ASSESSMENT OF POTENTIAL TOXIC INFLUENCE OF URANIUM TRIAL MINING IN THE KAROO URANIUM PROVINCE

By

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EXECUTIVE SUMMARY

An assessment of uranium trial mining on four mining sites in the Karoo Uranium Province, South Africa revealed localised above-background values for U, Mo, Pb, Cu, As and Fe in surface - and ground water, soils, sediment and crops. Inadequate remedial action on cessation of mining activities in 1980 led to the presence of uranium ore in stockpiles, open pits, mining shafts, mining equipment and waste dumps within featured areas.

Heavy metal contamination is suppressed by the lack of run–off and the dry climate experienced within the mining areas. However, the heavy metal content in surface water and sediment within the open pits on Rietkuil and Mooifontein is especially high. These values pose a risk for human ingestion and may cause cancer in the long term or renal damage over the short term. These pits are easily accessed, lack a fence and are used for a drinking medium by fauna and as a growth medium for flora. The easily accessed Cameron Shaft on Ryst Kuil is a matter of concern due to the possible presence of the radioactive inert gas, radon.

Farm owners were unaware of the possible toxic effects of uranium and coherent heavy metals. This led to previous usage of mine water for crop irrigation, the moving and feeding of livestock as well as wildlife amongst uranium ore stockpiles, swimming in water-filled open pits and using crushed uranium ore for gravel road maintenance and construction.

The presence of uranium ore in stockpiles and the coherent effects on the water, soils, sediment, fauna and flora and possibly man, prioritises the remediation and rehabilitation of the of uranium trial mining sites within the Karoo Uranium Province.

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CHAPTER 1

INTRODUCTION

1.1 Overview

Traces of uranium mineralization occur throughout the Karoo Basin at different stratigraphic levels. Exploration for uranium commenced after radioactivity was detected at depth in the gamma log of an exploratory hole drilled for oil by SOEKOR near Beaufort West. Early in 1970 an American based exploration company embarked on a systematic search for uranium throughout the western world. The Karoo Basin was included in the search. Extensive car and airborne surveys located some several hundred sandstone-hosted uranium occurrences.

The uranium has never been fully exploited, but between 1976 and 1980 when the spot uranium price reached its zenith ($40 to $44/pound U), the largest deposits became marginally viable (Van der Merwe 1986, in Wilson and Annhaeusser 1998). This study focuses on four of these deposits, namely Ryst Kuil (on the farm Ryst Kuil 351), Rietkuil (on the farm Rietkuil 307), DR-3 (on the farm Drie Vaderlandsche Rietvalleyen 49) and Mooifontein (on the farm Mooifontein 76).

Uranium is a naturally occurring element that is present in soil, rocks, surface and underground water, air and plants and in more than 100 minerals as an important constituent. As a result it occurs in trace amounts in many foods and in drinking water. Uranium does not occur in concentrated deposits, and much of the ore from which uranium is recovered contains less than 0.1% uranium.

Uranium is consumed mainly in nuclear power stations. The advantage of a nuclear thermal reactor over other generators of electrical power is the extremely high energy-density of uranium. For example, 1kg of uranium as mined contains 7.11g of ^{235}U, which is in terms of energy equivalent to 19.2 tons of coal or 97.4 barrels of crude oil (Messel 1979). This advantage is largely offset by the high construction, safety and decommissioning costs of nuclear power stations. At present, growth in nuclear power is negligible due to the above considerations, as well as concerns about both the safety of nuclear reactors and the disposal of steadily increasing masses of nuclear waste. Uranium is also used on a small scale in nuclear research reactors, for the manufacture of nuclear weapons, as fuel for the propulsion of ships using a small nuclear reactor, and for the production of radioactive isotopes, which have various applications, the more important being in the fields of medicine and food irradiation (Wilson and Annhaeusser 1998).

The chemical toxicity of uranium has been recognized for more than two centuries. Animal experiments and human studies are conclusive about the metabolic adverse effects and toxicity of uranium compounds. There are several reports in the literature that uranium at very low concentrations (0.002 to 0.2 ppm) has a positive effect on the growth of plants and that it is a necessary nutrient in plant life (Dinse 1953, in Ammerman et al. 1980) while it has been demonstrated to be non-essential in animals (Ammerman et al. 1980).

1.2 Study area

The study area encompasses the Beaufort West, Laingsburg and Edenburg areas of the Karoo Uranium Province (fig. 1.1).

The Karoo Uranium Province extends from the north-eastern part of the Western Cape across the south-eastern part of the Northern Cape and into the Free State as far as Bloemfontein. It also stretches east to Aberdeen in the Eastern Cape and includes a smaller, crescent shaped, satellite area located between Clocolan and Phuthaditjaba (former Qwaqwa).

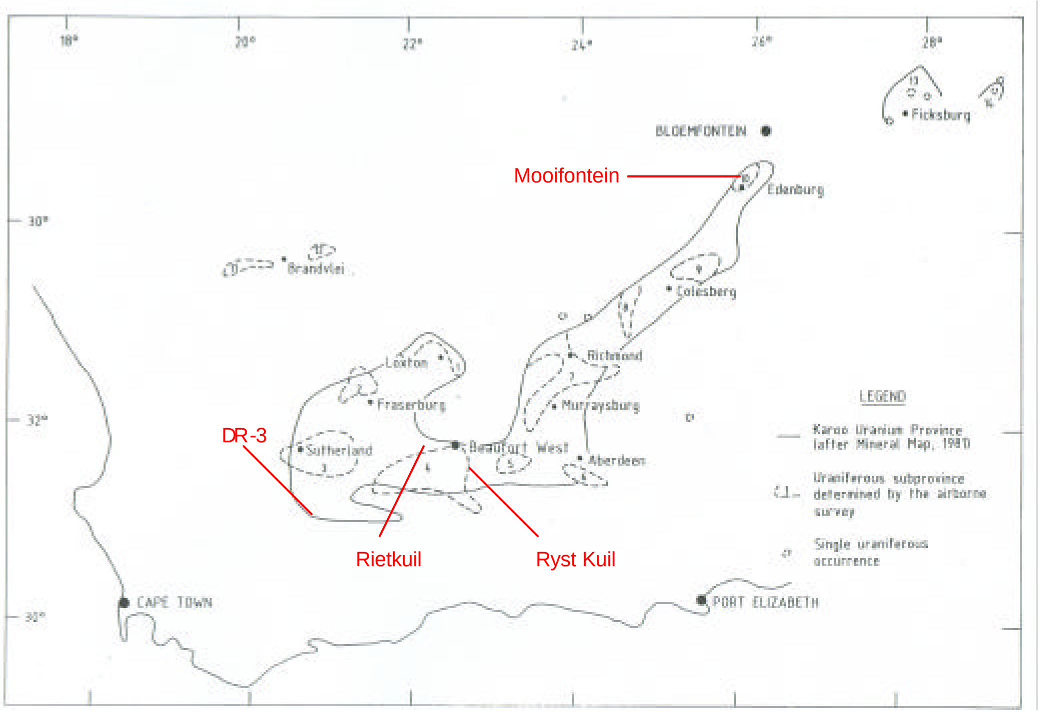


Figure 1.1 Karoo Uranium Province showing trial mining areas (After Cole et al. 1991). Scale 1:450 000.

1.3 Geological setting

The main Karoo Basin, which encompasses roughly 50 percent of the surface area of South Africa, contains the great Gondwana succession of glacial, marine, deltaic, fluvial and aeolian sedimentary units capped by basalts of Jurassic age (Cole et al 1991).

The Karoo Uranium Province predominantly occurs within the Late Permian Adelaide Subgroup (Beaufort Group), with the exception of the satellite area, which coincides with the Late Triassic Molteno and Elliot Formations. The sandstones in each of these units are similar in that they contain volcanic material and carbonate, and were deposited under semi-arid climatic conditions.

The Permo-Triassic Beaufort Group is exposed over an area of some 145 000km^2, with thicknesses up to 3000m. It is a fluvially derived succession composed of alternating mudstone and sandstone lithosomes with characteristic upward fining textures, red and purple colours, vertebrate fossils, desiccation cracks and paleopedogenic carbonate horizons. The Beaufort strata most probably accumulated on vast semi-arid alluvial plains mainly by floodplain aggradation (Smith et al. 1993).

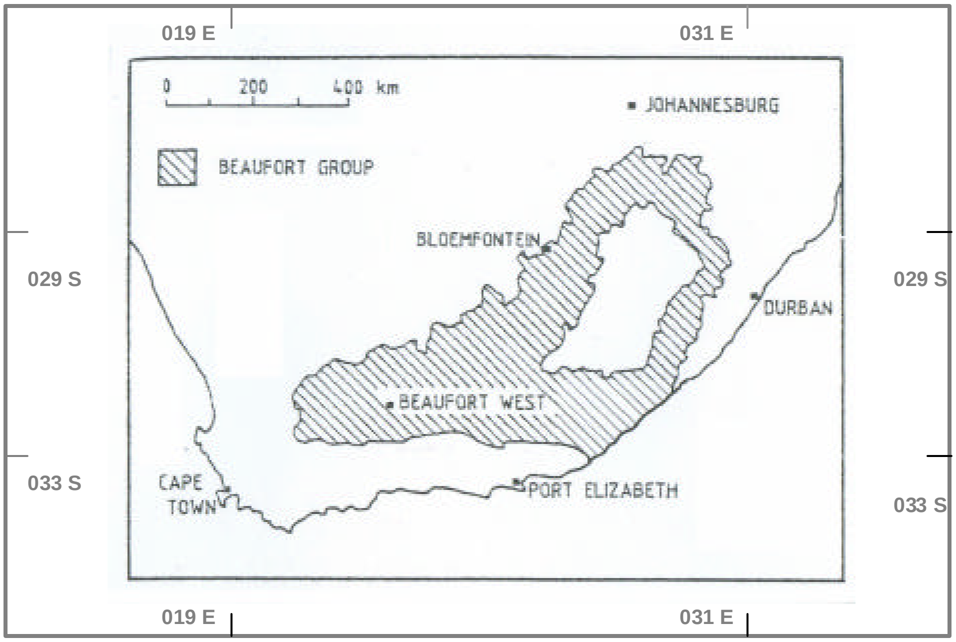
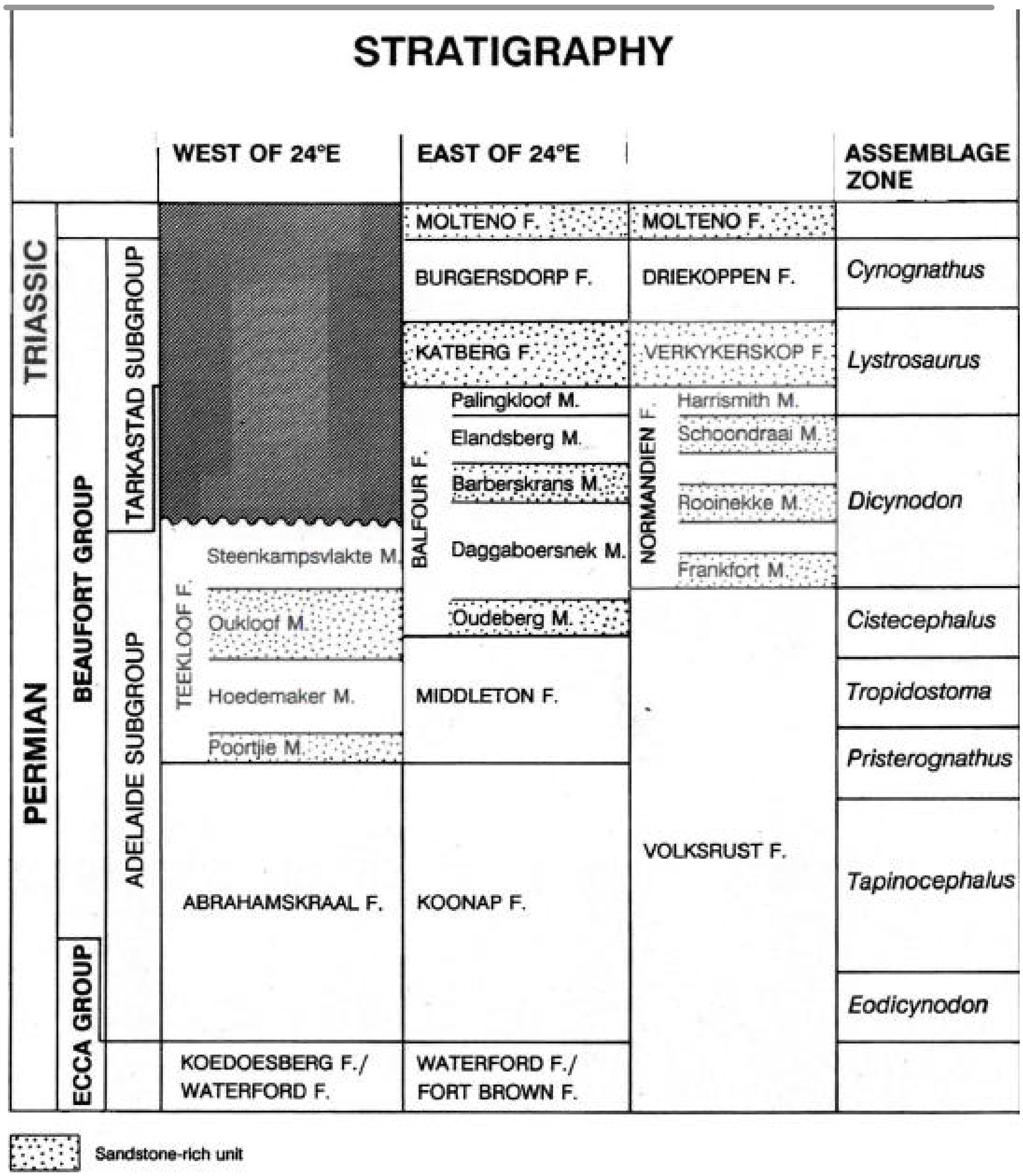


Figure 1.2 The locality of the Beaufort Group within South Africa. From Johnson (1989).

1.4 Uranium distribution in the Karoo

The localization of mineralization in the Beaufort Group may reflect the fact that only the lowermost part of the succession, which is confined to the south-western Karoo Basin, contains abundant volcanic deritritus (Elliot and Watts 1974, in Turner 1985). Although mineralization occurs throughout the Beaufort succession, significant mineralization is confined mainly to two prominent sandy units. The upper one, known as the Oukloof Sandstone, occurs within the flood basin facies association and is about 120m thick. The lower economically more important unit, the Poortjie Sandstone, attains a thickness of 150m and defines the contact between the high sinuosity channel facies and the flood basin facies association. This unit contains more than 50 percent of all known uranium occurrences in the area (Turner 1985).

Table 1.1 Generalized stratigraphy of the Beaufort Group in the Karoo Basin, west and east of 24°E. From Rubidge (1991).



STRATIGRAPHY

			WEST OF 24°E	EAST OF 24°E		ASSEMBLAGE ZONE
TRIASSIC				MOLTENO F. ▨	MOLTENO F. ▨	
	BEAUFORT GROUP	TARKASTAD SUBGROUP		BURGERSDORP F.	DRIEKOPPEN F.	*Cynognathus*
				KATBERG F. ▨	VERKYKERSKOP F. ▨	*Lystrosaurus*
				BALFOUR F. Palingkloof M.	NORMANDIEN F. Harrismith M.	
PERMIAN				Elandsberg M.	Schoondraai M. ▨	*Dicynodon*
				Barberskrans M. ▨	Rooinekke M. ▨	
		ADELAIDE SUBGROUP	TEEKLOOF F. Steenkampsvlakte M.	Daggaboersnek M.	Frankfort M. ▨	
			Oukloof M. ▨	Oudeberg M. ▨	VOLKSRUST F.	*Cistecephalus*
			Hoedemaker M.	MIDDLETON F.		*Tropidostoma*
			Poortjie M. ▨			*Pristerognathus*
			ABRAHAMSKRAAL F.	KOONAP F.		*Tapinocephalus*
	ECCA GROUP					*Eodicynodon*
			KOEDOESBERG F./ WATERFORD F.	WATERFORD F./ FORT BROWN F.		

▨ Sandstone-rich unit

1.5 Source

Three possible sources for the uranium mineralization in the Karoo Sequence have been suggested: (1) volcanic fragments in the host sandstone and interbedded tuffaceous material (Turner 1978, in Turner 1985), (2) Precambrian basement granites (1000 m.y.) which were actively shedding deritritus to the depositional basin at this time (Toens and Le Roux 1978, in Turner 1985) and (3) the surrounding shales (Von Backstrom 1974, in Turner 1985).

Acid and intermediate volcanics, which contain on average 6 and 1.7 ppm U respectively, are thought to be an important source of uranium, especially the more acidic types. It has been convincingly demonstrated by Smellie (1982) that post-deposition devitrification of calc alkaline volcanic deritritus is able to mobilize and re-concentrate uranium, leading to above average values of 200 to 300 ppm, with local enrichments of up to 3000 ppm.

1.6 Review of previous research

Although this study is primarily concerned with the possible toxic effects of uranium trial mining in the Karoo Uranium Province, the discovery of uranium in the Karoo and the resulting research is nevertheless significant. Each author is treated separately, with emphasis on contributions to our understanding of Karoo uranium mineralization, the toxic hazards of uranium and uranium mining related problems.

1.6.1 Karoo Uranium Province

The Karoo Uranium Province has been studied in detail since the detection of radioactivity in 1964 by H.D. Le Roex (Cole et al. 1991), near Fauresmith. Since the first published description of uranium occurrences in the Karoo by Von Backström (1973), numerous theses and papers have been compiled by many authors on related aspects.

Du Toit (1970, 1976) noted the presence of anomalous radioactivity in boreholes drilled for oil in the southern Karoo, and postulated the existence of a large uranium province.

Kubler (1977) made a detailed study of an area lying between the towns of Beaufort West, Fraserburg and Merweville, which included the nature and distribution of the sediments, the stratigraphy of the area, the depositional environment and the origin and nature of the uranium mineralization.

Cole (1979, 1980) and Cole et al. (1991) presented sedimentological investigations of the farms Rietkuil and Ryst Kuil in the Beaufort West district; he presented a detailed overview of Karoo uranium occurrences which included results of a groundwater follow-up, sedimentological, mineralogical and geochemical investigations, as well as ore controls and genesis of the uranium bearing ore.

Stear (1980) made a detailed study of the sedimentology in an area which incorporates parts of the Beaufort West and Prince Albert districts between the towns of Merweville in the west and Beaufort West in the east. He describes uranium mineralization in the lower Beaufort Group and reports on the Ryst Kuil and Rietkuil deposits.

Stuart-Williams (1981) worked in an area situated between Beaufort West and Fraserburg and studied the three dimensional geometry of the sandstones whilst examining controls on uranium mineralization and aimed to determine the depositional environment.

Turner (1985) made a detailed study of uranium mineralization in the Beaufort Group. He describes sedimentological, chemical and biochemical-organic controls and postulates sources for mineralization.

Le Roux (1985, 1993) made borehole analysis and studied selected uranium deposits such as DR-3, Mooifontein, Rosendal, River, Klipbankskraal, Banksgaten and Matjieskloof. He reconstructed sedimentological environments and examined extensions to known ore bodies. He furthermore evaluated the formation of uranium ore bodies in the Karoo Basin.

Le Roux and Toens (1986) reviewed the uranium occurrences in the Karoo Basin and evaluated regional and stratigraphic distribution, depositional environments, mineralogy and geochemistry as well as ore genesis and made case studies of Rietkuil and Ryst Kuil.

1.6.2 Uranium toxicity

Since the discovery of radioactivity in 1896 by Henri Becquerel, it has been proven that exposure to the isotopes of uranium produces both chemical and toxic hazards to humans and animals.

In their study on the tolerance domestic animals show towards uranium, Ammerman et al. (1980) found that the total uranium content of animal diets should not exceed 3 to 4 ppm. Their results show the toxicological effect to be similar in all animals studied, causing mainly kidney dysfunction.

Domingo et al. (1989) and Domingo (1994, 2001) review reproductive toxicity, maternal toxicity and embryo toxicity as well as post-natal effects of uranium and other toxic metals. His results show decreased fertility, embryo toxicity and reduced growth in offspring following uranium exposure at different gestation periods.

Athar and Vohora (1995) made a study of heavy metals in the environment and their health effects. They concluded that uranium is a highly toxic metal for both animals and man with a high incidence of lung cancer reported amongst uranium miners.

In their study on environmental uranium and human health, Taylor and Taylor (1997) give a high expected risk for cancer and other chemical or radiation induced illnesses as a result of inhalation of the radioactive gas radon, produced by the decay of ^{238}U.

Giddings (1998) addresses the chemical aspects of uranium toxicity and gives guidelines for drinking water quality. He further says that uranium mainly accumulates in the skeleton and kidneys where it can cause renal damage.

Durakovic (1999) states that soluble uranium compounds are definitely toxic with frequent fatal outcomes mainly because of lung and renal damage.

Ragnarsdottir and Charlet (2000, in Campbell et al. 2000) made an extensive study of uranium in the natural environment and show that uranium is harmful to all living organisms causing renal failure and amongst others liver dysfunction.

1.6.3 Uranium mining related problems

Harries and Ritchie (1983) measured pollution levels of run-off from a uranium waste rock dump at Rum Jungle Uranium Mine, Australia in which soluble salts are produced by pyritic oxidation. They concluded that in the case of metalliferous minerals, metals leached from the residues may give rise to additional pollution of ground - and surface waters in the environs of the mine.

Amaral et al. (1988) assessed the influence of the different sources on the increase of ^{226}Ra and ^{238}U surface water concentrations at Pocos de Caldas uranium mine, Brazil. The highest contributor was found to be from the waste rock because of its availability for leaching processes.

In his study on mining and the freshwater environment, Kelly (1988) finds that mining is a notorious industry from the point of view of pollution. Large amounts of overburden are removed only to get to a few tonnes of economically important minerals. This leads to a huge amount of waste tailings which impart relatively large impacts on the environment.

Petterson and Koperski (1991) made detailed investigations of the aerial dispersion of radioactive dust from a uranium mining and milling operation in Australia. They studied spatial distributions of the long-lived ^{238}U series and their origin, i.e. mining operations vs. natural background radiation. They concluded that the open pit has been the predominant contributor of U series radionuclides to the environment within the radius of several kilometres from the operations.

Akber et al. (1992) studied radon and its daughter concentrations at locations several kilometres away from the Ranger Uranium Mine in the Northern Territory of Australia, resulting from natural and mine-related sources. The mine related radiation exposure to mine workers and their families, due to aerial dispersion of radon from the mine, are described.

Shields et al. (1992) studied the adverse effects of uranium mining on a Navajo mining population around Shiprock on the Colorado Plateau, USA. These people were exposed to radiation from alpha and gamma emissions associated with uranium mines and housing, which probably led to the development of lung cancer.

Murray et al. (1993) used natural radionuclide transport as an analogue to determine the likely fate of uranium mine effluent in a seasonal river in Northern Australia. Previous modelling had assumed that only 20% of released activity would be retained on the flood plain. They recommend that complete retention should be assumed, thus increasing the predicted radiation dose to members of the public.

Allan (1995) states that terrestrial and aquatic ecosystem contamination by acid mine drainage and heavy metals are a global phenomenon. Regulations on mining activities have been applied only recently and often only to new mines.

Rahn et al. (1996) focussed their research on determining if abandoned mines constitute a major environmental hazard in the Black Hills, USA. They found that uranium mines contribute some radioactivity to surface water, but the impact is limited because of the dry climate and lack of runoff.

In their study on the human exposure to uranium mining and milling, Au et al. (1998) state that the extent of exposure to high concentrations of environmental toxicants is hazardous to health and also difficult to assess. Development of procedures which can be used to identify health hazards in the exposed public is probably the single most significant approach towards establishing effective programs for disease prevention.

Fernandez et al. (1998) studied acid rock drainage and radiological environmental impacts at a uranium mining site in Brazil. Mining and milling of uranium ore has the potential to cause environmental pollution of nearby water courses and aquifers by radionuclides, heavy metals and other contaminants. They concluded that depending on the mining project, underground or open pit, the volume of earth moved, and drainage will determine the extent of the potential associated impacts.

Veiga et al. (1998) studied the impact of radioactive and non-radioactive materials on human health in the off-site surface water environment downstream of a uranium mining and milling facility in Brazil. They concluded that water and vegetable ingestion are the most important exposure pathways; while most of the attention in these kinds of facilities is focussed on radiation risks, non-radioactive contaminants may be of greater concern.

Mudd (2001) made a study of in-situ leach (ISL) uranium mining. He considers the use of acid ISL problematic, due to higher salinity and some radionuclides in post-restoration monitoring of groundwater, compared with pre-mining conditions.

Schneider et al. (2001) investigated the characteristics of abandoned materials and mine wastes at the closed Königstein Uranium Mine in Germany in order to identify a suitable remedial approach for these materials.

Van Dam et al. (2002) present an overview of issues related to surface water contamination arising from uranium mining activities in the Alligator Rivers region of Northern Australia. Bio-accumulation in aquatic biota is also assessed, and is an issue of importance not only to ecosystem health, but also to the health of local people. The aquatic animals consumed represent potential sources of radiological dose, and as a result, a major component of the program to assess potential effects on human health, is the prediction of doses to local people living downstream of mining activities.

1.7 Research Objectives

The aims of this research include the following:

1. To determine the possible presence and localised extent of environmental impacts within the Karoo Uranium Province as a result of:

    a. Uranium trial mining
    b. Inadequate remedial processes

2. To inform local inhabitants and farm owners of the hazards of inadequate remedial processes and offer possible short term solutions.

3. To set a base for future environmental impact studies on trial mining sites within the Karoo Uranium Province.

CHAPTER 2

URANIUM

2.1 Physical and chemical properties of uranium

Uranium, element number 92, is one of the primeval radioactive elements that were formed during the universe-creating event. Uranium occurs naturally in the +2, +3, +4, +5 and +6 valence states, but is most commonly found in the hexavalent form. In nature, hexavalent uranium is commonly associated with oxygen as the uranyl ion, UO_2^{2+}. Major compounds of uranium include oxides, fluorides, carbides, nitrates, chlorides, acetates, and others. One of the characteristics of UO_2^{2+} ions is their ability to fluoresce under ultraviolet light.

Naturally occurring uranium is a mixture of three radionuclides (^{234}U, ^{235}U and ^{238}U), all of which decay by both alpha and gamma emissions. By weight, natural uranium is about 0.01% ^{234}U, 0.72% ^{235}U, and 99.27% ^{238}U. About 48.9% of the radioactivity is associated with ^{234}U, 2.2% is associated with ^{235}U, and 48.9% is associated with ^{238}U.

Uranium has 22 known isotopes all of which are radioactive with half-lives ranging from 1.3 min (^{227}U) to 4.468 x 10^9 yr (^{238}U). Radioactive isotopes are constantly changing into different isotopes by giving off radiation. The shorter the half-life the more radioactive and the longer the half-life the less radioactive the isotope will be (Taylor and Taylor 1997 and US Department of Health 1999).

2.2 Distribution in the earth

The average crustal abundance of uranium is 2 to 3 ppm (Plant et al. 1985, in Ragnarsdottir and Charlet 2000). Although uranium is very widely distributed throughout the earth's crust, in certain areas the underlying rock has a high silicate content, such as granite, where the uranium content is greater than the average, whereas in other regions with largely basic rocks (basalts), the concentration may be below the average.

Uranium concentrations in oceanic sediments range from 0.3 to 3.8mg/kg (Church 1973, in Ragnarsdottir and Charlet 2000), with averages of 1.2 to 1.3mg/kg in sedimentary rocks and 2.2 to 15mg/kg in granites (Langmuir 1978, in Ragnarsdottir and Charlet 2000). Arc magmas have concentrations from 0.1 to 3.2mg/kg (Turner et al. 1997, in Ragnarsdottir and Charlet 2000) and ophiolites range from 0.1mg/kg (pristine) to 0.4mg/kg (hydrothermally altered).

2.3 Mining and milling of uranium

Open-pit mining, in-situ leaching and underground mining are three techniques that have been used for mining uranium-containing ores. The two most commonly used mining methods are open-pit and underground mining. The choice of method is influenced by factors such as the size, shape, grade, depth, and thickness of the ore deposits. In-situ leaching involves leaching (or dissolving) uranium from the host rock with liquids without removing the rock from the ground and can only be carried out on unconsolidated sandstone uranium deposits located below the water table in a confined aquifer. A leaching solution is introduced into or below the deposit and pumped to the surface, where the uranium-pregnant liquor is processed in a conventional mill to precipitate the uranium as yellowcake (U_3O_8 and other oxides).

Ore mined in an open pit or underground mine is crushed and leached in a uranium mill. The initial step in conventional milling involves crushing, grinding, and wet and/or dry sorting of the crude ore to produce uniformly sized particles that are similar in size to beach sand. A slurry generated in the grinding circuit is transferred to a series of tanks for leaching by either an alkaline or acid process. Generally, leaching is a simple process whereby uranyl ions are extracted by a solvent. Uranyl ions are stripped from the extraction solvent and precipitated as yellowcake. Yellowcake is pressed, dried, banded, and shipped for refinement and enrichment. The by-product of this process is the leftover sand, known as tailings. Thus, tailings are the original sand minus much of the uranium plus residual process chemicals. Tailings are less radioactive than the original ore (US Department of Health 1999).

2.4 Uranium in the environment

Uranium is present in the environment as result of leaching from natural deposits, release in mill tailings, emissions from the nuclear industry, the combustion of coal and other fuels, and the use of phosphate fertilizers that contain uranium (Giddings 1998). Because of the wide distribution of uranium, very small concentrations of uranium occur in virtually all plants and animals and in most aquifers. Since the evolution of hominids ~4 million years ago, uranium has been a component of the human body (Taylor and Taylor 1997).

2.4.1 Uranium in air

In the air, uranium exists as dust. Very small dust-like particles of uranium fall out of the air onto surface water, plant surfaces, and soil, either by themselves or when rain falls. These particles of uranium eventually end up back in the soil or in the bottoms of lakes, rivers, and ponds, where they stay and mix with the natural uranium that is already there.

Mean levels of uranium in ambient air have been reported to be 0.02ng/m^3 in Tokyo (based on a 1979 to 1981 survey) (Hirose and Sugimura 1981, in Giddings 1998). The amount of uranium that has been measured in air in different parts of the United States ranges from 0.02ng/m^3 to 0.45ng/m^3. Even at the higher concentration, there is so little uranium in a cubic meter of air that less than one atom transforms each day.

On the assumption of a daily respiratory volume of 20m^3 and a mean urban airborne concentration of 0.05ng/m^3, the daily intake of uranium from air would be about 1ng (Giddings 1998).

2.4.2 Uranium in water

Uranium in water comes from different sources. Most of the uranium is leached from rocks and soil. Only a very small part is from the settling of uranium dust out of the air. Some of the uranium is simply suspended in water, like muddy water.

The amount of uranium that has been measured in drinking water in different parts of the United States is generally less than 1.5µg (1µg equals 1 x 10^{-3}mg) for every liter of water. It has been found that the levels of uranium in water in different parts of the United States are extremely low in most cases, and that water containing normal amounts of uranium is usually safe to drink. Because of the nature of uranium, not much of it gets into fish or vegetables, and most of that which gets into livestock is eliminated quickly in urine and faeces (US Department of Health 1999).

Worldwide soluble mean uranium concentrations generally range from 0.1µg/l to 10µg/l in rivers, lakes and groundwater (Spalding and Druliner 1981). In a survey of 130 sites in Ontario, Canada, conducted between 1990 and 1995, the mean of the average uranium concentrations in treated drinking water was 0.4µg/l (OMEE 1996, in Giddings 1998). Uranium concentrations of up to 700µg/l have been found in private supplies in Canada (Moss, 1985 in Giddings 1998). The mean concentration of uranium in drinking water in New York City, USA, ranges from 0.03 to 0.08µg/l (Fisenne and Welford 1986, in Giddings 1998). In five Japanese cities, the mean level in water supplies was 0.0009µg/l (Nozaki et al. 1970, in Giddings 1998).

2.4.3 Uranium in soil

Uranium is found naturally in soil in amounts that vary over a wide range, but the typical concentration is 3 ppm (US Department of Health 1999). Additional uranium can be added by industrial activities. Soluble uranium compounds can combine with other substances in the environment to form other uranium compounds. Uranium compounds may stay in the soil for thousands of years without moving downward into groundwater.

When large amounts of natural uranium are found in soil, it is usually soil with phosphate deposits. In areas like New Mexico in the USA, where uranium is mined and processed, the amount of uranium ranges from 0.1 to 5.1 ppm in soil. The amount of uranium in soil near a uranium fuel fabrication facility in the state of Washington USA, ranges from 0.8 to 4.6 ppm, with an average value of 1.7 ppm (US Department of Health 1999).

