

Chapter

Prospectivity Mapping Using Stream Sediment Geochemistry along the Orange River Catchment for Base Metal, Prieska, Northern Cape, South Africa

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Abstract

The Areachap Terrane, which is part of the Namaqua Sector of the Namaqua-Natal Belt in the Northern Cape Province, host volcanic-hosted Zn-Cu deposits at volcanic centres. The primary objective was to map Volcanogenic Massive Sulphide (VMS) mineralisation, determine the heavy metal contents of sediments, locate the source of anomalies and delineate targets for follow-up studies. Nine thousand three hundred and fourteen stream sediments samples collected were analysed using XRF. The element associated with their respective lithostratigraphy was calculated using spatial joint analysis tool. ArcGIS was used to display uni-elements maps and relevant multi-element maps. The delineated potential VMS mineralisation target is considered for further follow-up study. The M23 and M24 anomalies are delineated for Cu₂Ni mineralisation. M23 and M24 anomalies are sourced from ultramafic debris transported from the Ghaap Group; however, this potential target will require follow-up studies for verification. The correlation between the Cu-Pb-Zn anomaly with alkali elements (Nb, Zr, Th, and U) and REEs (in Table 9) suggests there is a possibility that the M26–M29 anomaly is alkali-granitic genetic origin. The As, Ba, Ce, Cr, Cu, Hf, Nd, Ni, Rb, Sr., S, V, Zr and Zn contents showed a heterogeneous spatial distribution, reflected by high coefficient of variation and large standard deviation.

Keywords: geochemical signature, mineralisation, base metals, uni-elements maps, multi-element maps, follow-up study

1. Introduction

The Republic of South Africa (RSA) is known to be among one of the world's most active mining countries. RSA hosts several deposits such as gold deposits in the Witwatersrand basin, diamond deposits in Kimberly, Platinum group elements (PGE) in the Bushveld Complex and Manganese deposits in the Griqualand West Basin, all to which, to some extent they control the economy of the country [1].

The Namaqua-Natal Metamorphic Province, particularly the Namaqua Sector has proven to be the remarkable mineralised sector in the country hosting Copperton deposit, which according to [2], and [3] is one of the world's giant Volcanic Hosted Massive Sulphide (VHMS) deposit.

The Namaqua-Natal Metamorphic Province (NNMP) is a tectonostratigraphic province that stretches 1400 km across South Africa, it extensively outcrops in the Northern Cape Province and Kwa-Zulu Natal Province and referred as Namaqua and Natal Sectors respectively and in Namibia. NNMP embrace igneous and metamorphic rocks formed or metamorphosed during the Namaqua Orogeny at 1200 Ma–1000 Ma. It is 400 km wide and has borders with the Kaapvaal Craton to the north and Pan-African (Gariiep and Saldania) belts in the west and south [4, 5].

The Namaqua Sector of the Namaqua-Natal Province is subdivided into a number of distinct, discontinuity-bounded domains: Richtersveld Subprovince, Bushmanland Terrane, Gordonia Terrane, and Kaaien Terrane (**Figure 1**; [6]). The Location of the study area is in western degree of the 2922 Prieska sheet, Northern Cape Province, South Africa (**Figure 1**).

The small portion of Kaapvaal Craton is part of the study area (**Figure 1**). The preserved basin on the Kaapvaal Craton, which is the part of the study area of this research, is Griqualand-West basin. The westernmost of Griqualand West basin exposures at the eastern edge of the Kheis Belt, thrust and fold belt that post-dates younger Olifantshoek red beds. In its extreme, south the Griqualand-West strata are truncated by later dextral shearing on the Brakbosch and Brulpan faults [6].

Geochemical data combined with mineralogical and other additional data sets such as geologic maps, mineral distribution, geophysical methods, among others, provides a foundation for classifying and evaluating mineral resource endowment and natural hazards. A mineral resource produces diagnostic textural, geologic, geophysical, and geochemical signatures when exposed at or near the surface of the earth. Geochemical exploration is based on outlining such dispersion halos and in the present study that will be done by chemical analyses of stream-drainage sediments.

There is different between regional and detailed surveys in terms objective, size of area being surveyed, sampling density, type and of material sampled. Ginsburg [7]

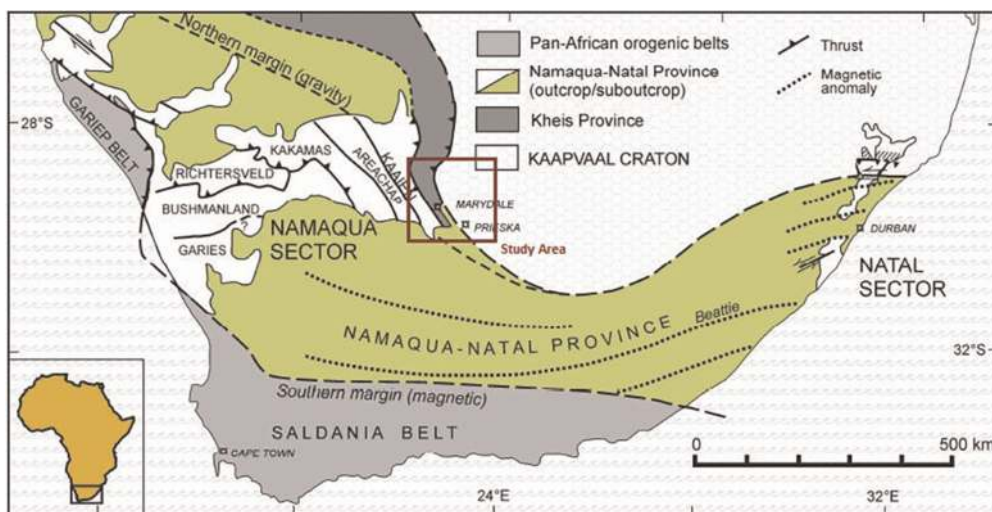


Figure 1. Map of Southern Africa showing Pan-African orogenic belts, NNP, Kheis Province and Kaapvaal craton [6].

recognised three scales of geochemical mapping and surveys depending on purpose and objective, namely, reconnaissance, prospecting and detailed. Regional survey can be conveniently discussed based on the number of stream sediment samples taken per square kilometres [8].

Regional geochemical mapping has been part of the core mapping function of the Council for Geoscience (CGS) since the 1970s. The Regional geochemical mapping program follow a systematic approach focussed on providing high quality- and high density datasets that will contribute to resolving issues relevant to modern South African geological society, namely, exploration, geological mapping, groundwater, environmental studies, and geological modelling. The principal objective of this geochemical orientation survey is to define the patterns of primary and secondary dispersion occurring in the study area particularly those of economically and environmentally interesting elements.

1.1 Research problem

The stream sediments composition of the research are is poorly understood. Mobility of the different elements varies considerably because of factors such as adsorption and Eh-pH conditions. Stream sediments programs worldwide had discovered numerous deposits.

1.2 Justification

The geochemical patterns obtained from this study will enable to link elements deficiencies and abundances with the underlying geology, structures and known mineral occurrences and mines. This will assist in tracing the source of anomalies encountered on stream sediments and delineate targets for follow-up studies within the Orange River catchment area.

1.3 Objectives of the study

1.3.1 Main objectives

The primary aim of this study is to map the VMS mineralisation potential of the Prieska area using the stream sediment data, determine geochemistry of stream sediments within the Orange River catchment area. This will enable the recognition of anomalies within the catchment area and trace their sources.

1.3.2 Specific objectives

The following specific objectives need to be met:

- To determine the solid geochemistry of the sediments from Orange River catchment
- To determine heavy metals content of the sediments
- Locate the source of anomalies and delineate targets for follow-up studies.

1.4 Hypothesis

- Geochemical and mineralogical anomalies of the sediments in the Orange River can be determined
- Metal content of stream Orange River sediments was introduced in solution
- Sources of resulted anomalies within the Orange River catchment can be traced.

1.5 Regional reconnaissance stream sediments survey history around the world

Large areas may be successfully explored using stream sediments geochemistry for indications of individual mineral deposits, groups of occurrences, or favourable geological environments. Sampling density ranges from one sample per 1 km² to one per 25 km² depending upon the type of target and drainage characteristics, and inherent in the reconnaissance concept is the need for more detailed sampling to determine the significance of regional anomalies [9, 10]. The government agencies, Council for Geological Survey and mining companies are mostly responsible to carry out Regional stream sediments surveys. Successful stream sediments surveys conducted around the globe.

The Geological Survey of Zambia in Africa employed regional and provincial scale geochemical mapping in systematic geological mapping. Analyses were for 20 elements by semi quantitative XRF. The Institute of Mining Research at the University of Zimbabwe (formerly known as Rhodesia) had been active in regional geochemical research projects since 1976. Some of the studies done by the institute include a regional stream sediment reconnaissance of 1350 km² of the Sabi Tribal Trust Land at a density of one sample per km² [11], and a survey of 1664 km² near West Nicholson, Zimbabwe, at same density [12] employing multi-element in both cases. In southern Africa, most mining companies devote a greater effort to regional soil sampling than to drainage reconnaissance and it had been estimated that more than 95% of samples collected by the major companies in 1973 were taken from soil grids [13].

