *et al*., 1999; Neveling *et al*., 1999). The rocks are generally more weathered at the top because of the rain and snow in Winter, this and the relatively humid climate of the area encourage a lot of vegetation on top of the rocks. The primary structures observed in the rocks include tabular and through cross bedding, ripple marks, lamination and

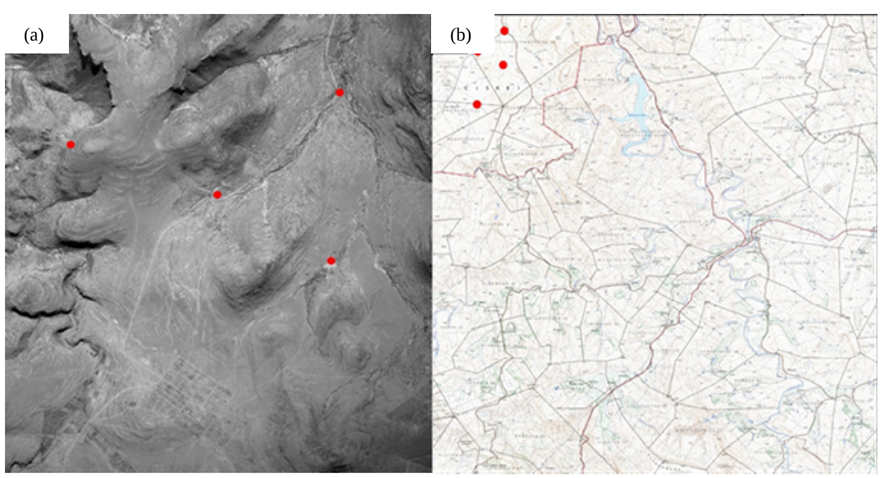


Fig. 3: Aerial photo and topographic maps used in constructing the lithographic map of the study area: a) Aerial photo and b) Topographic map

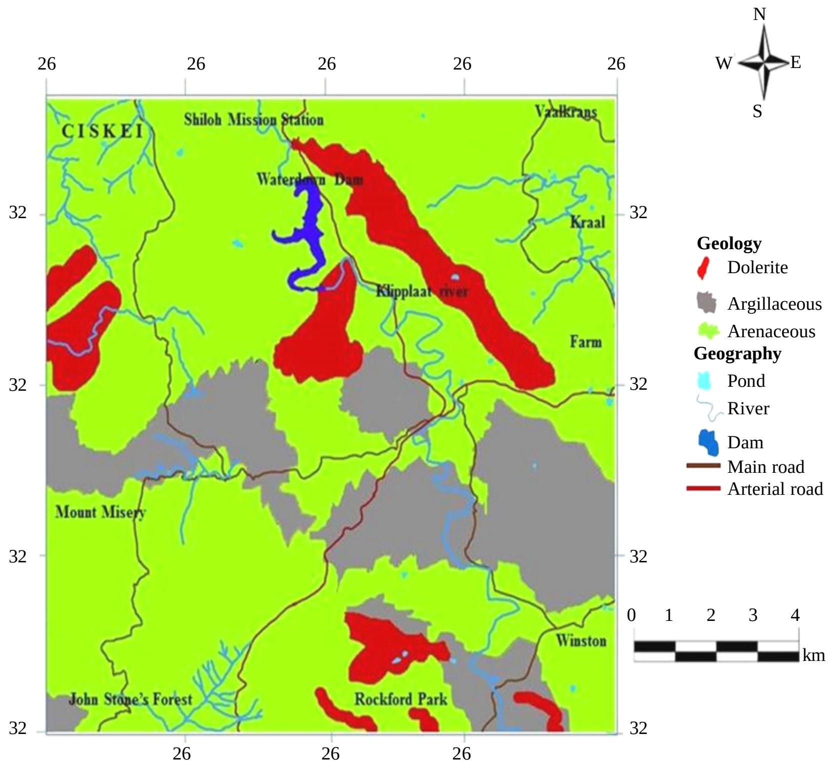


Fig. 4: Final lithological map of argillaceous mudstones, shales and arenaceous sandstones of Katberg and Burgersdorp formations, Whittlesea, South Africa