2.4.4 Uranium in food

Uranium has been detected in a variety of foodstuffs. The highest concentrations are found in shellfish, and lower levels have been measured in fresh vegetables, cereals and fish. The average per capita intake of uranium in food has been reported to be 1.3 µg/day (Fisenne et al. 1987, in Giddings 1998) and 2 to 3µg/day (Sing et al. 1990, in Giddings 1998) in the USA and 1.5µg/day in Japan.

Plants can absorb uranium from the soil onto their roots without absorbing it into the body of the plant. Therefore, root vegetables like potatoes and radishes that are grown in uranium contaminated soil may contain more uranium than if the soil contained levels of uranium that were natural for the area (US Department of Health 1999).

2.4.5 Uranium in glass and ceramics

Lenda and Councell (1992, in Giddings 1998) performed leaching studies to determine the quantity of uranium leaching from 33 glass items and two ceramic items in which uranium was used as colouring agent. Uranium bearing glasses leached a maximum of 30µg of uranium per litre, whereas the ceramic glazed items released approximately 300 000µg of uranium per litre.

2.4.6 Uranium exposure

Uranium exposure can result from drinking uranium-contaminated water, eating uranium-contaminated food or breathing in uranium-rich dust or decay products of uranium such as radon gas. Uranium taken in from industrial activities is in addition to what is taken in from natural sources. It is possible that a person may eat and drink more uranium if they live in an area with naturally higher amounts of uranium in the soil or water or if they live near a uranium-contaminated hazardous waste site. A person can also take in (or ingest) more uranium if you eat food grown in contaminated soil, or drink water that has unusually high levels of uranium. Normally, very little of the naturally occurring uranium in lakes, rivers, or oceans gets into the fish or seafood we eat. The amounts in the air are usually so small that they can be safely ignored (US Department of Health 1999).

The daily intake for uranium from each source for adults is estimated to be: air, 0.001µg; drinking water, 0.8µg and food 1.4µg (Giddings 1998). Thus the total daily intake is approximately 2.2µg or 0.037µg/kg of body weight for a 60kg adult.

Daily intake of uranium in food and water varies from 1 to 5µg uranium per day in uncontaminated regions and 13 to 18µg per day or more in uranium mining areas (Taylor and Taylor 1997).

As yet, no definitive evidence has been presented that uranium deposited in the human body at the levels encountered in the normal environment directly causes any detrimental effects (Taylor and Taylor 1997).

2.5 Uranium metabolism

When a person breathes in uranium-rich dust, some of it is exhaled and some stays in the lungs. The size of the uranium dust particles and how easily they dissolve determines where in the body the uranium goes and how it leaves the body. Uranium dust may consist of small, fine particles and coarse, big particles. The big particles are caught in the nose, sinuses, and upper part of the lungs where they are blown out or pushed to the throat and swallowed. The small particles are inhaled down to the lower part of the lungs. If they do not dissolve easily, they stay there for years and cause most of the radiation dose to the lungs from uranium. They may gradually dissolve and go into the blood. If the particles do dissolve easily, they go into the blood more quickly. A small part of the uranium swallowed will also go into the blood which carries uranium throughout the body (US Department of Health 1999).

According to Igarashi et al. (1987, in Giddings 1998) it has been estimated that the total body burden of uranium in humans is 40µg, with approximately 40% of this being present in the muscles, 20% in the skeleton, and 10%, 4%, 1%, and 0.3 % in the blood, lungs, liver and kidneys, respectively.

Once equilibrium is attained in the skeleton, uranium is excreted in the urine and faeces. Under alkaline conditions most of the uranium is stable and excreted in the urine. If the pH is low, the uranium complex dissociates to a variable degree, and the uranyl ion may then bind to cellular proteins in the tabular wall, which may then impair tabular function (Giddings 1998).

This distribution is rapid; within an hour most of the parenteral dose of uranium is deposited in the bone, and 20 percent will already have appeared in the urine. After a period of about one month, most of the uranium found in the bone is still at this site. The kidney may contain 1 or 2 percent of the original dose; the remainder is accounted for in the urine (Ammerman et al. 1980).

2.6 Uranium toxicology

Uranium is harmful to living organisms if the metal or its decay products enter the body (Ragnarsdottir and Charlet 2000). The toxicity is dependent upon and modified by many factors and most of the reported studies have been conducted with laboratory animals (Ammerman et al. 1980).

Uranium is a chemical substance that causes radiation and chemical effects. A few people have developed signs of kidney disease after intake of large amounts of uranium (Taylor and Taylor 1997, Durakovic 1999 and Giddings 1998). Animals have also developed kidney disease after they have been treated with large amounts of uranium (Pavlakis et al. 1996). There is also a chance of getting cancer from any radioactive material like uranium (Ragnarsdottir and Charlett 2000). Natural and depleted uranium are only weakly radioactive and are not likely to cause cancer from their radiation. No human cancer of any type has ever been seen as a result of exposure to natural or depleted uranium. Uranium decays into other radionuclides, which however can cause cancer if a person is exposed to enough of them for a long enough period (US Department of Health 1999).

Renal toxicity is a major adverse effect of uranium, but the metal has toxic effects on the cardiovascular system, liver, muscular and nervous system as well. Any possible direct risk of cancer or other chemical – or radiation induced detrimental health effects from uranium deposited in the human body is probably less than 0.005% in contrast to an expected indirect risk of 0.2% to 3% through inhaling the radioactive inert gas radon (Taylor and Taylor 1997).

2.7 The radiation environment

The first recorded awareness of the effects of environmental radiation on humans was reported by Georgious Agricola, a latinization of the name George Brauer. In 1556 he reported on the development of a “mountain sickness” amongst silver miners in the Erz Mountains of East Germany and Czechoslovakia. These miners exhibited a mortality rate of nearly 75% from lung diseases, later attributed to the radon gas from uranium deposits in the mines (Wilkening 1990).

2.7.1 Radiation Exposure

Radiation exposure in the natural and urban environment is focused upon radon, the only radioactive gas that is formed by the decay of uranium and thorium (Ball et al. 1991 and Bottrell 1993, in Ragnarsdottir and Charlet 2000).

The gas is ingested respiratoraly where it can cause damage as severe as lung cancer (Jones 1995, in Ragnarsdottir and Charlet 2000). In the open air, the concentration of radon is generally very low. Radon becomes a hazard only when found in concentrations such as those encountered in unventilated uranium mines. However in areas built on or out of rocks containing high quantities of uranium, the radon levels can rise well above background levels.

Naturally occurring uranium is radioactive but poses little radioactive danger because it gives off very small amounts of radiation. Uranium transforms into another element and gives off radiation. When the transformation product is radioactive, it keeps transforming until a stable product is formed. During these decay processes, the parent uranium, its initial decay products, and their subsequent decay products each release radiation. Radon and radium are two of these products. Most of the radiation given off by uranium cannot travel far from its source. If the uranium is outside the human body, such as in soil, most of its radiation cannot penetrate the skin and enter the body. Unlike other kinds of radiation, the alpha radiation ordinarily given off by uranium cannot pass through solid objects. To be exposed to radiation from uranium, a person has to eat, drink, or breathe it, or get it on their skin (US Department of Health 1999).

CHAPTER 3

TRIAL MINING AREAS IN THE KAROO URANIUM PROVINCE

3.1 Ryst Kuil

3.1.1 Introduction

The farm is situated about 50 km from Beaufort West along the road to Rietbron. The radioactive sandstone on the southern part of the property was detected by radiometric surveys carried out by Esso Minerals Africa Inc. The uranium bearing sandstone correlates with the lowermost Poortjie Member of the Teekloof Formation (table 1.1) and the regional geology is shown in figure 3.1.1.

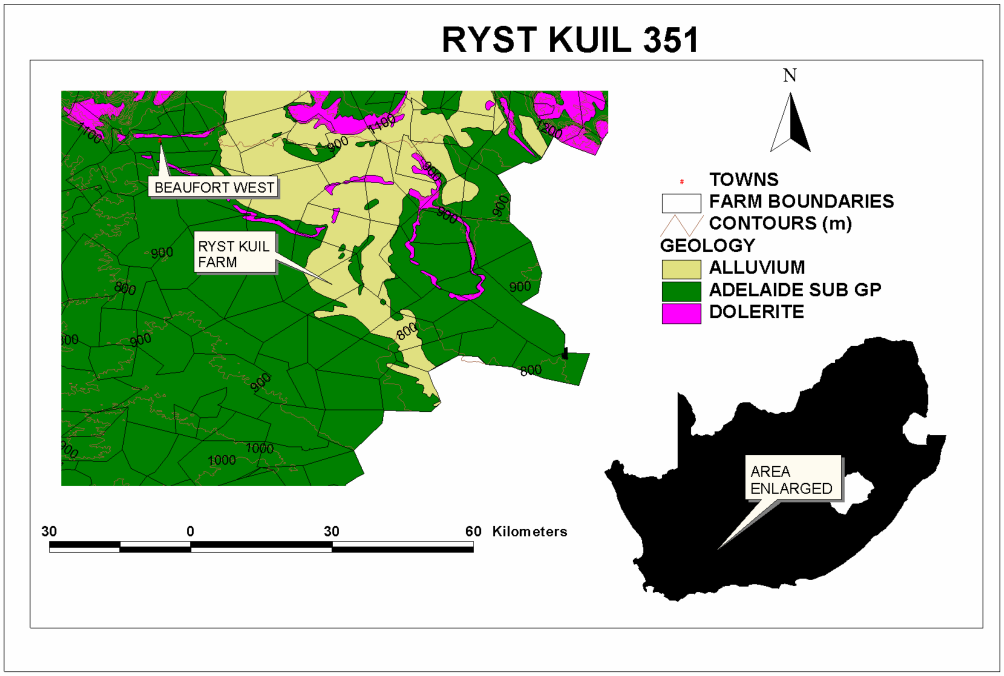


Figure 3.1.1 Regional geology of area surrounding the Ryst Kuil trial mining area. Map compiled using Arcview 3.2 and the Environmental and Tourism Potential Atlas (2001) for the Western Cape.

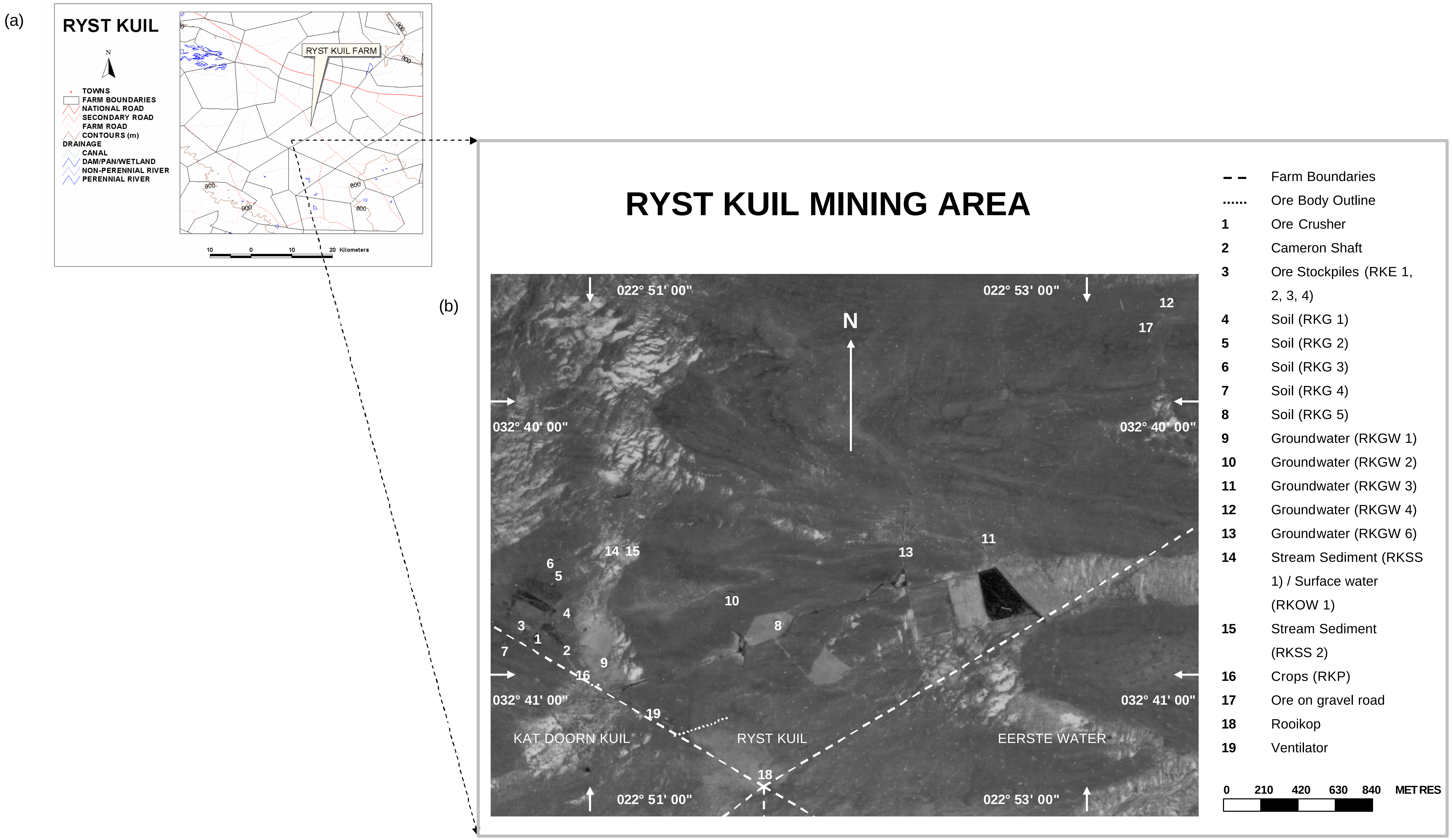


Figure 3.1.2 (a) and (b). Location map showing Ryst Kuil farm. (a) Study area. Map compiled using Arcview 3.2 and Environmental and Tourism Potential Atlas (2001) for the Western Cape (b) 1:21 000 part of aerial photograph (Nr. 9159, strip 8, job 1015. 1:60 000 - 1999) of mining activities in southern corner of Ryst Kuil. The numbering on photograph shows mainly sampling localities and is explained in the text. The ore body outline is from Harrison (1979).

3.1.2 Mining structures and equipment

Numerous mining related structures and equipment are visible within the area. These include a 25m high crusher, waste disposal site, a ventilation structure, core samples and cemented housing foundations.

Figure 3.1.3 Waste disposal site on Ryst Kuil (no. 3 on location map).

Figure 3.1.4 Ore crusher in background on Ryst Kuil (no. 1 on location map).

Figure 3.1.5 Collapsed core sample storage on Ryst Kuil (no. 1 on location map).

Figure 3.1.6 Disused ventilation pipe with unlocked trap door leading into Cameron shaft (no. 19 on location map).

3.1.3 Cameron Shaft

A pre-development programme consisting of infill-drilling, beneficiation tests and trial mining was completed during 1979. An incline shaft was blasted to the ore zone to test various mining methods and to relate radiometric data with chemical assay sampling underground. The Cameron Shaft is inclined at 6° from the horizontal and enters the subsurface in the mudstones and siltstones which overlie the Ryst Kuil Sandstone. The bottom-out point is nearly 500m from the entrance and lies 54m below the surface (Brynard 1993).

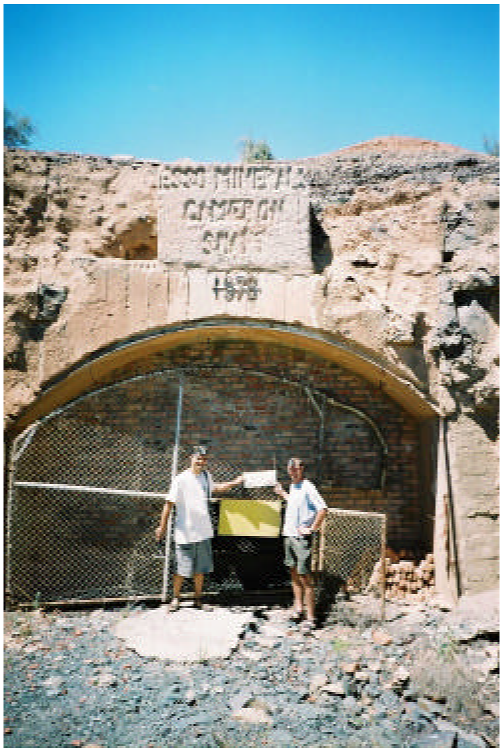


Figure 3.1.7 Cameron Shaft inscribed with *Esso Minerals Cameron Shaft 1978*. Entrance into the shaft is gained freely (no. 2 on location map).

3.1.4 Ore stockpiles and barrels

The ore was crushed and barrelled into 200l containers, probably for shipment overseas where enrichment processes were performed. Of these, there remain 370 ore-containing barrels and 116 ore stockpiles.

Figure 3.1.8 Barrels filled with uranium ore and ore stockpiles on Ryst Kuil (no. 3 on location map).

Figure 3.1.9 Rust in 200 litre barrel (no. 3 on location map).

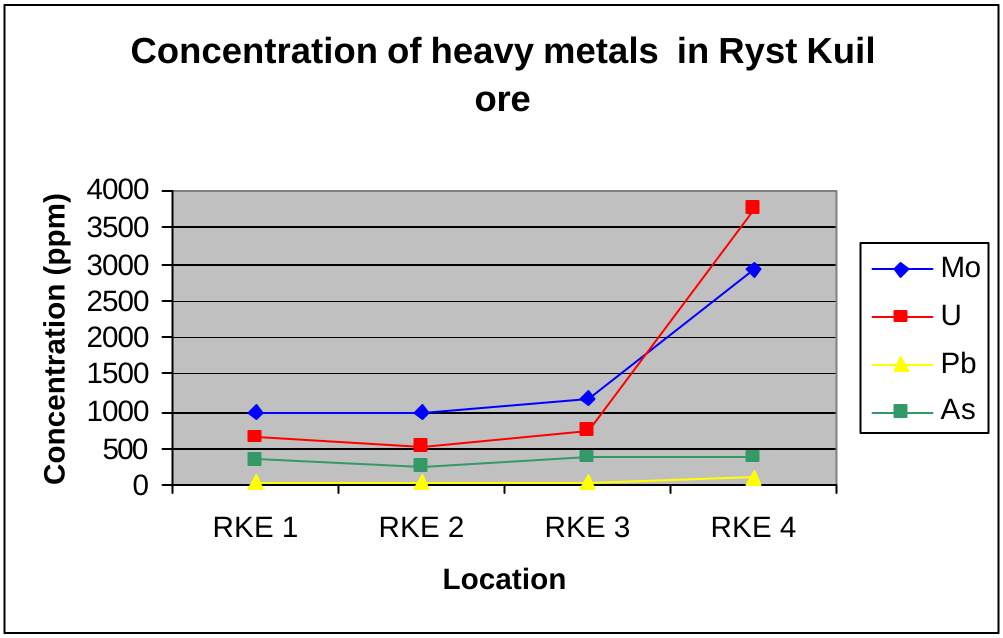


Figure 3.1.10 Concentration (ppm) of heavy metals in Ryst Kuil ore (Detailed analytical results in Appendix C1).

Figure 3.1.11 Due to the lack of knowledge regarding the toxicity of uranium, livestock have been allowed to graze amongst the ore stockpiles on Ryst Kuil (no. 3 on location map).

Table 3.1.1 Estimated total volume (m^3) and tonnage of ore stockpiles and barrels on surface of Ryst Kuil.

	Ore stockpiles (Rounded to 100)	**Barrels (Rounded to 10)**	**Total**
Volume (m^3)	12×10^2	7.4×10^1	19.4×10^2
Tonnage (t)	21×10^2	1.3×10^1	22.3×10^2

For detail on techniques used, see Ore Quantity Calculations in Appendix A1, for sampling techniques see Appendix A2 and for analytical results see Appendix C1.

3.1.5 Water

Ground – and surface water were sampled for heavy metal analysis. Results were compared with background values, Environmental Guidelines for Heavy Metals in South Africa (DWAF 1996) and concentrations obtained from the World Health Organization (WHO 2003) (see Appendix B1). Water was sampled for arsenic, copper, iron, molybdenum, lead and uranium. (See Appendix A2 for sampling methods and Appendix C1 for detailed analytical results).

3.1.5.1 Groundwater

Groundwater samples were taken at six different locations (including one background location). At present the arsenic and uranium concentrations in groundwater samples on Ryst Kuil are ideal (Appendices B1 and C1) (DWAF 1996).

The following graphs represent only above-background concentration levels of heavy metals in groundwater on Ryst Kuil.

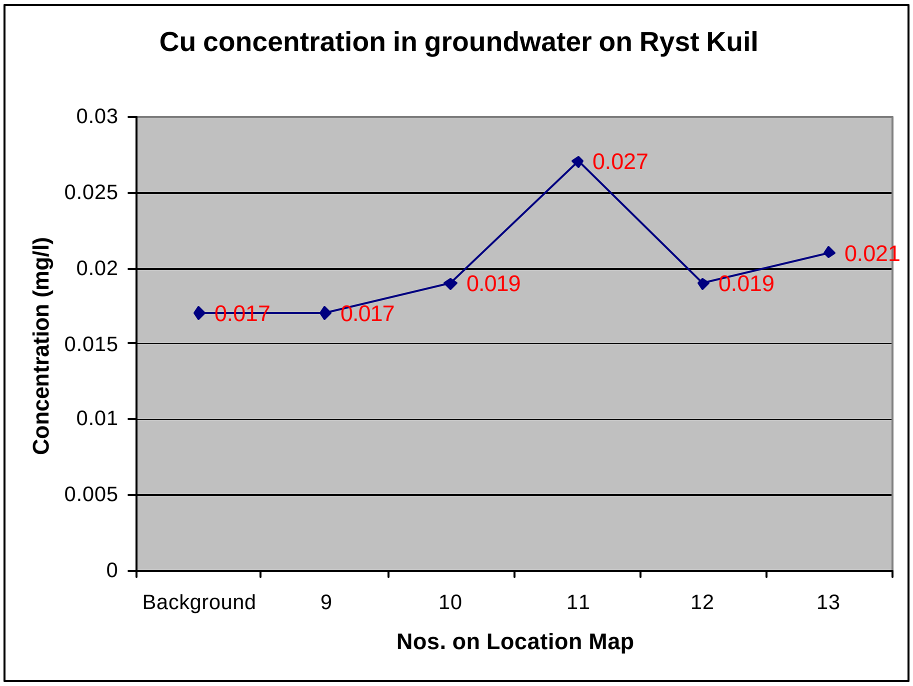


Figure 3.1.12 Above-background copper concentrations (mg/l) in groundwater on Ryst Kuil. Red values are above ideal for aquatic ecosystems (DWAF 1996).

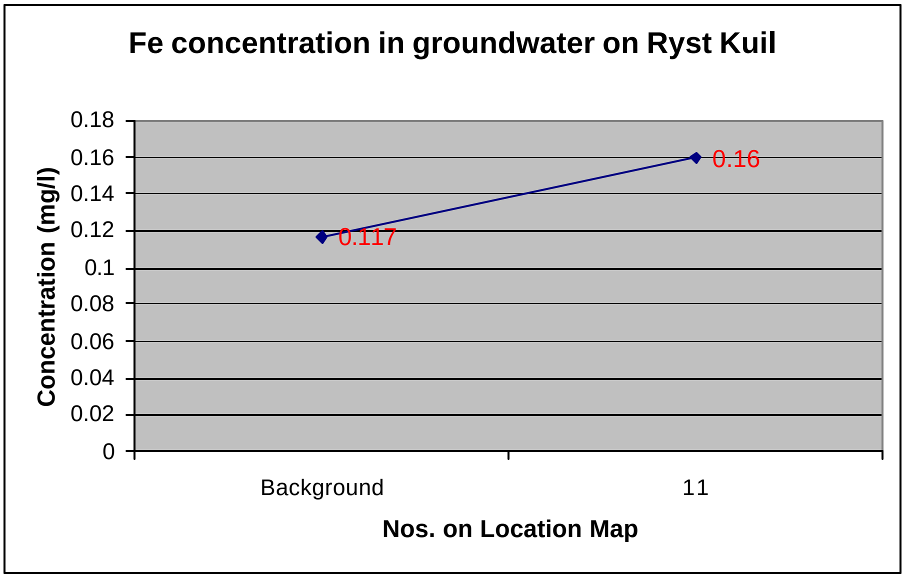


Figure 3.1.13 Above-background iron concentration (mg/l) in groundwater on Ryst Kuil. Red values are above ideal for domestic use (DWAF 1996).

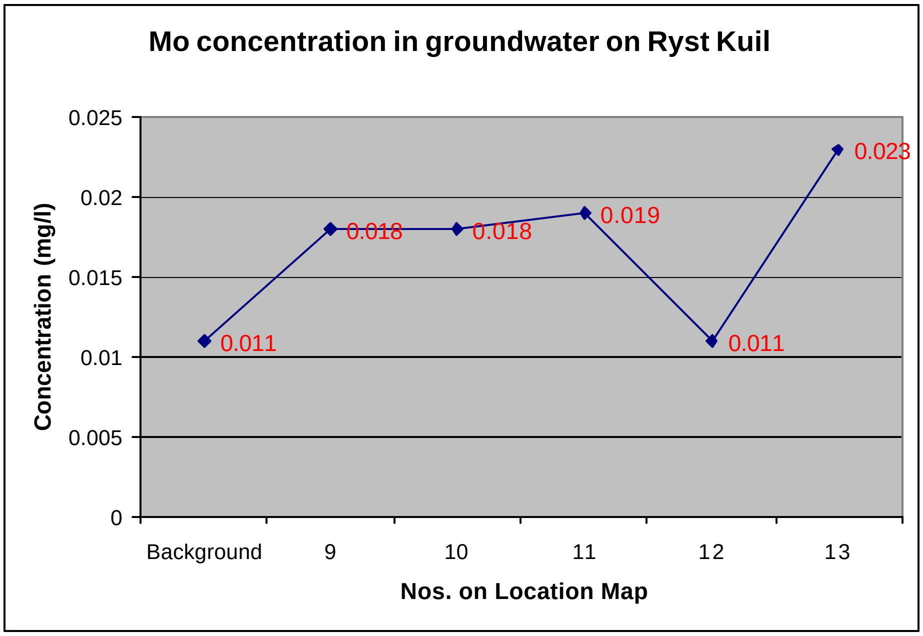


Figure 3.1.14 Above-background molybdenum concentrations (mg/l) in groundwater on Ryst Kuil. Red values are above ideal for agricultural use (DWAF 1996).

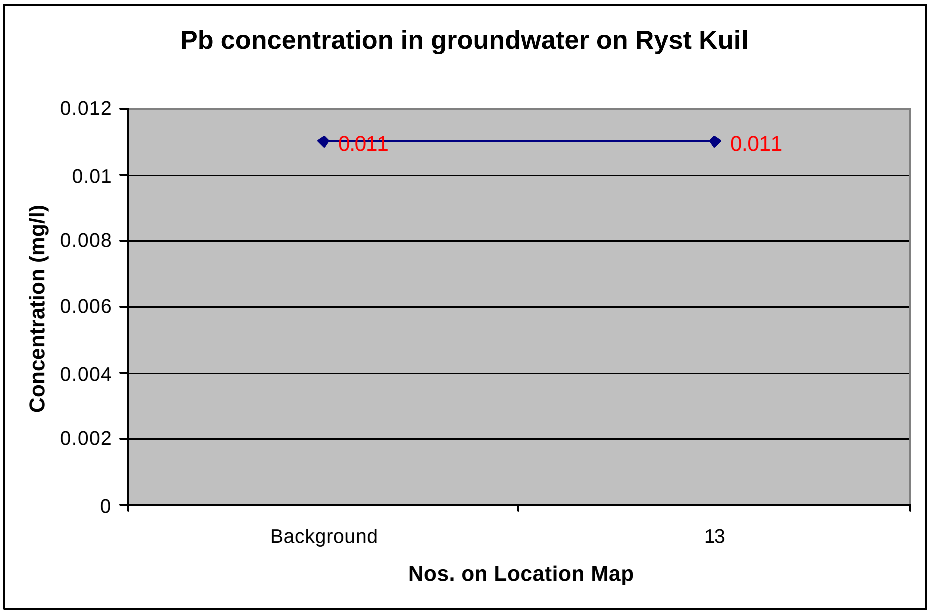


Figure 3.1.15 Equal to background lead concentrations (mg/l) in groundwater on Ryst Kuil. Red values are above ideal for domestic use and aquatic ecosystems (DWAF 1996).

3.1.5.2 Surface Water

Due to relative aridity of the area and the absence of surface water, only one location was sampled. No background value could be obtained.

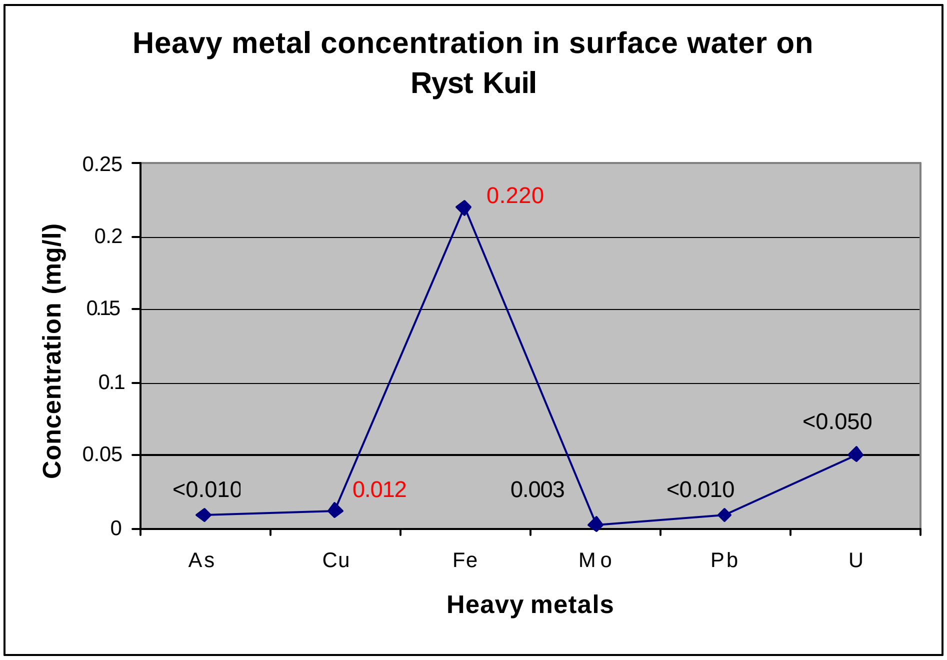


Figure 3.1.16 Heavy metal concentrations (mg/l) in surface water on Ryst Kuil. Copper values are above ideal for aquatic ecosystems, whilst iron is above ideal for domestic use (DWAF 1996). Sample taken at no. 15 on locality map.

3.1.6 Soil

Soil was sampled at five locations including one background location. (See Appendix A2 for sampling methods and Appendix C1 for detailed analytical results). Results were compared with background values and normal ranges of heavy metals in soils and stream sediment as derived from Alloway (1993) (Appendix B3).

Arsenic and molybdenum values are all below background and below normal (Appendices C1 and B3) (Alloway 1993). The following graphs represent only above-background concentration levels of heavy metals in soil on Ryst Kuil.

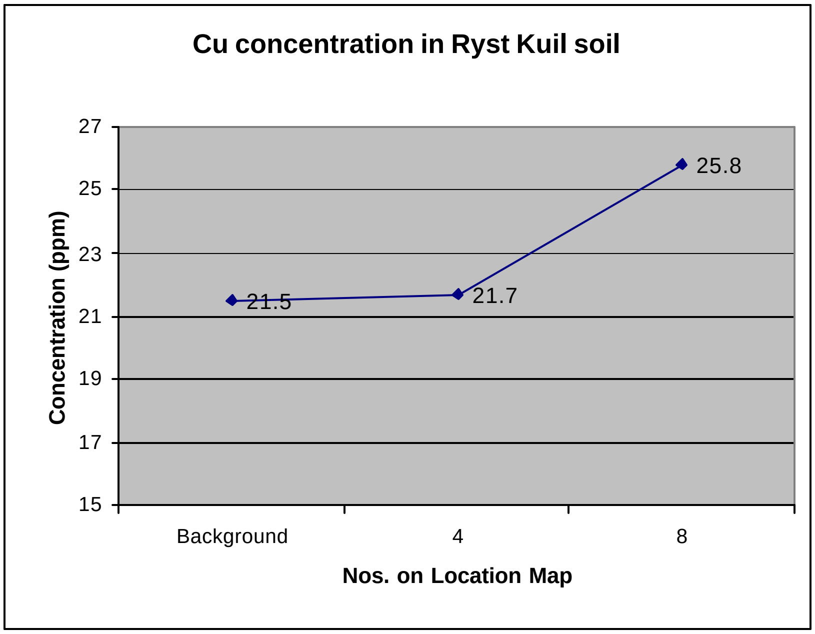


Figure 3.1.17 Copper concentration (ppm) in soil samples on Ryst Kuil showing above background levels. No values are above normal (Alloway 1993).