In Australia, during 1976, there was a low level of activity as only 4250 stream sediments were collected; the number was expected to decline in 1977. Nevertheless, in the more favourable humid zones most mineral exploration companies make fixed use of regional stream sediment sampling since stream sediments are of limited use in the more arid regions because of low density of drainage and dilution by the wind-blown material. Two size fractions approach may be employed in arid regions, minus-120 mesh and minus-4-plus -16 mesh with coarser fraction containing gossan fragments and multiple grains cemented by metal-rich iron hydroxides [10].

In southern British Columbia portion and Yukon during 1976, Stream sediments sampling took place over an area of 75,000 km² (Cameroon, 1976). According to Meyer et al. [10], Smee and Ballantyne [14] reported that the British Columbia portion of the program covered 46,800 km² at a mean density of one sample per 13 km² and in the Yukon 2200 stations were sampled over an area of 28,490 km², giving the same degree of coverage. More than 90% of stream sediment activities of the Geological Survey of Canada and Federal-Provincial Uranium Reconnaissance Program that commenced in 1975 are related. Rose and Keith [15] concluded that stream sediments were preferable to water for reconnaissance drainage surveys for uranium for eastern Pennsylvania.

2. Methodology

Several techniques including geological mapping and stream sediments geochemistry were used to investigate stream sediments geochemical patterns of the Orange River catchment prospecting area in order to accomplish the goals and objectives set out for this study. A descriptive methodology is summarised in the below flow chart (**Figure 2**). The steps followed in order to achieve the objectives of this study are desktop study, reconnaissance survey, fieldwork, laboratory work, data analysis and interpretation, discussion, conclusions and recommendations.

2.1 Desktop study

In order to acquire first-hand information about the study area. Prior to field visit, the information from previous work on geology, nature of mineralisation and previous exploration conducted in the Orange River catchment prospect is studied. Information is sources from Books, unpublished technical reports, geological reports, topographical maps, journals and internet sources.

2.2 Fieldwork

A reconnaissance survey was undertaken prior to detailed or actual fieldwork. During this, a snap survey of geology, vegetation, and accessibility of the study area was undertaken. The aim is to locate the ground, target areas indicated by outcrops of

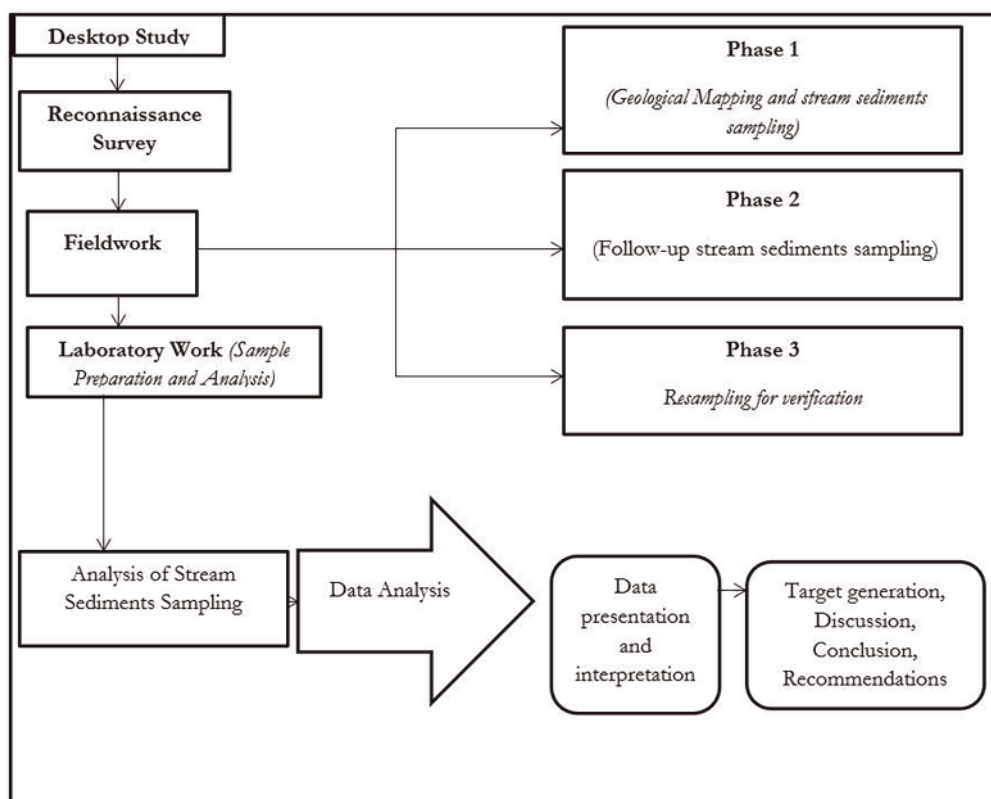


Figure 2. Flow chart indicating methods and procedures applied during the study.

different lithologies. The general attitudes of lithologies at the prospects, rock outcrops, and quantity of samples and duration of fieldwork were established. Additionally, a thorough study of topography, vegetation, pedology, drainage patterns and characteristics of rocks was also to gather as much information as possible in the study area. Stream distribution was also assessed which drain into the Orange River catchment prospect.

Field observations were transferred to a base map before being digitised using ArcGIS 10.3.1. The observations were transferred to a field base map; using diverse colours to discriminate the streams distribution mapped in the area. The spatial extent of each lithology and lithology contacts as well as stream distribution were trace on the map. Field notes includes describing the coordinates and nature of contact with other rock types and soil colour where there is limited outcrops.

2.3 Laboratory work

The sample analysis was conducted by the Council for Geoscience (CGS) laboratory in Pretoria. Sieve shaker, drying oven, atomic absorption spectrometry (Perkin Elmer Analyst 400, AAS), PANanalytical-Axios XRF were used for sample preparation and analysis.

2.3.1 Sample preparation

This section describes the methods used to prepare stream sediments samples collected from the Orange River catchment prospect for laboratory analysis.

2.3.1.1 Drying and milling

Samples are oven dried at 105–110 °C. Once completely dry, samples were first sieved through a 2 mm sieve to remove gravels and organic materials and subsequently sieved through a – 125 µm fraction size and milled to 85% -75 µm. The milled samples were placed in labelled sample bags ready for analysis.

2.3.2 Sample analysis

The prime requirement for mineral exploration survey is the availability of analytical procedures capable of high precision, low detection limit and acceptable accuracy.

2.3.2.1 Stream sediments geochemical analysis using XRF

The PANanalytical-Axios XRF was used for geochemical analysis of stream sediments. The milled samples roasted at 1000 °C for at least three hours in order to oxidise Fe²⁺ and S and to determine loss of ignition (LOI). Glass disks for XRF analysis were prepared by fusing 1 g sample and 8 g of flux (35% LiBO₂ and 64.71% Li₂B₄O₇) at 1050 °C for major element analysis. Major element oxides (SiO₂, TiO₂, Al₂O₃, Fe₂O₃, MnO, MgO, CaO, Na₂O, K₂O, P₂O₅ and Cr₂O₃) and trace element (Ni, Cu, Co, As, Zn, Pb, Cr, Ba, Sc, Sr., V, Th, U, Y, Zr) were analysed.

Trace element analysis was achieved by mixing 12 g milled sample and a 3 g Hoechst wax and then pressing into a powder briquette by a hydraulic press with the applied pressure at 25 ton. The glass disks and wax pellets were analysed by PANalytical-Axios XRF. XRF has the advantage of being non-destructive, multi-elemental, fast and cost

effective compared to other competitive techniques such as Atomic Absorption Spectrometry (ASS) or Inductively Coupled Plasma Spectrometry (ICP OES).

X-rays are produced by irradiating a sample with high energy photons produced by primary X-ray tube. When a high energy primary X-ray collides with an atom, an electron can be ejected from a low energy level creating an electron vacancy. When an electron from a higher energy level fills the vacancy, a secondary X-ray is created characteristic of that element. XRF analysis devices can be largely categorised into wavelength-dispersive X-ray spectrometry (WDX) and energy-dispersive X-ray spectrometry (EDX). WDX disperses the fluorescent X-ray generated in the sample using dispersion crystal and measures it using a goniometer, resulting in a large size. The detector in EDX on the other hand, has a superior energy resolution and requires no dispersion system, which enable downsizing of the device. Interaction of X-rays with sample creates secondary diffracted beams of X-rays related to inter-planar spacing in the crystalline powder according Bragg's Law:

$$n\lambda = 2d\sin\theta \quad (1)$$

Where: n is an integer, λ is the wavelength of X-rays; d is the inter-planar spacing generating the diffraction and is the θ diffraction angle.

The XRF was calibrated by identification of optimum conditions of several variable factors for each element, like identifying correct elemental peak and background, pulse height, collimator mask, counting time, dead time, followed by matrix and inter-element interference corrections. This was achieved by repeated analysis of certified reference material and correcting the variables to yield elemental concentration close to known values. This included 12/76 (amphibolite standard).