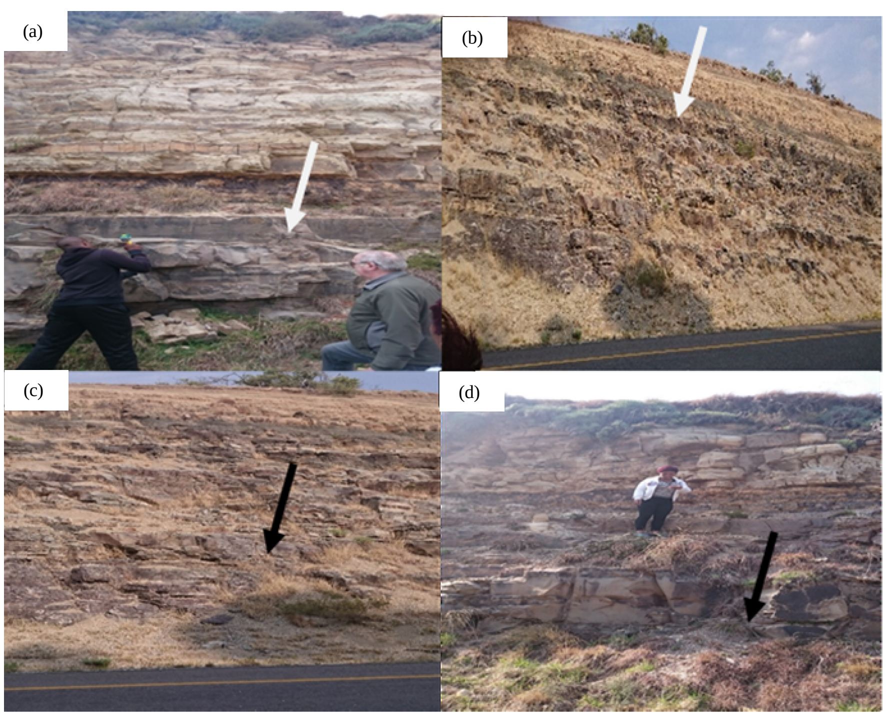


Fig. 5: The evidence of argillaceous rocks interbedded with arenaceous rocks: a, b) Shale between sandstones (white arrow) and c, d) Mudstones between sandstones (black arrow)