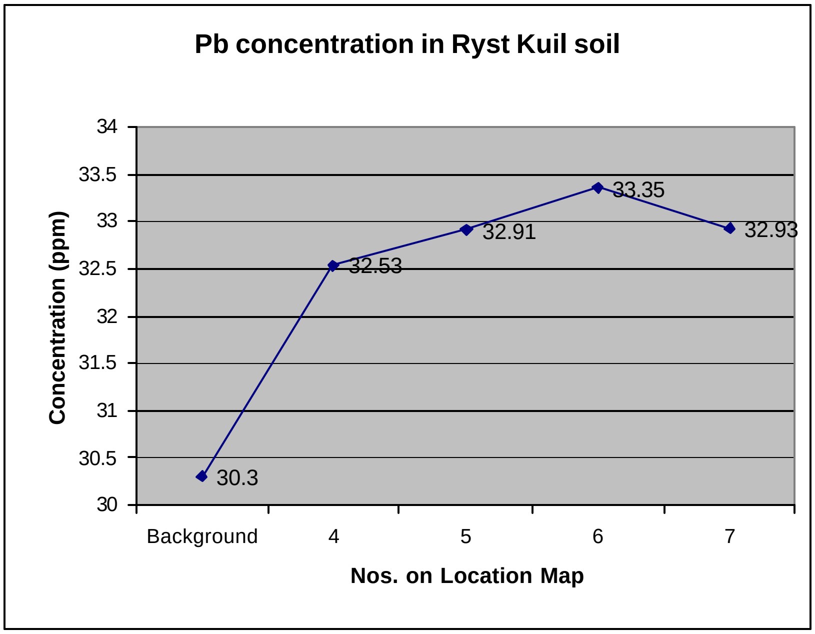


Figure 3.1.18 Lead concentration (ppm) in soil samples on Ryst Kuil showing above background levels. No values are above normal (Alloway 1993).

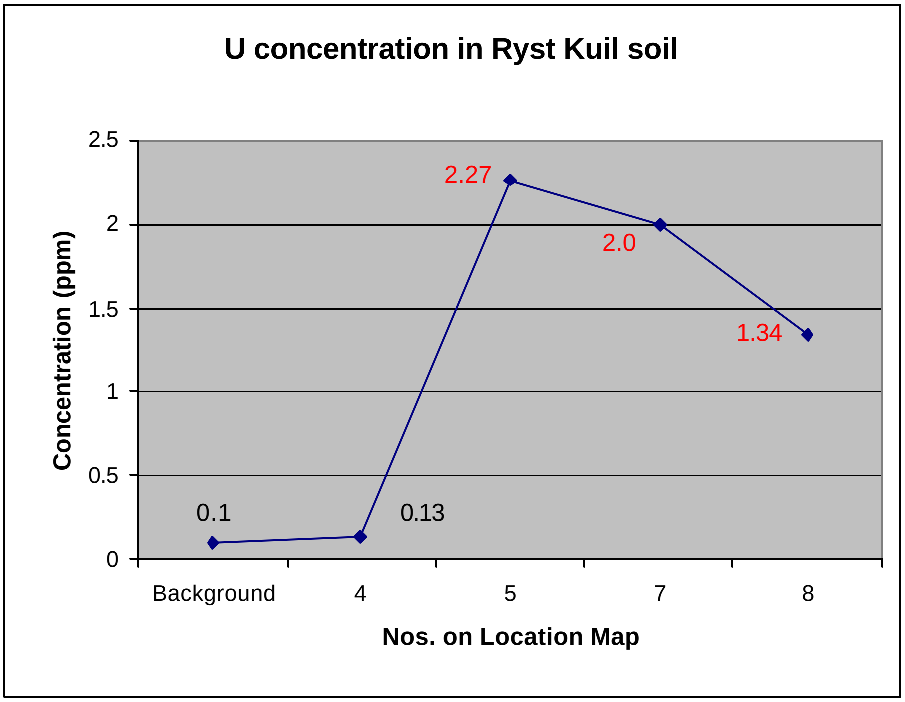


Figure 3.1.19 Uranium concentration (ppm) in soil samples on Ryst Kuil showing above-background levels. Red values are above normal (Alloway 1993).

3.1.7. Stream sediment

Stream sediment was sampled at three locations including one background location. (See Appendix A2 for sampling methods and Appendix C1 for detailed analytical results). Concentrations were compared with normal ranges of heavy metals in soils and stream sediment as derived from Alloway (1993) (Appendix B3).

Molybdenum values are all below background and below normal (See Appendices C1 and B3) (Alloway 1993). The following graphs represent only above-background concentration levels of heavy metals in stream sediment on Ryst Kuil.

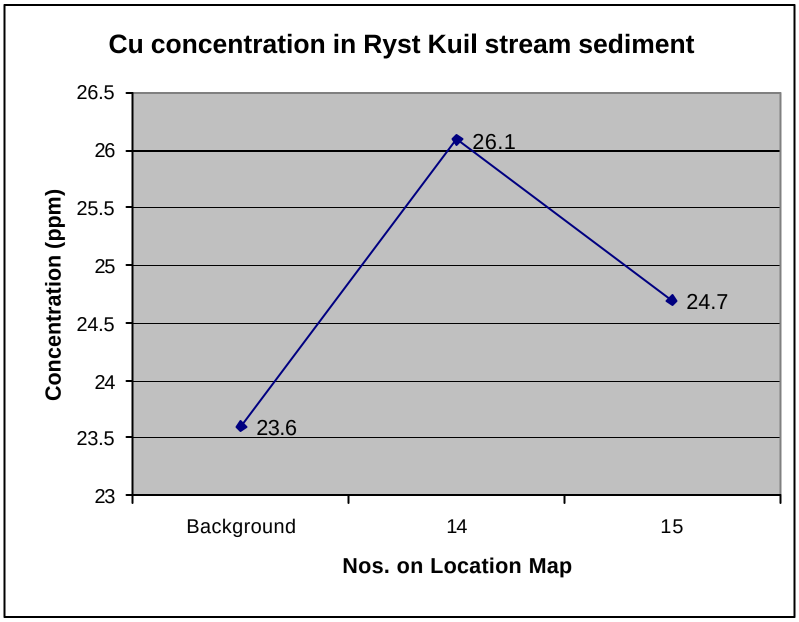


Figure 3.1.20 Copper concentration (ppm) in stream sediment samples on Ryst Kuil showing above-background levels. No values are above normal (Alloway 1993).

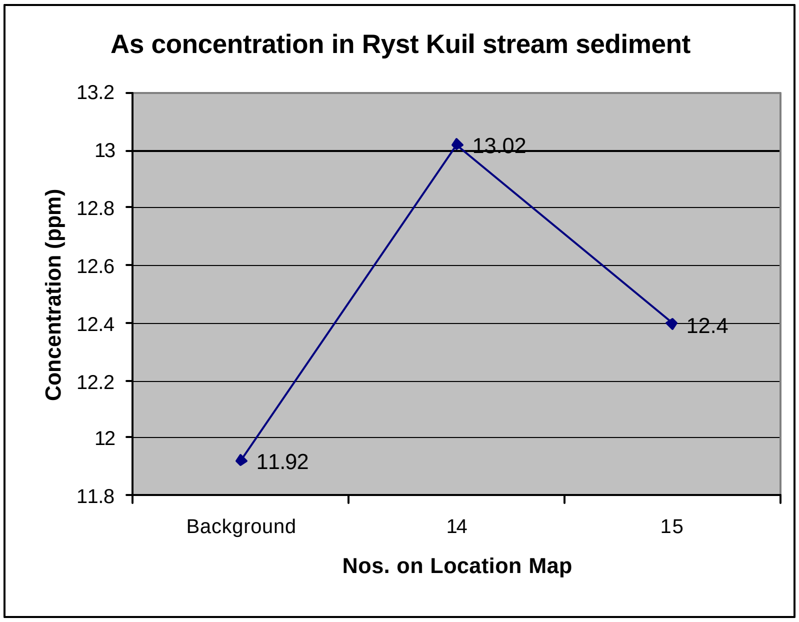


Figure 3.1.21 Arsenic concentration (ppm) in stream sediment samples on Ryst Kuil showing above-background levels. No values are above normal (Alloway 1993).

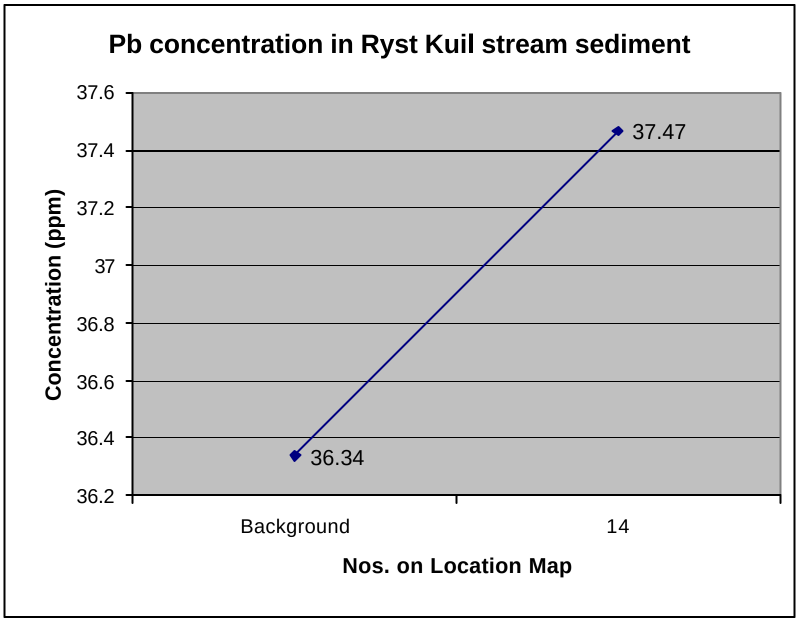


Figure 3.1.22 Lead concentration in stream sediment samples on Ryst Kuil showing above-background levels. No values are above normal (Alloway 1993).

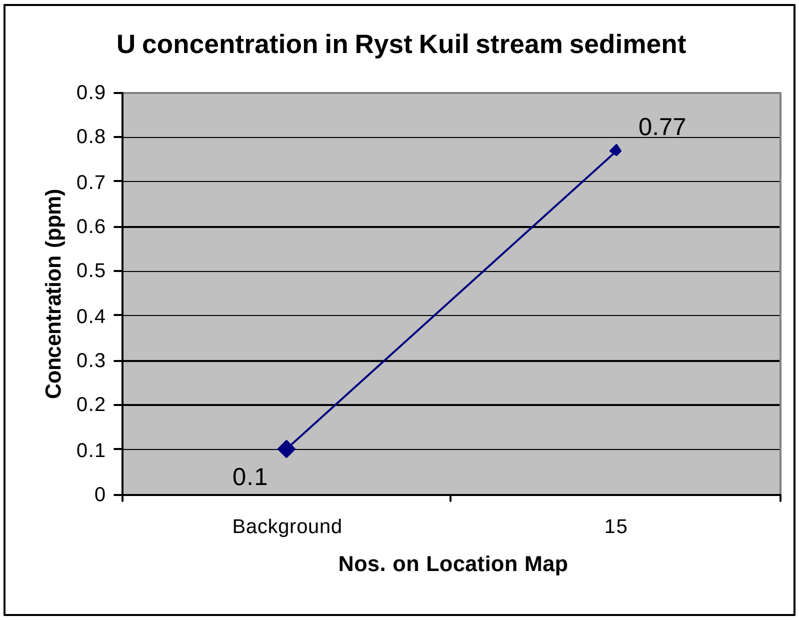


Figure 3.1.23 Uranium concentration in stream sediment samples on Ryst Kuil showing above-background levels. No values are above normal (Alloway 1993).

3.1.8 Crops

Crops of the invader plant, Oldman Saltbush *(Atriplex nummularia)*, grows within the mining area. These salt bushes are grazed extensively by sheep and other animals.

Figure 3.1.24 Oldman Saltbush *(Atriplex nummularia)* crops growing within the mining area. These crops are extensively grazed by animals up to the level shown (no. 16 on location map).

Crops were sampled and their leaves only analysed for heavy metal composition (See Appendix A2 for sampling methods and Appendix C1 for detailed analytical results).

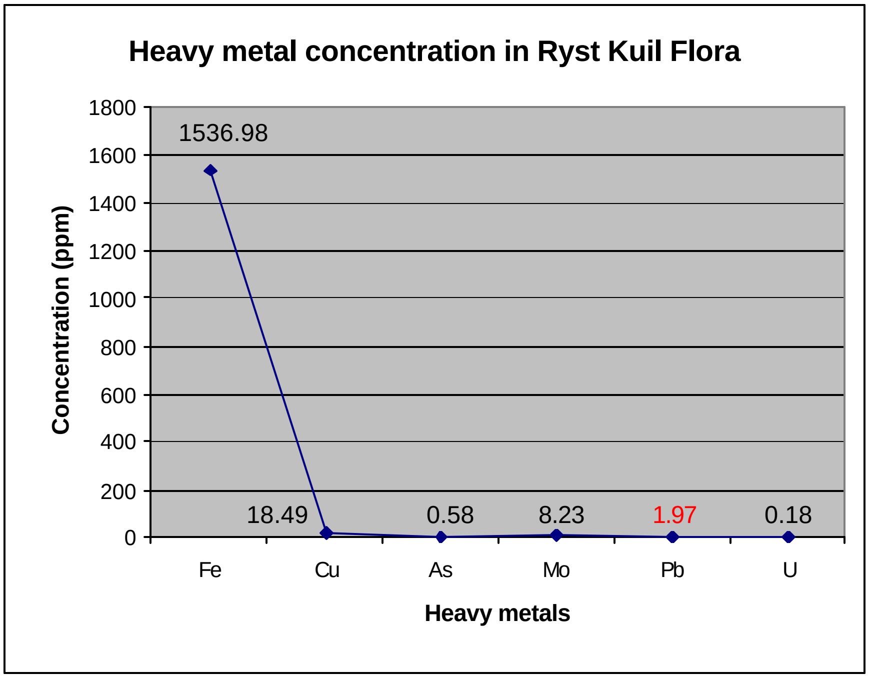


Figure 3.1.25 Heavy metal concentration in Old Man Saltbush growing within mining area on Ryst Kuil (No. 16 on location map). Red values are above ideal (Act 54 1972 and Waldbott 1973).

3.1.9 Background concentrations

The dry nature of the area leads to a scarcity of surface water. Thus, no background surface water could be obtained. Groundwater, soil and stream sediment background values were all obtained upstream, to the north on the farm Kat Doorn Kuil (See location map).

3.1.10 Gravel road maintenance

The availability of crushed uranium ore on the farm and the lack of knowledge regarding the toxicity of uranium led to the stockpiled ore being used for gravel road maintenance.

Figure 3.1.26 Uranium ore used for gravel road maintenance on farm Ryst Kuil (no. 17 on location map).

3.2 Rietkuil

3.2.1 Introduction

Uraniferous sandstone on the farm Rietkuil crops out mainly south of the road from Beaufort West to Merweville. Exploration on the surface showings of this farm and a sub-surface occurrence on the adjoining farm Lang Leegte 304 were carried out by Union Carbide SA Ltd. The strata forms part of the upper Abrahamskraal Formation, below the Poortjie Member (table 1.1) and the regional geology is shown in figure 3.2.1

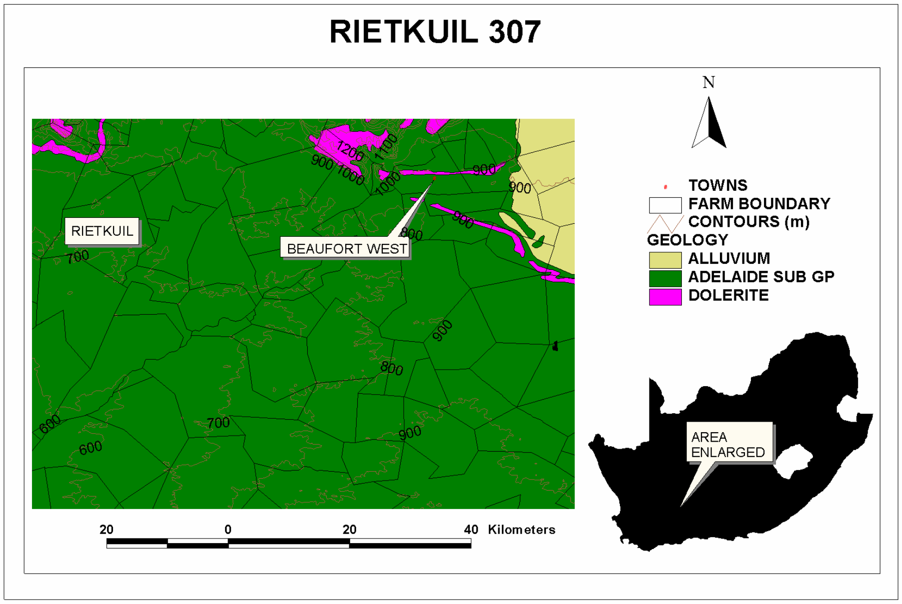
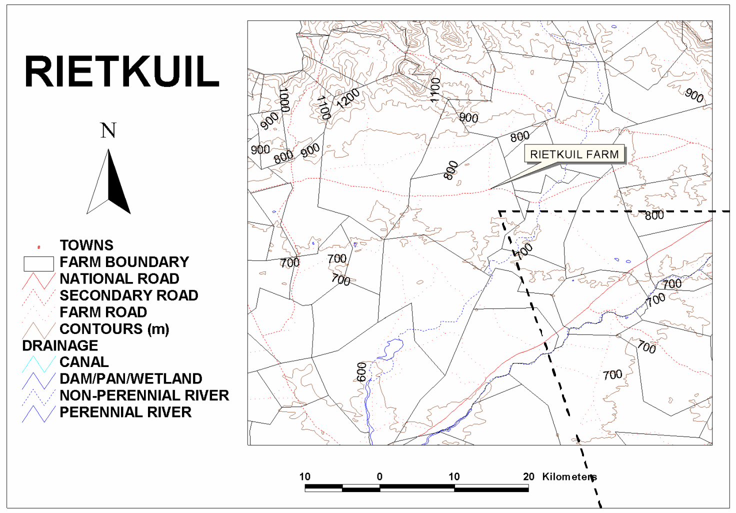


Figure 3.2.1 Regional geology of area surrounding the Rietkuil trial mining area. Map compiled using Arcview 3.2 and the Environmental and Tourism Potential Atlas (2001) for the Western Cape.

Mineralization was discovered in 1970 by an airborne radiometric survey. The main mineralized outcrop covers an area of 25 000m^2 and contains over 30 "hotspots" which are normally patches of black mineralized "koffieklip" measuring up to 5m x 5m. Green and yellow secondary minerals are very common and consist mainly of hydrated silicates, arsenates and phosphates of U, Ca and Cu (Turner 1979).



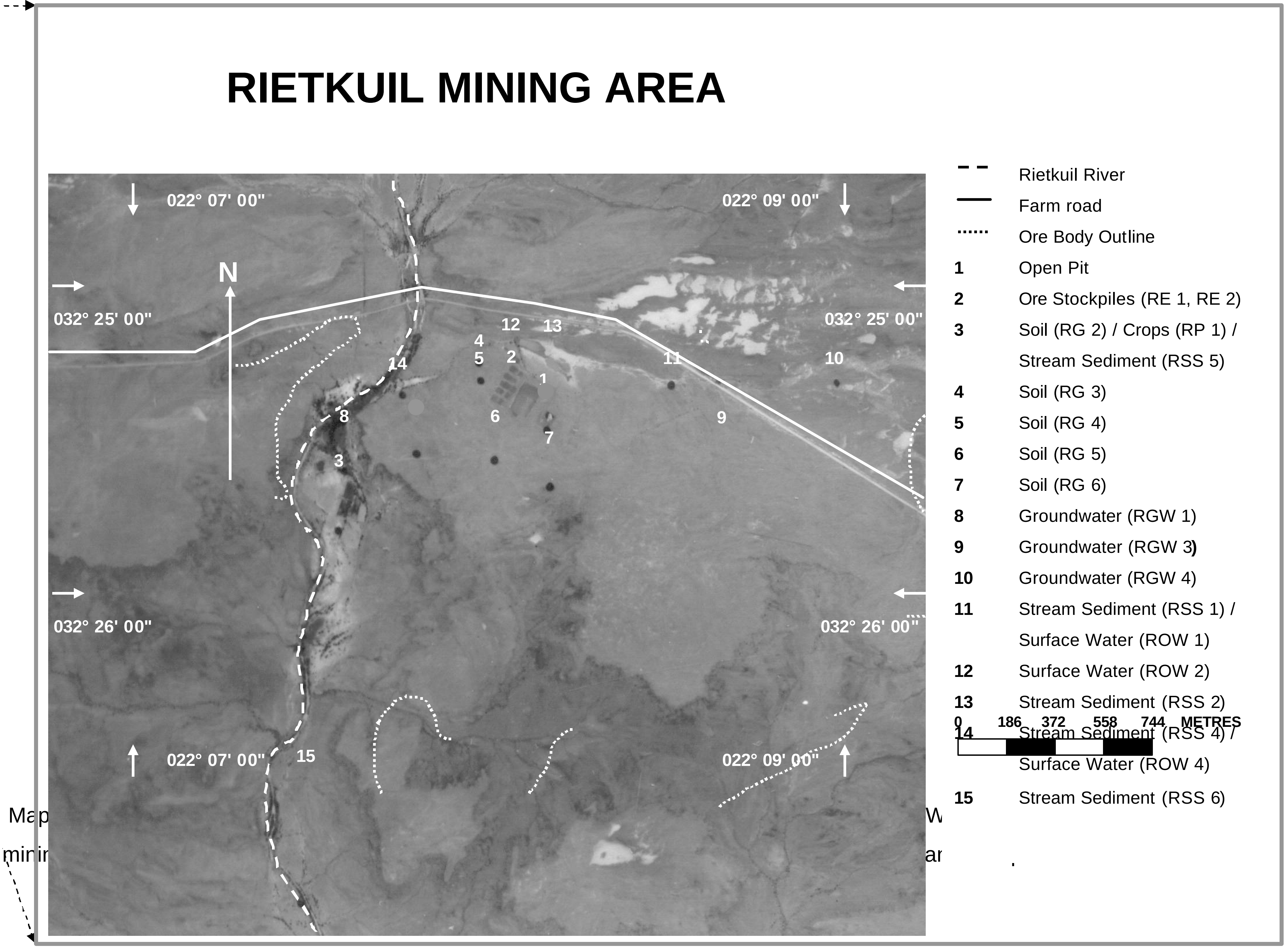


Figure 3.2.2 (a) and (b). Location map showing Rietkuil farm. (a) Map W aerial photograph (no. 0692, strip 5, job 1015. 1:60 000 - 1999) of mini ar . The ore body outline is from Kubler (1977).

3.2.2 Open pit

The test mining pit, excavated in 1977, covers an area of 5600m^2 and is approx 10m deep (Turner 1979).

Figure 3.2.3 Open pit on farm Rietkuil with vehicle, located at top of ramp leading into pit, used for scale. Irrigation dam is visible in the background (No. 1 on location map).

3.2.3 Ore stockpiles

Ten stockpiles are situated in an open dump yard on the edge of a large man-made dam used for crop irrigation downstream. Another smaller irrigation dam is located further downstream. The ore stockpiles are also a haven for a colony of rock hyraxes *(Procavia capensis)*.

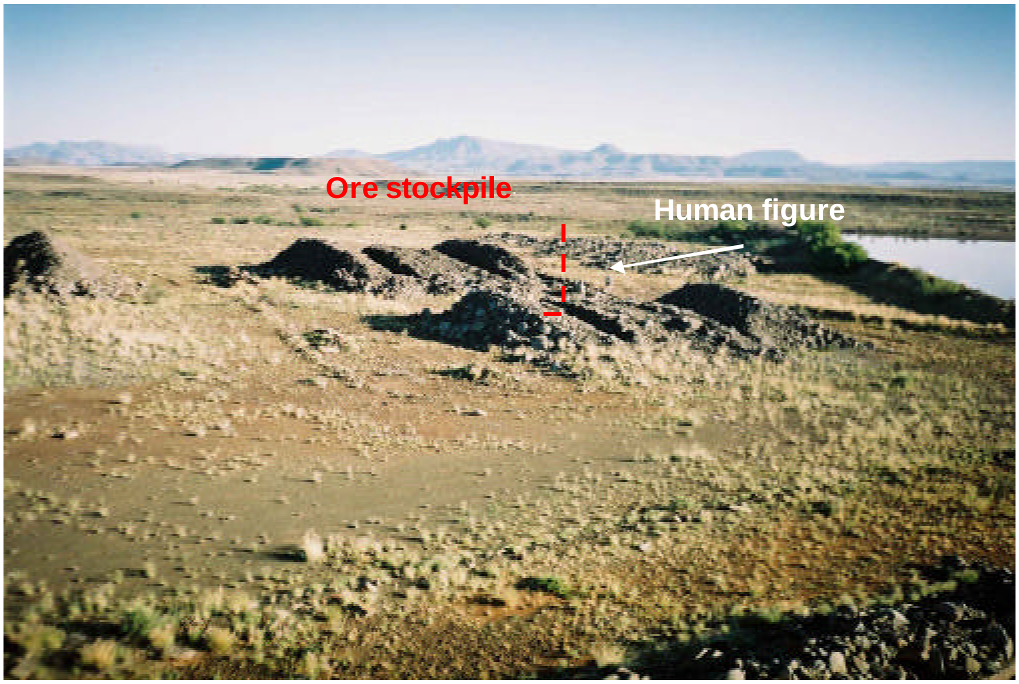


Figure 3.2.4 Ore stockpiles on Rietkuil with dashed column showing one stockpile. Human figure used for scale. The first of two large irrigation dams is situated to the right (No. 2 on location map).

Figure 3.2.5 Part of ore stockpile on Rietkuil. Figure on right used for scale (No. 2 on location map).

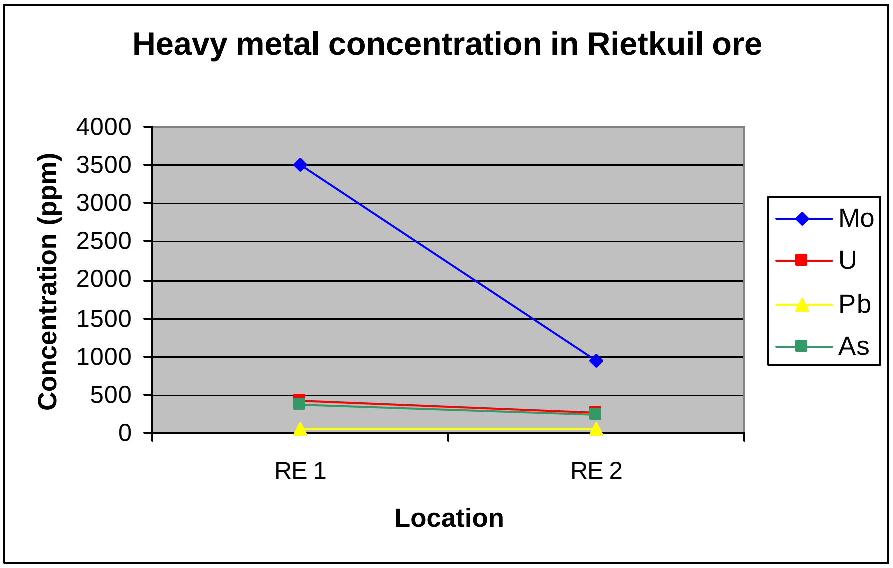


Figure 3.2.6 Heavy metal concentration (ppm) in Rietkuil ore.

Table 3.2.1 Estimated total volume (m^3) and tonnage (t) of stockpiled uranium ore on surface of Rietkuil.

Ore **(m^3)**	**Ore** **(Rounded to 100)** **(t)**
36×10^2	95×10^2

For detail on techniques used, see Ore Quantity Calculations under Appendix A1, for sampling methods see Appendix A2 and for analytical results see Appendix C2.

3.2.4 Water

Ground – and surface water were sampled for heavy metal analysis. Results were compared with background values, Environmental Guidelines for Heavy Metals in South Africa (DWAF 1996) and concentrations obtained from the World Health Organization (WHO 2003) (see Appendix B1). Water was sampled for arsenic, copper, iron, molybdenum, lead and uranium. (See

Appendix A2 for sampling methods and Appendix C2 for detailed analytical results).

3.2.4.1 Groundwater

Groundwater samples were taken at four different locations (including one background location). At present the arsenic, molybdenum and uranium concentrations in groundwater samples on Rietkuil are ideal (Appendices B1 and C2) (DWAF 1996).

The following graphs represent only above-background concentration levels of heavy metals in groundwater on Rietkuil.

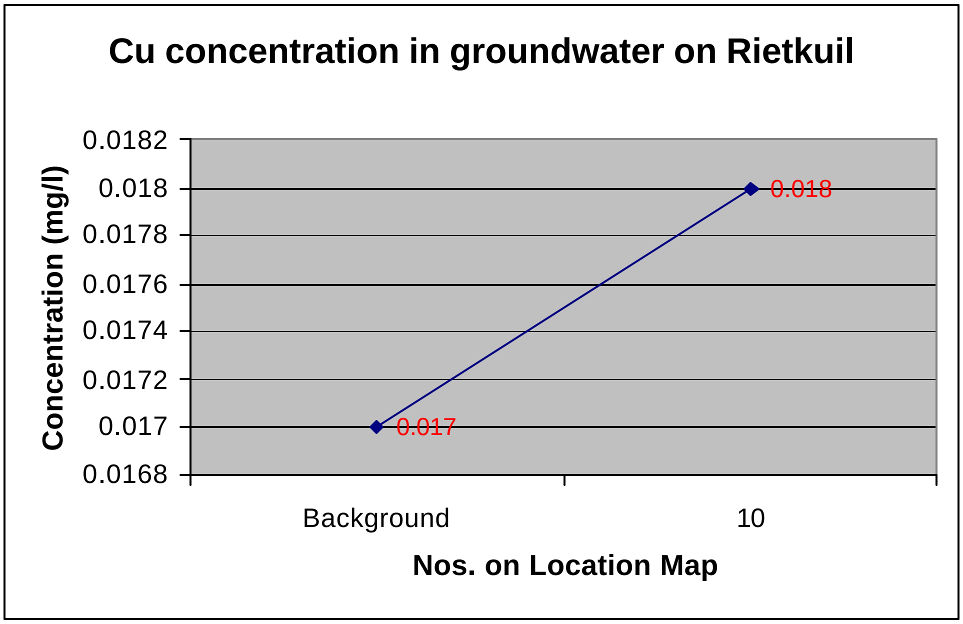


Figure 3.2.7 Above-background copper concentrations (mg/l) in groundwater on Rietkuil. Red values are above ideal for aquatic ecosystems (DWAF 1996).

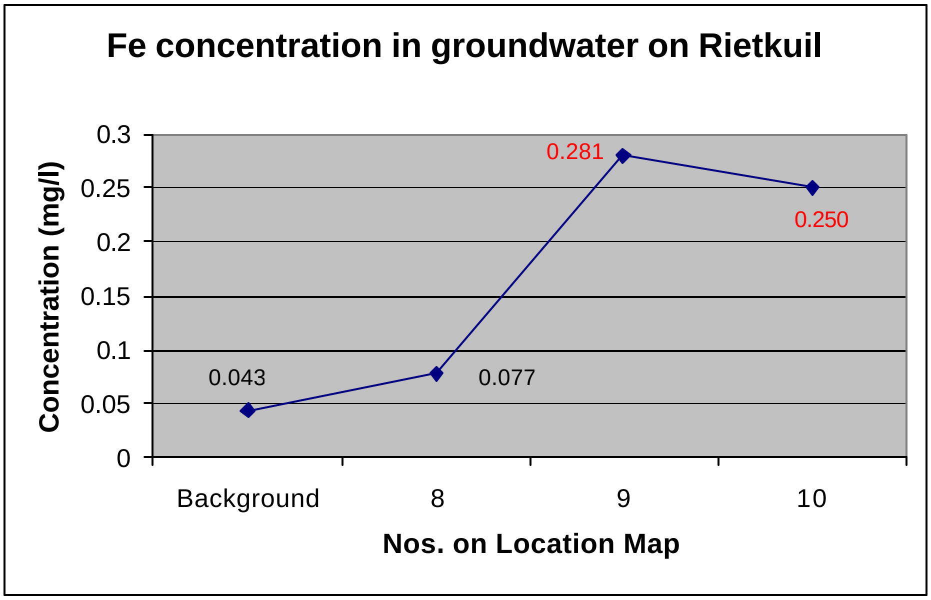


Figure 3.2.8 Above-background iron concentrations (mg/l) in groundwater on Rietkuil. Red values are above ideal for domestic use (DWAF 1996).