The weighted inverse distance interpolation (IDW) method was used to convert point XRF data into continuous geochemical maps using ArcGIS, the IDW parameters used were: power = 2, maximum neighbours = 15, minimum neighbours = 10, cell Size = Maximum of Inputs.

2.3.3 Quality control and quality assurance

It is vitally important that an analysis is precise but the accuracy is not generally so crucial, although some indication of accuracy is needed for most purposes in mineral exploration [16]. Quality assurance program should aim to assess the quality and accuracy at all stages of measurement process, from site selection and sampling through sample handling, preparation and analysis. Subsequently, a quality control/quality assurance See **Table 1** for the results of the reference material and lower limit of detection for each element. The glass disk R422 was analysed firstly with the calibration standards and then every 12 hours during analysis of the sample. The three sediment reference material GSD-9, GSD-11 and GSD-14 were repeatedly analysed every 30 samples to evaluate the precision of the analysis, **Table 1** summaries the results of the reference material and each lower detection limit of each element.

The statistical tests of standard samples repeatability can be based on replicate assays of a certified standard in one laboratory or, conversely, inter laboratory analyses. Blank samples for materials that have very low grade of a metal of interest are usually inserted in a batch of samples being processed. The main purpose of using blanks is to monitor laboratory for a possible contamination of samples, which are mainly caused by poor housekeeping, and insufficient thorough cleaning of equipment.

Oxide (wt %) Element (ppm)	Lower level of determination	GSD-9				GSD-11				GSD-14			
		N = 391				N = 525				N = 435			
		Certified	Average	Standard	% RMS	Certified	Average	Standard	% RMS	Certified	Average	Standard	% RMS
SiO ₂	0.01	64.89	68.20	3.20	4.70	76.25	77.29	3.17	4.10	57.25	53.43	2.51	4.69
TiO ₂	0.01	0.92	0.94	0.01	1.34	0.35	0.35	0.00	1.02	2.40	2.29	0.04	1.84
Al ₂ O ₃	0.01	10.58	11.30	0.72	6.40	10.37	10.41	0.56	5.39	13.39	11.75	0.77	6.56
Fe ₂ O ₃	0.01	4.86	4.82	0.13	2.63	4.39	4.15	0.08	1.96	9.50	9.75	0.17	1.77
MnO	0.00	0.08	0.08	0.00	2.91	0.32	0.31	0.01	3.10	0.16	0.17	0.00	2.52
MgO	0.01	2.39	2.57	0.15	5.64	0.62	0.64	0.06	8.68	3.40	3.27	0.17	5.10
CaO	0.01	5.35	5.99	0.26	4.31	0.47	0.45	0.02	4.70	3.50	3.17	0.15	4.60
Na ₂ O	0.01	1.44	1.68	0.17	10.15	0.46	0.52	0.06	11.73	2.00	2.03	0.17	8.21
K ₂ O	0.01	1.99	2.18	0.03	1.29	3.28	3.43	0.05	1.43	2.30	2.28	0.04	1.60
P ₂ O ₅	0.00	0.15	0.17	0.01	4.56	0.06	0.07	0.01	8.32	0.23	0.22	0.01	5.86
Ag	4.00		5.00	1.00	19.20								
As	4.00	8.40	13.00	4.90	38.00	188.00	195.00	3.00	1.60	18.00	11.00	8.00	71.40
Ba	5.00	430.00	430.00	9.70	2.30	260.00	258.00	7.40	2.90	760.00	810.00	18.10	2.20
Ce	10.00	78.00	79.00	12.20	15.40	58.00	59.00	8.70	14.70	10.00	107.00	11.50	10.80
Co	4.00	14.40	13.00	0.20	1.90	8.50	8.00	0.50	6.70	28.00	28.00	0.60	2.30
Cr	4.00	85.00	89.00	2.60	2.90	40.00	36.00	2.70	7.50	243.00	244.00	7.50	3.10
Cu	2.00	32.10	33.00	1.40	4.10	78.60	78.00	2.00	2.60	66.00	72.00	2.50	3.50
Ga	2.00	14.00	18.00	3.00	16.90	18.50	19.00	3.40	17.20	25.00	30.00	4.00	13.70
Hf	5.00	9.70	11.00	0.70	6.90	5.40	6.00	0.80	14.70	13.00	15.00	1.20	8.00
Mo	2.00	0.64			5.90	7.00	7.00	0.50	7.70	2.70	4.00	0.50	13.90

Oxide (wt %) Element (ppm)	Lower level of determination	GSD-9				GSD-11				GSD-14			
		N = 391				N = 525				N = 435			
		Certified	Average	Standard	%	Certified	Average	Standard	%	Certified	Average	Standard	%
			RMS				RMS				RMS		
Nb	3.00	17.70	22.00	2.90	13.20	25.00	29.00	2.80	9.70	72.00	86.00	4.90	5.70
Nd	3.00	34.00	37.00	7.80	20.09	27.00	23.00	6.40	27.80	45.00	51.00	10.10	19.70
Ni	2.00	32.30	34.00	1.00	2.80	14.40	18.00	1.20	7.10	87.00	100.00	3.70	3.70
Pb	2.00	23.00	23.00	0.90	8.10	636.00	627.00	14.70	2.30	66.00	68.00	3.20	4.70
Rb	2.00	80.00	84.00	2.20	2.60	408.00	417.00	10.50	2.50	87.00	92.00	3.40	3.70
S	3.00	150.00	217.00	6.70	3.10	170.00	178.00	14.50	8.10	175.00	175.00	16.10	9.20
Sb	3.00	0.80				14.90	11.00	1.30	11.60	2.70	4.00	0.70	18.70
Sc	3.00	11.10	16.00	4.30	26.90	7.40	8.00	3.80	45.20	18.00	21.00	4.30	20.50
Sn	3.00	2.60	5.00	2.10	42.30	370.00	400.00	7.90	2.00	9.50	8.00	3.90	47.70
Sr	2.00	166.00	168.00	1.90	1.10	29.00	34.00	1.10	3.30	216.00	327.00	5.40	230
Ta	3.00	1.30				5.70	5.00	1.40	24.80	5.00	4.00	0.80	19.60
Th	3.00	12.40	11.00	1.90	17.00	23.30	48.00	2.10	4.30	12.40	12.00	2.20	17.40
U	3.00	2.60	4.00	0.80	20.60	9.10	8.00	1.20	15.20	3.00	4.00	1.50	37.20
V	4.00	97.00	105.00	5.40	2.50	46.80	39.00	3.60	9.20	190.00	230.00	20.30	8.80
W	3.00	1.76				126.00	97.00	3.80	3.90	5.60	5.00	0.90	18.10
Y	3.00	26.50	25.00	0.60	2.30	42.70	37.00	2.00	5.50	3.40	34.00	1.50	5.30
Zn	3.00	78.00	72.00	0.60	0.90	373.00	368.00	9.50	2.60	165.00	183.00	5.20	2.80
Zr	3.00	370.00	391.00	9.00	2.30	152.00	156.00	5.60	3.60	524.00	560.00	17.40	3.10

Table 1. The Lower limit of detection (LLD) of each element and the reference material obtained results.

2.3.4 Data processing and evaluation

Analytical data processing aims, firstly, at reducing random and/or systematic errors resulting from field survey and/or laboratory analysis, and secondly, at identifying whether the data contain some useful information indicating the source, pathway and trap of coal concentrations in the study area. The careful analysis of such data, using standard computer software packages, is an important and affordable way of adding value to an exploration programme.

2.3.4.1 Statistical data analysis

Statistical methods have been widely applied to interpret analytical data sets and define anomalies. However, such methods need to be used cautiously since the data are typically and spatially dependent on each sample site and a range of different processes that may have influenced the element abundance measured. The data are also imprecise because of unavoidable variability in sampling methods and media and the level of analytical precision.

Moon [16] indicated that the aim of mineral exploration is to define significant anomalies. Anomalies are defined by statistically grouping data and comparing these with geology and sampling information. Strong anomalies detected may be for instance due to a combination of factors such as sampling and analytical errors, or contaminations which do not represent mineralisation. The absence of anomaly on the other hand may not necessarily mean the absence of mineralisation in the area of study. Such absence may be due to low rate of weathering in the area, buried or blind mineralisation, or dilution between source and sample site [17].

The use of descriptive statistics helps us to simplify large amounts of data into a simpler summary. Numerical and graphical methods are the two commonly used methods. Numerical method enables one to compute statistics such as mean and standard deviation while, graphical methods are better suited than numerical for identifying patterns in the data sets. The numerical and graphical methods complement each other and it is therefore wise to use both. Consequently, histograms, and summary statistical information were used in this study to identify patterns in data sets. According to Riemann et al. [18], a graphical inspection of analytical data is necessary as the first step in data analysis. The best means of statistical grouping data is graphical examination using histograms and box plots [19, 20].

