# ORIGIN OF SODIUM AND ITS APPLICATIONS TO MINE WATER REMEDIATION AND REDUCTION IN THE SOUTH AFRICAN COAL MINE ENVIRONMENT

**N. MALAZA and B. ZHAO**

Department of Geology, Faculty of Science and Agriculture, University of Fort Hare, Private Bag X1314, Alice 5700, South Africa; E-mail: tkmalaza@yahoo.co.uk; bzhao@ufh.ac.za

## ABSTRACT

High Sodium (Na) concentrations cause a major problem for the use of mine water in agriculture and other purposes in most of the South African collieries. The objective of this study was to gain a qualitative understanding of the high Sodium (Na) problem in most of South African coal mine environments. This study has identified the major sodium containing minerals, rock types and possible localities, which are conclusive. It concluded the following: 1) Na-bearing albite ($NaAlSi_3O_8$) is the most probable source for sodium in the coal mine environment based on microscopic, SEM and XRD studies; 2) Sandstone is the most probable source rock of sodium to be released in mine water in the sodium problem coalfields; 3) There is clearly no sodium problem in the Witbank and Waterberg coalfields; 4) It seems the high sodium water is readily available once the roof (mostly sandstone) is incompetent; and 5)No major sodium problems in some of the coalfields such as the Witbank and Waterberg coalfields are probably due to their sub-basin nature.

## 1. INTRODUCTION

High Sodium (Na) concentrations cause a major problem for the use of mine water in agriculture and other purposes and occurs in most of the coalmine environments in South Africa. Typical examples are: Highveld and Vryheid coalfields with high concentration of sodium. However, some coalfields such as Witbank and Waterberg coalfields do not present the sodium problem. The aim of the study was to investigate the: 1) coal depositional environment, e.g. marine, salt lake, or fresh water systems; 2) Forms of the Na salts, e.g. $NaSO_4$, NaCl or others; 3) Occurrence, e.g. in pore water, or solid salts, fine-grained NaCl, or connate brine water or post-depositional process; Source rock types, e.g. coal seams, roof and country rocks; and 4) Locality of Na, e.g., perched aquifers, pore water, or within fractures.

However, no study has been carried out to determine the source of the high Na content in these types of environments. In this study, we provide mineralogical and geochemical evidence for the source of the high Na content in the South African (SA) coal mine environment. The results show that the main basin environment which is of marine deposition possesses high sodium levels compared to the sub basin environments, which is of fresh water deposition.

## 2. GEOLOGICAL SETTING

All the South African coalfields occur in the Karoo Supergroup, forming in the Karoo

sedimentary basin environment in South Africa. The Karoo rocks cover almost two thirds (2/3) of the South African land on shore (Snyman, 1998) (Figure 1).