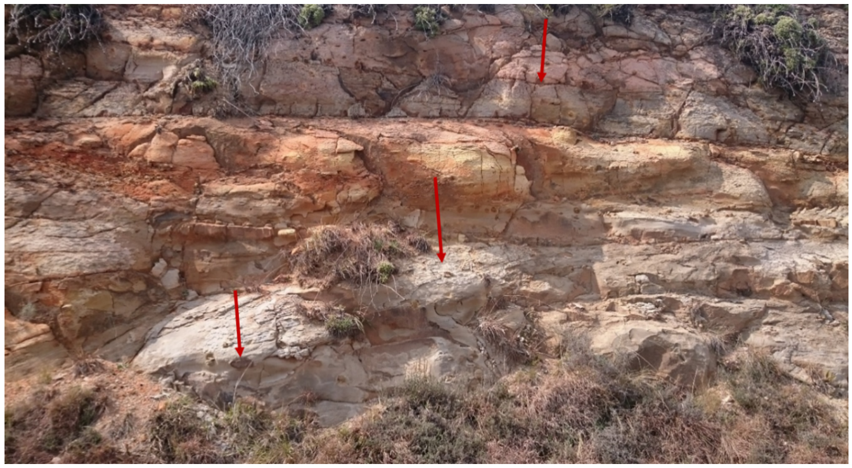

Fig. 6: Red concretions (red arrows) of the Burgersdorp formation

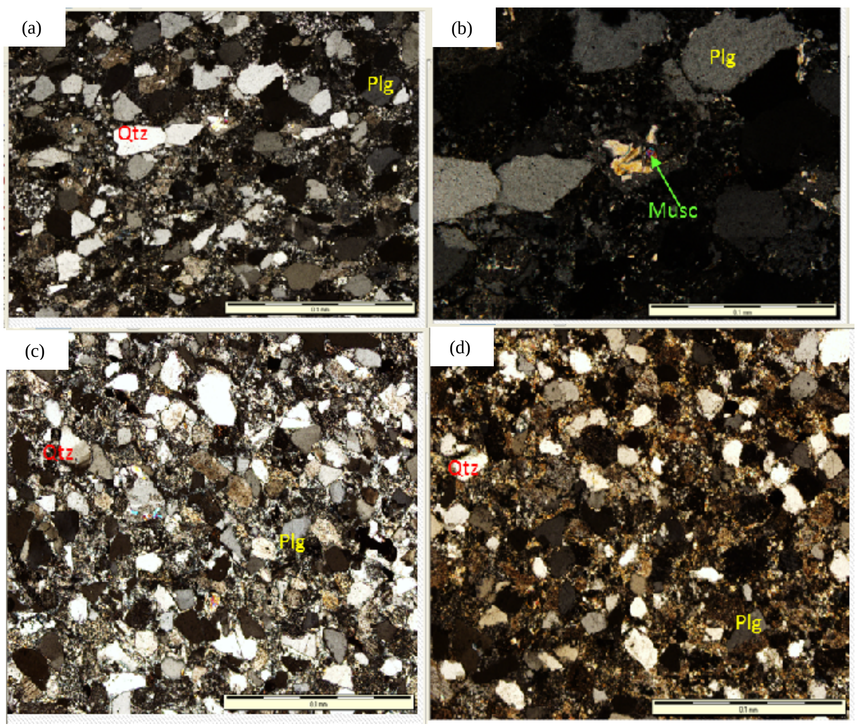


Fig. 7: a, b) Thin sections of sandstone samples from Katberg formation and c , d) Thin sections of sandstone samples from Burgersdorp formation observed under plane and cross polarized light (Qtz-Quartz, Plg-Plagioclase Feldspar, Musc-Muscovites)

lineation, there are lots of lineation structures exposed on the rocks which helped to have an idea of the direction of flow during deposition at different times (McBride *et al*., 2003). Faults, joints fractures, veins, dykes and sills are the observed secondary structures. Extensive sandy deposits resulted from multi channelled braided river systems that replaced the meandering rivers of the underlying Adelaide subgroup (Neveling *et al*., 2006; Groenewald and Kitching, 1995; Johnson, 1976) this changed most likely as a result of increased erosion of the landscape due to widespread extinction of plant groups during the end-Permian mass extinction.

**Petrographic analysis:** Figure 7 shows the mineral content of sandstone samples from the two formations. Both samples revealed the presence of quartz, plagioclase