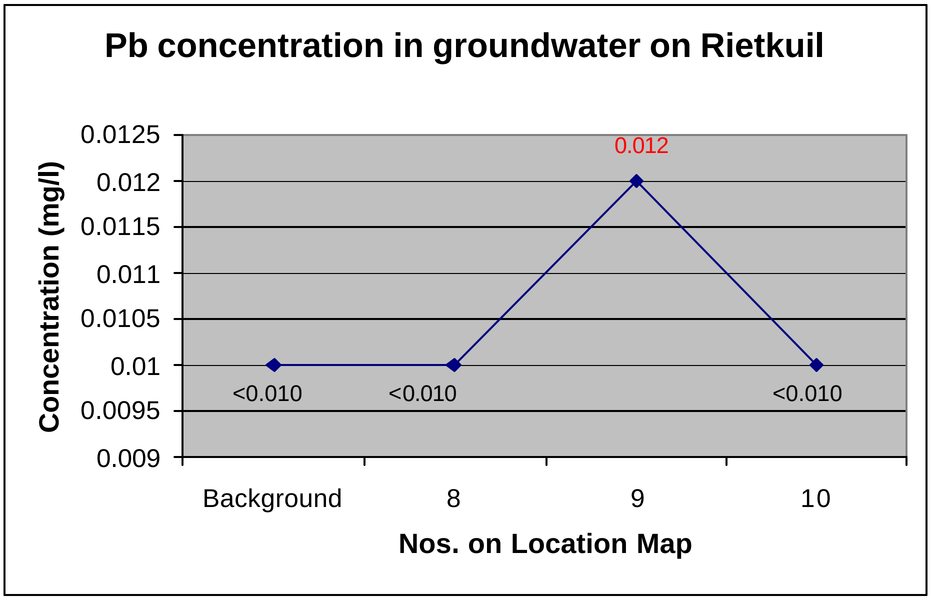


Figure 3.2.9 Above-background lead concentrations (mg/l) in groundwater on Rietkuil. Red values are above ideal for domestic use and aquatic ecosystems (DWAF 1996).

3.2.4.2 Surface water

Four different locations were sampled (including one background location). Copper concentrations in surface water at Rietkuil are all above ideal (DWAF 1996), but below background, whilst iron concentrations are, with the exception of the sample from the open pit (no. 1 on location map), above ideal (DWAF 1996), but all below background. With the exception of ROW 4 (no. 14 on location map) lead values are above ideal (DWAF 1996), but all below background (See Appendices B1 and C2).

The following graphs represent only above-background concentration levels of heavy metals in surface water on Rietkuil.

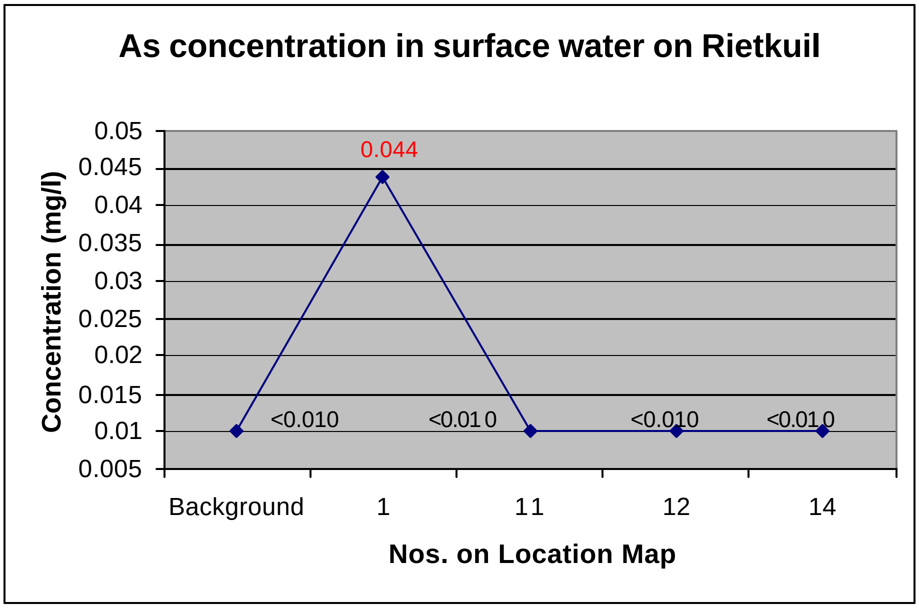


Figure 3.2.10 Above-background arsenic concentrations (mg/l) in surface water on Rietkuil. Red values are above ideal for domestic use (WHO 2003) and aquatic ecosystems (DWAF 1996).

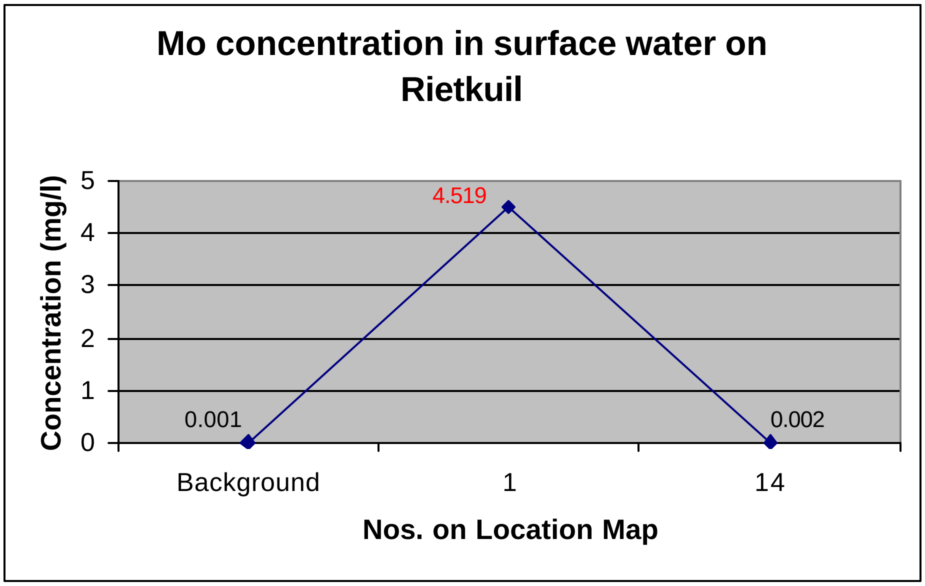


Figure 3.2.11 Above-background molybdenum concentrations (mg/l) in surface water on Rietkuil. Red values are above ideal for agricultural use (DWAF 1996).

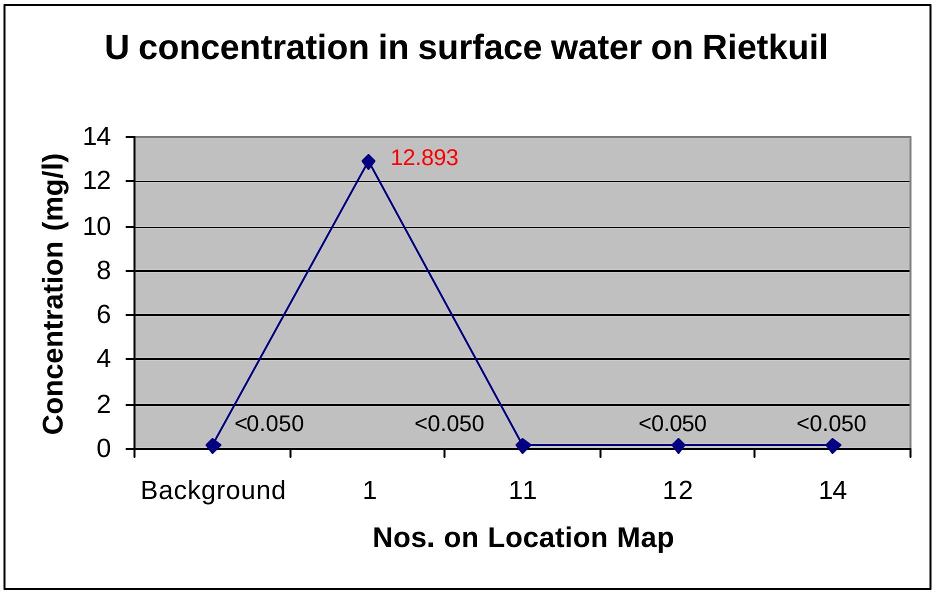


Figure 3.2.12 Above-background uranium concentrations (mg/l) in surface water on Rietkuil. Red values are above ideal for domestic (WHO 2003) and agricultural use (irrigation) (DWAF 1996).

3.2.5 Soil

Soil was sampled at six locations including one background location (See Appendix A2 for sampling methods and Appendix C2 for detailed analytical results). Concentrations are compared with normal ranges of heavy metals in soils and stream sediment as derived from Alloway (1993) (Appendix B3). Copper and molybdenum concentrations are all below background and below normal (Appendices B2 and C2) (Alloway 1993).

The following graphs represent only above-background concentration levels of heavy metals in soil on Rietkuil.

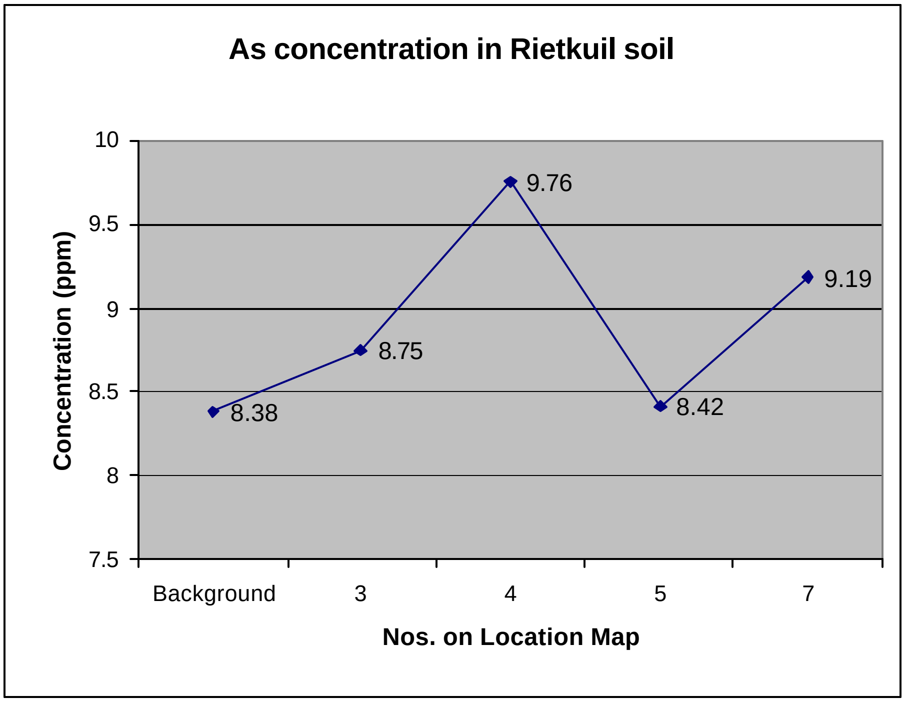


Figure 3.2.13 Arsenic concentration (ppm) in soil samples on Rietkuil showing above-background levels. No values are above normal (Alloway 1993).

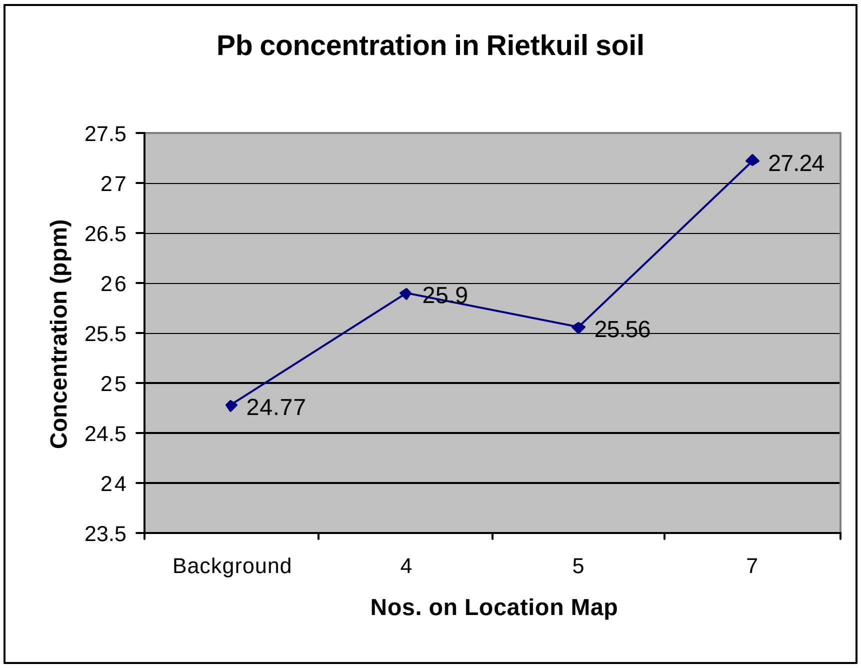


Figure 3.2.14 Lead concentration (ppm) in soil samples on Rietkuil showing above-background levels. No values are above normal (Alloway 1993).

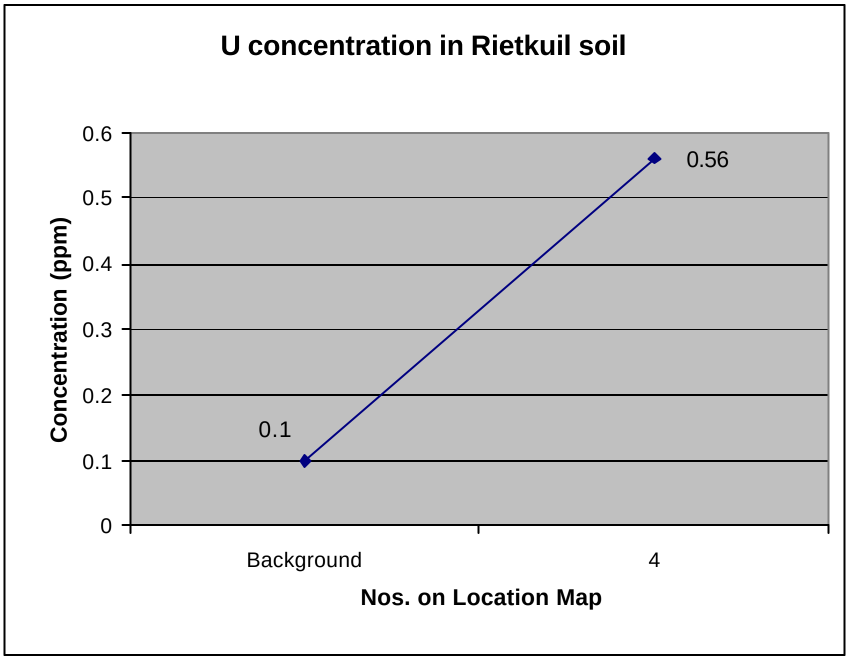


Figure 3.2.15 Uranium concentration in soil samples on Rietkuil showing above-background levels. No values are above normal (Alloway 1993).

3.2.6 Stream sediment

Stream sediment was sampled at seven locations including one background location (See Appendix A2 for sampling methods and Appendix C2 for detailed analytical results). Concentrations are compared with normal ranges of heavy metals in soils and stream sediment as derived from Alloway (1993) (Appendix B3). Lead concentrations are below background and below normal (Appendices B2 and C2) (Alloway 1993).

The following graphs represent only above-background concentration levels of heavy metals in stream sediment on Rietkuil.

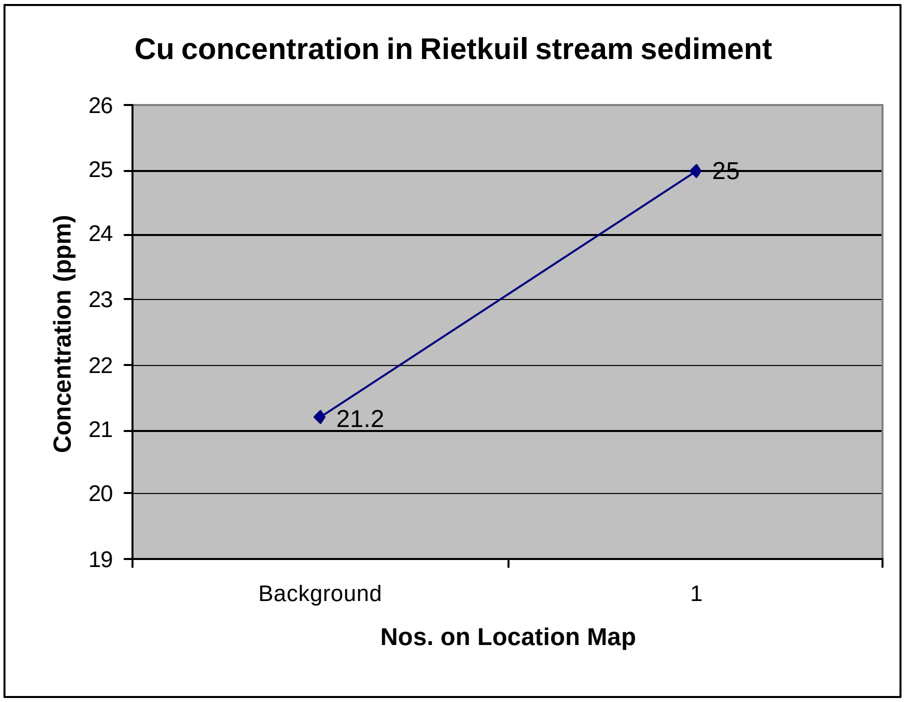


Figure 3.2.16 Copper concentration (ppm) in stream sediment on Rietkuil showing above-background levels. Concentrations are below normal (Alloway 1993).

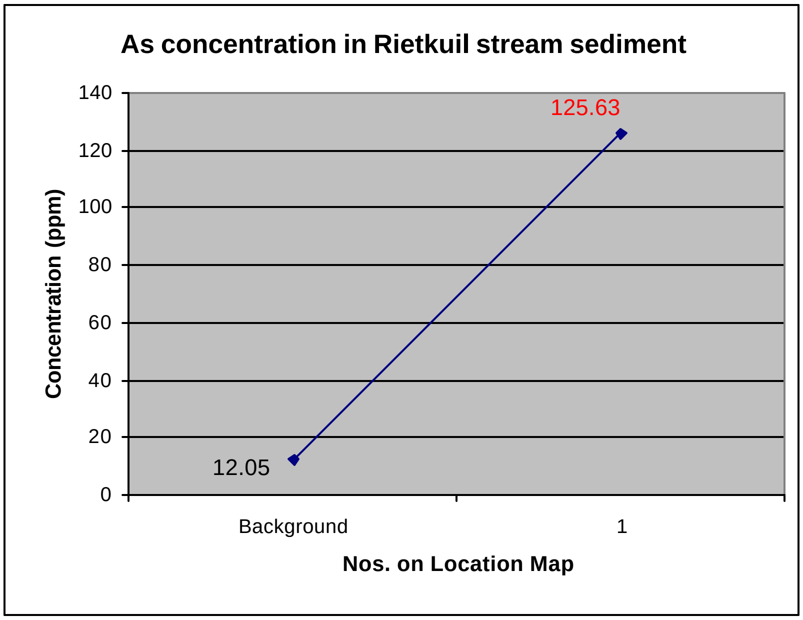


Figure 3.2.17 Arsenic concentration (ppm) in stream sediment on Rietkuil showing above-background levels. Red values are above normal (Alloway 1993).

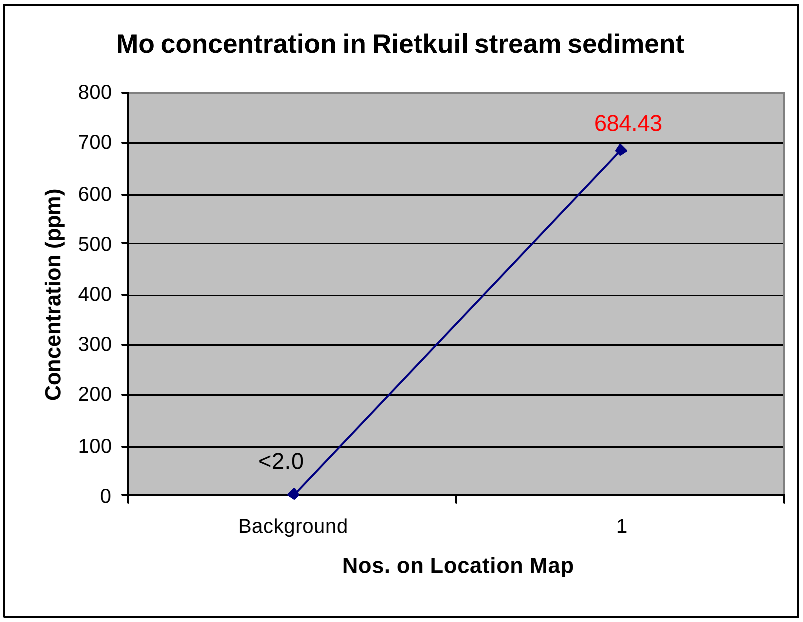


Figure 3.2.18 Molybdenum concentration in stream sediment on Rietkuil showing above-background levels. Red values are above normal (Alloway 1993).

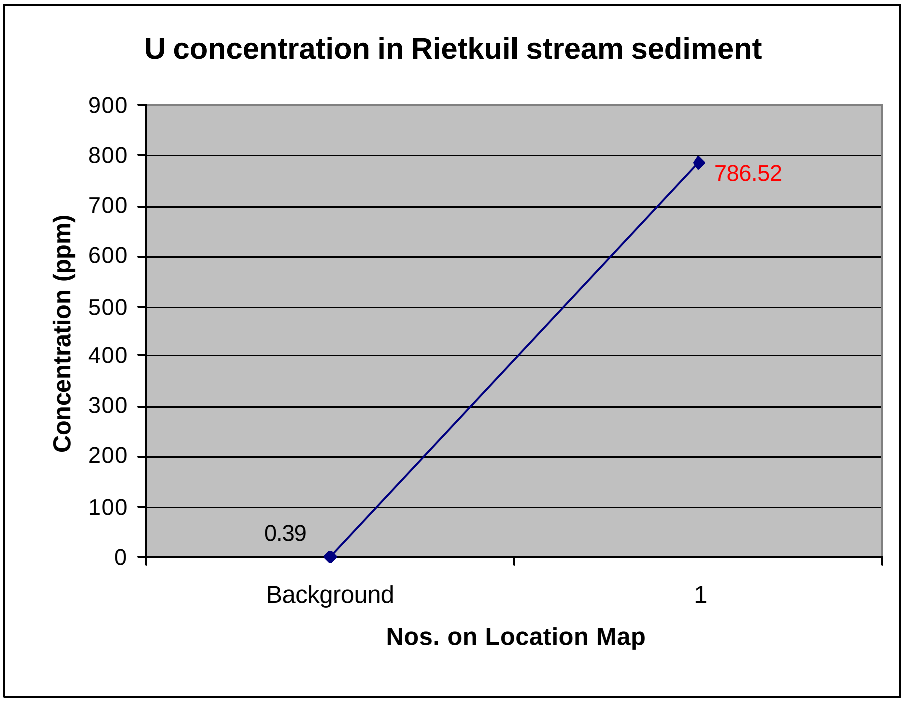


Figure 3.2.19 Uranium concentration in stream sediment on Rietkuil showing above-background levels. Red values are above normal (Alloway 1993).

3.2.7 Crops

Lucerne crops were sampled and analysed for heavy metal composition (See Appendix A2 for sampling methods and Appendix C2 for detailed analytical results). All of the material except the roots was sampled.

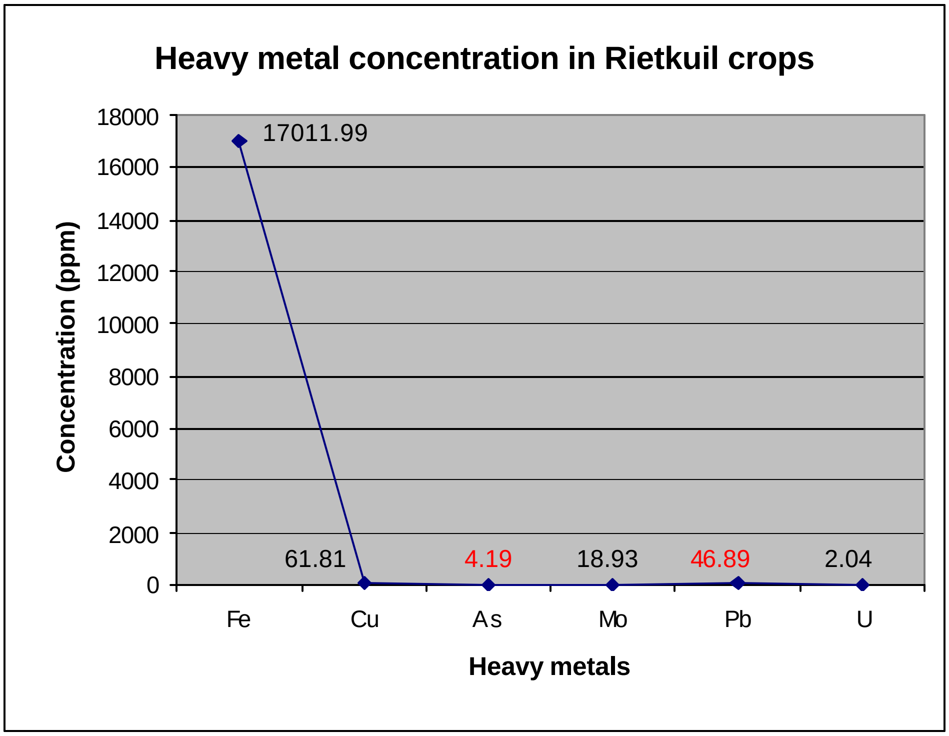


Figure 3.2.20 Heavy metal concentration in lucerne crops growing downstream of mining area on Rietkuil (No. 3 on location map). Red values are above ideal (ATSDR 1999-2002, Act 54 1972 and Waldbott 1973).

3.2.8 Background concentrations

Surface – and groundwater as well as stream sediment and soil background samples were collected upstream from the northern parts of Rietkuil.

3.3 DR-3

3.3.1 Introduction

This anomaly, located to the north of Laingsburg, is unusual in that it occurs exceptionally lower in the stratigraphy than other known large sandstone uranium deposits in the lower Beaufort Group of the Karoo Supergroup. The Johannesburg Consolidated Investment Company Ltd (JCI) was involved in the exploration and trial mining activities in the area.

The deposit is located a few hundred metres lower than the level of the Poortjie Sandstone, 100m below the Koornplaats Member, within the middle Abrahamskraal Formation (table 1.1) (Loock et al. 1994). The regional geology of the area is shown in fig 3.3.1.

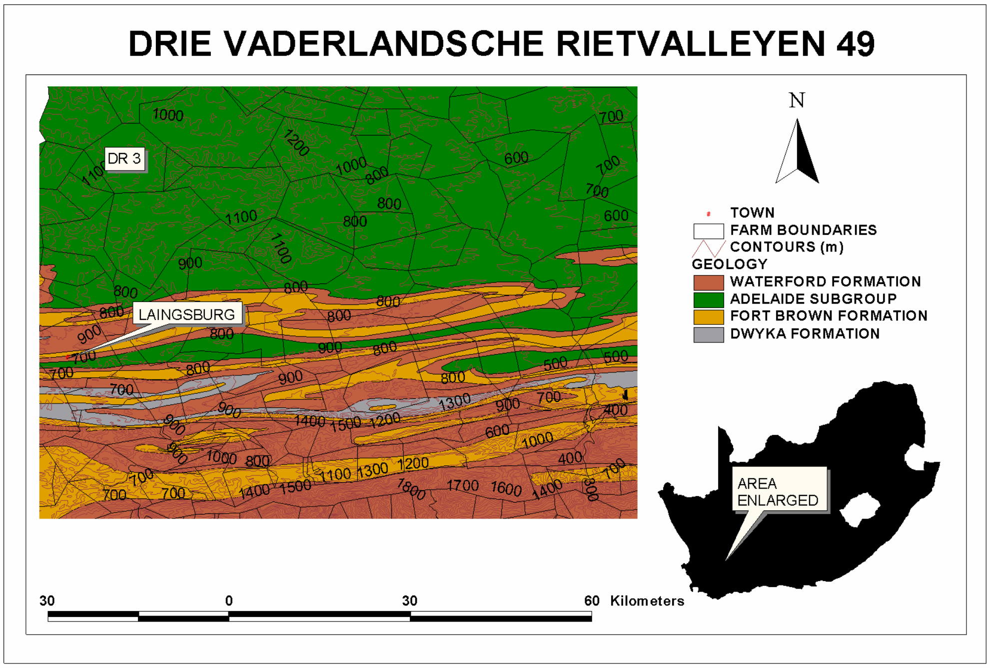


Figure 3.3.1 Regional geology of area surrounding the DR-3 trial mining area. Map compiled using Arcview 3.2 and the Environmental and Tourism Potential Atlas (2001) for the Western Cape.

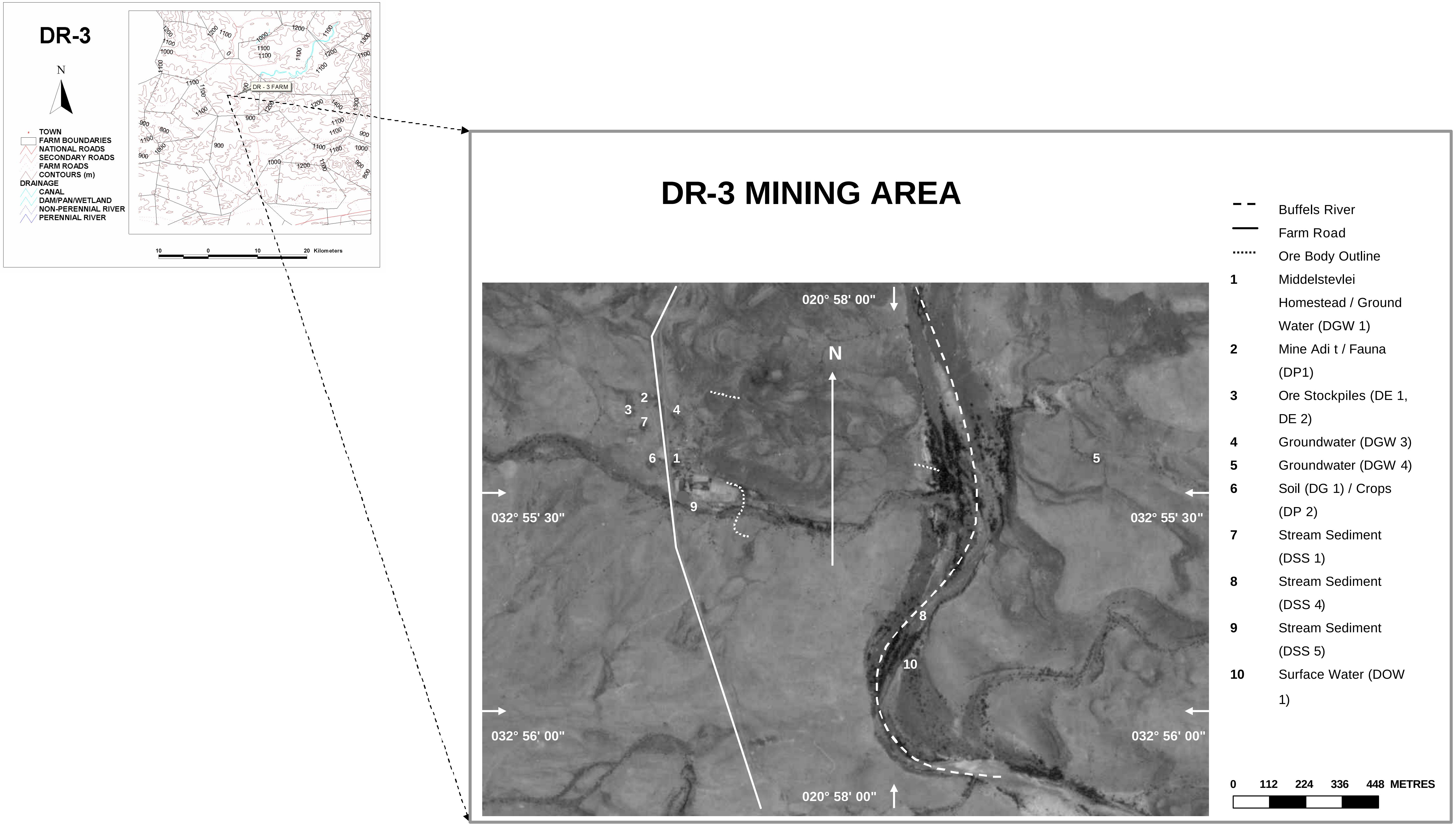


Figure 3.3.2 (a) and (b). Location map showing DR-3 farm. (a) Map compiled using Arcview 3.2 and Environmental and Tourism Potential Atlas (2001) for the Western Cape (b) 1:12 000 part of aerial photograph (no. 8622, strip 11, job 1014. 1:60 000 - 1998) showing area surrounding mining activities on DR-3. The numbering on the photograph is explained on the following pages. The ore body outline is from Wadley and Hoffmann (1986).