3. Data presentation and interpretation

The geology map retrieved from the CGS database, was compiled on ArcGIS software (**Figure 3**). The area is comprised of the Transvaal Sequence, Olifantshoek Supergroup, Kaaien Terrane, Areachap Group and Karoo Supergroup. The Transvaal Sequence is confined to the north-central part of the Kaapvaal Craton [21]. It overlies the Witwatersrand foreland basin (Supergroup) and is overlain by Bushveld Complex [21]. The three basins – the Transvaal basin, and Griqualand West basin, in South Africa, and the Kanye basin in Botswana basins are preserved on the Kaapvaal Craton [21].

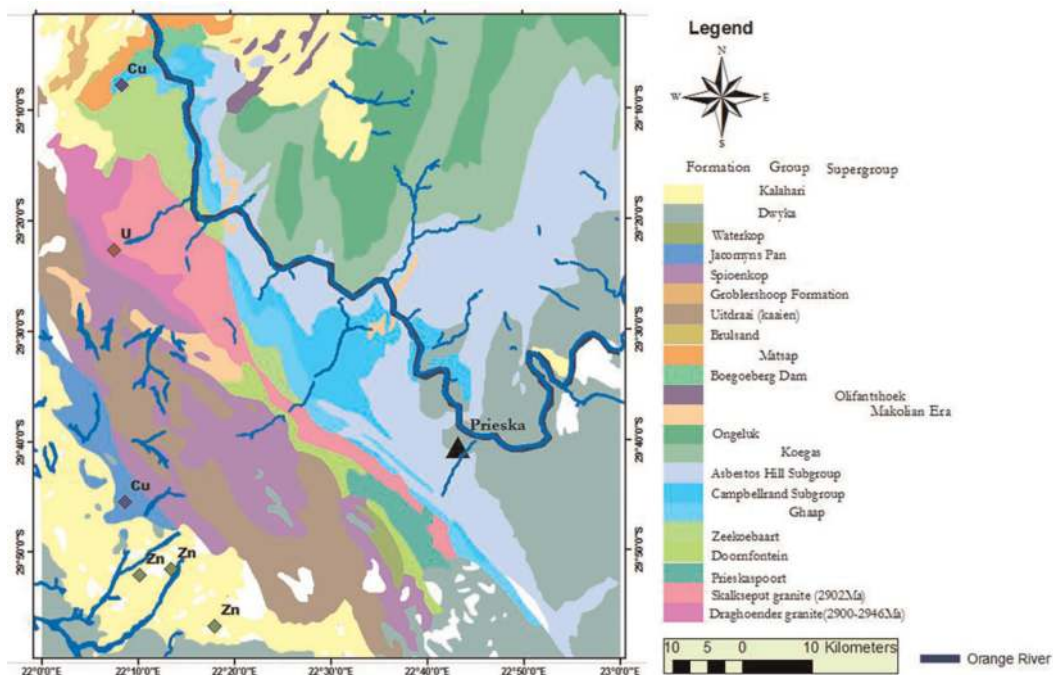


Figure 3.
 The Geology of the Prieska map.

3.1 Univariate stream sediment geochemistry

The geochemical data was transformed into a raster data with a cell size of 1 km using weighted inverse distance interpolation method. A maximum of four points were used to calculate a value for each cell location. First, the raster maps of the unielements were visualised in ArcGIS and compared to the underlying geology and known base metal occurrences. Univariate statistical methods was used to extract information from a data set of values for a single element, frequency histograms are created using GIS geostastical analyst tool, to examine the frequency distribution and identify the type of distribution, the all elements Histograms are on none transformation.

The only elements that correlates (**Table 2**) importantly with the known base metals occurrence in Prieska area as discussed in this section. The copper, lead, zinc, gold and silver minerals are associated with Volcanogenic Massive Sulphide (VMS) deposits. Prieska area is underlain by the Areachap Terrane, known to host VMS and Sedimentary exhalative deposit (SEDEX) deposits, including the mined out Copperton deposit, approximately 10 km southwest of the Prieska town. The Areachap terrane is overlain by up to 100 m of Karoo sediments that limited historical exploration.

The elemental distribution maps are plotted using the Jenks natural classification system. The elemental population is classified into five break points;

1. The first break is minimum to mean value, and
2. Second break is from mean to (mean plus standard deviation) value, the first two break are regarded as a background value, values above the threshold calculates **Table 3** are anomalous,

	Ag	As	Ba	Ce	Co	Cc	Cu	Ga	Hf	Mo	Nb	Nd	Ni	Pb	Rb	S	Sb	Sc	Sc	Sn	Sc	Ta	Th	U	V	W	Y	Zn	Zr
Af	10,000																												
As	0.1552	10,000																											
Ba	0.0520	-0.0555	10,000																										
Ce	0.0956	0.5085	-0.0218	10,000																									
Co	0.1271	0.0562	0.0767	0.0064	10,000																								
Cr	0.1998	0.4000	-0.0958	0.2664	0.5850	10,000																							
Cu	0.0738	-0.0106	0.5897	-0.0222	0.2059	0.6006	10,000																						
Ga	0.1201	0.1445	0.3487	-0.0953	0.1985	0.0926	0.1297	10,000																					
Hf	0.1611	0.0188	-0.0435	0.6219	0.0443	0.4811	-0.0134	0.1140	10,000																				
Mo	0.1508	0.4587	0.1155	0.4859	0.1453	0.3451	0.2328	-0.0075	0.4829	10,000																			
Nb	0.4435	0.6413	0.1369	0.4409	0.0939	0.4380	0.0356	0.3268	0.3157	0.4147	10,000																		
Nd	0.1358	0.5690	-0.0068	0.3967	-0.0168	0.3239	-0.0245	-0.0169	0.7506	0.3212	0.5731	10,000																	
Ni	0.1609	-0.0154	0.0303	-0.0828	0.7213	0.5889	0.1484	0.2066	0.0004	0.0565	0.0926	-0.0727	10,000																
Pb	0.2079	0.0909	0.5272	0.1199	0.0348	0.0140	0.3975	0.3629	0.1723	0.1611	0.3920	0.1846	0.0470	10,000															
Rb	0.0999	0.0098	0.4749	0.0740	-0.1606	-0.2758	0.0678	0.5134	0.0385	-0.0054	0.2702	0.0929	-0.0889	0.4933	10,000														
S	-0.0072	-0.0354	0.2343	0.0001	-0.0166	-0.0475	0.1906	-0.0291	-0.0377	0.0375	-0.0501	-0.0048	-0.0014	0.0529	-0.0482	10,000													
Sb	-0.0034	0.0161	0.0213	0.0036	-0.0242	-0.0089	0.0064	0.0041	-0.0144	-0.0094	-0.0080	0.0031	-0.0122	-0.0098	0.0575	-0.0063	10,000												
Sc	0.2047	-0.0250	0.0318	-0.1328	0.4429	0.2516	0.0639	0.2282	-0.0301	0.0183	0.1180	-0.1172	0.2640	0.0207	0.0119	-0.0715	0.0271	10,000											
Sn	0.0304	0.0776	0.0155	0.0503	0.0261	0.0482	0.0054	0.0062	0.0402	0.0568	0.0500	0.0601	0.0250	0.5404	0.0168	-0.0106	0.0187	-0.0079	10,000										
Sr	0.0695	-0.0067	0.1634	0.0728	0.1555	0.1554	0.0720	0.1295	-0.0078	0.0549	0.0924	0.0699	0.0793	0.0682	-0.0083	0.2750	0.0156	0.0796	-0.0029	10,000									
Ta	0.1460	0.6796	-0.0043	0.3454	0.0778	0.3385	0.0015	0.2528	0.6254	0.3035	0.5409	0.4318	0.0610	0.1471	0.0602	-0.0345	-0.0151	-0.0390	0.0562	0.0001	10,000								
Th	0.2442	0.6040	0.1355	0.4527	0.0881	0.3830	0.0042	0.3247	0.7713	0.3685	0.3119	0.5952	0.0532	0.3880	0.3286	-0.0708	-0.0072	0.0508	0.0870	0.0994	0.5251	10,000							
U	0.4857	0.6433	0.0206	0.4750	0.1511	0.4374	0.0340	0.0623	0.7311	0.4912	0.7532	0.5298	0.0777	0.2401	0.1082	-0.0399	-0.0052	0.1456	0.0738	0.0748	0.4471	0.7055	10,000						
V	0.2149	0.4729	0.1704	0.3644	0.4582	0.6379	0.1149	0.4151	0.6194	0.2823	0.6647	0.5072	0.3049	0.2850	0.1388	-0.0441	0.0091	0.2151	0.0459	0.2889	0.4409	0.7084	0.5656	10,000					
W	0.1762	0.7146	-0.0475	0.4144	0.0653	0.3628	0.0655	0.2838	0.6472	0.3569	0.5250	0.4742	0.1001	0.1219	-0.0574	0.0089	-0.0233	-0.1385	0.0592	-0.0880	0.6536	0.4426	0.3475	0.3731	10,000				
Y	0.0760	0.6310	0.1944	0.4462	0.0596	0.2291	0.0368	0.1847	0.6366	0.3524	0.6057	0.4921	-0.0679	0.2747	0.3773	-0.0808	0.0349	0.1034	0.0384	0.1085	0.3644	0.6741	0.6577	0.5464	0.0729	10,000			

	Ag	As ₂	Ba	Ce	Co	Cc	Cu	Ga	Hf	Mo	Nb	Nd	Ni	Pb	Rb	S	Sb	Sc	Sn	Sc	Ta	Th	U	V	W	Y	Zn	Zr
Zn	0,0507	-0,0406	0,6355	-0,0231	0,1166	0,0117	-0,9213	0,1624	-0,0329	0,2150	0,0267	-0,0194	0,0852	0,4360	0,1348	0,1933	0,0016	0,0126	-0,0011	0,0920	-0,0125	0,0093	0,0037	0,1061	0,0443	0,0403	10,000	
Zr	0,1553	0,3292	-0,0691	0,6256	0,0378	0,4734	-0,0244	0,0292	0,9365	0,5239	0,7904	0,7295	-0,0231	0,1445	0,0038	-0,0438	-0,0143	-0,0294	0,0488	0,6015	0,7495	0,7394	0,5776	0,5925	0,6669	-0,0501	10,000	
	Very Strong Correlation																											
	Moderate to strong correlation																											
	Moderate Correlation																											

Table 2.
 The summary statistics of all the analysed elements.