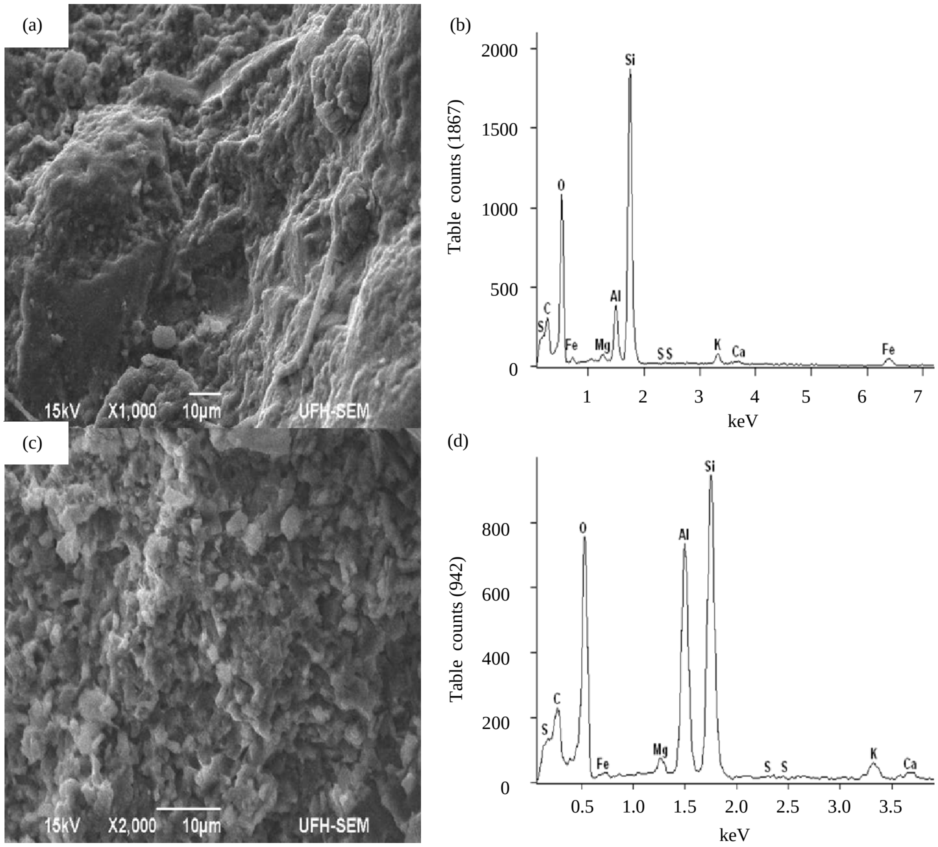


Fig. 8: SEM micrographs showing morphology: a) Katberg; c) Burgersdorp formation sandstones and energy dispersive spectrum; b) Kateberg and d) Burgersdorp formation

Table 1: The Lithostratigraphy of Karoo supergroup with emphasis on Beaufort Group (Nyambe and Utting, 1997; Catuneanu *et al*., 2005a, b; Mcatrthy and Rubridge, 2005)

| Karoo supergroup | | | | |
|---|---|---|---|---|
| Group/subgroup | Formation | Lithology | Thickness (M) | Assemblage zone |
| Stormberg | Molten | Sandstone, Shale | 450 | |
| **Beaufort** | | | | |
| Tarkastad | Burgersdorp | Mudstone, Sandstone, Shale | 1000 | Cynagnathus |
| | Katberg | Sandstone | 900 | Lystrosaurus |
| Adelaide | Balfour | Mudstoae, Shale, Sandstone | 2150 | Dicynodon |
| | Middleton | Shale, Sandstone, Mudstone | 1500 | Tropidostoma |
| **ECCA** | | | | |
| Abrahamsicraal | Koonap | Sandstone, Shale | 1300 | Tapinocephalus |

feldspar and muscovite minerals. The thin sections were viewed under plane and crossed polarised light. The same minerals are observed in the sandstone samples from both formations (Table 1).

**Scanning Electron Microscope (SEM) analysis:** Results of the SEM analyses of sandstone samples from both formations is shown in Fig. 8. The presence of pore spaces and clay minerals were observed in both formations. Energy dispersive-ray (Fig. 8) revealed the presence of C, O, Mg, Ca, Fe in the Katberg formation However, the Burgersdorp formation revealed the presence of the same elements with addition of Sulphur (S) which was absent in Katberg formation.