3.3.2 Trial mining adit

In order to obtain a larger metallurgical sample, to provide additional geological data and to test mining conditions and techniques, a 50m - long adit was excavated 500m north-west of the Middelstevlei homestead during October and November 1980. During this time approximately 500t of material was excavated. After blasting, each round was stored in an open dump yard (Wadley and Hoffmann 1986).

Figure 3.3.3 Entrance to sealed trial mining adit on DR-3.

3.3.3 Ore stockpiles and barrels

Twenty-five ore dumps remain in the mining area as well as eight ore containing barrels, each of 200l capacity. These are situated 500m upstream from the Middelstevlei homestead.

According to Wadley and Hoffmann (1986) certain dumps were incorporated into a 50t bulk metallurgical sample which was submitted for pilot plant studies.

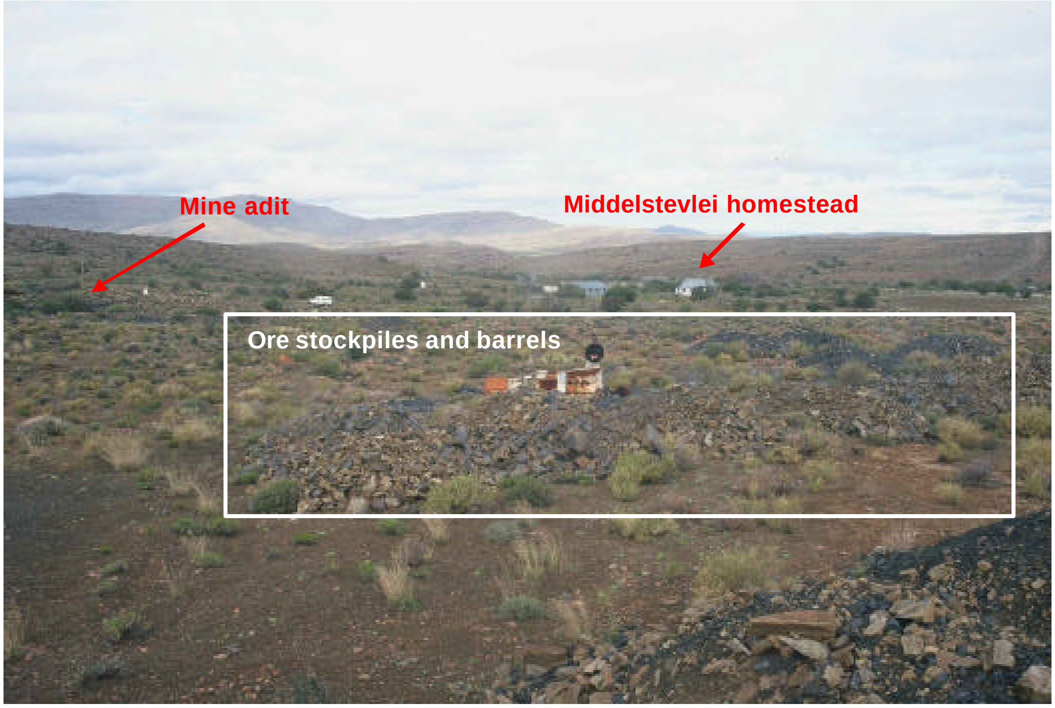


Figure 3.3.4 Ore stockpiles and barrels with Middelstevlei homestead visible in background.

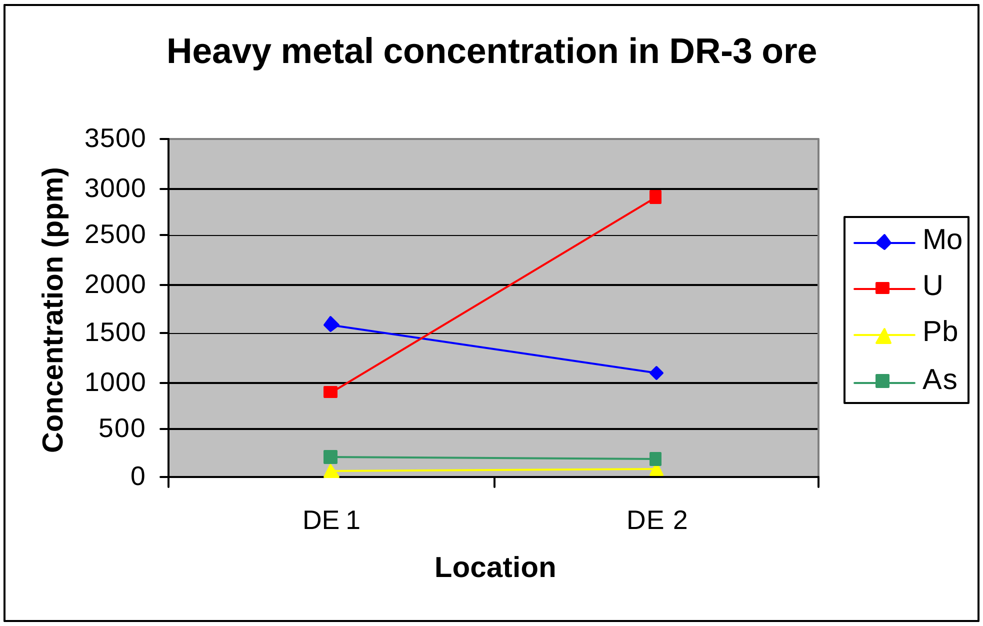


Figure 3.3.5. Uranium concentration (ppm) in DR-3 ore.

Figure 3.3.6 Rust in 200l ore containing barrels (No. 3 on location map).

Table 3.3.1 Estimated total volume (m^3) and tonnage (t) of ore in stockpiles and barrels on surface of DR-3.

	Ore stockpiles (Rounded to 10)	**Barrels (Rounded to 1)**	**Total**
Volume (m^3)	80	1.6	81.60
Tonnage (t)	11×10^1	2	11.2×10^1

For detail on techniques used, see Ore Quantity Calculations under Appendix A1, for sampling methods see Appendix A2 and for analytical results see Appendix C3.

3.3.4 Water

Ground – and surface water were sampled for heavy metal analysis. Results were compared with background values, Environmental Guidelines for Heavy Metals in South Africa (DWAF 1996) and concentrations obtained from the World Health Organization (WHO 2003) (see Appendix B1). Water was sampled for arsenic, copper, iron, molybdenum, lead and uranium. (See Appendix A2 for sampling methods and Appendix C3 for detailed analytical results).

3.3.4.1 Groundwater

Samples were taken at four different locations (including one background location). Arsenic, molybdenum, lead and uranium concentrations are ideal (DWAF 1996). All iron concentrations, with the exception of DGW 3 (no. 4 on location map), in groundwater at DR-3 are above ideal (DWAF 1996), but below background (Appendix B1 and C3).

The following graphs represent only above-background concentration levels of heavy metals in groundwater on DR-3.

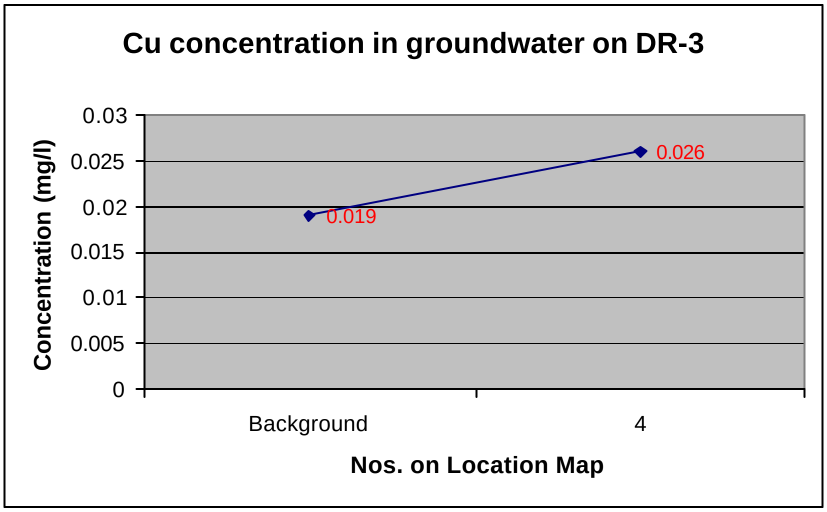


Figure 3.3.7 Above-background copper concentrations (mg/l) in groundwater on DR-3. Red values are above ideal for aquatic ecosystems (DWAF 1996).

3.3.4.2 Surface water

Due to the relative aridity experienced within the area, surface water sampling was limited to one only.

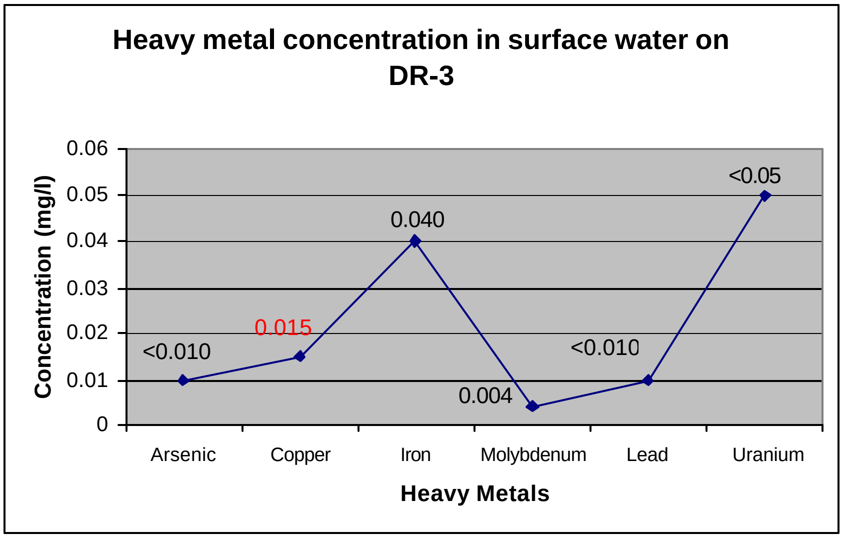


Figure 3.3.8 Heavy metal concentrations (mg/l) in surface water on DR-3. Sample was taken at no. 10 on locality map. Copper values are above ideal for aquatic ecosystems (DWAF 1996).

3.3.5 Soil

Soil was sampled at one location only. (See Appendix A2 for sampling methods and Appendix C3 for detailed analytical results). Concentrations are compared with normal ranges of heavy metals in soils and stream sediment as derived from Alloway (1993) (Appendix B3).

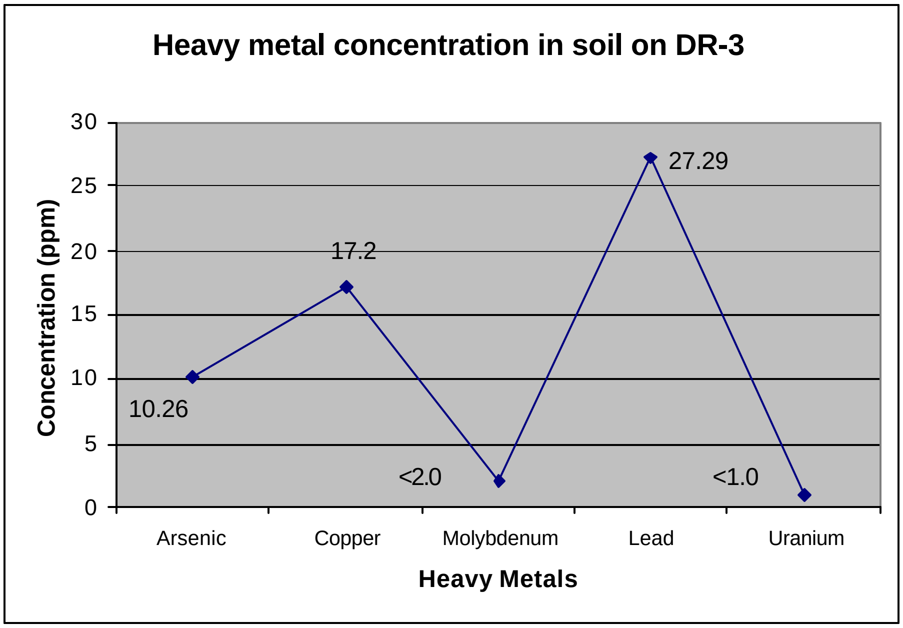


Figure 3.3.9 Heavy metal concentration in soil on DR-3. Sample was taken at no. 6 on locality map. No values are above normal (Alloway 1993).

3.3.6 Stream sediment

Stream sediment was sampled at five locations including two background locations. (See Appendix A2 for sampling methods and Appendix C3 for detailed analytical results). Concentrations are compared with normal ranges of heavy metals in soils and stream sediment as derived from Alloway (1993) (Appendix B3). All lead values are below background and below normal (Appendices C3 and B3) (Alloway 1993).

The following graphs represent only above background concentration levels of heavy metals in stream sediment on DR-3.

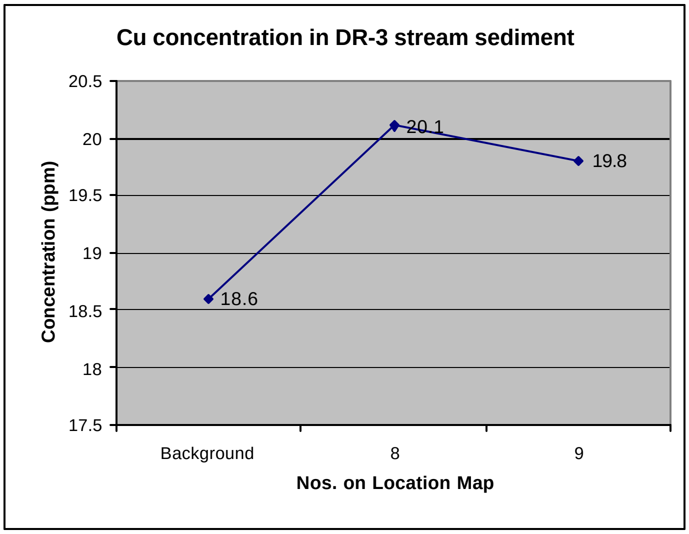


Figure 3.3.10 Copper concentrations (ppm) in stream sediment on DR-3 showing above background levels. No values are above normal (Alloway 1993).

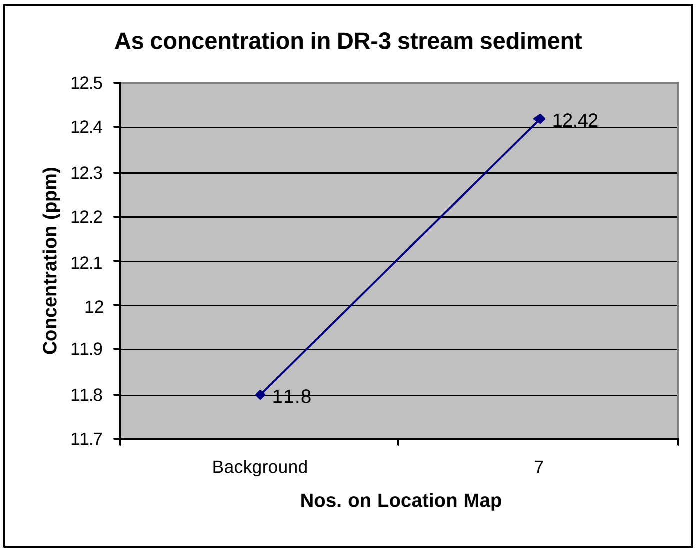


Figure 3.3.11 Arsenic concentrations (ppm) in stream sediment on DR-3 showing above-background levels. No values are above normal (Alloway 1993).

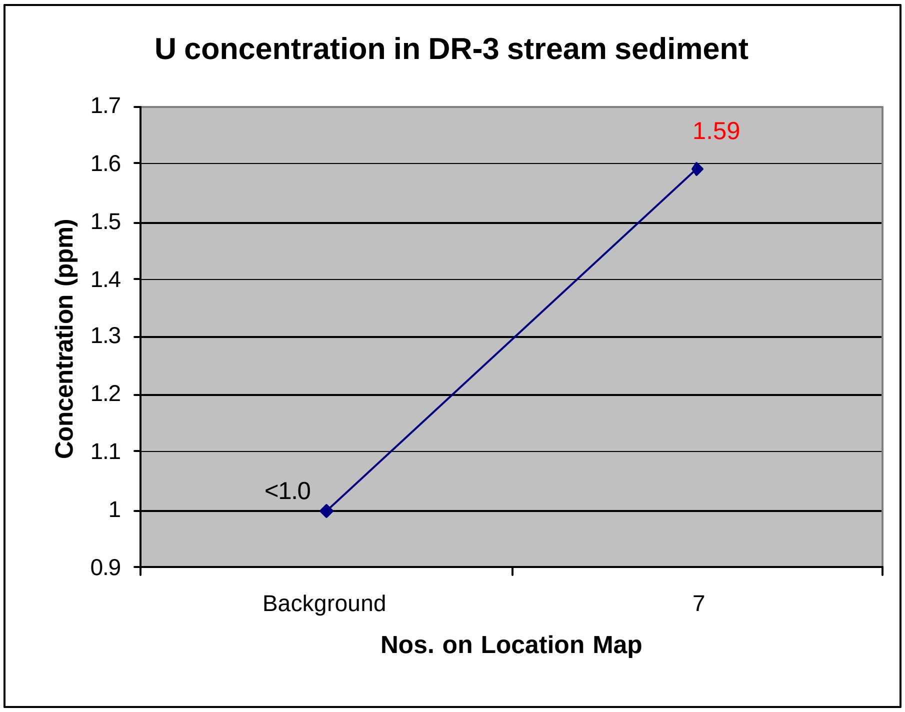


Figure 3.3.12 Uranium concentrations (ppm) in stream sediment on DR-3 showing above-background levels. Red values are above normal (Alloway 1993).

3.3.7 Crops

Onion crops were sampled and analysed for heavy metal composition (See Appendix A2 for sampling methods and Appendix C3 for detailed analytical results).

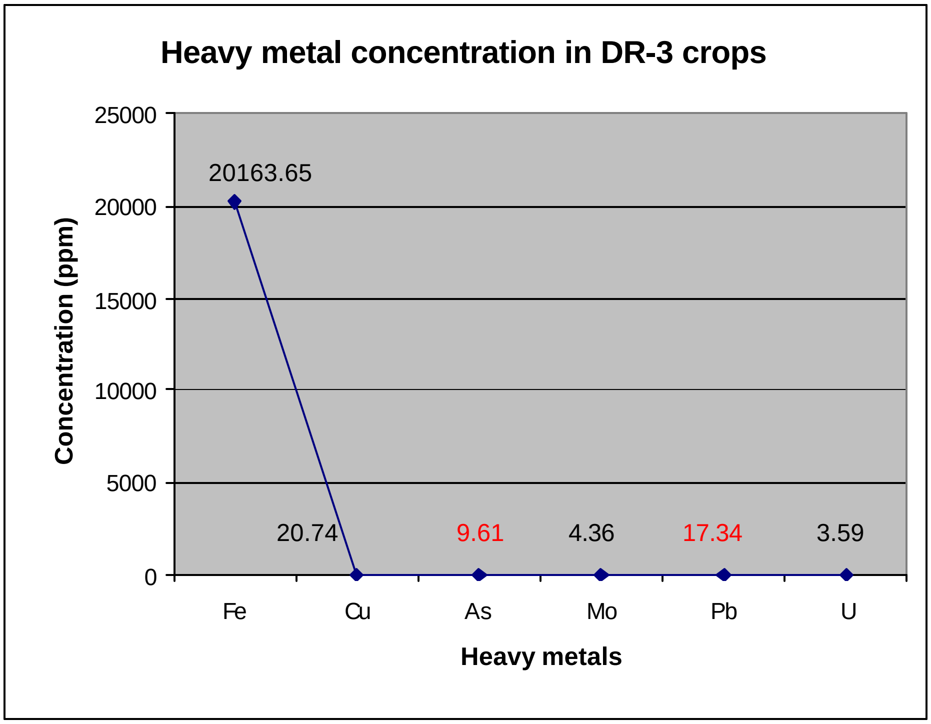


Figure 3.3.13 Heavy metal concentration in onion crops growing downstream of mining area on DR-3 (No. 6 on location map). Red values are above ideal (ATSDR 1999 – 2002, Act 54 1972 and Waldbott 1973).

3.3.8 Background concentrations

Groundwater and stream sediment background samples were taken upstream, on the adjoining farm Koornplaats.

3.4 Mooifontein

3.4.1 Introduction

The Mooifontein deposit and trial mining area is located approximately 10km northeast of Edenburg in the Free State. The site was prospected by Rio Tinto Exploration (Pty) Ltd. during the period 1977 to 1980 (Le Roux 1985). The area is located within the upper Balfour Formation (Le Roux 1985) of the Adelaide Subgroup (table 1.1) and the regional geology is shown in fig. 3.4.1.

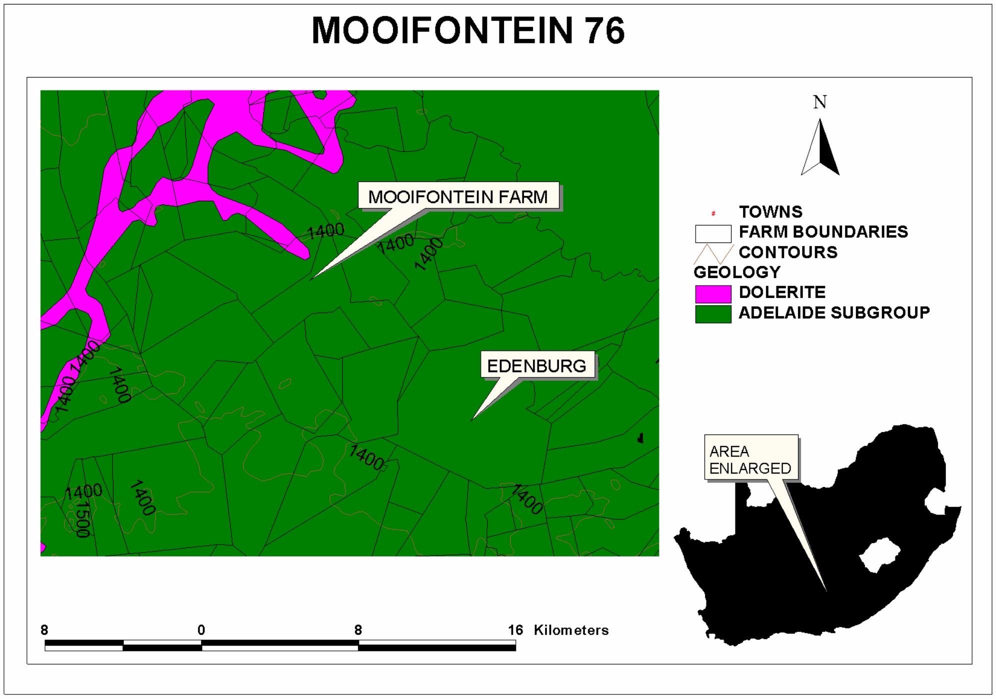


Figure 3.4.1 Regional geology of area surrounding the Mooifontein trial mining area. Map compiled using Arcview 3.2 and the Environmental and Tourism Potential Atlas (2001) for the Free State.

The mineralization differs from most uranium deposits in the southern Karoo by their greater mean thickness and the fact that they are more continuous (Le Roux and Hambleton-Jones 1991).

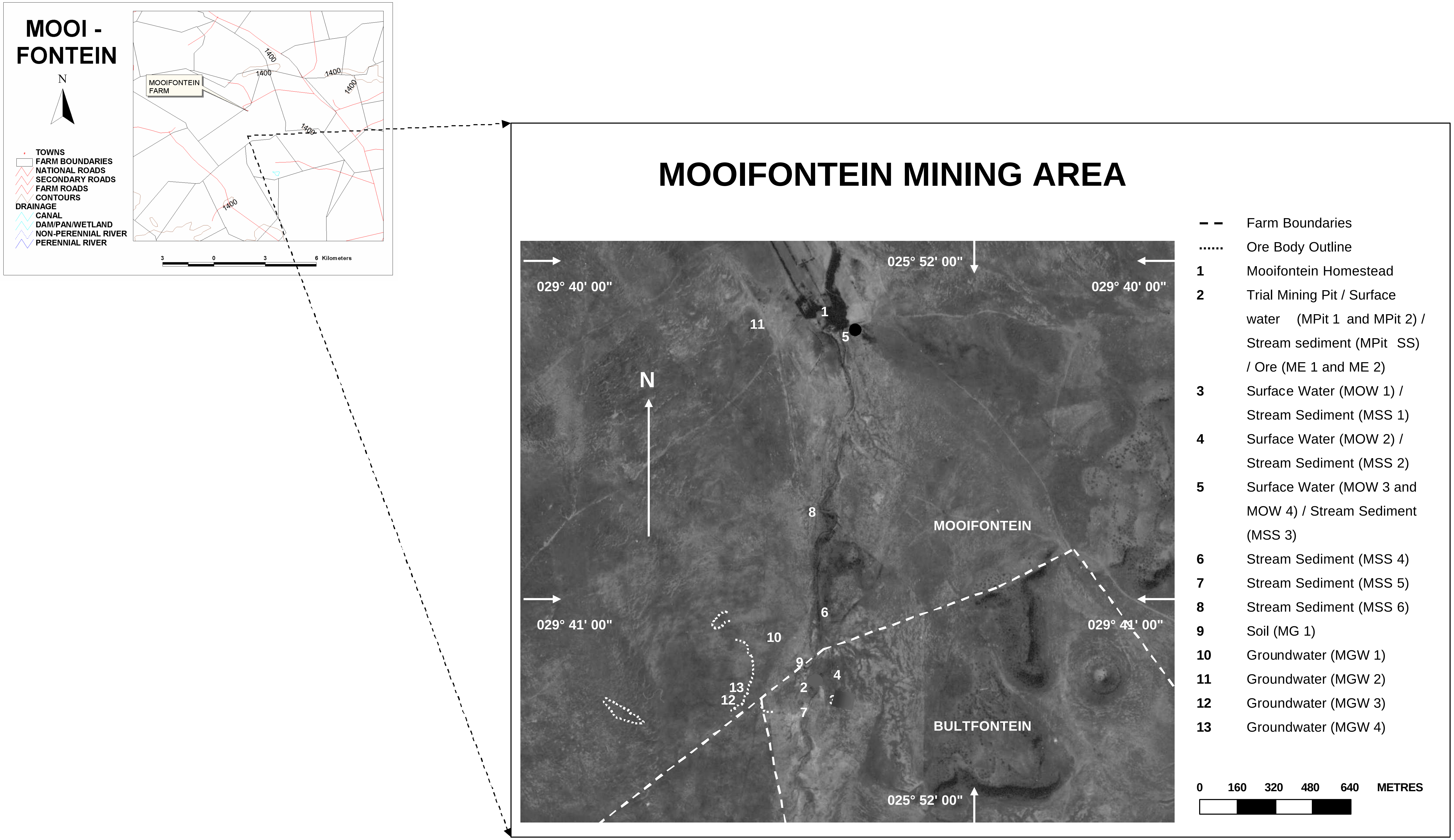


Figure 3.4.2 (a) and (b). Location map showing Mooifontein farm. (a) Map compiled using Arcview 3.2 and Environmental and Tourism Potential Atlas (2001) for the Free State (b) 1: 16 000 part of aerial photograph (no. 1227, strip 10, job 1023. 1:50 000 - 1999) of mining activities on Mooifontein The numbering on the photograph shows mainly sampling localities and is explained in text. The ore body outline is from Le Roux (1985).

3.4.2 Open Pit

The open pit excavated by Rio Tinto (Le Roux 1985) covers an area of 50m^2 and is approximately 2m deep up to water level. The open pit is actually situated on the farm Bultfontein (see location map) not on Mooifontein, but for purposes of literature reference in the past and present, the name Mooifontein will be used. The open pit and surrounds is located within a fenced-off area, but lacking a gate and giving easy access to all. The pit is permanently flooded (personal communication by the owner of Bultfontein and Le Roux 1985) with water levels reaching 1 to 2 metres in depth.

Figure 3.4.3 Water-filled 50m^2 open pit on Mooifontein, person on top used for scale. No. 2 on location map.

3.4.3 Ore stockpiles

The stockpiles are situated in the vicinity of the open pit, next to a tributary of the Riet River, approximately 2 km upstream from the Mooifontein homestead.

Figure 3.4.4 Uranium ore stockpiles on surface of Mooifontein. No. 2 on location map.

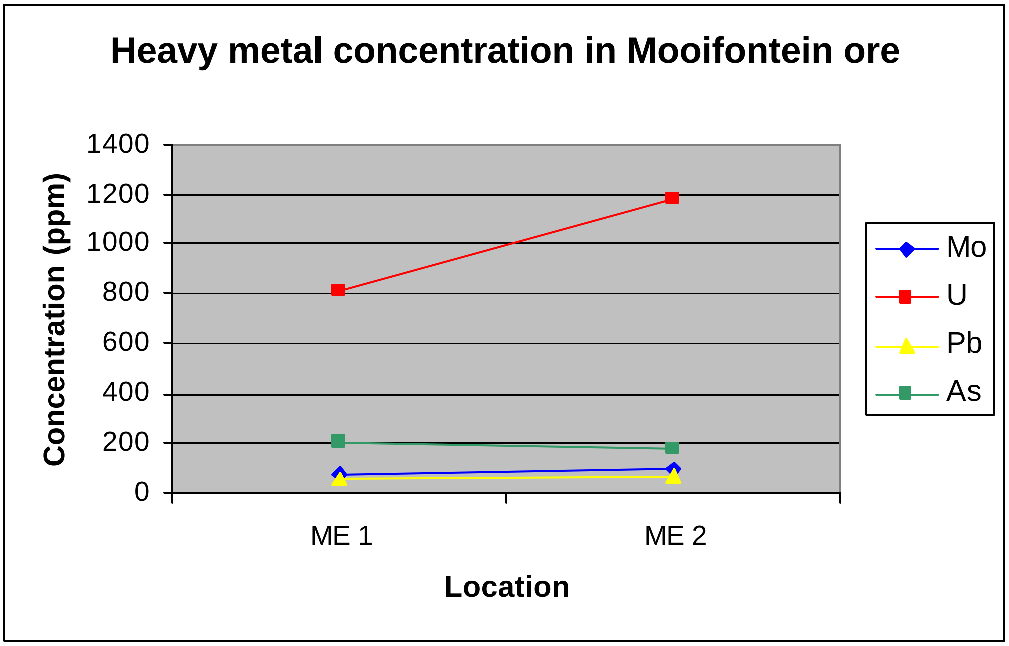


Figure 3.4.5 Heavy metal concentration (ppm) in Mooifontein ore.

Table 3.4.1 Estimated total volume (m^3) and tonnage (t) of stockpiled uranium ore on surface of Mooifontein.

Ore stockpiles (Rounded to 10) (m^3)	**Ore stockpiles (Rounded to 10) (t)**
40	60

For detail on techniques used, see Ore Quantity Calculations under Appendix A1, for sampling techniques se Appendix A2 and for analytical results see Appendix C4.

3.4.4 Water

Ground – and surface water were sampled for heavy metal analysis. Results were compared with background values, Environmental Guidelines for Heavy Metals in South Africa (DWAF 1996) and concentrations obtained from the World Health Organization (WHO 2003) (see Appendix B1). Water was sampled for arsenic, copper, iron, molybdenum, lead and uranium. (See Appendix C4 for detailed analytical results).

3.4.4.1 Groundwater

Samples were taken at five different locations (including one background location). At present the arsenic and uranium concentrations in groundwater samples on Mooifontein are ideal (Appendices B1 and C4) (DWAF 1996).

The following graphs represent only above-background concentration levels of heavy metals in groundwater on Mooifontein.