Element	Count	Minimum	Maximum	Mean	Standard Deviation	Skewness	&\$\$\$;	Quantile1	Median	Quantile3	Threshold values	Mean + 3 SD	Coefficient Variation
SiO2 (%)	9312	18.993	80.991	47.074	4.408	-0.535	6.054	44.797	47.382	49.804	55.891	60.299	0.093651
TiO2 (%)	9312	0.238	7.230	1.161	0.342	3.891	32.579	0.988	1.095	1.224	1.845	2.188	0.294575
Al2O3 (%)	9312	2.592	19.816	9.756	1.748	-0.076	3.303	8.562	9.753	10.980	13.251	14.999	0.179152
Fe2O3 (%)	9312	2.766	26.504	7.607	1.659	1.579	9.573	6.685	7.328	8.271	10.925	12.584	0.218062
MnO (%)	9312	0.036	2.281	0.133	0.082	6.192	87.683	0.094	0.114	0.141	0.297	0.379	0.617984
MgO (%)	9312	0.000	7.909	1.315	0.761	2.045	10.105	0.830	1.092	1.593	2.838	3.599	0.578966
CaO (%)	9312	0.189	31.877	1.737	1.737	5.547	51.711	1.012	1.240	1.705	5.211	6.948	0.999938
Na2O (%)	9312	0.000	6.769	0.566	0.168	6.231	206.536	0.471	0.555	0.637	0.902	1.070	0.29633
K2O (%)	9312	0.535	3.266	2.067	0.311	-0.249	3.443	1.890	2.059	2.282	2.688	2.999	0.150348
P2O5 (%)	9312	0.029	1.052	0.139	0.051	3.117	35.630	0.107	0.135	0.162	0.240	0.290	0.364042
As (ppm)	9312	4.000	120.910	15.802	13.874	2.235	9.991	6.145	11.450	20.240	43.551	57.425	0.878017
Ag (ppm)	9312	4.000	25.270	5.392	2.452	3.519	19.435	4.000	4.240	6.050	10.296	12.748	0.454685
Ba (ppm)	9312	91.180	4187.720	410.752	76.653	24.597	1080.028	382.565	409.805	439.865	564.058	640.711	0.186616
Ce (ppm)	9312	10.000	864.010	78.027	55.741	4.665	36.596	53.200	64.390	79.425	189.510	245.251	0.714379
Co (ppm)	9312	4.000	56.420	14.733	4.017	1.149	6.949	12.050	14.140	16.790	22.766	26.783	0.272629
Cx (ppm)	9312	49.790	1052.880	141.762	40.500	4.198	49.516	119.470	131.680	151.535	222.762	263.262	0.285688
Cn (ppm)	9312	7.370	2357.040	34.465	31.879	53.683	3534.044	28.510	32.780	37.740	98.223	130.102	0.924974
Ga (ppm)	9312	6.250	46.420	19.769	4.425	0.143	2.650	16.040	19.890	23.160	28.618	33.043	0.223816
Hf (ppm)	9312	5.000	245.440	23.292	14.397	3.954	30.123	15.850	19.820	25.720	52.085	66.482	0.618101
Mo (ppm)	9312	2.000	13.550	2.143	0.568	7.505	84.540	2.000	2.000	2.000	3.279	3.846	0.264826
Nb (ppm)	9312	3.000	112.200	25.264	8.482	2.075	13.720	20.650	24.060	28.115	42.229	50.711	0.335735
Nd (ppm)	9312	3.000	459.830	40.511	27.490	4.003	31.632	26.270	34.815	44.850	95.490	122.980	0.678578

Element	Count	Minimum	Maximum	Mean	Standard Deviation	Skewness	&\$\$\$;	Quantile1	Median	Quantile3	Threshold values	Mean + 3 SD	Coefficient Variation
Ni (ppm)	9312	11.360	460.500	39.559	12.345	7.908	192.598	33.180	37.620	43.905	64.250	76.595	0.31207
Pb (ppm)	9312	2.000	167.110	18.776	5.030	7.963	192.132	16.420	18.745	20.950	28.836	33.866	0.267912
Kb (ppm)	9312	21.170	142.690	86.942	13.467	-0.688	4.017	80.355	88.400	95.525	133.876	127.343	0.154898
Sb (ppm)	9312	3.000	4.300	3.001	0.026	36.635	1554.275	3.000	3.000	3.000	3.052	3.077	0.008499
S (ppm)	9312	54.920	32965.370	233.027	471.570	49.696	3037.767	146.985	195.115	257.120	1176.166	1647.735	2.023673
Sa (ppm)	9312	3.000	230.040	3.611	3.976	31.589	1458.505	3.000	3.000	3.000	11.562	15.538	1.100919
Se (ppm)	9312	3.000	50.180	18.183	5.077	0.135	3.687	14.930	17.930	21.355	28.337	33.413	0.279187
Sr (ppm)	9312	18.170	975.050	113.523	28.744	8.948	201.199	100.590	133.045	123.810	171.010	199.754	0.253195
Ta (ppm)	9312	3.000	61.570	7.556	6.478	2.620	12.424	3.000	5.285	9.130	20.513	26.992	0.857349
Th (ppm)	9312	3.000	132.240	13.868	6.750	4.161	40.510	10.270	12.970	15.890	27.367	34.116	0.486706
U (ppm)	9312	3.000	25.760	4.041	1.842	3.467	22.295	3.000	3.075	4.450	7.726	9.568	0.455809
V (ppm)	9312	16.180	836.190	126.384	33.836	3.657	41.490	108.250	123.520	137.885	194.057	227.893	0.267726
W (ppm)	9312	3.000	51.750	6.318	5.147	2.546	12.203	3.000	3.980	7.850	16.612	21.759	0.814664
Y (ppm)	9312	3.960	112.390	27.021	7.211	2.420	18.762	23.030	26.635	29.860	41.443	48.654	0.266869
Zn (ppm)	9312	11.990	5347.830	66.145	68.394	58.378	4155.871	53.120	62.850	74.285	202.933	271.327	1.034011
Zx (ppm)	9312	111.870	9242.850	1023.432	671.759	3.605	24.477	669.530	855.425	1144.235	2366.950	3038.709	0.656379

Table 3.
Correlation Matrix.

3. From the threshold to mean + 3*standard deviation value is highly anomalous and
4. The fifth break is the value from mean + 3*standard deviation value to maximum value.

The primary aim of the exploration target generation is twofold; to generate new areas for exploration activity where favourable geology and no mineral occurrences are coincident, and secondly a rethink in areas of known mineralisation on the possibilities of other styles or models of mineralisation. The geology of Prieska area and the geochemistry was joined using the Analysis tool spatial joint; the aim is to calculate the mean values of Uni-element of the lithostratigraphic unit. **Table 4** below refers to the lithostratigraphic unit with their associated elements. Based on [22] the five Fuzzy operators are useful for combining exploration datasets, Fuzzy AND, OR, Algebraic product, algebraic sum and γ -operator. In this study Fuzzy OR operation was applied to combine maps of relevant indicator elements associated with the geology (**Table 4**).