Table 2: Percentage composition of elements in Katberg sandstones

| Elements | Concentration (%) | Error (%) |
|---|---|---|
| C | 16.84 | 0.72 |
| O | 39.80 | 0.63 |
| Mg | 0.56 | 0.07 |
| Al | 5.03 | 0.16 |
| Si | 28.95 | 0.28 |
| K | 1.79 | 0.18 |
| Ca | 0.63 | 0.09 |
| Fe | 6.40 | 0.63 |

The EDX analysis (Table 2 and 3) revealed that the sandstones from both Katberg and Burgersdorp formations both have the same elemental composition except that the Burgersdorp sandstones contain sulphur of about 0.20%. The iron content of Katberg sandstone is

Table 3: Percentage composition of elements in Burgerdrop sandstones

| Elements | Composition (%) | Error (%) |
|---|---|---|
| C | 16.84 | 0.83 |
| O | 37.06 | 0.72 |
| Mg | 0.99 | 0.09 |
| Al | 13.86 | 0.20 |
| Si | 21.77 | 0.33 |
| S | 0.20 | 0.07 |
| K | 2.51 | 0.13 |
| Ca | 0.93 | 0.12 |
| Fe | 5.83 | 0.48 |

slightly higher than that of Burgersdorp. The aluminium content in Katberg is 5.06% which is much lower than in Burgersdorp which contains 13.86%. This may be responsible for the prominent red colour of Burgersdorp sandstones in some parts (Catuneanu, 2006; McCarthy and Rubridge, 2005).

## CONCLUSION

Based on the results of this study, it is evident that the Katberg and Burgersdorp formations are indeed interbedded, more research is still recommended in order to know the extent of inter-bedding. It is proposed that all prominent sandstone units in the upper Beaufort Group should be classified as Katberg formation and all prominent shale and mudstone units should be classified as Burgersdorp formation. The areas with dolerite intrusions also indicate a possibility of groundwater which can be explored. These formations are important geologic markers and the give lots of information concerning the processes that have occurred such as evidence of the mass extinction which took place several million years ago and also the animals which existed before the mass extinction (Damiani *et al*., 2000). The conclusions by many researchers based on biostratigraphy (Veveling *et al*., 1999; Rubidge *et al*., 1999; Hancox and Rubidge, 2001; Nevelling *et al*., 2005; Cisneros, 2008) that the base of the Burgersdorp formation displays thin, weak and lenticularly channelled sandstones which are dominated by horizontal stratification, indicating strong genetic links with the arenaceous Katberg formation should be reviewed and considered for the lithology of these formations as well.

## REFERENCES

Bordy, E.M., O. Sztano, B.S. Rubidge amd A. Bumby, 2009. Tetrapod burrows in the Southwestern main Karoo Basin (Lower Katberg Formation, Beaufort Group), South Africa. Palaeontol. Africana, 44: 95-99.

Botha, J. and R.M. Smith, 2006. Rapid vertebrate recuperation in the Karoo Basin of South Africa following the end-Permian extinction. J. Afr. Earth Sci., 45: 502-514.

Botha, J. and R.M. Smith, 2007. Lystrosaurus species composition across the Permo-Triassic boundary in the Karoo Basin of South Africa. Lethaia, 40: 125-137.

Catuneanu, O. and H.N. Elango, 2001. Tectonic control on fluvial styles: the Balfour Formation of the Karoo Basin, South Africa. Sediment. Geol., 140: 291-313.

Catuneanu, O., 2006. Principles of Sequence Stratigraphy. Elsevier, New York, USA., ISBN-13: 978-0-444-51568-1, Pages: 376.

Catuneanu, O., H. Wopfner, P.G. Eriksson, B. Cairncross and B.S. Rubidge *et al*., 2005a. The Karoo basins of South-central Africa. J. Afr. Earth Sci., 43: 211-253.

Catuneanu, O., R. Guiraud, P. Eriksson, B. Thomas and R. Shone *et al*., 2005b. Phanerozoic evolution of Africa. J. Afr. Earth Sci., 43: 211-253.