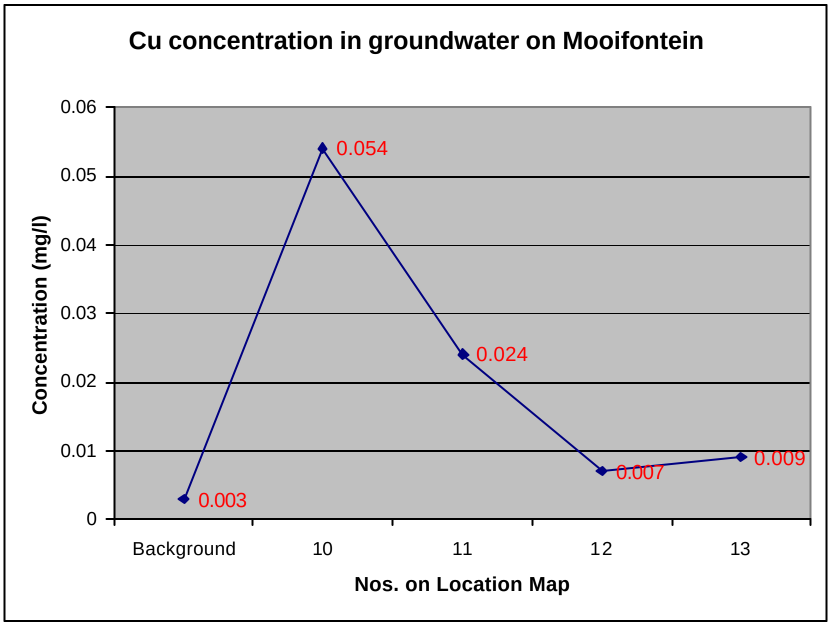


Figure 3.4.6 Above-background copper concentrations (mg/l) in groundwater on Mooifontein. Red values are above ideal for aquatic ecosystems (DWAF 1996).

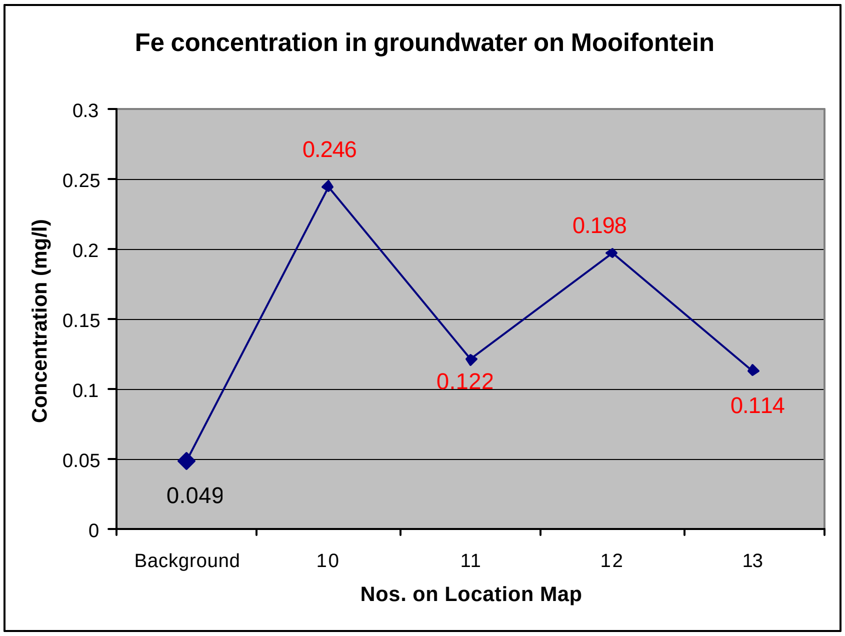


Figure 3.4.7 Above-background iron concentration (mg/l) in groundwater on Mooifontein. Red values are above ideal for domestic use (DWAF 1996).

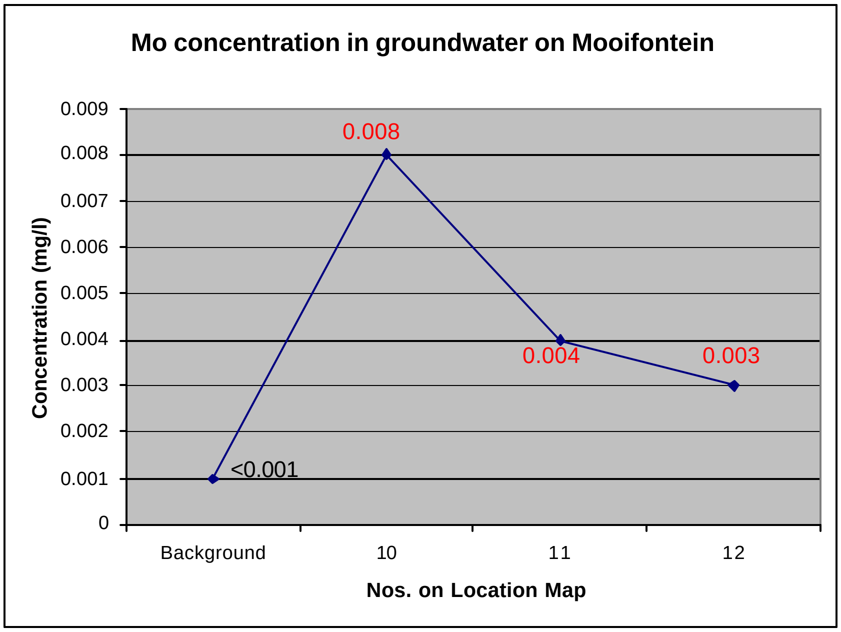


Figure 3.4.8 Above-background molybdenum concentrations (mg/l) in groundwater on Mooifontein. Red values are above ideal for agricultural use (DWAF 1996).

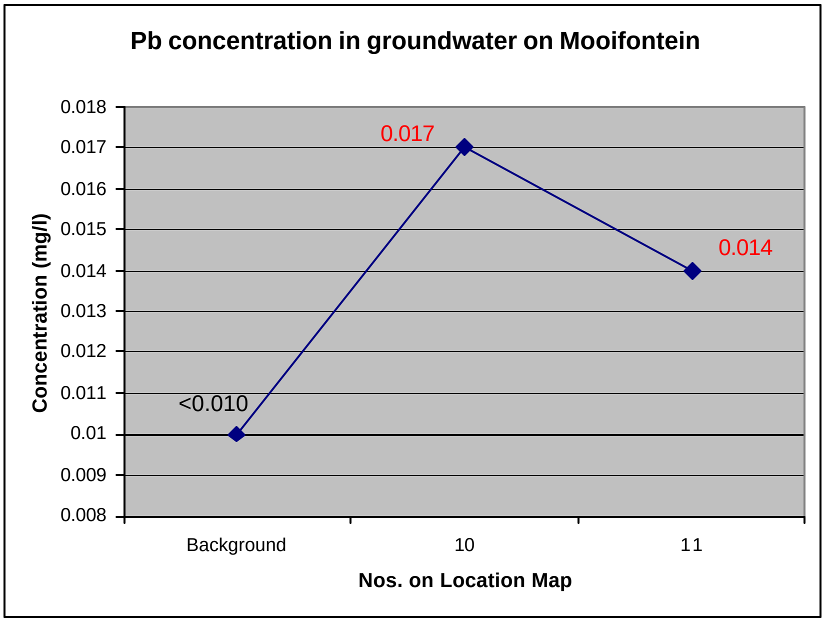


Figure 3.4.9 Above-background lead concentrations (mg/l) in groundwater on Mooifontein. Red values are above ideal for domestic use and aquatic ecosystems (DWAF 1996).

3.4.4.2 Surface water

Samples were taken at seven different locations (including one background location). Copper and iron concentrations in surface water on Mooifontien are all above ideal (DWAF 1996), but below background, whilst lead concentrations are all, except for samples MOW 1 and MOW 2, above ideal (DWAF 1996), but below background for aquatic ecosystems (See Appendices B1 and C4).

The following graphs represent only above-background concentration levels of heavy metals in surface water on Mooifontein.

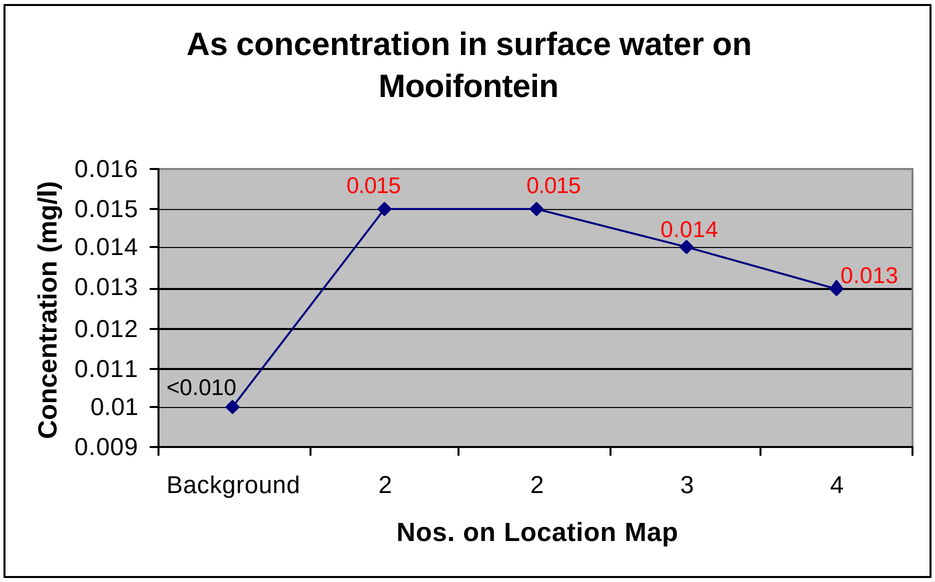


Figure 3.4.10 Above-background arsenic concentrations (mg/l) in surface water on Mooifontein. Red values are above ideal for domestic use (WHO 2003) and aquatic ecosystems (DWAF 1996).

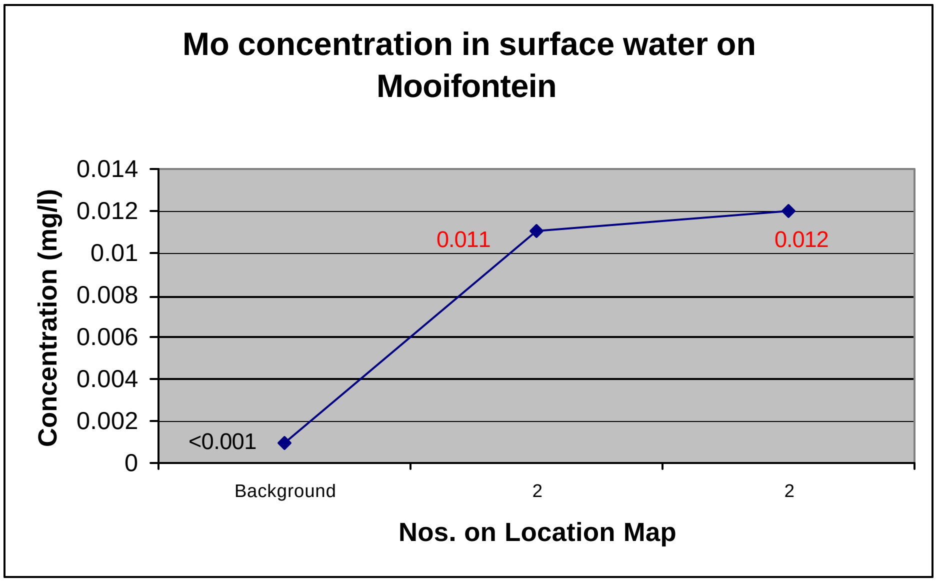


Figure 3.4.11 Above-background Mo concentrations (mg/l) in surface water on Mooifontein. Red values are above ideal for agricultural use (DWAF 1996).

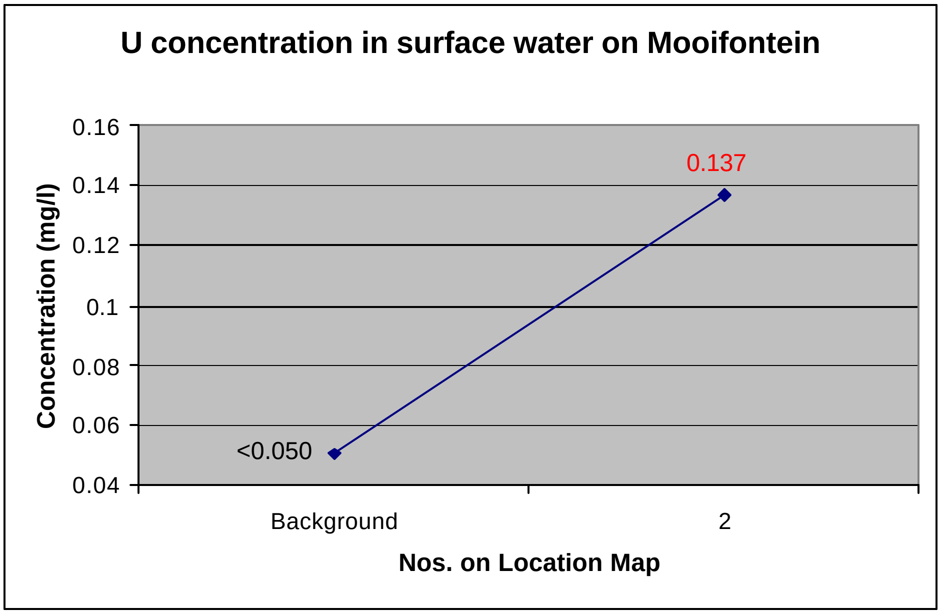


Figure 3.4.12 Above-background U concentrations (mg/l) in surface water on Mooifontein. Red values are above ideal for domestic and agricultural use (WHO 2003 and DWAF 1996).

3.4.5 Soil

Soil was sampled at two locations; including one background location (Sampling techniques are available in Appendix A2). Concentrations were compared with normal ranges of heavy metals in soils and stream sediment as derived from Alloway (1993) (Appendix B3). Copper, molybdenum and uranium concentrations are below background and below normal (Appendices B3 and C4) (Alloway 1993).

The following graphs represent only above-background concentration levels of heavy metals in soil on Mooifontein.

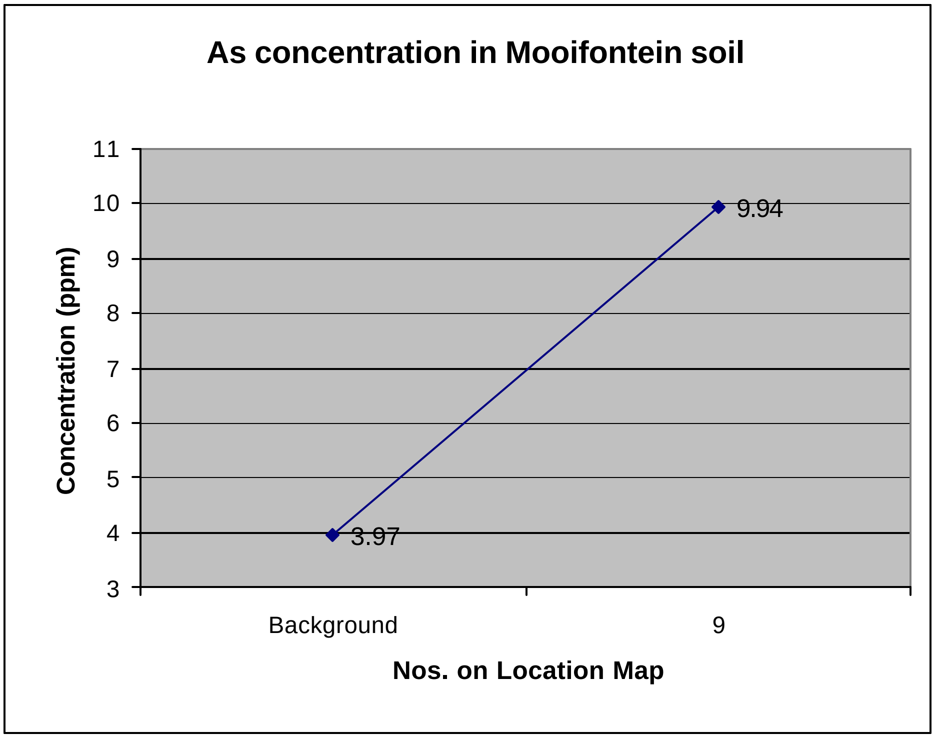


Figure 3.4.13 Arsenic concentrations (ppm) in soil on Mooifontein showing above background levels. No values are above normal (Alloway 1993).

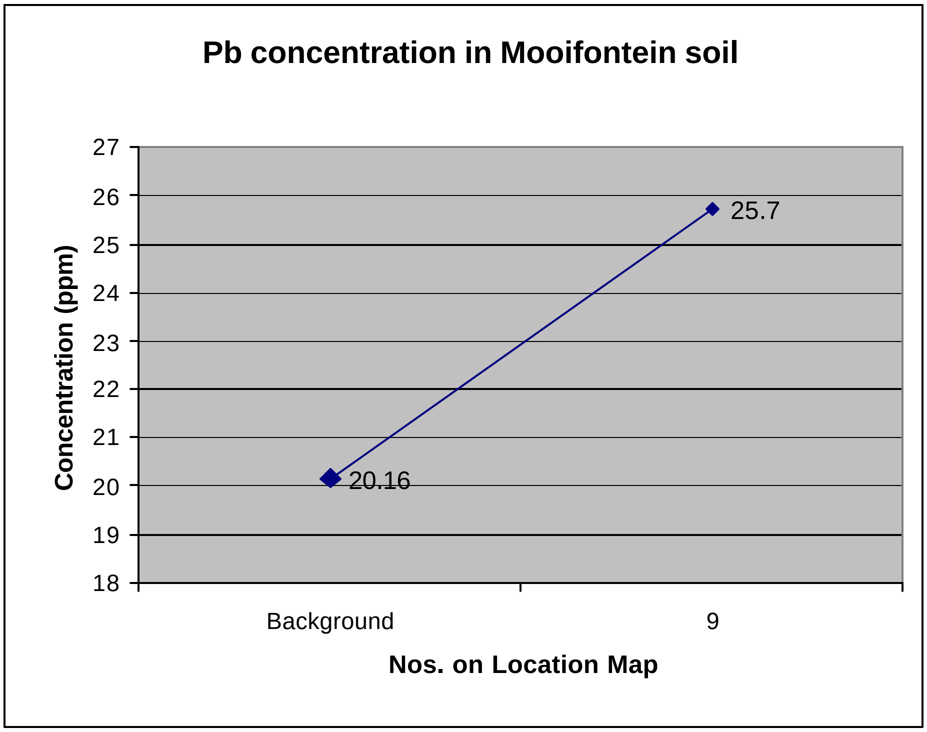


Figure 3.4.14 Lead concentrations (ppm) in soil on Mooifontein showing above-background levels. No values are above normal (Alloway 1993).

3.4.6 Stream sediment

Stream sediment was sampled at eight locations including one background location (Sampling techniques are available in Appendix A1). Concentrations are compared with normal ranges of heavy metals in soils and stream sediment as derived from Alloway (1993) (Appendix B3). Molybdenum concentrations are below background and below normal (Appendices B3 and C4) (Alloway 1993).

The following graphs represent only above-background concentration levels of heavy metals in stream sediment on Mooifontein.

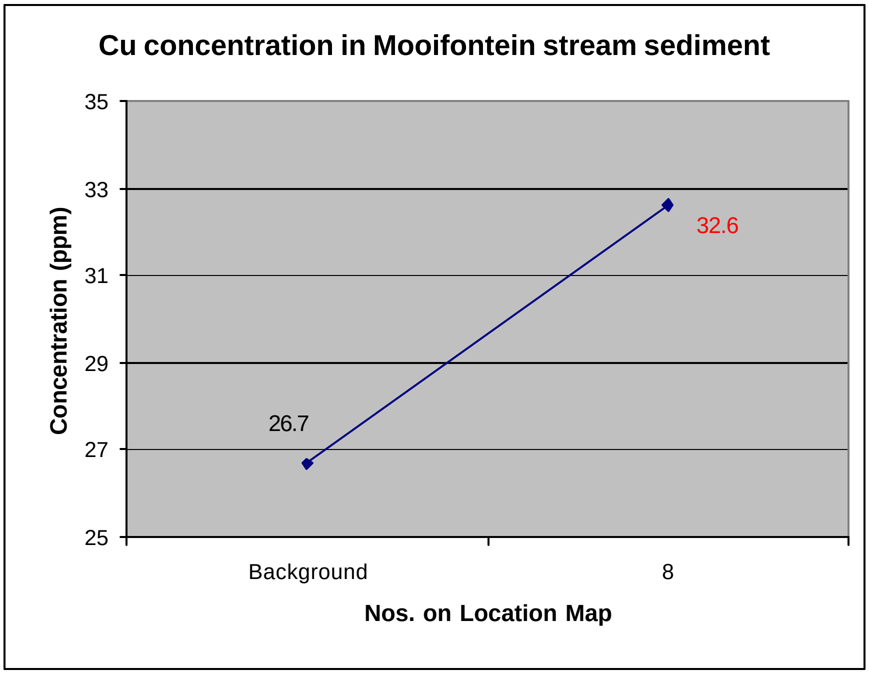


Figure 3.4.15 Above-background concentration (ppm) of copper in stream sediment on Mooifontein. Red values are above normal (Alloway 1993).

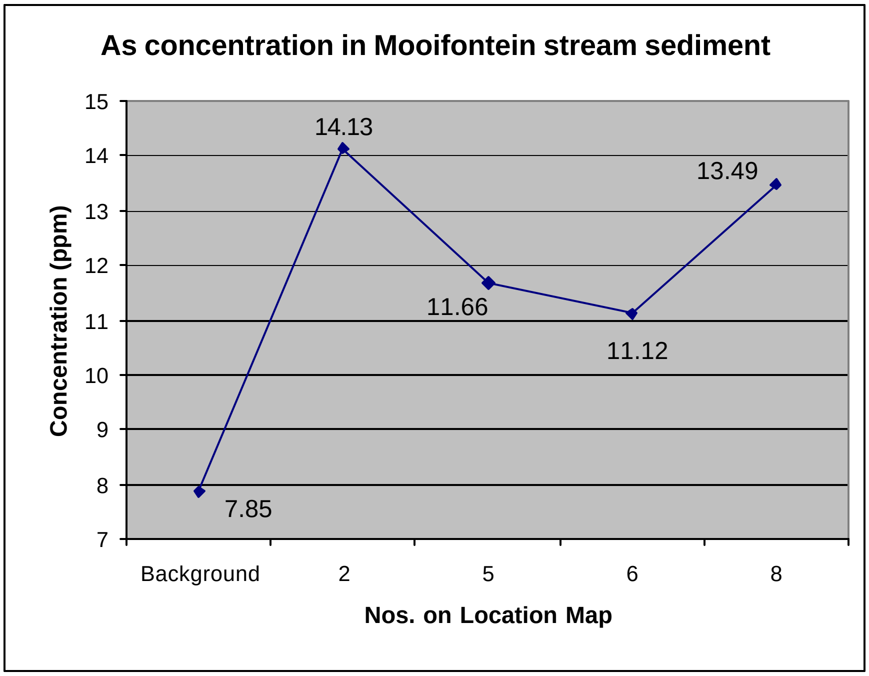


Figure 3.4.16 Above-background concentration (ppm) of arsenic in stream sediment on Mooifontein. All values are below normal (Alloway 1993).

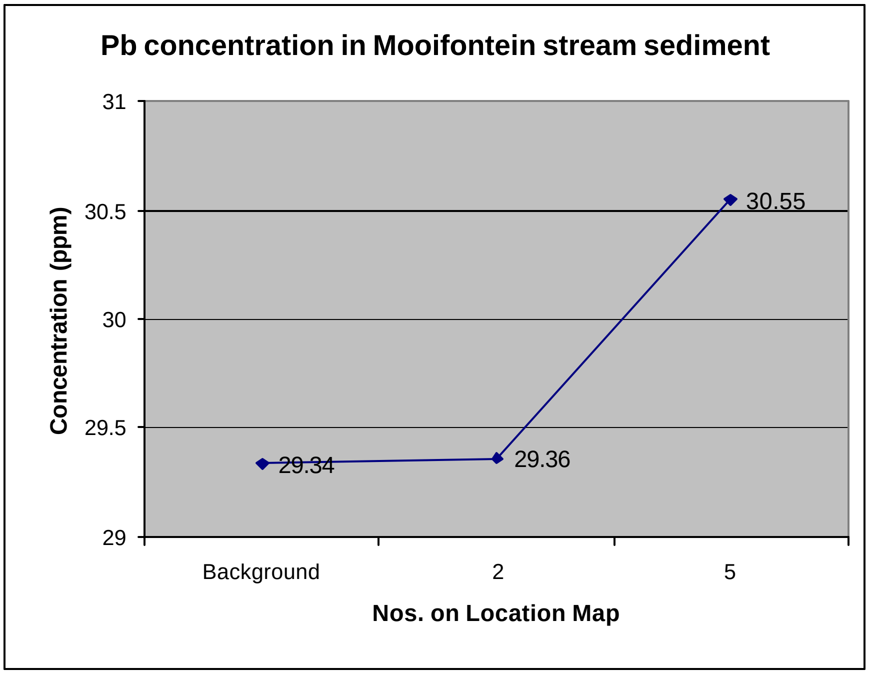


Figure 3.4.17 Above-background concentration (ppm) of lead in stream sediment on Mooifontein. All values are below normal (Alloway 1993).

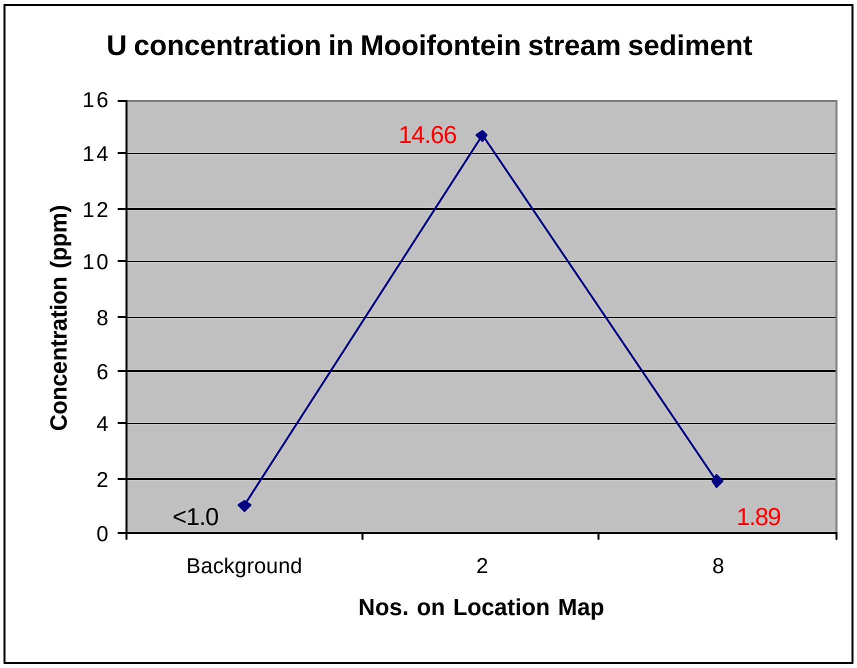


Figure 3.4.18 Above background concentration (ppm) of uranium in stream sediment on Mooifontein. Red values are above normal (Alloway 1993).

3.4.7 Background concentrations

Groundwater -, soil - and stream sediment background samples were taken upstream, on the adjoining farm Bultfontein (See locality map).

CHAPTER 4

IMPACT OF RELATED MINING ACTIVITIES ON THE ENVIRONMENT

4.1 Introduction

Mining operations have gone on for thousands of years and abandoned mines and mining operations are found throughout the world. Mines are local phenomena and their major environmental impacts are largely local, however, the dispersion of heavy metals can be regional and even global (Allan 1995).

Mining and metal beneficiation industries have developed into sophisticated operations, yet the basic causes of pollution remain unchanged. This chapter illustrates the environmental impact of inadequate remediation of uranium mining through two case studies.

4.2 Königstein

The Königstein Uranium Mine, in Saxony, East Germany, was closed in 1990 ending production in the former German Democratic Republic. The uranium deposit was mined conventionally in the 1970's and from 1981 it was mined by in-situ leaching. This involved injection of dilute sulphuric acid into the ore body, which in some cases required blasting to make the sandstone host rock sufficiently permeable. A waste dump of about $4 \times 10^6 m^3$, abandoned equipment and building wastes were left at Schüsselgrund valley near Königstein.

The impact of the Schüsselgrund mine dump on the aquatic environment was evaluated based on the evolution of the contaminants dissolved in the dump water and the amount of water released from the dump per year. For the waste material, the long-term behaviour of mine waste reactions with dump material was considered. Results are conclusive that the disposal of water treatment residues, asbestos cement, rubble, glass and porcelain in the Schüsselgrund mine dump causes no additional contaminant release (Schneider et al. 2001).

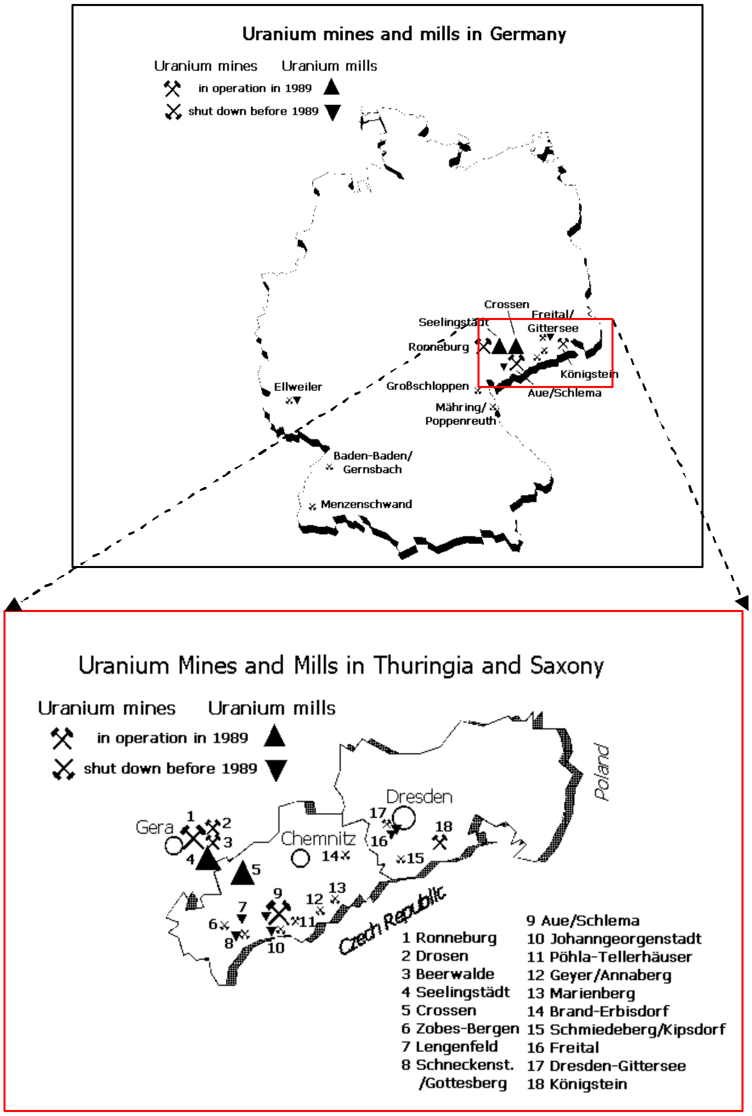


Figure 4.1 Location of uranium mines and mills in former Democratic Republic of Germany (East Germany). From www.antenna.nl/wise/uranium/uwis.html#1

The principal concerns for the restoration of this site are centered on the flooding of the underground mine workings that will occur after the mine is closed down. There is potential for the contamination of surrounding groundwater and surface water streams with U, Ra, SO_4, Fe and other heavy metals. Although small–scale flooding trials are currently being conducted, restoration is still not complete and the mine still represents a threat to the surrounding aquifer, an important groundwater source for the region (Mudd 2001).

4.3 Rum Jungle

Rum Jungle, an abandoned uranium open cut operation, is located in the tropical north of Australia, 85km south of Darwin. Mining was carried out between 1954 and 1964 and operations ceased in 1971 (Harries et al. 1997).