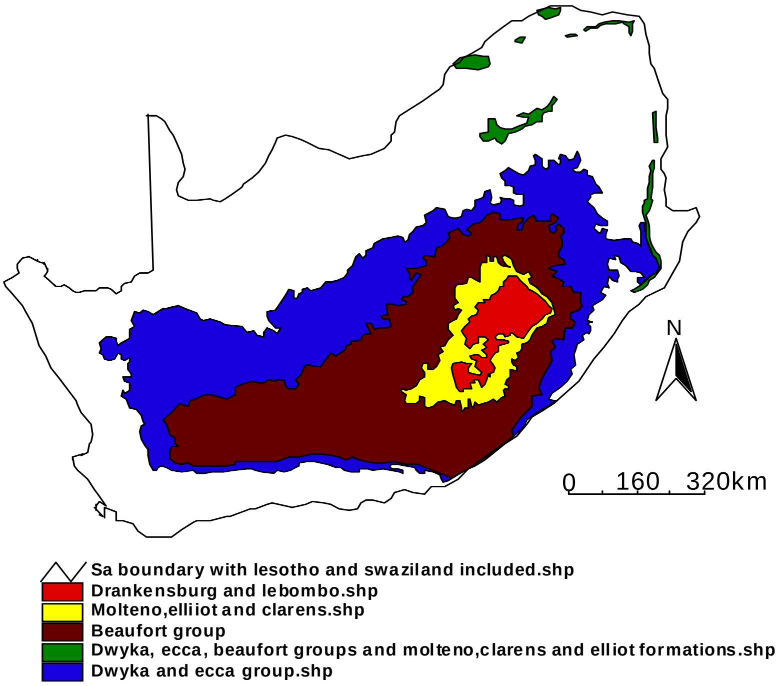


Figure 1. Karoo Supergroup in South Africa, Lesotho and Swaziland

The Late Carboniferous (290-332 Ma.) to Middle Jurassic (159-180 Ma) Karoo basin forms one of the most complete stratigraphic successions in the world that span this time interval (Snyman, 1998). Along a dip-oriented profile, the Karoo sedimentary basin displays a wedge-shaped geometry with a maximum preserved thickness in excess of 6 km adjacent to the Cape Fold Belt (Figure 2). The Karoo basin is a typical foreland basin related to the Cape Fold Belt uplifting (Visser, 1986). Figure 2 also shows the locality of some of the coalfields that overly the older tectonic units such as the Kaapvaal Craton (>3.0 Ga) in the centre, Limpopo Mobile Belt (2.7 Ga) in north and the Namaqua-Natal belt (1.0 Ga) in south and the Cape Fold Belt (0.256 Ga) in the far south. The Karoo basin was developed on the Cape Supergroup (350-500 Ma.), specifically in the south and west of the basin. The sedimentary portion of the basin fill includes:

- The distinctive glacial tillite (diamictite) of the Dwyka Group on the bottom.
- Marine sedimentary rock of the Ecca Group containing most of the coal seams.
- Continental sedimentary rock of the Beaufort and Stormberg groups.
- The volcanic Drakensberg Group on the top, which is related to the break-up of Gondwanaland. (Johnson et al, 2006)

## 3. METHODOLOGIES

Sandstone, shales, dolerite and coal samples were collected from the Highveld, Witbank, Waterberg and Vryheid coalfields (Figure 2). Microscopic mineralogical study and X-ray diffraction (XRD) analysis were carried out in order to determine the mineralogical composition and type, specifically for Na-containing minerals. The results were supplemented with an XRF analysis to determine the geochemical components of different rock types and coal materials and to identify any Na anomaly in different rock types, lithologies and strata or localities. Scanning electron microscopy (SEM) was used to determine the mineralogy and phases of fine-grained minerals, specifically clay minerals and fine Na-containing minerals, e.g. albite in this study. Water quality determination was carried out using AA (cations) and Ion chromatography (anions). Sedimentary basin analysis was carried out in order to determine the environment in which Na-containing minerals were formed, e.g. sea water, salt lake, or post-depositional process. A geochemical model was constructed using the newly obtained information from this study (for treatment and management purpose).