Chan, M.A., B. Beitler, W.T. Parry, J. Ormo and G. Komatsu, 2004. A possible terrestrial analogue for haematite concretions on Mars. Nat., 429: 731-734.

Cisneros, J.C., 2008. New basal procolophonid reptile from the Katberg formation (Lower Triassic) of the South African Karoo. Palaeoworld, 17: 126-134.

Cole, D.I., 1992. Evolution and Development of the Karoo Basin. In: Inversion Tectonics of the Cape Fold Belt, Karoo and Cretaceous Basins of Southern Africa, De Wit, M.J. and I.G.D. Ransome (Eds.). August Aime Balkema, Amsterdam, The Netherlands, pp: 87-100.

Damiani, R., J. Neveling, P.J. Hancox and B.S. Rubidge, 2000. First trematosaurid temnospondyl from the Lystrosaurus Assemblage Zone of South Africa and its biostratigraphic implications. Geol. Mag., 137: 659-665.

Damiani, R.J., 2001. Parotosuchus (Amphibia, Temnospondyli) from the Cynognathus Assemblage Zone (Early Triassic) of South Africa: Cranial morphology and relationships. Alcheringa, 25: 351-379.

De Kock, M.O. and J.L. Kirschvink, 2004. Paleomagnetic constraints on the Permian-Triassic boundary in terrestrial strata of the Karoo Supergroup, South Africa: Implications for causes of the end-Permian extinction event. Gondwana Res., 7: 175-183.

Diskin, S., S. Coetzee, M. Wendorff and M. Lethsolo, 2010. A study of the heavy mineral suite of the sandstone of the Ecca Group of the Karoo Supergroup. Geophys. Res., 12: 15411-15411.

Du Plessis, G.P., 2018. The relationship between geological structures and dolerite intrusions in the Witbank Highveld coalfield, South Africa. Master Thesis, University of the Free State, Bloemfontein, South Africa.

Groenewald, G.H. and J.W. Kitching, 1995. Bio-Stratigraphy of the Lystrosaurus Assemblage Zone. In: Biostratigraphy of the Beaufort Group (Karoo Supergroup), Rubidge, B.S. (Ed.). South African Committee for Stratigraphy (SACS), South Africa, pp: 35-39.

Groenewald, G.H., 1996. Stratigraphy of the Tarkastad Subgroup, Karoo Supergroup, SouthAfrica. Ph.D. Thesis, University of Port Elizabeth, Port Elizabeth, South Africa.

Hancox, P.J. and B.S. Rubidge, 2001. Breakthroughs in the biodiversity, biogeography, biostratigraphy and Basin analysis of the Beaufort Group. J. Afr. Earth Sci., 33: 563-577.

Hiller, N. and N. Stavrakis, 1984. Permo-Triassic fluvial systems in the Southeastern Karoo Basin, South Africa. Palaeogeogr. Palaeoclimatol. Palaeoecol., 45: 1-21.

Johnson, M.R., 1976. Stratigraphy and sedimentology of the Cape and Karoo Sequences in the Eastern Cape Province. Ph.D Thesis, Rhodes University, Grahamstown, South Africa.

Johnson, M.R., C.J.V. Vuuren, W.F. Hegenberger, R. Key and U. Show, 1996. Stratigraphy of the Karoo Supergroup in Southern Africa: An overview. J. Afr. Earth Sci., 23: 3-15.

Kent, L.E., 1980. Stratigraphy of South Africa. Department of Minerals and Energy Affairs, South Africa, Pages: 690.

Keyser, A.W. and G.H. Groenewald, 1995. An Introduction to the Biozonation of the Beaufort Group. In: Biostratigraphy of the Beaufort Group (Karoo supergroup), Rubidge, B.S. (Ed.). South African Committee for Stratigraphy (SACS), South Africa, pp: 1-2.

McBride, E.F., M.D. Picard and K.L. Milliken, 2003. Calcite-cemented concretions in Cretaceous sandstone, Wyoming and Utah, USA. J. Sediment. Res., 73: 462-483.