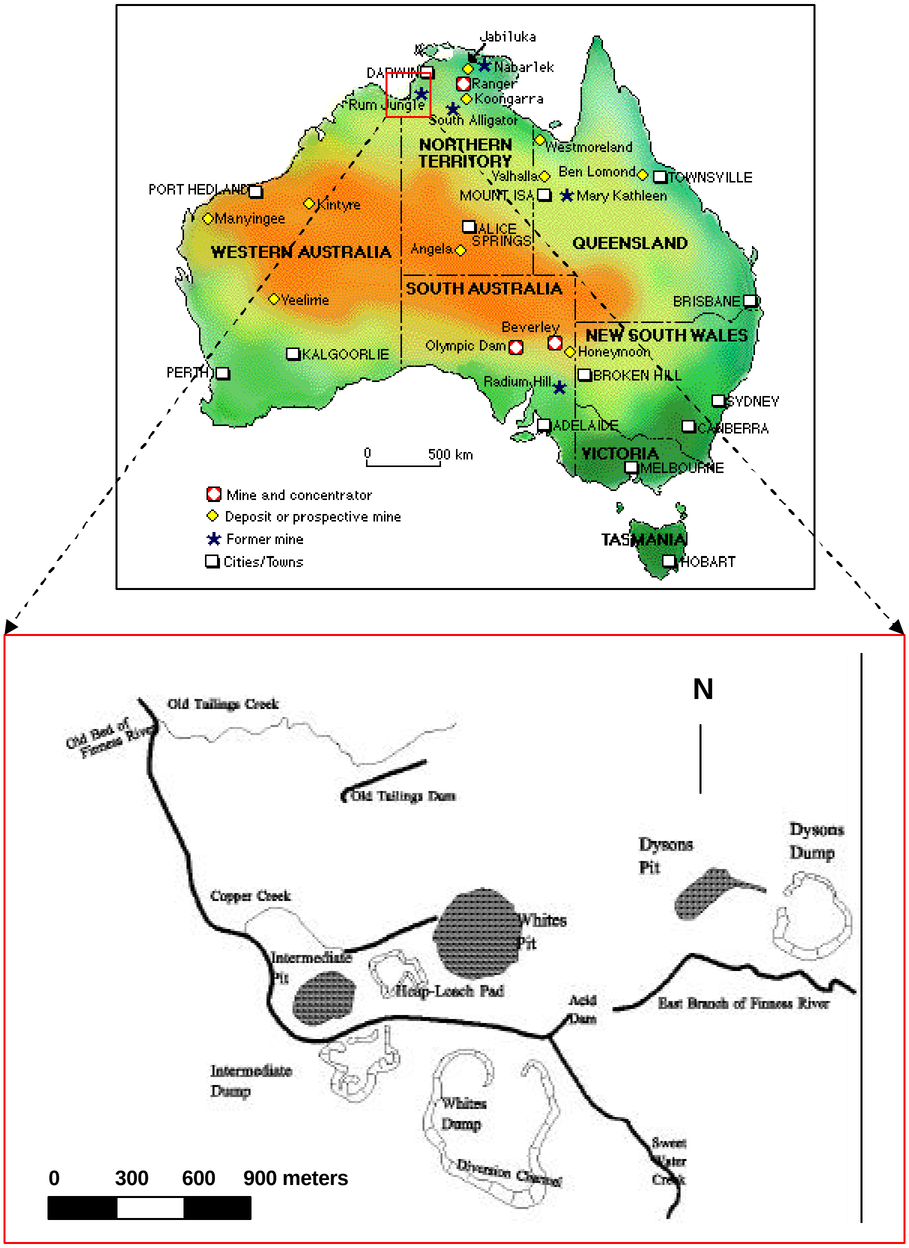


Figure 4.2. Rum Jungle Uranium Mine in the Northern Territories of Australia. From www.sea-us.org.au/oldmines/rumjungle.html and www.uic.com.au/fmine.htm#rumj

On abandonment of the site the main waste management concerns were three waste rock dumps containing 10Mt waste rock and covering an area of 51ha; three water-filled open cuts of total area 22ha; a tailings disposal area containing 0.6Mt tails over 31ha and a copper heap leach pile containing 0.3Mt ore over 2ha. The waste rock dumps contain pyrite and other metal sulphides associated with the uranium ore body. Results show that the water running off the dumps was acidic and polluting the streams that flow through the mine site (Harries and Ritchie 1983).

Within a few years the Rum Jungle mine had become one of Australia's most notorious pollution problems, due to oxidation of sulphides by bacteria and the consequent release of acid and metals into the East Finniss River. The monsoonal climate and 1500mm rainfall coupled with the pyritic mineralization in the area created ideal conditions for such processes. Rehabilitation at the Rum Jungle uranium mine was a failure during the 1980’s, whilst a rehabilitation project begun in 1993, was successful in restoring the area. This represents a span of some 40 years between creation of a major environmental problem and its remediation, which, however, did not undo the damage already done.

CHAPTER 5

LEGISLATION IN SOUTH AFRICA

5.1 Introduction

Since the advent of mining in South Africa, some regulatory measures have been in existence for the mining industry to protect and conserve the environment. Early legislation placed responsibilities in this regard on the owner of a mine until such time as the owner has been issued with a certificate releasing him from such responsibilities.

5.2 Mining

According to the Minerals Act no. 50 (1991) section 1, a mine is any excavation in the earth, including the portion under the sea or under other water or in any tailings, as well as any borehole, whether being worked or not, made for the purpose of searching for or winning a mineral; or any other place where a mineral deposit is being exploited, including the mining area and all buildings, structures, machinery, mine dumps, access roads or objects situated on such area and which are used or intended to be used in connection with such searching, winning or exploitation or for the processing of such mineral. Mining is, under the same Act no. 50 (1991) section 1, the making of any excavation or borehole or the exploitation of any mineral deposit in any other manner, for the purpose of winning a mineral, including any prospecting in connection with the winning of such a mineral.

5.2.1 Rehabilitation of surface

According to the Minerals Act no. 50 (1991), section 38, the rehabilitation of the surface of land concerned in any prospecting or mining shall be carried out by the holder of the prospecting permit or mining authorization concerned in accordance with the environmental management programme, as an integral part of the prospecting or mining operations concerned, simultaneously with such operations.

The legislation regarding the rehabilitation of surface at the termination of mining related was according to the Mining Rights Act 20 of 1967 (Repealed the Minerals Act no. 50 of 1991) non-existent.

Figure 5.1 Mining areas in the Karoo Uranium Province. Clockwise from top left: Ryst Kuil ore crusher with ore stockpiles and barrels in background. Rietkuil open pit with discarded empty barrels. DR-3 ore stockpiles and barrels with Middelstevlei homestead in background. Mooifontein open pit.

5.2.2 Removal of mine related structures and objects

The Minerals Act no. 50 (1991) section 40, requires that whenever a prospecting permit or mining authorization which is held is suspended, cancelled, is terminated or lapses, and the prospecting for or exploitation of any mineral which was authorized under such permit or authorization finally ceases, the person who was the holder of such permit or authorization immediately prior to such suspension, cancellation, termination or lapsing, as the case may be, shall demolish all buildings, structures or any other thing which was erected or constructed in connection with prospecting or mining operations on the surface of the land concerned and shall remove all debris as well as any other object which the Director: Mineral Development concerned may require.

Various mine related objects are scattered over the four mines including structures and mine related waste dumps on Ryst Kuil as well as large quantities of ore stockpiles on all four mines (figure 5.1). The legislation regarding the removal of mine related structures and objects during the termination of mining related activities in the Karoo Uranium Province during 1979 and 1980 was the Mining Rights Act no. 20 (1967).

Mining Rights Act no. 20 (1967) section 33, subsection 3, states that with every mining lease granted, the last holder of the lease or any person entitled to the plant machinery or equipment on the area leased, shall when any such lease terminates or is for any other reason terminated, remove all plant, machinery and equipment, but shall not remove or destroy any material used for supporting underground workings or plant or material required to prevent damage to the mine or workings and no compensation shall be payable in respect thereof.

5.3 Hazardous substances

Hazardous substances can be divided, according to the Hazardous Substances Act 15 (1973), into Group I, Group II or Group III and Group IV hazardous substances.

A Group IV hazardous substance is radioactive material which is outside a nuclear installation and is not material which forms part of or is used or intended to be used in the nuclear fuel cycle.

Act 15 (1973) requires that no person shall produce or otherwise acquire, or dispose of, or import into the Republic or export from there, or be in possession of, or use, or convey or cause to be conveyed, any Group IV hazardous substance, except in terms of a written approval, which is in accordance with the prescribed conditions; and such further conditions as the Director-General may in each case determine.

The Hazardous Substances Act 15 (1973) was already drafted during trial mining in the Karoo Uranium Province. It was therefore the responsibility of the Mining and Exploration Companies to adhere to Act 15 (1973) on termination of activities and/or to see to the adherence of farm owners to the act.

5.4 Water

According to the Water Act no. 36 (1998) section 19, subsection 1, land owner, a person in control of land or a person who occupies or uses the land on which any activity or process is or was performed or undertaken; or any other situation exists, which causes, has caused or is likely to cause pollution of a water resource, must take all reasonable measures to prevent any such pollution from occurring, continuing or recurring.

In the case of Ryst Kuil, Rietkuil and DR-3 the current farm owners are in charge of the mines, whilst in the case of Mooifontein the fenced off area, which includes the open pit and ore stockpiles, belongs to a South African exploration company.

The Water Act no. 36 (1998) section 19, subsection 1, implies that the owners of the featured mining areas are responsible for the remediation of their land, but subsection 3 says, should the farm owner fail to comply, or comply inadequately to remedy the pollution, a catchment management agency may take the measures it considers necessary to remedy the situation.

This catchment management agency may recover all costs incurred as a result of it acting from the following persons:

(a) Any person who is or was responsible for, or who directly or indirectly contributed to, the pollution or the potential pollution;

(b) The owner of the land at the time when the pollution or the potential for pollution occurred, or that owner's successor-in-title;

(c) Any person who negligently failed to prevent -

  (i) The activity or the process being performed or undertaken; or

  (ii) The situation from coming about.

The catchment management agency may in respect of the recovery of costs claim from any other person who, in the opinion of the catchment management agency, benefited from the measures which caused the pollution, to the extent of such benefit.

CHAPTER 6

DISCUSSION

6.1 Introduction

Uranium trial mining in the Karoo Uranium Province and the accompanying lack of proper remediation led to above-background heavy metal concentration in streams, soils, sediment and crops with localized values reaching concentrations above maximum allowed for human or faunal consumption.

6.2 Heavy Metal Contamination

The presence of uranium ore stockpiles on depicted mining sites is a source of downstream heavy metal contamination. The impact is however limited due to the lack of runoff and dry climate experienced in the study areas. A similar study performed by Rahn et al. (1996) on uranium mining in the Black Hills, USA, concluded that the effect of mine released contaminants to the environment is limited due to the dry climate. The Black Hills receive an annual precipitation of 400 to 600mm. Beaufort West receives an annual precipitation of 250mm, Laingsburg an average of 142mm and Edenburg 467mm (South African Weather Service 1990, 2002 and 2003).

An increase in precipitation in the Karoo Uranium Province, leading to a change in climate, may cause an increase in mine effluent causing detrimental effects on the environment. Studies performed on similar sites in wetter climates prove that the amount of effluent released from mine tailings, stockpiles and others is dependant on the climate. Murray et al. (1993), Akber et al. (1992) and Harries and Ritchie (1983) performed studies on environmental contamination as a result of leaching from uranium mines in northern Australia, where the mean annual precipitation is 1500mm Amaral et al. (1988) and Azevedo et al. (1987) performed studies on environmental impact on leaching from uranium mines on the Pocos de Caldas plateau in Brazil where the annual precipitation is 1700mm.

Heavy metal contamination may cause harmful effects to the top of the food chain through the process of biomagnifications. Through biomagnifications, the level of chemicals in any given organism increases through its intake of food. The heavy metal concentration of the prey is absorbed by the predator and accumulates. These processes may end up causing harmful effects to man (Kelly 1988).

6.2.1 Ryst Kuil

An estimated 2200t of uranium ore in stockpiles and barrels with grades reaching up to 0.35% U and 0.3% Mo is a source of localized pollution within the mining area and downstream of this site.

The Ryst Kuil mining area shows signs of uranium contamination in soils, with values reaching double the normal concentration of 1 ppm (Alloway 1993). These concentrations are found in the mining area (no. 5 on location map) and on the adjoining farm Kat Doorn Kuil, in the immediate vicinity of the mine (no. 7 on location map). A value of 1.37 ppm U was analyzed in a cultivated field to the east of the mine (no. 8 on location map). This land was previously irrigated through pumping of water from an exploratory borehole in the Cameron Shaft (personal communication with the owner of Ryst Kuil). These values are however still within the acceptable concentrations of uranium in soils (US Department of Health 1999).

Copper, molybdenum, lead and iron concentrations in water, soils and sediment are occasionally above background and above ideal (DWAF 1996 and Alloway 1993), downstream (no. 10, 11, 13, 14 and 15 on location map) and in the immediate vicinity of the site (no. 4 and 9 on location map). These are presently of relatively small concern as they are within the acceptable concentrations of heavy metals in water, soils and sediment (SABS 1999 and US Department of Health 1999).

Above maximum allowed lead concentrations in crops of Old Man Saltbush may cause poisoning in humans through consumption of animals feeding on these crops (Act 54 of 1972) (Appendix C1).

A matter of concern is the easy access gained into the abandoned Cameron Shaft, either through the main entrance (no. 2 on locality map) or via the trap door at the ventilator (no. 19 on locality map). Although no radon (^{222}Rn) measurements were taken for the current study, BEIR IV (1988) and Ragnarsdottir and Charlet (2000) state that underground mining of uranium is associated with an increased risk of lung cancer. Miners are placed at risk by the combination of radon and inadequate ventilation. Numerous studies performed by BEIR IV (1988) of underground miners exposed to radon daughters in the air of mines have shown an increased rate of lung cancer in comparison with non-exposed populations. Laboratory animals exposed to radon daughters also developed lung cancer.

6.2.2 Rietkuil

The mine has an estimated 6100t of stockpiled uranium ore with a grade reaching 0.05%, whilst molybdenum concentrations are in the vicinity of 0.35%. The stockpiles are a potential hazard for the local environment. Results show above-background values for groundwater to the east of the stockpiles (no. 9 and 10 on location map). These values are within the acceptable concentration of heavy metals in water (SABS 1999).

A high concentration of uranium, molybdenum and arsenic is present within the surface water and sediment in the open pit (no. 1 on location map). The uranium concentration in the water is more than 1000 times the ideal value for human consumption (WHO 2003), 45 times higher than the recommended concentration for human consumption (DWAF 1996) and 9 times higher than the human consumption value above which there is a high cancer risk over the long term and a high risk of renal damage over the short term (livestock watering is not available from DWAF 1996). The molybdenum concentration is 450 times the ideal value for livestock watering (human consumption is not available from DWAF 1996 or WHO 2003) and the arsenic is 4 times higher than the ideal value for human consumption and within the limits of livestock watering (DWAF 1996).

The sediment within the pit has an arsenic value 3 times higher than the normal concentrations in stream sediment and soil, whilst the molybdenum is 300 times higher and the uranium 700 times higher (Alloway 1993). Contaminated sediments may pose an ecological risk to aquatic biota either through direct exposure or as a source of bioaccumulation of heavy metals through the food chain (Heiskary 1996).

Lead, uranium and arsenic concentrations in soils downstream from the mine show (no. 4 and 5 on location map) an above-background concentration, but are still within the acceptable limits (US Department of Health 1999). Copper, molybdenum, lead and iron concentrations in water, soil and sediment are not above background downstream or in the immediate vicinity of the site.

Lead and arsenic concentrations in lucerne crops may cause poisoning in humans through consumption of animals feeding on these crops (Appendix C2) (Act 54 of 1972).

6.2.3 DR-3

An estimated total of 112t of uranium ore in stockpiles and barrels, with a grade in the vicinity of 0.35% uranium and 0.16% molybdenum, is located 500m northwards of the Middelstevlei homestead.

The effects of heavy metal pollution within the mining area and surrounds are scarce. Surface and groundwater concentrations are conclusive that any contamination is of low grade and only in the vicinity of the mine. Stream sediment concentrations (no. 7 on location map) downstream from the ore stockpiles show an above-normal uranium concentration of 1.59 ppm, this is however still within the normal values of contaminated soils and stream sediment (US Department of Health 1999).

Above maximum allowed arsenic and lead concentrations in onion crops may cause heavy metal poisoning in humans (Act 54 of 1972). Taking into account the maximum allowed human daily limit for heavy metal ingestion, the uranium and molybdenum values in onions are above normal and may cause poisoning if these are consumed on a daily basis (Appendix C3) (ATSDR 1999-2002, Opresko 1993 and WHO 1998).

A sample of algae (no. 2 on location map) on soil, 10 metres from the adit entrance, shows high concentrations of arsenic (182 ppm), lead (75 ppm), molybdenum (53 ppm) and uranium (148 ppm) (US Department of Health 1999).

6.2.4 Mooifontein

Uranium ore in stockpiles is estimated at 60t with uranium reaching grades of up to 0.12%. The molybdenum concentrations are in the order of 0.01% whilst arsenic concentrations are 0.02%.

A high concentration of uranium and arsenic in the surface water and sediment was obtained from the open pit (no. 2 on location map) on Mooifontein. The arsenic content in water is 1.5 times higher than the ideal level for human consumption (livestock watering is not available from DWAF 1996 or WHO 2003). The uranium content of the water is almost 15 times higher than the ideal concentration for human consumption (WHO 2003) and within limits available from DWAF (1996).

The uranium content in stream sediment is 14 times higher than the normal concentration (Alloway 1993). The stream sediment is a potential hazard as it is a growth medium for aquatic plants and bottom feeders. Due to the easy access to the water within the open pit, it is a regularly used for water consumption by domestic animals (personal communication by the owner Bultfontein) and other fauna.

Heavy metal concentrations in groundwater locations (no. 10, 11 and 12 on location map) are above background and above ideal (DWAF 1996). The high values, with the exception of those at the Mooifontein homestead, can be attributed to the close vicinity of the ore body. The values are however within the accepted concentration limits of heavy metals in water (SABS 1999).

The uranium content of stream sediment downstream (no. 8 on location map) of the open pit is above normal, but still within allowed concentration levels (US Department of Health 1999). The stream sediment levels at the Mooifontein homestead (no. 5 on location map), further downstream are within ideal concentration limits (Alloway 1993).

CHAPTER 7

CONCLUSIONS

7.1 Introduction

An assessment on the effects of uranium trial mining in the Karoo Uranium Province revealed the presence of anomalous heavy metal concentrations in water, sediment, soils and crops. These values are locally above maximum allowed for human and/or faunal consumption. The failure to properly remediate the trial mining areas through removing ore stockpiles, waste and mining structures as well as preventing entry into open pits and shafts leads to the existence of an environmental hazard.

Trial mining areas in the Karoo Uranium Province and its influence on the environment are of a smaller scale than similar studies performed by workers such as Schneider et al. (2001) at Konigstein Uranium mine, East Germany and Harries et al. (1997) at Rum Jungle Uranium mine, northern Australia. The results obtained in the present investigation are however of a disturbing nature revealing previously underestimated and overlooked sources of localised pollution of hazardous substances.

A more detailed study of the environmental impact of uranium ore stockpiles and the fate of mine effluent in the study areas is necessary before any finalized conclusions can be made. It is however important to control the mine effluent as soon as possible due to above-background heavy metal concentrations in soil and sediment downstream from the stockpiles.

The heavy metal content in the Rietkuil and Mooifontein open pits is of a serious nature and all possible action is necessary to avoid any exposure hereof to living organisms. The structures on Ryst Kuil are at present not an imminent hazard, whereas the easy access gained into the Cameron Shaft needs immediate attention.

7.2 Remedial suggestions

Processing of ore grade metals introduces a variety of chemicals to streams including nitrogen compounds from blasting operations, colloidal suspended solids and many trace metals of non-ore grade (As, Cu, Fe, Pb). The basic problem with mining is the enormous volume of wastes. Disposal on land has been the historic procedure, but it is clear that in nearly all cases this results in acid mine drainage and heavy metal dispersal and contamination, whilst disposal into waterways injects the contaminants directly. However, under specific conditions subaqueous disposal greatly reduces acid mine drainage, but toxic metals are still released or recycled or other impacts occur on biota (Allan 1995). Remediation should include the following:

A. Short term:

i. Asses the extent of local and regional pollution.

ii. Closure of entrance leading into Rietkuil open pit.

iii. Repairing the fence surrounding the Mooifontein open pit and closing of fence entrance.

iv. Locking the trap door leading into the Cameron Shaft on Ryst Kuil.

v. Repairing and locking the gate which gives access into the Cameron Shaft.

B. Long term:

i. Control the major sources of contamination (stockpiles) through selling, burial, liming, covering or removal.

The open pits and shafts within the study areas may well be needed by future generations when techniques to extract lower grade ore are used or developed or when the economics change. Any remediation causing the infill of these pits and shafts may cause the prevention of future reopening.

7.3 Further study

The ore stockpiles on the mining sites are hazardous and have the potential to cause further heavy metal pollution on a larger scale downstream from the mining sites. The following are selected areas that need further research:

7.3.1 Contamination of environment

a. The influence of uranium ore in stockpiles on surrounding vegetation and microbial diversity, as described by Steyn (1949) and Schippers et al. (1995).

b. The use of water and sediment as drinking or growth mediums in open pits on Rietkuil and Mooifontein and the influence thereof on living organisms.

c. The heavy metal content of living organisms in selected trial mining areas and the influence of bioaccumulation and biomagnifications.

d. Assessment of possible acid mine drainage.

7.3.2 Radon measurements

a. The measurement of radon (^{222}Rn) concentrations in the Cameron Shaft on Ryst Kuil through similar methods as described by Ellis (1998) and its influence on fauna entering the shaft.

7.3.3 Wind dispersion

a. The dispersion of heavy metals in air in a downwind direction from the uranium ore stockpiles with a similar method as described by Petterson and Koperski (1991).

7.3.4 Remedial investigations

a. The best possible remedial action to take regarding the presence of uranium ore in stockpiles, the open pits on Rietkuil and Mooifontein, the Cameron Shaft on Ryst Kuil and adit on DR-3.

7.3.5 Geochemical mapping

a. The drawing of detailed geochemical maps on a demarcated grid network depicting the heavy metal content in soils, flora, water and sediment.

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APPENDIX A1

1. Ore Quantity Calculations

The amount of ore on surface in each of the four study areas was calculated in order to obtain an estimate of the quantity available for possible environmental pollution. In the case of Ryst Kuil, DR-3 and Mooifontein the average volume of ore stockpiles was estimated in the field with a tape measure and mathematical equations for cones. The volume of ore on surface at Rietkuil was estimated as the amount excavated from the open pit. The position of ore in the pit was observed with a scintillation counter and the volume calculated with a tape measure. It is however possible that a fraction of ore has been removed from the surface of Rietkuil for metallurgical analysis.

It must be taken into account that these calculations are merely estimations and were recorded with all the tools available to the author. A more accurate recording will involve a bigger operation and more sophisticated and larger machinery.

In order to estimate the bulk ore mass available on the surface, the ore density was calculated. A representative sample of ore in stockpiles and barrels on Ryst Kuil, DR-3 and Mooifontein were taken for weight and volume measurements as well as density calculations. The density of in situ ore at Rietkuil was calculated by measuring the weight and volume of a square cut ore block. More accurate density calculations are possible if larger amounts can be used for measurements of weight and volume.

The following formula was used to obtain the bulk mass (tonnes) of ore on the surface of the four farms featuring in this study:

$$\textbf{Bulk mass (t)} = \textbf{density (g/cm}^3\textbf{)} \times \textbf{bulk volume (m}^3\textbf{)}$$

1.1 Density calculations for Ryst Kuil

1.1.1 Ore stockpiles

Table A1. Density calculations for ore in stockpiles on Ryst Kuil

Weight of sample (g)	Vol. of sample (cm^3)	Density of sample (g/cm^3)
8400	4680	1.79

1.1.2 Ore containing barrels

Table A2. Density calculations for ore in barrels on Ryst Kuil

Weight of sample (g)	Vol. of sample (cm^3)	Density of sample (g/cm^3)
8430	4670	1.80

1.2 Density calculations for Rietkuil

1.2.1 In situ ore

Table A3. Density calculations for in situ ore on Rietkuil

Weight of sample (g)	Vol. of sample (cm^3)	Density of sample (g/cm^3)
1280	485	2.64

1.3 Density calculations for DR-3

1.3.1 Ore stockpiles

Table A4. Density calculations for ore in stockpiles on DR-3

Weight of sample (g)	Vol. of sample (cm^3)	Density of sample (g/cm^3)
3817	2703	1.41

1.3.2 Ore containing barrels

Table A5. Density calculations for ore in barrels on DR-3

Weight of sample (g)	Vol. of sample (cm^3)	Density of sample (g/cm^3)
3254	2468	1.31

1.4 Density calculations for Mooifontein

1.4.1 Ore stockpiles

Table A6. Density calculations for ore in stockpiles on Mooifontein

Weight of sample (g)	Vol. of sample (cm^3)	Density of sample (g/cm^3)
5272	3408	1.54

APPENDIX A2

2. Sampling

Sampling in general means to obtain a sample in a form and amount suitable for analysis, which is representative of the total material to be analysed. Representative in this respect means, that the sample has to show a maximum of similarity to the total entity to be studied (Wagner 1995).

In the present study sampling was considered a very important contributor and all necessary steps were taken to ensure correct sampling, preparation and storage techniques. Sampling included the following:

2.1 Water

The movement of water and the diffusion of dissolved substances lead to different geochemical processes taking place in the Earth's crust. To a great extent they are responsible for the redistribution of chemical elements in soil and further on to the biosphere. Anthropogenic activities lead to disposal of a large amount of wastes to water basins which slowly accumulates in the oceans. This is one of the reasons that make the determination of metals and toxic elements in water an important task in environmental pollution control.

Sample preparation and storage for the present study including techniques as described by Djingova and Kuleff (2000) and Greenberg et al (1985) are as follows:

a. Use of plastic water containers.
b. Cleansing of sample bottles with Hydrochloric Acid (30% HCl) before sampling.
c. Rinsing with sample medium before sampling.
d. Filtering through ALBET low ash filter paper.
e. Lowering pH to 2 with Nitric Acid (55% HNO_3) after sampling.
f. Storage at 4 °C after sampling.

2.2 Surface water

Manual grab samples were taken at different sampling locations as described by Djingova and Kuleff (2000) 0.5m below the surface where possible.

2.3 Groundwater

Manual samples were taken in open boreholes (where possible) through means of a down the hole bailer. Only the top 1m of groundwater was sampled.

2.4 Soil

The processes of rock weathering lead to the formation of soils where additionally the climate, biological activity, relief etc. play very important roles. In the present study the following techniques were used in sampling, storage and treatment of soils as described by Djingova and Kuleff (2000) and Boulding (1994):

a. Stainless steel scoop used.
b. Top 30cm sampled.
c. Samples cooled to 4°C.
d. Samples dried in laboratory at 110°C.
e. Removal of stones roots and living organisms.

2.5 Stream sediment

Stream sediment samples were taken due to surface variations caused by seasonal stratification, rainfall, run-off, wind and lack of surface water. The following sample preparation methods as described by Djingova and Kuleff (2000) and Boulding (1994) were followed:

a. Stainless steel scoop used.
b. Top 30cm sampled.

c. Samples cooled to 4°C.
d. Samples dried in laboratory at 110°C.
e. Removal of stones roots and living organisms.

2.6 Crops

Plants are living organisms which, thanks to photosynthesis, are responsible for oxygen production. They are also an extremely important link in the food chain collecting from the soil, air and water and transmitting further to man and animals. The elemental composition of plants usually reflects the geochemical features of the area in which they grow. Crop samples were taken where applicable as follows:

a. Bulk sample taken of leaves, stems and roots where possible
b. Samples cooled to 4°C.

2.7 Ore

2.7.1 Stockpiles

Ore stockpiles were randomly sampled by removing the top layer of rock and sampling qualitatively from the top to the bottom of the dump. This technique allows for the most representative sample possible to be taken. Equipment used included a stainless steel scoop.

2.7.2 Barrels

Barrels were randomly sampled and overturned in order to retrieve a sample representing all the rock within. Equipment used included a stainless steel scoop.

APPENDIX A3

3. Analytical Techniques

3.1 Ore, soils and stream sediment

Whole rock geochemical analysis were processed on a PHILLIPS PW 1404 X-ray spectrometer with the help of Prof W.A. van der Westhuizen, chairman of the Geology Department, University of the Free State. Major element analyses were executed on fused glass discs, using the technique of Norrish and Hutton (1969). Trace elements and Na were analysed for on pressed power briquettes. Loss at 110°C was determined and is reported as H_2O^-. Loss on ignition at 1000°C was determined and is reported as L.O.I.

3.2 Water

Water samples were analyzed at the Institute for Ground Water Studies at the University of the Free State by Inductively Coupled Plasma Optical Emission Spectroscopy. ICP-OES is used for qualitative and quantitative determination of metals and certain non-metals in solution. The liquid sample is nebulised into a plasma where the temperature is sufficiently high to break chemical bonds, liberate elements present and transform them into a gaseous atomic state. A number of the atoms pass into the excited state and emit radiation. The frequency of this radiation is characteristic of the element that emitted it and as such can be used for identification purposes.

3.3 Crops

All plant material was subjected to high temperature organic material removal. Thereafter 50mg of the sample was dissolved in HF/HNO_3 at 260°C using high pressure microwave digestion. Samples were analysed in duplicate using ICP-MS on 4 point calibration from 0 to 100ppb using an Elan6100 ICP-MS.

APPENDIX B1

1. Water Quality Guidelines

The Department of Water Affairs and Forestry is the custodian of South Africa's water resources. Part of its mission is to ensure that the quality of water resources remains fit for recognized water uses and that the viability of aquatic ecosystems are maintained and protected. The South African Water Quality Guidelines are technical documents aimed at users with a basic level of expertise concerning water quality management and is used for comparison. Although these Water Quality Guidelines are preliminary for use on surface water, the groundwater analytical results were also compared as groundwater guidelines are not available (DWAF 1996).

The World Health Organization gives certain guidelines for water quality as draft documents (WHO 2003). These are presented with the guidelines of DWAF (1996).

The water quality guidelines of DWAF (1996) are further divided into numerous sub divisions, the following guidelines being relevant for the present study:

- Domestic use
- Agricultural use (irrigation)
- Agricultural use (livestock watering)
- Aquatic ecosystems

All guidelines feature the relevant ideal metal concentration in (mg/l).

1.1 Domestic use

Table B1. Recommended metal concentrations (mg/l) for domestic use. Modified from DWAF (1996) and WHO (2003).

	Uranium	Molybdenum	Arsenic	Lead	Copper	Iron
DWAF (1996)	0.07 - 0.284	N/A	0 - 0.01	0.01	0 - 1	0 - 0.1
WHO (2003)	0.009	N/A	0.01	N/A	2	N/A

N/A. Not available

1.2 Agricultural use (irrigation)

Table B2. Recommended metal concentrations (mg/l) for agricultural use (irrigation). Modified from DWAF (1996).

	Uranium	Molybdenum	Arsenic	Lead	Copper	Iron
DWAF (1996)	0 - 0.01	0 - 0.01	0 - 0.1	0 - 0.2	0 - 0.2	0 - 5

1.3 Agricultural use (livestock watering)

Table B3. Recommended metal concentrations (mg/l) for agricultural use (livestock watering). Modified from DWAF (1996).

	Uranium	Molybdenum	Arsenic	Lead	Copper	Iron
DWAF (1996)	N/A	0 - 0.01	0 - 1	0 - 0.1 (a) 0 - 0.5 (b)	0 - 0.5 (a) 0 - 1 (b) 0 - 5 (c)	0 - 10

Copper

a. Sheep

b. Cattle
c. Horses, pigs and poultry

Lead
a. All other livestock
b. Pigs

1.4 Aquatic ecosystems

Table B 4. Recommended metal concentrations (mg/l) for aquatic ecosystems. Modified from DWAF (1996).

	Uranium	Molybdenum	Arsenic	Lead	Copper	Iron
DWAF (1996)	N/A	N/A	0.01	0.0002	0.0003	N/A

N/A. Not available

APPENDIX B2

2.1 Maximum Human Ingestion Levels

In the following section the maximum levels from the Foodstuffs, Cosmetics and Disinfectants Act 54 (1972) as amended by Regulation no. 358 (1994) for inhalation and ingestion of heavy metals in South Africa are used where possible. These standards are used together with the Minimal Risk Levels for Heavy Metals in the USA as derived from The Agency for Toxic Substances and Disease Registry (US Department of Health 1999, 2000 and 2002), the lowest observable adverse effects levels (Opresko 1993 from www.antenna.nl/wise/uranium/utox.html), figures obtained from The World Health Organization (1998) from www.antenna.nl/wise/uranium/utox.html and heavy metal toxic levels (Waldbott 1973).

Table B5. Modified minimal risk levels for heavy metal human ingestion.