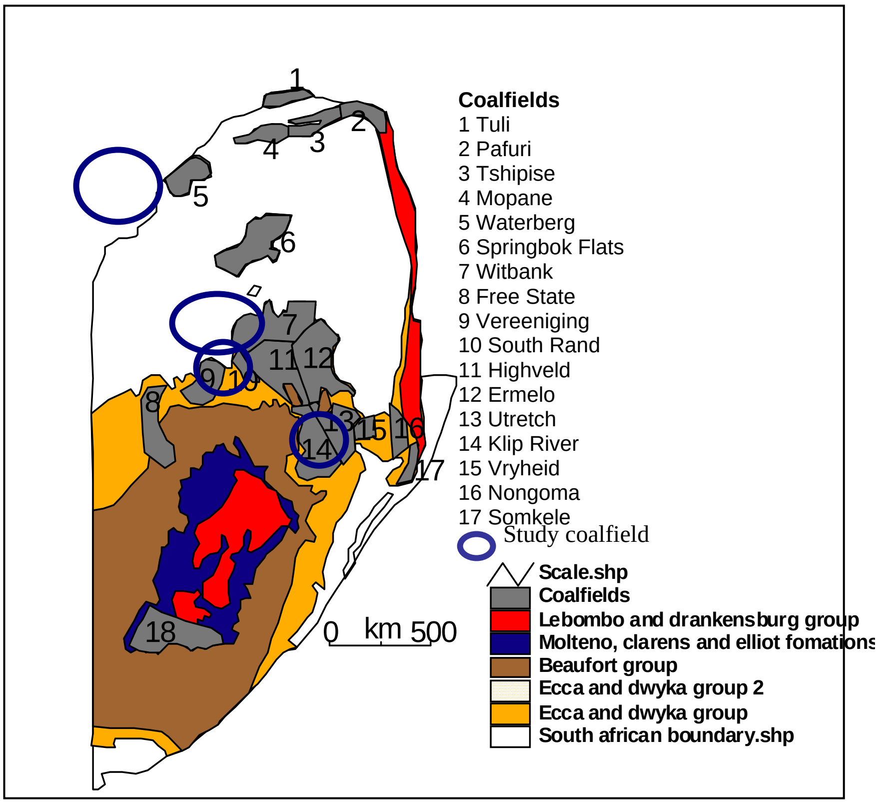


Figure 2. Coalfields of South Africa

## 4. RESULTS AND DISCUSSION

Table 1 summarises the major characteristics in different research sites. There is a clear difference in the mineralogy and geochemical compositions in high sodium problem sites (collieries) in Highveld and Vryheid coalfields and other collieries (no sodium problem in mine water) in Witbank and Waterberg coalfields. This shows the different depositional environments, i.e., the former two in Brandspruit and Vryheid Colliery in the marine depositional environment and Witbank and Waterberg in the fresh water depositional environment.

Table 1. Comparison of the major characteristics in different collieries

| **Coalfield** | **Colliery** | **Mineralogy** | | | **Geochemistry** |
|---|---|---|---|---|---|
| | | **Microscopic Study** | **XRD** | **SEM** | **XRF** |
| Highveld, high Na | Brandspruit | The sandstone and shales are mostly dominated by quartz, K-feldspar and albite. Most of the albite shows partial dissolution and alteration along the cleavage planes. The grains are rounded to sub-rounded and tend to a tubular shape | Sandstone: quartz, plagioclase, K-feldspar, micas and clay minerals dominated. The plagioclase is the second dominating minerals after quartz. Mudstones: quartz, kaolinite and the feldspars. Coal: kaolinite dominates, over 60%. | Sandstones show some intergrowths of albite and newly formed albite. This clearly shows that the Na may be from the Na-bearing albite | Higher Na2O concentration (0.57% in average; 0.64% in shale/mudstone) |
| Vryheid, High Na | Vaalkrantz | Observation from both sandstone and shales almost the same as that of Brandspruit. | Results almost the same as that of Brandspruit Colliery | Observation of Vaalkrantz Colliery was almost the same as Brandspruit | Higher Na2O Concentration (0.75% in average in sandstone; 1.40% in chert/quartzite) |
| Witbank, low Na | Arnot | All sandstone samples are dominated by quartz and trydmetite (alteration of quartz). only a few K-feldspar and no albite observed. | No plagioclase observed | | Less than 0.2 w%, Negligible for $Na_2O$ |
| Waterberg, low Na | Malatleng | Sandstone samples are dominated by quartz, only a few K-feldspar. No plagioclase observed. | No plagioclase observed | | Less than 0.04 w%, negligible for Na2O |

Figure 3 presents the histograms of mineral concentrations in sandstone and shales showing all the minerals (quartz is excluded due to its high concentration) in different collieries. They further directly show the difference of mineral concentrations specifically for albite, K-feldspar, clays and some other components in different collieries. The collieries with high sodium problems contain high concentrations of feldspar, specifically albite in Brandspruit and Vaalkrantz collieries while the collieries without sodium problem contain low feldspar and almost no albite, but with higher concentration of kaolinite. Figure 4 presents histograms of oxides analysed by XRF. The collieries with high sodium problems contain high concentrations of $Na_2O$, (Brandspruit and Vaalkrantz collieries), while the collieries without sodium problem contain low $Na_2O$.