McCarthy, T.S. and B. Rubridge, 2005. The Story of Earth and Life: A Southern Africa Perspective on a 4.6 Billion-Year Journey. Struik Christian Media, Cape Town, South Africa.

McKay, G. and J.R. Harris, 2016. Comparison of the data-driven random forests model and a knowledge-driven method for mineral prospectivity mapping: A case study for gold deposits around the Huritz Group and Nueltin Suite, Nunavut, Canada. Nat. Resour. Res., 25: 125-143.

Neveling, J., B.S. Rubidge and P.J. Hancox, 1999. A lower Cynognathus Assemblage Zone fossil from the Katberg Formation (Beaufort Group, South Africa). South Afr. J., Sci., 95: 555-556.

Neveling, J., P.J. Hancox and B.S. Rubidge, 2005. Biostratigraphy of the lower Burgersdorp Formation (Beaufort Group: Karoo supergroup) of South Africa-implications for the stratigraphic ranges of early Triassic tetrapods. Palaeontol. Afr., 41: 81-87.

Neveling, J., P.J. Hancox, R. Damiani and B.S. Rubidge, 2000. Early triassic faunas from the lystrosaurus and cynognathus assemblage Zones, South Africa. J. Vertebr. Paleontol., 20: 60A-60A.

Njue, L.M., 2010. Geological field mapping. Proceedings of the 2010 Conference on Short Course V on Exploration for Geothermal Resources, October 29-November 19, 2010, Geothermal Training Programme-UNU-GTP, Geothermal Development Company, Nairobi, Kenya, pp: 1-8.

Nyambe, I.A. and J. Utting, 1997. Stratigraphy and palynostratigraphy, Karoo Supergroup (Permian and Triassic), mid-Zambezi Valley, Southern Zambia. J. Afr. Earth Sci., 24: 563-583.

Oghenekome, M.E., 2012. Sedimentary environments and provenance of the Balfour Formation (Beaufort Group) in the area between Bedford and Adelaide, Eastern Cape Province, South Africa. Ph.D Thesis, University of Fort Hare, Alice, South Africa.

Rubidge, B.S., 1995. Biostratigraphy of the Eodicynodon Assemblage Zone. In: Biostratigraphy of the Beaufort Group (Karoo Supergroup), Rubidge, B.S. (Ed.). South African Committee for Stratigraphy (SACS), South Africa, pp: 3-7.

Rubidge, B.S., S. Modesto, C. Sidor and J. Welman, 1999. Eunotosaurus africanus from the Ecca-Beaufort contact in Northern Cape Province, South Africa-implications for Karoo basin development. South Afr. J. Sci., 95: 553-554.

Smith, R., B. Rubidge and M.V.D. Walt, 2012. Therapsid Biodiversity Patterns and Paleoenvironments of the Karoo Basin, South Africa. In: Forerunners of Mammals: Radiation, Histology, Biology, Chinsamy-Turan, A. (Ed.). Indiana University Press, Bloomington, Indiana, USA., ISBN:9780253356970, pp: 30-62.

Smith, R.M.H., 1990. A review of stratigraphy and sedimentary environments of the Karoo Basin of South Africa. J. Afr. Earth Sci., 10: 117-137.

Smith, R.M.H., P.G. Eriksson and W.J. Botha, 1993. A review of the stratigraphy and sedimentary environments of the Karoo-aged basins of Southern Africa. J. Afr. Earth Sci., 16: 143-169.

Stavrakis, N., 1980. Sedimentation of the Katberg Sandstone and adjacent formations in the South-Eastern Karoo Basin. South Afr. J. Geol., 83: 361-374.

Stavrakis, O., 1979. The effect of agricultural change upon social relations and diet in a village in northern Belize. Ph.D. Thesis, University of Minnesota, Minneapolis, Minnesota.