The elements of the highest mean averages associated with the Spioenkop Formation is the Cu, Ga, Zn and Rb (**Figure 4**). Cu and Zn correlates very strong at the correlation coefficient of 0.97. The distribution of the two elements strongly correlated with the known VMS Copperton deposit. **Figures 5–7** displays a Fuzzy OR overlap multi-element map of Cu, Ga, Zn and Rb. The map index poorly delineate Spioenkop Formation, the second dispersion occur in Uitdraai Formation, Jacomyns pan Formation, Globershoop, and Spioenkop Formation. The observed mineralisation potential areas are M1 and M2. The M1 anomaly is associated with the known mine area named Copperton Deposit, Prieska mine, the M1 anomaly is overlaying the Kalahari and Dwyka Group The Prieska Cu_Zn is known as the VMS deposit, the most common commodities or minerals exploited in this area are the Zinc, Copper and Sphalerite. The Mine known as a medium scale abandoned mine. The M2 anomaly is in close vicinity to the Orange River catchment, the anomaly is overlaying the Campbellrand subgroup. Campbell Rand Subgroup belongs to the Ghaap Group. The base mineralisation have been recorded in Ghaap Group is Pering deposit far

Geology (lithostratigraphy)	Elements
Zeekobraat	W, Fe
Spioenkop	Cu, Ga, Rb, Zn
Uitdraai	V
Waterkop	Ba
Ongeluk lava Formation	Co, Ni
Prieskaspoort	Cr, S, Sr., Mg
Koegas Group	Nd, Pb, Th
Jacomyns Pan	Ag
Kalahari Group	Sn
Builsand	Hf, Mo, Nb, Sc, Ta, U
Boegoeberg Dam	Zr, As
Asbestos Hill	Ce

Table 4. Relevant indicator elements associated with the geology.

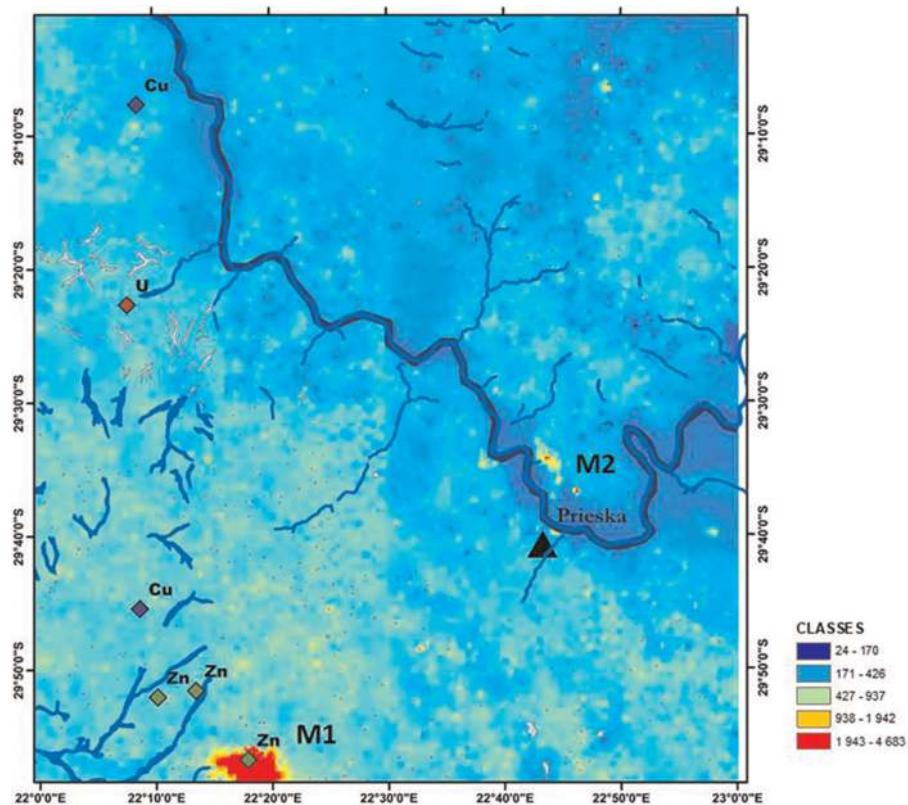


Figure 4. Fuzzy OR overlay multi-element map index of Cu, Ga, Zn, and Rb.

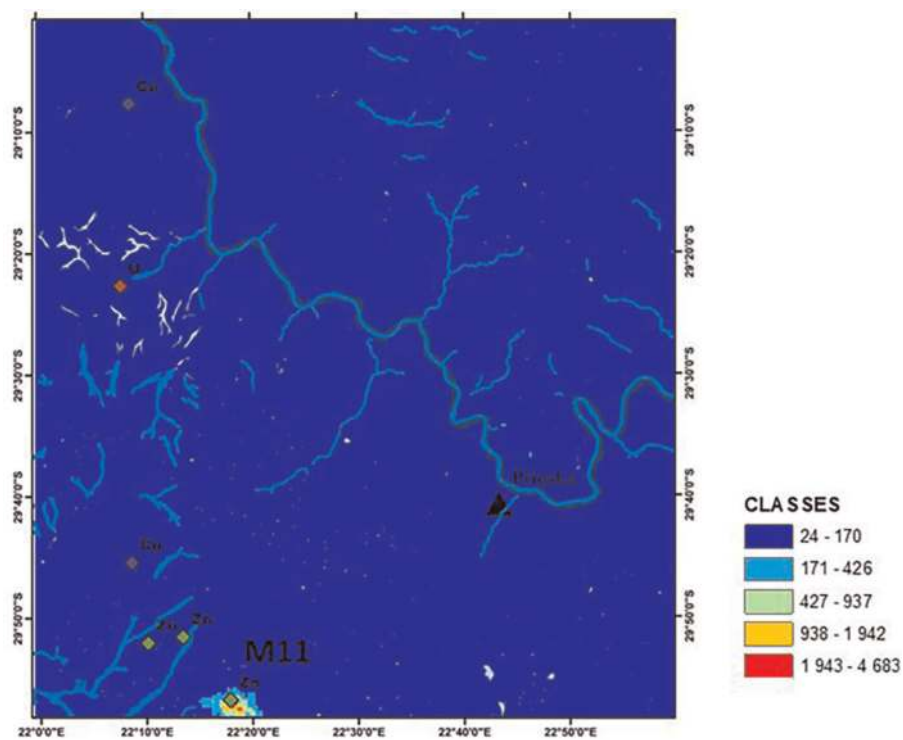


Figure 5. The Fuzzy OR overlay map for Cu_Zn index.

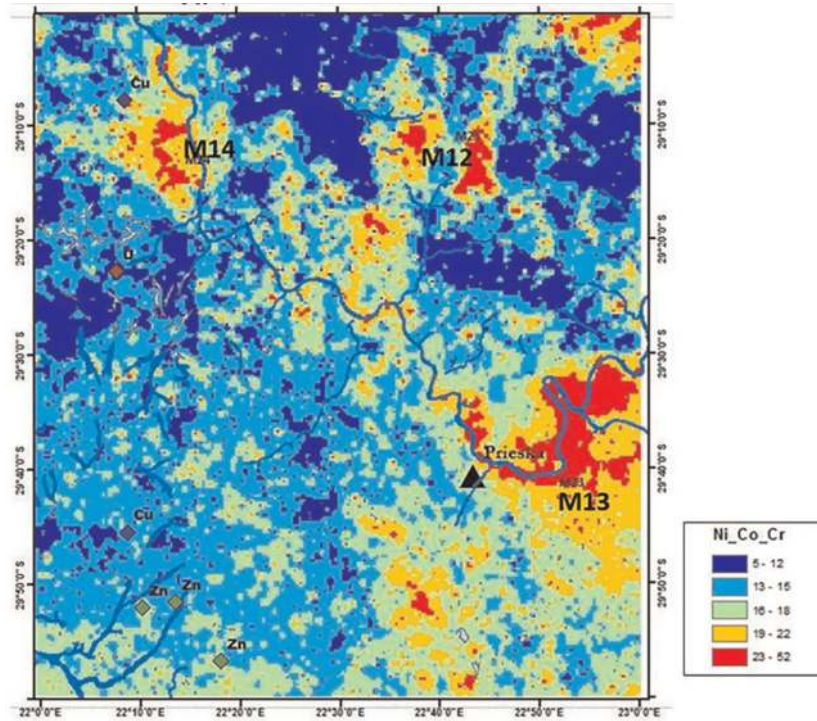


Figure 6.
The Fuzzy OR overlay map for Ni, Co and Cr index.