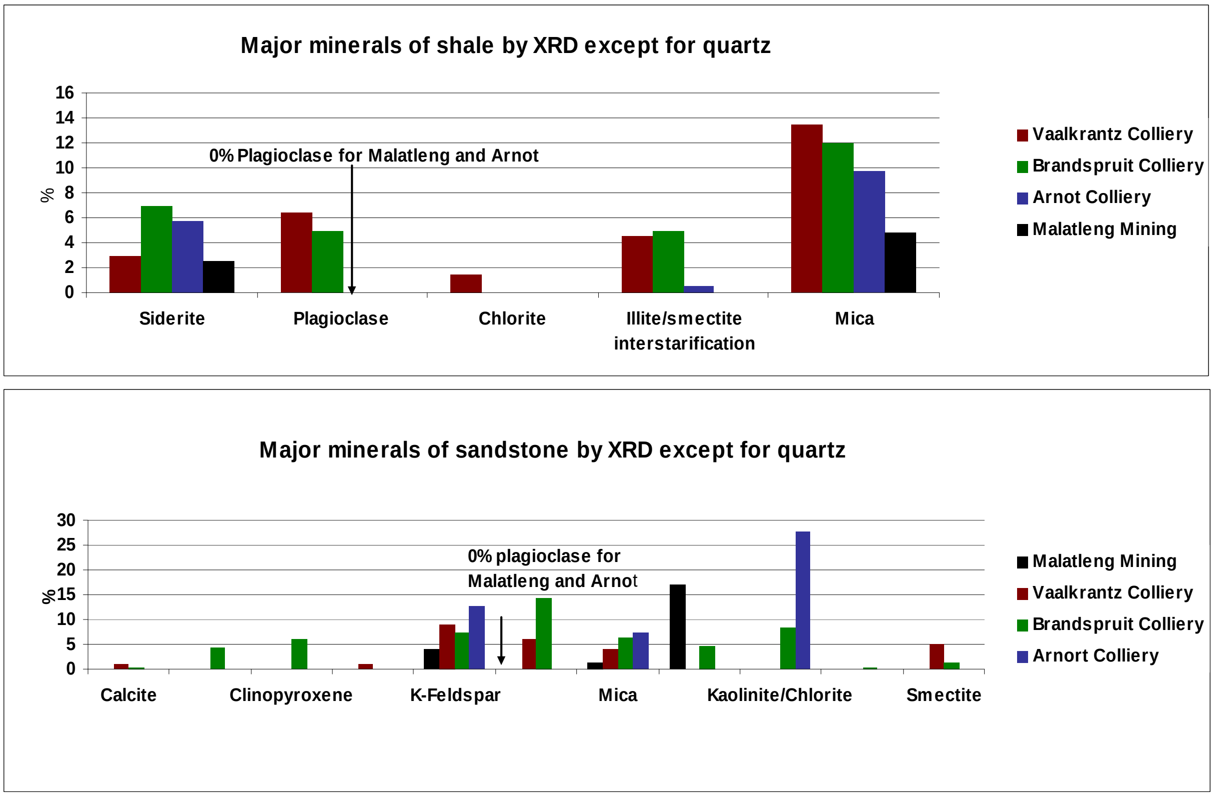


Figure 3. Major minerals of shale and sandstone by XRD in all the study sites

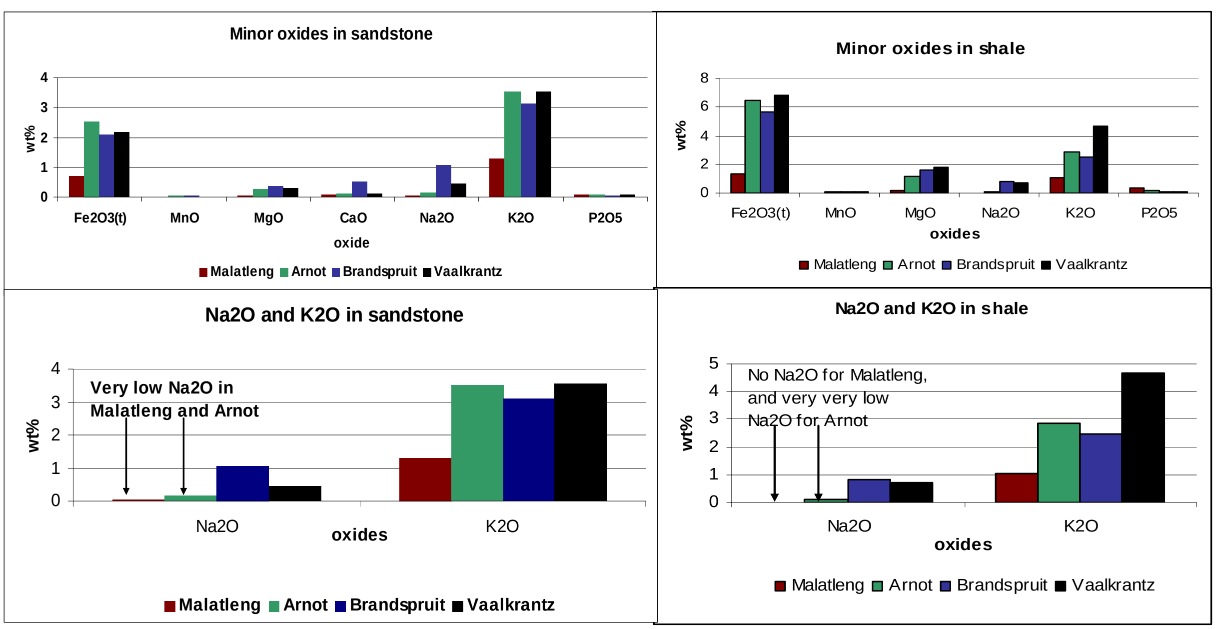


Figure 4. Oxide comparisons in all the study sites

Figure 5 below shows the photomicrographs of sandstone from Brandspruit and Vaalkrantz, the both show albite twinning. Figure 6 shows photomicrographs of sandstone from Arnot and Malatleng, there are no traces of