	ATSDR (1999 - 2002) (mg/day)	Act 54 (1972) (ppm)	Opresko (1993) (mg/day)	WHO (1998) (mg/day)	Waldbott (1973) (mg/day)
As	0.35	0.1 - 2.5	N/A	N/A	N/A
Cu	1.4	30	N/A	N/A	N/A
Fe	N/A	N/A	N/A	N/A	N/A
Pb	N/A	0.1 - 1	N/A	N/A	0.1 - 0.3
Mo	N/A	N/A	0.35	N/A	N/A
U	0.14	N/A	N/A	0.042	N/A

N/A Not available.

(mg/day) Daily intake for 70kg body weight.

APPENDIX B3

3.1 Soil and stream sediment contamination

Soil and stream sediments are key component ecosystems, both natural and agricultural, being essential for the growth of plants and the degradation and recycling of dead biomass (Alloway 1993).

Table B6. Normal levels (mg/kg) of heavy metals in soil

	Alloway (1993) (mg/kg)
As	1 - 40
Cu	30
Pb	42
Mo	2
U	1

APPENDIX C1

ANALYTICAL RESULTS

The geochemical data is reported in this appendix without any corrections for volatile content of the samples.

1. Ryst Kuil

1.1 Ore

Table C1.1 Major element concentrations (%) of Ryst Kuil ore sampled on different ore stockpiles.

	RKE 1 (no. 3 on map) (%)	RKE 2 (no. 3 on map) (%)	RKE 3 (no. 3 on map) (%)	RKE 4 (no. 3 on map) (%)
SiO_2	65.51	63.03	62.38	48.37
TiO_2	0.59	0.58	0.54	0.55
Al_2O_3	13.98	13.14	12.89	10.35
Fe_2O_3	3.49	3.57	3.84	3.70
MnO	0.19	0.34	0.37	0.85
MgO	1.03	0.95	0.88	0.58
CaO	3.79	5.36	6.03	14.35
Na_2O	3.47	3.26	3.22	2.08
K_2O	1.97	1.66	1.77	1.60
P_2O_5	0.17	0.16	0.17	0.39
H_2O-	0.25	0.45	0.38	0.46
LOI	3.68	4.66	4.51	12.45
TOT	98.14	97.16	96.96	95.71

Table C1.2 Minor element concentrations (ppm) of Ryst Kuil ore.

	RKE 1 (no. 3 on map)	RKE 2 (no. 3 on map)	RKE 3 (no. 3 on map)	RKE 4 (no. 3 on map)

	(ppm)	(ppm)	(ppm)	(ppm)
Rb	80.9	66.7	78.8	123.9
Ba	627.3	484.4	493.2	369.1
Sr	288.1	246.8	280.2	365.6
Zr	265.3	262.6	247.6	324.5
Nb	24.8	22.5	27.9	79.8
Ni	34.6	22.3	25.8	49.6
Zn	73.6	67.7	67.7	92.9
Cr	52.5	60.6	67.5	47.1
Cu	15.7	27.4	20.5	13.3
V	107.5	109.9	103.4	84.3
Y	25.8	22.8	22.6	20.9
Sc	11.7	15.1	14.8	15.1
Co	30.5	22.8	26.3	17.1
As	348.61	259.26	377.55	358.69
Pb	40.66	43.61	45.07	95.05
Mo	991.70	977.24	1155.21	2919.31
U	633.95	525.19	740.36	3763.08

1.2 Soil

Table C 1.3 Major element concentrations (%) of Ryst Kuil soil samples.

	RKG 1 (no. 4 on map) (%)	**RKG 2 (no. 5 on map) (%)**	**RKG 3 (no. 6 on map) (%)**	**RKG 4 (no. 7 on map) (%)**	**RKG 5 (no. 8 on map) (%)**	**RKG 6 (background) (%)**
SiO_2	68.12	63.84	68.32	69.93	65.49	68.90
TiO_2	0.66	0.57	0.57	0.67	0.62	0.64
Al_2O_3	14.13	16.09	14.13	13.81	15.19	13.98
Fe_2O_3	5.24	5.65	5.24	4.54	5.25	5.39
MnO	0.06	0.08	0.08	0.07	0.07	0.08
MgO	1.36	1.62	1.36	1.28	1.71	1.30
CaO	0.66	0.80	0.64	0.69	0.94	0.56
Na_2O	1.09	0.66	0.87	1.48	1.00	1.13
K_2O	3.12	3.68	2.77	2.91	3.39	2.85
P_2O_5	0.11	0.20	0.13	0.08	0.14	0.11

H_2O-	0.94	1.84	1.59	0.73	1.21	1.12
LOI	3.15	4.04	3.31	2.81	4.07	3.63
TOT	98.65	99.08	99.01	98.99	99.08	99.96

Table C1.4 Minor element concentrations (ppm) of Ryst Kuil soil samples.

	RKG 1 (no. 4 on map) (ppm)	**RKG 2 (no. 5 on map) (ppm)**	**RKG 3 (no. 6 on map) (ppm)**	**RKG 4 (no. 7 on map) (ppm)**	**RKG 5 (no. 8 on map) (ppm)**	**RKG 6 (background) (ppm)**
Rb	151.1	166.4	132.8	137.8	156.1	133.9
Ba	1467.2	997.1	1268.9	590.2	1003.0	713.6
Sr	98.5	97.4	91.6	103.8	163.6	92.1
Zr	234.4	207.4	231.5	281.7	203.6	239.2
Nb	12.0	10.1	10.2	12.6	11.0	11.8
Ni	24.1	26.6	25.3	23.3	25.7	25.3
Zn	78.8	92.2	77.3	75.1	88.7	79.4
Cr	73.8	94.1	74.8	70.9	73.5	75.6
Cu	21.7	20.0	19.4	19.6	25.8	21.5
V	110.5	123.3	118.3	92.4	110.3	107.8
Y	32.3	31.4	28.5	31.8	33.7	31.6
Sc	14.8	16.0	13.8	9.5	14.1	12.0
Co	23.1	28.7	24.1	20.8	25.6	28.8
As	11.28	11.89	12.44	10.21	10.65	13.13
Pb	32.53	32.91	33.35	32.93	28.66	30.30
Mo	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
U	0.13	2.27	<1.0	2.0	1.34	0.1

1.3 Crops and plants

Table C1.5 Minor element concentrations (ppm) of Ryst Kuil crop sample.

	RKP (no. 16 on map) (ppm)
Fe	1536.98

Cu	18.49
As	0.58
Mo	8.23
Pb	1.97
U	0.18

1.4 Stream sediment

Table C1.6 Major element concentrations (%) of Ryst Kuil stream sediment samples

	RKSS 1 (no. 14 on map) (%)	**RKSS 2 (no. 15 on map) (%)**	**RKSS 3 (background) (%)**
SiO_2	60.23	59.31	64.84
TiO_2	0.55	0.52	0.62
Al_2O_3	16.04	15.58	15.44
Fe_2O_3	6.25	5.56	5.49
MnO	0.08	0.09	0.09
MgO	1.91	2.12	1.43
CaO	1.25	2.20	0.87
Na_2O	0.57	0.59	0.83
K_2O	3.61	3.51	3.13
P_2O_5	0.14	0.15	0.10
H_2O-	2.13	2.14	1.80
LOI	5.72	6.56	4.28
TOT	98.48	98.35	98.91

Table C1.7 Minor element concentrations (ppm) of Ryst Kuil stream sediment samples

	RKSS 1 (no. 14 on map)	**RKSS 2 (no. 15 on map)**	**RKSS 3 (background)**

	(ppm)	(ppm)	(ppm)
Rb	174.2	165.8	149.4
Ba	1132.3	1401.6	721.3
Sr	149.9	220.4	189.0
Zr	176.1	159.5	192.5
Nb	10.1	9.6	9.4
Ni	26.6	26.9	26.0
Zn	99.1	97.0	88.3
Cr	98.3	85.6	83.8
Cu	26.1	24.7	23.6
V	131.3	116.0	123.9
Y	30.2	31.3	30.7
Sc	14.8	21.3	18.2
Co	29.5	27.0	29.0
As	13.02	12.40	11.92
Pb	37.47	33.79	36.34
Mo	<2.0	<2.0	<2.0
U	<1.0	0.77	0.1

1.5 Surface Water

Table C 1.8 Surface water concentrations (mg/l) taken at Ryst Kuil uranium mine.

	RKOW 1 (no. 14 on map) (mg/l)
Arsenic	<0.010
Copper	0.012
Iron	0.220
Molybdenum	0.003
Lead	<0.010
Uranium	<0.050

1.6 Groundwater

Table C 1.9 Ground water concentrations (mg/l) taken at Ryst Kuil uranium mine.

	RKGW 1 (mg/l) (no. 9 on map)	RKGW 2 (mg/l) (no. 10 on map)	RKGW 3 (mg/l) (no. 11 on map)	RKGW 4 (mg/l) (no. 12 on map)	RKGW 5 (mg/l) (Background value)	RKGW 6 (mg/l) (no. 13 on map)
Arsenic	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Copper	0.017	0.019	0.027	0.019	0.017	0.021
Iron	0.044	0.098	0.160	0.039	0.117	0.073
Molybdenum	0.018	0.017	0.019	0.011	0.011	0.023
Lead	<0.010	<0.010	<0.010	<0.010	0.011	0.011
Uranium	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050

APPENDIX C2

2. Rietkuil

2.1 Ore

Table C2.1 Major element concentrations (%) of Rietkuil ore.

	RE 1 **(no. 2 on map)** **(%)**	**RE 2** **(no. 2 on map)** **(%)**
SiO_2	66.65	71.49
TiO_2	0.50	0.53
Al_2O_3	13.51	13.55
Fe_2O_3	3.05	3.27
MnO	0.16	0.10
MgO	0.88	0.88
CaO	4.23	2.03
Na_2O	2.43	2.68
K_2O	1.64	1.73
P_2O_5	0.19	0.12
H_2O-	1.08	0.77
LOI	4.48	3.34
TOT	98.80	100.50

Table C2.2 Minor element concentrations (ppm) of Rietkuil ore.

	RE 1 **(no. 2 on map)** **(ppml)**	**RE 2** **(no. 2 on map)** **(ppm)**
Rb	69.2	66.2
Ba	483.6	736.5
Sr	204.9	195.5
Zr	260.8	277.9
Nb	25.4	16.0
Ni	22.3	18.0

Zn	54.1	56.5
Cr	41.1	41.9
Cu	16.2	18.3
V	85.0	87.1
Y	21.0	25.9
Sc	10.4	11.1
Co	15.8	24.5
As	357.70	237.58
Pb	57.28	65.16
Mo	3504.36	958.99
U	419.69	272.59

2.2 Soil

Table C2.3 Major element concentrations (%) of Rietkuil soil samples.

	RG 1 (background) (%)	**RG 2 (no. 3 on map) (%)**	**RG 3 (no. 4 on map) (%)**	**RG 4 (no. 5 on map) (%)**	**RG 5 (no. 6 on map) (%)**	**RG 6 (no. 7 on map) (%)**
SiO_2	76.61	67.75	72.23	76.25	75.77	73.91
TiO_2	0.57	0.50	0.54	0.53	0.51	0.53
Al_2O_3	12.32	12.01	13.53	12.15	12.32	12.90
Fe_2O_3	3.35	3.33	3.81	3.03	3.10	3.55
MnO	0.06	0.05	0.05	0.04	0.06	0.04
MgO	0.84	1.13	0.98	0.69	0.68	0.85
CaO	0.58	2.29	0.71	0.62	0.46	0.52
Na_2O	2.26	1.52	1.75	2.52	2.33	1.92
K_2O	1.76	2.14	2.37	1.66	1.76	2.11
P_2O_5	0.06	0.12	0.10	0.07	0.06	0.07
H_2O-	0.25	0.97	1.56	0.76	0.90	1.17
LOI	1.95	5.54	2.36	2.20	1.95	2.18
TOT	100.61	97.35	99.98	100.52	99.91	99.76

Table C2.4 Minor element concentrations (ppm) of Rietkuil Soil samples.

	RG 1 (background) (ppm)	RG 2 (no. 3 on map) (ppm)	RG 3 (no. 4 on map) (ppm)	RG 4 (no. 5 on map) (ppm)	RG5 (no. 6 on map) (ppm)	RG 6 (no. 7 on map) (ppm)
Rb	75.3	92.1	100.2	67.3	74.3	91.3
Ba	629.9	588.5	704.1	520.4	433.9	610.3
Sr	130.9	316.8	130.6	141.7	133.1	136.3
Zr	307.3	201.8	277.8	420.8	302.1	283.2
Nb	8.4	8.1	9.1	8.7	8.4	9.1
Ni	14.2	15.0	17.6	13.7	16.2	16.2
Zn	50.5	59.7	58.0	44.3	48.1	53.6
Cr	55.1	46.6	59.5	52.2	46.4	54.1
Cu	15.9	13.9	14.7	11.3	11.5	14.4
V	87.1	81.0	84.6	74.8	82.3	82.6
Y	21.1	23.1	25.3	22.3	22.2	23.4
Sc	12.0	7.6	10.1	7.0	8.0	7.3
Co	16.5	13.8	20.4	14.4	16.0	17.1
As	8.38	8.75	9.76	8.42	7.78	9.19
Pb	24.77	22.76	25.90	25.56	24.29	27.24
Mo	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
U	0.1	<0.1	0.56	<0.1	<0.1	<0.1

2.3 Crops and plants

Table C2.5 Minor element concentrations (ppm) of Rietkuil Plant sample

	RP 1 (no. 3 on map) (ppm)
Fe	17011.99
Cu	61.81
As	4.19
Mo	18.93
Pb	46.89
U	2.04

2.4 Stream sediment

Table C2.6 Major element concentrations (%) of Rietkuil stream sediment samples

	R PIT (no. 1 on map) (%)	RSS 1 (no. 11 on map) (%)	RSS 2 (no. 13 on map) (%)	RSS 3 (back-ground) (%)	RSS 4 (no. 14 on map) (%)	RSS 5 (no. 3 on map) (%)	RSS 6 (no. 15 on map) (%)
SiO_2	64.26	70.22	67.32	68.31	73.65	69.91	67.09
TiO_2	0.43	0.54	0.60	0.61	0.47	0.49	0.68
Al_2O_3	11.17	13.16	14.47	14.14	12.17	11.66	16.11
Fe_2O_3	2.45	4.02	4.78	4.78	3.15	3.53	5.14
MnO	0.09	0.07	0.05	0.08	0.05	0.06	0.08
MgO	1.13	1.09	1.37	1.46	0.66	1.14	1.60
CaO	6.09	0.83	0.74	0.84	0.60	2.43	0.98
Na_2O	2.34	1.34	1.40	1.70	2.59	1.64	1.52
K_2O	1.45	2.54	3.41	2.99	1.70	2.14	3.51
P_2O_5	0.10	0.09	0.10	0.12	0.10	0.15	0.13
H_2O-	1.36	1.47	1.16	0.55	2.06	1.20	0.56
LOI	7.64	3.00	2.87	2.67	1.94	4.08	2.94
TOT	98.52	98.36	98.27	98.26	99.13	98.43	100.34

Table C2.7 Minor element concentrations (ppm) of Rietkuil stream sediment samples

	R PITSS (no. 1 on map) (ppm)	RSS 1 (no. 11 on map) (ppm)	RSS 2 (no. 13 on map) (ppm)	RSS 3 (back-map) (ppm)	RSS 4 (no. 14 on map) (ppm)	RSS 5 (no. 3 on map) (ppm)	RSS 6 (no. 15 on map) (ppm)
Rb	68.0	110.8	153.3	134.6	66.6	92.5	151.3
Ba	487.5	785.6	684.1	762.2	576.5	690.2	624.1
Sr	291.4	123.3	105.3	138.9	119.3	299.9	123.4
Zr	208.2	236.8	214.3	219.0	250.7	193.0	212.0
Nb	22.3	11.1	13.4	13.7	7.3	9.5	12.8

Ni	21.0	18.2	21.1	22.5	14.2	17.4	22.5
Zn	63.4	67.0	81.6	79.2	49.0	60.9	83.8
Cr	37.4	60.1	63.2	61.1	48.5	51.2	51.2
Cu	25.0	16.9	15.1	21.2	10.4	16.2	18.3
V	67.4	95.8	106.7	98.6	83.9	83.3	97.5
Y	17.9	27.7	32.9	33.3	19.7	24.3	34.3
Sc	15.4	11.4	12.0	8.3	6.4	12.3	12.0
Co	13.3	20.3	22.0	25.3	17.5	15.2	23.2
As	125.63	8.73	9.87	12.05	8.53	9.82	11.55
Pb	29.65	27.36	29.44	34.10	23.83	25.28	28.88
Mo	684.43	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
U	786.52	<1.0	<1.0	0.39	<1.0	<1.0	0.19

2.5 Surface Water

Table C2.8 Surface water concentrations (mg/l) taken at Rietkuil uranium mine.

	ROW 1 (mg/l) (no. 11 on map)	**ROW 2 (mg/l) (no. 12 on map)**	**ROW 3 (mg/l) (Background)**	**ROW 4 (mg/l) (no. 14 on map)**	**R PIT (mg/l) (no. 1 on map)**
Arsenic	<0.010	<0.010	<0.010	<0.010	0.044
Copper	0.035	0.023	0.046	0.014	0.014
Iron	0.450	0.622	1.165	0.307	0.022
Molybdenum	0.002	0.001	0.001	0.002	4.519
Lead	0.010	0.016	0.022	<0.010	0.011
Uranium	<0.050	<0.050	<0.050	<0.050	12.893

2.6 Groundwater

Table C2.9 Ground water concentrations (mg/l) taken at Rietkuil uranium mine.

	RGW 1 (mg/l)	**RGW 2 (mg/l)**	**RGW 3 (mg/l)**	**RGW 4 (mg/l)**

	(no. 8 on map)	**(Background)**	**(no. 9 on map)**	**(no. 10 on map)**
Arsenic	<0.010	<0.010	<0.010	<0.010
Copper	0.016	0.017	0.012	0.018
Iron	0.077	0.043	0.281	0.250
Molybdenum	0.009	0.008	0.004	0.009
Lead	<0.010	<0.010	0.012	<0.010
Uranium	<0.050	<0.050	<0.050	<0.050

APPENDIX C3

3. DR-3

3.1 Ore

Table C3.1 Major element concentrations (%) of DR-3 ore.

	DE 1 (no. 3 on map) (%)	DE 2 (no. 3 on map) (%)
SiO_2	74.20	68.30
TiO_2	0.50	0.50
Al_2O_3	14.05	13.37
Fe_2O_3	3.05	3.58
MnO	0.08	0.14
MgO	0.84	0.96
CaO	1.06	3.35
Na_2O	2.80	2.45
K_2O	2.05	2.23
P_2O_5	0.19	0.28
H_2O-	0.67	0.60
LOI	1.97	3.68
TOT	101.44	99.44

Table C3.2 Minor element concentrations (ppm) of DR-3 ore.

	DE 1 (no. 3 on map) (ppm)	DE 2 (no. 3 on map) (ppm)
Rb	88.7	133.2
Ba	485.0	917.2
Sr	250.5	301.9
Zr	227.9	226.8

Nb	27.3	60.8
Ni	16.6	34.1
Zn	56.4	76.1
Cr	43.2	43.2
Cu	7.6	16.2
V	77.6	82.4
Y	18.9	26.8
Sc	9.5	11.7
Co	18.1	31.3
As	205.5	177.87
Pb	68.19	91.66
Mo	1586.11	1073.83
U	885.02	2889.98

3.2 Soil

Table C3.3 Major element concentrations (%) of DR-3 soil sample

	DG1 (no. 6 on map) (%)
SiO_2	70.73
TiO_2	0.60
Al_2O_3	14.49
Fe_2O_3	4.34
MnO	0.04
MgO	1.50
CaO	0.96
Na_2O	1.45
K_2O	3.22
P_2O_5	0.12
H_2O-	0.44
LOI	2.97
TOT	100.85

Table C3.4 Minor element concentrations (ppm) of DR-3 soil sample

	DG1 (no. 6 on map) (ppm)
Rb	138.0
Ba	669.2
Sr	190.9
Zr	218.3
Nb	11.5
Ni	19.1
Zn	74.7
Cr	55.8
Cu	17.2
V	91.4
Y	30.7
Sc	12.9
Co	19.6
As	10.26
Pb	27.29
Mo	<2.0
U	<1.0

3.3 Crops and plants

Table C3.5 Major element concentrations (%) of DR-3 plant and crop samples

	DP 1 (no. 2 on map) (%)	**DP 2 (no. 6 on map) (%)**
SiO_2	66.22	N/a
TiO_2	0.63	N/a
Al_2O_3	15.93	N/a
Fe_2O_3	4.60	N/a
MnO	0.10	N/a

MgO	1.41	N/a
CaO	0.95	N/a
Na_2O	1.54	N/a
K_2O	2.77	N/a
P_2O_5	0.19	N/a
H_2O-	0.84	N/a
LOI	4.99	N/a
TOT	100.17	N/a

N/a Not available

Table C3.6 Minor element concentrations (ppm) of DR-3 plant samples

	DP 1 (no. 2 on map) (ppm)	**DP 2 (no. 6 on map) (ppm)**
Rb	115.1	N/a
Ba	839.5	N/a
Sr	173.8	N/a
Zr	221.5	N/a
Nb	13.9	N/a
Ni	29.6	N/a
Zn	92.2	N/a
Cr	94.1	N/a
Cu	20.0	20.74
V	123.3	N/a
Y	31.4	N/a
Sc	16.0	N/a
Co	28.7	N/a
As	182.08	9.61
Pb	75.91	17.34
Mo	53.96	4.36
U	148.21	3.59

N/a Not available

3.4 Stream sediment

Table C3.7 Major element concentrations (%) of DR-3 stream sediment samples

	DSS 1 (no. 7 on map) (%)	DSS 2 (background) (%)	DSS 3 (background) (%)	DSS 4 (no. 8 on map) (%)	DSS 5 (no. 9 on map) (%)
SiO_2	69.01	68.66	70.00	69.82	68.46
TiO_2	0.61	0.63	0.64	0.62	0.66
Al_2O_3	14.98	15.26	15.17	15.14	15.77
Fe_2O_3	4.67	4.80	4.96	4.90	5.02
MnO	0.06	0.05	0.08	0.09	0.07
MgO	1.51	1.52	1.63	1.56	1.84
CaO	1.04	1.03	1.02	1.00	1.04
Na_2O	1.38	1.38	1.49	1.50	1.45
K_2O	3.38	3.39	3.41	3.36	3.77
P_2O_5	0.11	0.12	0.14	0.14	0.13
H_2O-	1.09	0.49	0.49	0.41	0.48
LOI	3.00	2.89	2.67	2.65	2.85
TOT	100.83	100.23	101.70	101.19	101.54

Table C3.8 Minor element concentrations (ppm) of DR-3 stream sediment samples

	DSS 1 (no. 7 on map) (ppm)	DSS 2 (background) (ppm)	DSS 3 (background) (ppm)	DSS 4 (no. 8 on map) (ppm)	DSS 5 (no. 9 on map) (ppm)
Rb	149.0	149.0	148.4	146.8	168.4
Ba	729.6	701.4	728.2	733.0	661.5
Sr	160.9	156.7	165.5	169.5	142.5
Zr	209.7	216.8	213.1	219.5	203.1
Nb	12.4	12.5	13.0	12.7	13.5

Ni	20.1	20.6	20.4	21.8	22.4
Zn	76.3	81.2	80.5	79.2	83.7
Cr	53.8	63.8	58.5	56.7	58.7
Cu	16.4	18.6	18.5	20.1	19.8
V	98.7	101.1	98.2	93.7	101.0
Y	32.1	34.1	34.9	34.4	35.5
Sc	9.5	8.9	14.1	13.8	15.1
Co	24.0	23.5	26.0	25.6	22.9
As	12.42	9.65	11.80	11.07	10.87
Pb	28.66	26.67	32.16	29.42	26.49
Mo	<2.0	<2.0	<2.0	<2.0	<2.0
U	1.59	<1.0	<1.0	<1.0	<1.0

3.5 Surface Water

Table C3.9 Surface water concentrations (mg/l) taken at DR-3 uranium mine.

	DOW 1 (no. 10 on map) (mg/l)
Arsenic	<0.010
Copper	0.015
Iron	0.040
Molybdenum	0.004
Lead	<0.010
Uranium	<0.050

3.6 Groundwater

Table C3.10 Ground water concentrations (mg/l) taken at DR-3 uranium mine.

	DGW 1 (no. 1 on map)	**DGW 2 (Background)**	**DGW 3 (no. 4 on map)**	**DGW 4 (no. 5 on map)**

	(mg/l)	**(mg/l)**	**(mg/l)**	**(mg/l)**
Arsenic	<0.010	<0.010	<0.010	<0.010
Copper	0.011	0.019	0.026	0.017
Iron	0.128	0.164	0.033	0.145
Molybdenum	0.004	0.008	0.005	0.003
Lead	<0.010	<0.010	<0.010	<0.010
Uranium	<0.050	<0.050	<0.050	<0.050

APPENDIX C4

4. Mooifontein

4.1 Ore

Table C4.1 Major element concentrations (%) of Mooifontein ore.

	ME 1 (no. 2 on map) (%)	ME 2 (no. 2 on map) (%)
SiO_2	70.95	69.44
TiO_2	0.62	0.52
Al_2O_3	14.11	13.01
Fe_2O_3	3.64	3.51
MnO	0.09	0.19
MgO	1.56	1.04
CaO	1.82	5.05
Na_2O	1.59	1.57
K_2O	2.63	2.36
P_2O_5	0.17	0.16
H_2O-	0.91	0.70
LOI	3.19	5.40
TOT	101.29	102.94

Table C4.2 Minor element concentrations (ppm) of Mooifontein ore.

	ME 1 (no. 2 on map) (ppm)	ME 2 (no. 2 on map) (ppm)
Rb	115.5	106.4
Ba	1614.7	1279.1
Sr	276.8	298.0
Zr	218.1	187.9

Nb	25.9	30.9
Ni	20.4	22.0
Zn	72.2	65.6
Cr	46.6	54.3
Cu	11.7	15.5
V	98.7	119.5
Y	24.4	23.7
Sc	8.0	10.4
Co	21.0	11.8
As	38.45	58.07
Pb	53.86	60.68
Mo	76.56	88.55
U	810.28	1174.82

4.2 Soil

Table C4.3 Major element concentrations (%) of Mooifontein soil samples

	MG 1 (no. 9 on map) (%)	**MG 2 (Background) (%)**
SiO_2	65.65	67.52
TiO_2	0.67	1.01
Al_2O_3	13.22	14.80
Fe_2O_3	4.79	6.21
MnO	0.11	0.11
MgO	3.16	2.35
CaO	4.64	3.76
Na_2O	1.76	1.42
K_2O	2.18	2.12
P_2O_5	0.07	0.08
H_2O-	0.08	0.15
LOI	6.47	2.79
TOT	102.81	102.32

Table C4.4 Minor element concentrations (ppm) of Mooifontein soil samples.

	MG 1 (no. 9 on map) (ppm)	MG 2 (Background) (ppm)
Rb	88.9	74.0
Ba	7.7.8	556.8
Sr	333.5	199.6
Zr	187.7	276.4
Nb	9.0	13.0
Ni	26.2	39.1
Zn	65.2	59.7
Cr	115.0	199.1
Cu	25.0	36.0
V	112.5	161.0
Y	24.8	20.5
Sc	18.5	22.2
Co	24.6	28.6
As	9.94	3.97
Pb	25.70	20.16
Mo	<2.0	<2.0
U	<1.0	<1.0

4.3 Stream sediment

Table C4.5 Major element concentrations (%) of Mooifontein stream sediment samples

	MPIT SS (no. 2 on map) (%)	MSS 1 (no. 3 on map) (%)	MSS 2 (no. 4 on map) (%)	MSS 3 (no. 5 on map) (%)	MSS 4 (no. 6 on map) (%)	MSS 5 (no. 7 on map) (%)	MSS 6 (no. 8 on map) (%)	MSS 7 (Back – ground) (%)
SiO_2	63.81	55.27	65.27	67.32	63.44	66.03	62.86	68.39
TiO_2	0.60	0.51	0.62	0.68	0.68	0.58	0.73	0.73
Al_2O_3	12.12	10.94	12.02	12.41	13.13	12.29	14.07	15.25

Fe_2O_3	4.17	3.83	4.04	4.54	5.03	3.92	6.18	4.99
MnO	0.11	0.07	0.08	0.09	0.14	0.10	0.21	0.07
MgO	1.81	2.26	1.94	2.22	2.34	2.73	2.71	1.19
CaO	5.75	11.96	5.08	4.75	5.50	4.72	5.03	1.04
Na_2O	1.17	0.85	1.21	1.39	1.13	0.99	1.10	0.96
K_2O	2.26	1.73	1.96	2.30	2.29	2.09	2.33	2.62
P_2O_5	0.08	0.02	0.06	0.10	0.11	0.05	0.09	0.12
H_2O-	0.85	1.16	1.29	0.51	0.39	0.52	0.69	0.71
LOI	6.89	12.72	7.64	5.37	8.19	7.78	5.65	5.14
TOT	99.60	101.34	101.21	101.67	102.37	101.89	101.65	101.21

Table C4.6 Minor element concentrations (ppm) of Mooifontein stream sediment samples

	MPIT SS (no. 2 on map) (ppm)	**MSS 1 (no. 3 on map) (ppm)**	**MSS 2 (no. 4 on map) (ppm)**	**MSS 3 (no. 5 on map) (ppm)**	**MSS 4 (no. 6 on map) (ppm)**	**MSS 5 (no. 7 on map) (ppm)**	**MSS 6 (no. 8 on map) (ppm)**	**MSS 7 (Back–ground) (ppm)**
Rb	86.0	70.5	77.3	89.8	94.6	78.3	95.8	104.1
Ba	765.1	582.1	608.7	710.1	827.9	670.1	823.7	911.4
Sr	280.1	311.4	263.2	257.9	284.8	345.5	246.1	192.6
Zr	211.0	173.9	217.3	224.1	214.1	173.1	194.3	227.8
Nb	9.6	7.5	6.0	9.5	10.1	7.0	10.4	9.1
Ni	24.3	21.2	26.1	23.9	29.3	24.5	39.9	28.3
Zn	55.2	52.8	51.0	58.6	63.6	53.1	67.7	75.2
Cr	89.5	84.8	100.6	115.0	126.6	98.0	151.7	131.4
Cu	18.4	16.6	20.9	19.8	22.8	20.4	32.6	26.7
V	111.9	100.6	96.6	118.9	128.6	103.5	145.1	130.2
Y	23.5	19.8	17.8	27.3	27.6	19.5	26.5	27.2
Sc	16.6	23.7	18.2	12.6	16.9	19.4	20.0	18.5
Co	22.2	13.8	15.5	23.5	26.8	19.9	33.8	27.6
As	14.13	7.84	7.20	11.66	11.12	7.36	13.49	7.85
Pb	29.36	17.58	21.04	30.55	25.04	22.72	28.79	29.34
Mo	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
U	14.66	<1.0	<1.0	<1.0	<1.0	<1.0	1.89	<1.0

4.5 Surface Water

Table C 4.7 Surface water concentrations (mg/l) taken at Mooifontein uranium mine.

	MOW 1 (no. 3 on map) (mg/l)	**MOW 2 (no. 4 on map) (mg/l)**	**MOW 3 (no. 5 on map) (mg/l)**	**MOW 4 (no. 5 on map) (mg/l)**	**MOW 5 Back - ground (mg/l)**	**MPIT 1 (no. 2 on map) (mg/l)**	**MPIT 2 (no. 4 on map) (mg/l)**
Arsenic	0.014	0.013	<0.010	<0.010	<0.010	0.015	0.015
Copper	0.004	0.004	0.005	0.003	0.049	0.004	0.004
Iron	0.486	1.073	0.257	0.216	1.353	0.328	0.305
Molybdenum	0.002	0.003	0.002	0.006	<0.001	0.011	0.012
Lead	<0.010	0.011	0.013	<0.010	0.027	0.013	0.019
Uranium	<0.050	<0.050	<0.050	<0.050	<0.050	0.137	0.137

4.6 Groundwater

Table C4.8 Groundwater concentrations (mg/l) taken at Mooifontein uranium mine.

	MGW 1 (no. 10 on map) (mg/l)	**MGW 2 (no. 11 on map) (mg/l)**	**MGW 3 (no. 12 on map) (mg/l)**	**MGW 4 (no. 13 on map) (mg/l)**	**MGW 5 Back – ground (mg/l)**
Arsenic	<0.010	<0.010	<0.010	<0.010	<0.010
Copper	0.054	0.024	0.007	0.009	0.003
Iron	0.246	0.122	0.198	0.114	0.049
Molybdenum	0.008	0.004	0.003	<0.001	<0.001
Lead	0.017	0.014	<0.010	<0.010	<0.010
Uranium	<0.050	<0.050	<0.050	<0.050	<0.050