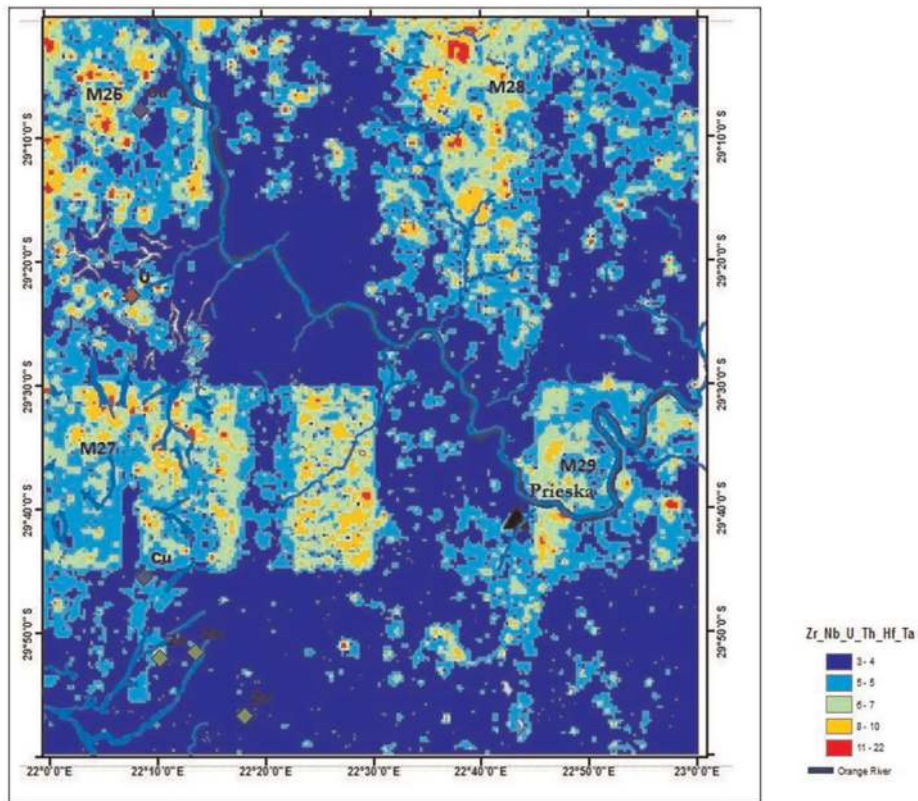


Figure 7.
The Fuzzy OR overlay of Zr_Nb_U_Th_Hf_Ta.

northeast about 150 km from the study area. The Host rocks to Zn–Pb mineralisation on the Ghaap Plateau are stromatolitic dolomites, with minor oolitic dolomites, chert and carbonaceous shale beds of the Campbell Rand Subgroup (Gutzmer, 2006). The occurrence of the M2 potential mineralisation zones requires follow-up studies.

There is a very strong correlation between the Co and Ni, and moderate to strong correlation between Co and Cr indicator elements. The correlations of Co-Ni-Cr are the indicator of mafic- ultramafic geological index. The strong correlation between Co and Ni can also indicate the base metal mineralization. The Ni-Co covers the sulphides and oxides of interest (Co-Ni-Cr) in ultramafic rocks. Co-Ni is a pathfinder of Ni-Cu.

The anomaly M3 – M7 (**Figure 8**) are Co-Ni high values. The M3 potential mineralisation area to the west of Prieska town covers the Dwyka Group, this mineralisation is at the very close vicinity to the Orange River catchment (primary stream) dominant mostly to the south of the catchment. The Co-Ni anomaly (M3) to the north of the Catchment is similar to the Cu-Ga-Zn-Rb anomaly M2, these anomalies cover the Campbellrand Subgroup at the same area, and therefore this outline the new potential of base metal mineralisation. The M4 anomaly overlay the Dwyka Group, Asbestos Hills and the Skalkseput Granite. The M4 anomaly trends to the north-west following the Skalkseput Granite lithology, at the M7 the Co-Ni anomaly covers the Skalkseput Granite and is associated with the known occurring Uranium commodity.

The M5 Co-Ni anomaly is in close vicinity with the known small Copper occurrence. The anomaly is evident in and around the Orange River Catchment. This will require follow up study to confirm the parent source of the anomaly, because of its

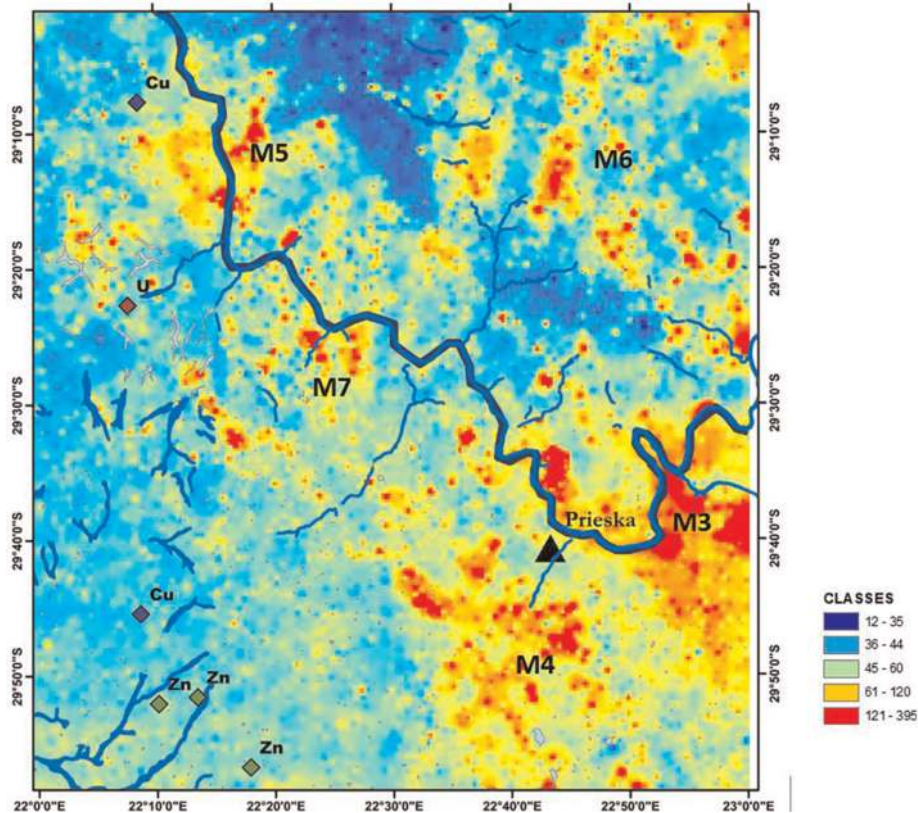


Figure 8.
The Fuzzy OR overlay multi-element map index of Co and Ni.

close vicinity with the known Cu occurrence the Co-Ni correlation may possibly indicate the Base (Cu_Zn) mineralisation. Unlike the M7 anomaly associated with Spioenkop Formation and Ongeluk lava Formation. The M6 anomaly overlay the Ongeluk Lava Formation, and Asbestos Hill.

The elements of the highest mean averages associated with the Brulsand are the Hf, Mo, Nb, Sc, Ta, and U. The Hf, Sc, Mo, Nb, and Ta are transition elements and most of are typically treated as being immobile during metamorphic processes and therefore can be useful in understanding the effects of metamorphism. U strongly correlates with Hf, Ta and Nb, and moderately correlates with Mo. The M8 potential mineralisation (**Figure 9**) consist of isolated cluster of potential mineralisation zones overlying the Asbestos Hills Subgroup, Koegas Group, Kalahari group, Olifantshoek Supergroup. M9 is associated with known metals occurrences; Cu and U, the isolated cluster of anomalies towards the know Prieska Copperton mine. The M9 potential mineralisation zones on the west of Orange River catchment overlies the Draghoender granite/gneiss, Skalkseput granite, Uitdraai Formation and Zeekoebaart Formation. Granitic rocks rich in pyrochlore, euxenite, brannerite, thorite yield soils rich in Nb, Ta, Ti, rare earths, Sc and Zr, are enriched in dark heavy minerals. The radioactive species originally contained in the parent rocks form a major fraction [23]. The Sc, U, Nb, and Ta are indicators of uranium-bearing minerals in granitic, syenitic, magmatitic, pegmatitic and aplitic bodies and complexes. Strauss and Elsenbroek (2006) found in a study on South African alkali and carbonatite complexes that Nb is by far the strongest and most common indicator for these complexes in soils followed by Zr.

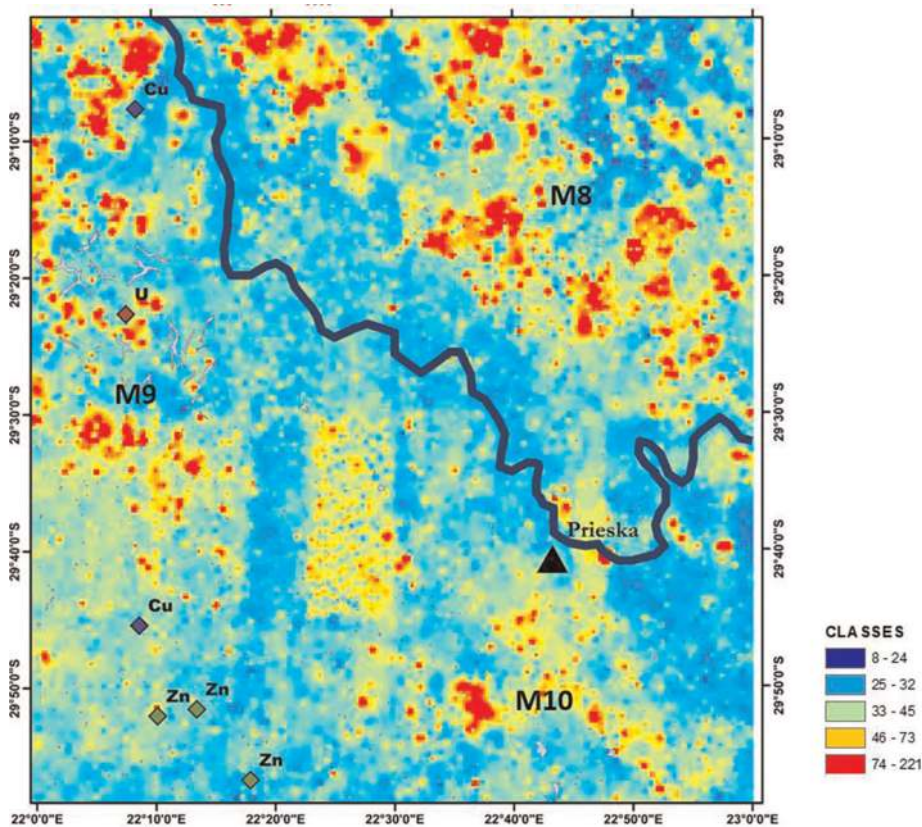


Figure 9.
The Fuzzy OR overlay of Mo, Nb, Sc, Ta, and U.