albite. Fig 7 shows SEM photographs with albite and K-feldspar grains highlighted.

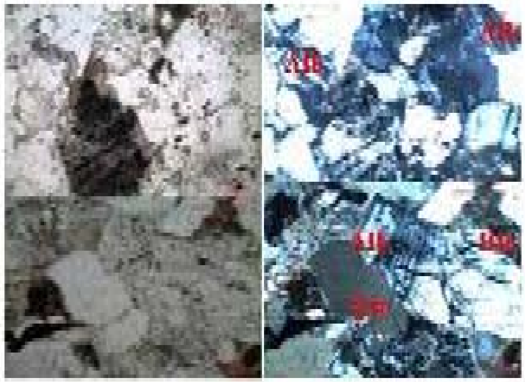

Figure 5. Photomicrographs of sandstone samples from Brandspruit and Vaalkrantz Colliery (plane and crossed polarised)

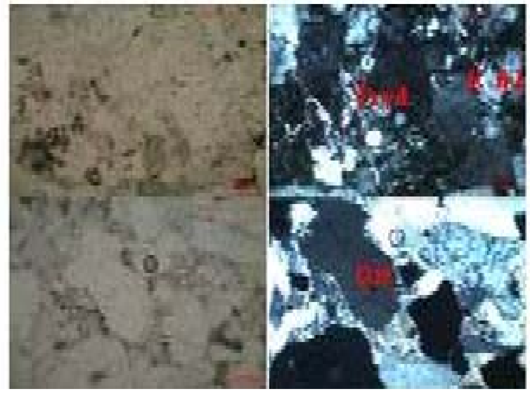

Figure 6. Photomicrographs of sandstone samples from Arnot and Malatleng and Vaalkrantz Colliery (plane and crossed polarised). No albite observed.

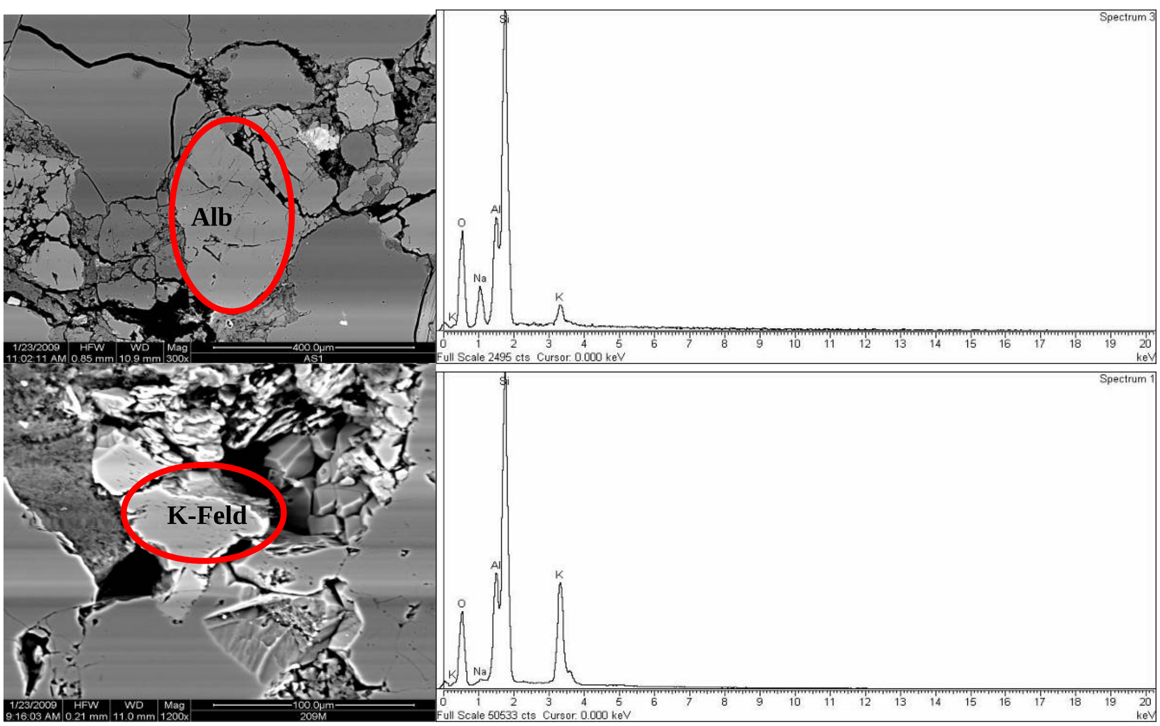


Figure 7. SEM photographs of sandstone samples showing plagioclase feldspar (albite) and K-feldspar from Brandspruit and Vaalkrantz Colliery

Figure 8 below shows a mineralogical comparison of XRD results in all the study collieries.