3.2 Stream sediment exploration target generation: economic geology synthesis map of Prieska area

The following geochemical indices are potential target generators for the Prieska area based on the predominant geology in the area coupled with the single element distribution patterns. The Cu_Zn for VMS Zn_Cu deposit, Ni_Co_Cr ultramafic Ni_Cr (\pm Cu) deposit and Zr_Nb_U_Th_Hf-Ta for the heavy mineral placer deposits. First, new raster files for each index element is created by using of the inverse distance weighted interpolation (IDW). Then the indices were calculated using the fuzzy overlay OR function from ARCGIS, the advantage of using fuzzy OR overlay is generally provides a better result in cases where the indicator elements are not always associated and is better suited for the secondary dispersion where associated elements in the primary environment are likely to be separated.

The anomaly (**Figure 5**) delineates the known Copperton mine in Prieska area, the Copperton ore body occurs in a series of quartz-feldspar rocks quartz-biotite gneisses and quartz- plagioclase–amphibole gneisses as Copperton Volcanic Pile.

The anomaly M12 associated with Koegas Group, Ongeluk lava Formation and Asbestos Hill Subgroup (**Figure 6**) is a preferred potential target for ultramafic Ni_Cr (\pm Cu) deposit. The anomaly overlies the banded Iron Formation of the Asbestos Hill Subgroup; the Asbestos Hill Subgroup is Fe-rich. The anomaly M14 is associated with the known Cu occurrence straddles the Campbell Rand Subgroup, and Zeekoebaart Formation is the secondary target. Anomaly M13 is also identified as the secondary potential target for ultramafic Ni_Cr (\pm Cu) associated with Dwyka Group.

Zr_Nb_U_Th_Hf-Ta are high field strength elements associated with the carbonatites deposits and alkaline magmatic complexes, however the carbonatites deposits are unknown to occur around the Prieska geology area. The high field strength elements are primary indicators of the REE deposit. These elements are associated as incompatible ions, within alkaline igneous melts, which by their emplacement is controlled by the failed rift zone or deep-seated suture.

The anomalies of the Zr_Nb_U_Th_Hf-Ta (**Figure 7**) may be due to thorium in waste rock or sediment; dust from mining activities in the surrounding, and possible water contamination from spillage or leakage of chemical solutions used to leach and process ore. Asbestiform amphiboles that are present in waste dumps. The correlation of the Cu-Pb-Zn anomaly with alkali elements (Nb, Zr, Th, and U) and REEs suggests there is a possibility that the M26–M29 anomaly are alkali-granitic genetic origin. The anomaly could therefore indicate the presence of Cu, Pb, Zn and As sulphides associated with alkali elements and REEs, which makes it a very promising target however the map (**Figure 7**) display a batch effect specifically anomaly M26 and 27, and therefore it is not suitable for interpretation.

4. Conclusions and recommendations

Prieska study area generally forms part of the Namaqua Metamorphic Province and the Griqualand-West Basin. The Kalahari Aeolian sand covers the geology on the area around Prieska Cu-Zn mine. The host sequence in the Copperton district is, from the base: Smouspan Gneiss Member, Prieska Copper Mines Member, and Vogelstruisbult Member. The aeolian sand extensively covers the research area. The secondary dispersion patterns of the elements in the stream sediments may also

destroy the primary association of elements. To overcome this difficulty, a Fuzzy OR overlay of indicator applied. Fuzzy OR generally provides a better result in cases where the indicator elements are not always associated and is better suited for the secondary dispersion where associated elements in the primary environment are likely to be separated.

The descriptive statistics (**Table 3**) results shows that the Ag, Co, Ga, Mo, Nb, Pb, Sb, Sn, Sc, Ta, Th, U, and W concentrations exhibited generally low standard deviation and coefficient of variation values, suggesting a homogenous spatial distribution. In contrast As, Ba, Ce, Cr, Cu, Hf, Nd, Ni, Rb, Sr., S, V, Zr and Zn contents showed a heterogeneous spatial distribution, reflected by high coefficient of variation and large standard deviation. The difference between the median and mean values of high coefficient of variation of the As, Ba, Ce, Cr, Cu, Hf, Nd, Ni, Rb, Sr., S, V, Zr and Zn may be attributed to the extremely high values of these trace elements.

The Fuzzy OR maps give a summary of the potential targets for mineralisation within the study area. Anomaly M1 and M2 associated with Spioenkop Formation though the anomaly does not delineate the Spioenkop Formation but Dwyka Group Sediments, Kalahari Group and Campbell Rand Subgroup. These anomaly signatures are characterised by the one or more of these elements Cu, Ga, Zn, Rb, Pb, Mo, and Ba. Barium is a powerful indicator tool of gossan and be used as an indicator for Zn–Pb deposit. The dataset shows a significant relationship between the Ba and Zn. The relationship between these elements therefore delineate M1 and M2 as potential target for VMS deposit.

The anomaly M2 in close vicinity to the Orange River Catchment, a follow-up study is therefore recommended. The Cu and Zn are generally interpreted as pollution related or may be as a result of metal dispersion from the mine waste. The Zn and Cu high concentrations are not distributed across the Prieska area, the Fuzzy OR overlay of these elements are only elevated in the known Copperton mine area and on the M2 potential VMS mineralisation target area. The anomaly M2 associated with Campbell Rand Subgroup may be as a result of metal dispersion or sourced from the parent underlying rocks.

The Pb and S are also elevated on the known Copperton mine, these elements strongly correlates with the Zn. The Pb and S are likely to be associated with the generic anthropogenic source including sewage discharge, agricultural practises and various kinds of industrial activities. M11 is definitely a VMS mineralisation target, the anomaly overlies the Copperton mine. The high Cu, Zn and Pb are derived from the ore minerals related VMS deposits. The Fe elevated concentration are derived from both primary minerals which are not directly related to the VMS or Co_Ni (\pm Cu) (illustrated in **Figures 4 and 8**) mineralisation within the study area or from ore related minerals of deposits hosted in Banded Iron formation of the Asbestos Hills Subgroup.

The Cr, Ni reflect ultramafic fraction of the stream sediments. The Ni and Cr originate from direct ophiolitic sequences erosion and the recycling of the rocks enriched in ultramafic debris. The M13 and M14 anomaly are traced along the Orange river Catchment, on the Ghaap group which occurs NW to SE of the study area and north of the Orange River Catchment. Ghaap Group consists of shale, sandstone, andesite, and dolomite, and comprised of the magnesium, carbonate-rich Formation such as Vryburg Formation. M13 and M24 potential mineralisation are possibly sourced from ultramafic debris transported from the Ghaap Group by the Orange River Catchment, however this potential target will require follow-up studies for verification. There is a very high Cu-Zn correlation coefficient calculated for samples near the Copperton deposit.

4.1 Recommendations

Indicator elements in stream sediments sample represents either mineralisation or post- mineralisation processes. The processes that affect the indicator elements distribution patterns, these process includes weathering, erosion of ore bodies and adjacent mineralised rock, contamination of pollutants, regolith, topographic gradient vegetation density and/or climate. In this study integration of mineral exploration methods such as remote sensing, geophysics and petrography are recommended, this follow-up studies will assist in determining the extent of the anomaly.

The airborne geophysics studies must be conducted over the research area. Low level airborne electromagnetic (EM) surveys over the target area (M1-M29) especially the M2 and M3 which delineate the possibility of the base metal mineralisation is recommended. The high density stream sediments sampling on the grid and a depth of at least 50 meters to minimise the effect of Aeolian sand cover must be conducted. Petrography is another important tool, to understand the mineralogy of the study area underlying rocks. The detailed analysis of minerals by optical microscopy in thin section and micro-texture and structure is recommended in order to understand the origin and history of the rock.


Remote sensing will also be advantageous in conducting geological traverses of the study area in which anomalies of one or more of the above mentioned elements occur to establish the significance of the anomalies. Remote sensing imagery will also provide information on rock composition or rock alteration which is associated with the indicative of the presence of mineral deposits. Ore deposits are localised along regional and local fracture patterns, the Landsat and radar images are used to map these fracture pattern. Using multiple tools of exploration such as geology, structures, geochemistry, and drainage pattern are recommended for use in ArcGIS as thematic layers to generate the potential mineralisation targets.

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