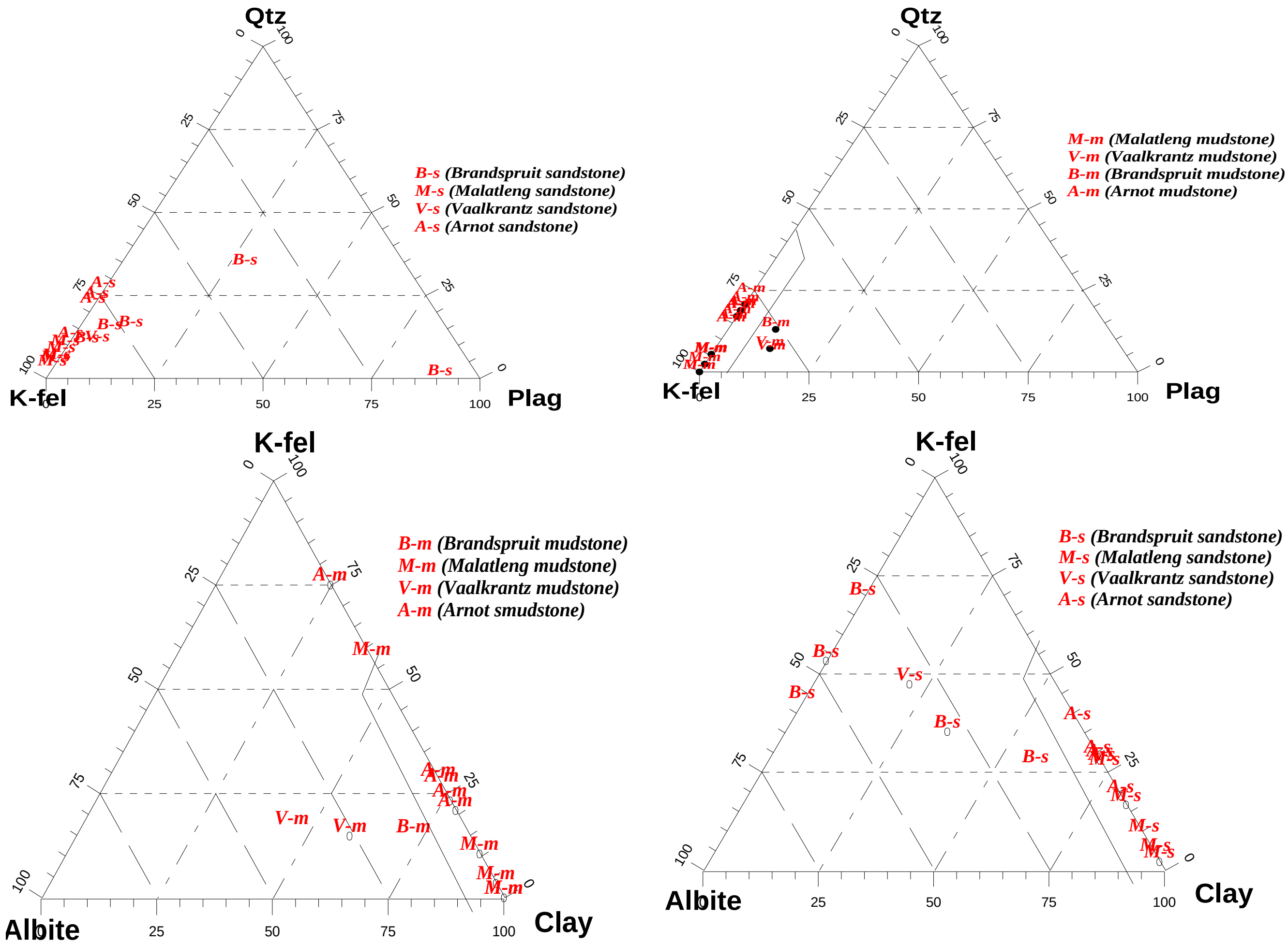


Figure 8. Ternary plots of quartz-albite-K-feldspar (top) and K-feldspar-albite clays of sandstone

## 5. CONCLUSIONS

Based on the results and above discussion, the following conclusions are reached:

- Na-bearing albite (plagioclase) is the most probable source of sodium in the coal mine environment based on microscopic, SEM and XRD studies;
- Sandstone, containing plagioclase, specifically albite is mostly probably the source rock of the sodium being released into mine water in the sodium problem coalfields;
- There are no sodium problems in the Witbank and Waterberg coalfields that have been proved by current water quality and this study;
- It seems that the high sodium water is readily available in the aquifer once the roof rocks become incompetent rather than immediately leaching from the sandstone materials; and
- No major sodium problems in some coalfields such as the Witbank and Waterberg coalfields. This is mostly probably due to their sub-basin nature, i.e., more isolated fresh water sedimentary environment of some coalfields.

## 6. ACKNOWLEDGEMENTS

Special thanks are to the Water Research Commission for funding this project (WRC Project No. K5/1663//3), specifically to Mr Meiring du Plessis (Manager). Thanks are also extended to the collieries and project for providing the sites for study including Brandspruit, Vaalkrantz, Arnot collieries and Malatleng Exploration project.

## 7. REFERENCES

Johnson, M.R. van Vuuren, C.J., Visser, J.N.J., Cole, D.I., de V. Wickens, H, Christie, A.D.M., Roberts, D.L., and Brandl, G. (2006). Sedimentary rocks of the Karoo Supergroup. In Johnson M.R, Anhaeusser, C.R. and Thomas, R.J (Eds.). The Geology of South Africa. The Geological Society of South Africa, Johannesburg/Council for Geoscience, Pretoria, 461-500.

Snyman, J.P. (1998). Coal In The mineral resources of South Africa (M..G.C. Wilson, and C.R. Anhaeusser, Eds.): Handbook, Council for Geoscience, 16, p.136-p161.

Visser, J.N.J, (1994). A Permian argillaceous syn- to post-glacial foreland sequence in the Karoo Basin, South Africa. In: M. Deynoux, J.M.G. Miller, E.W. Domack, N. Eyles, I.J. Fairchild and G.M. Young (Eds.): *Earth's Glacial Record. International Geological Correlation Project* vol. 260, Cambridge University Press, Cambridge, pp. 193–203.