Prospecting For Iron and Titanium Using Termitaria

Kinaichu James. G, Kiptoo Jackson .K, Onditi Anam. O.
Department of Chemistry, Jomo Kenyatta University of Agriculture and Technology,
P.O Box 62000-00200 Nairobi, Kenya
* E-mail of the corresponding author: gichurukinaichu@yahoo.com

Abstract
Mining activities begin with mineral prospecting and exploration, which can be quite expensive. A number of mineral prospecting methods are known such as excavation of soil for analysis, phyto- prospecting, and hydro-geochemical prospecting among others. Ants and termites are known to burrow up to 55 meters to water tables. In the process, they bring up debris, which may contain traces of minerals in mineralized areas. Qualitative and quantitative analysis of anthills' and termite mound soil samples can be used as preliminary tests for prospects of finding a given mineral. Termitaria sampling has been used in other parts of the world such as Australia, India and Ghana. The study sought to find out whether there are significant levels of iron and titanium in anthills soil samples compared to top soil samples from Kwale, Kathwana and Kithiori, which are mineralized areas in Kenya. Flame atomic absorption spectroscopy was used to determine the metals under study after acid digestion. The control samples had lower concentrations of iron for all the three areas; 20.63±0.09 mg/g compared to mean concentration of anthill of 25.3±0.06 mg/g in Kwale, 90.53±0.00 mg/g compared 98.53±0.29 mg/g at Kathwana and 82.63±0.22 mg/g compared to 89.46±0.00 mg/g at Kithiori. Titanium content in termitaria samples was higher than the control for all the three areas; 14.94±0.24 mg/g compared14.72±0.00 mg/g at Kwale, Kithiori18.47±0.03 mg/g compared to15.93±0.03 mg/g at Kithiori and 14.52±0.03 mg/g compared to13.13±0.00 mg/g at Kathwana. These results demonstrate the potential for use of termitaria soil sampling in mineral prospecting. For conclusive results of iron and titanium mineralization, multimedia sampling is recommended.
Keywords: Termitaria, Mineral Prospecting, Flame Atomic Absorption Spectroscopy.

1. Introduction

Minerals and metals are a critical part of developing a modern society providing essential products, wealth, jobs and other opportunities (Hodge, 2011). Mining has been, and in many cases remains, important to the economic development of a number of industrialized countries such as Australia, Canada, Sweden, and the United States, which in many ways based their development on their natural resources. Prospecting involves searching for mineral deposits with the view to mine it at a profit (www.atlascopcoexploration.com/1.0.1.0/354/TS3). Exploration is the term used for systematic examination of a deposit. A mineral prospector looks for surface exposure of minerals, by observing irregularities in colour, shape or rock composition. The recovery of metals from the earth starts with exploration. Biogeoprospecting of minerals involves the study of plants and animals activities that can lead to indication of occurrence of minerals (Horsnail R. F., 2001). Use of plants in prospecting for minerals is phyto-prospecting while use of animals is geozoological prospecting. In phyto-prospecting, chemical analysis of plants is carried out in order to detect the presence of mineralization beneath the earth surface. It is a cheaper method except that it requires identification and characterization of hyperaccumalators of minerals. Phyto-prospecting has an advantage over conventional soil sampling in that it does not disturb the environment very much as only small amounts of soils are dug for analysis (Nkoane, 2003).

Chemical applications for mineral exploration have been greatly developed and applied since at least the mid-1900s. Gold and uranium deposits were found in Canada through analysis of vegetation (Nkoane, 2003). A very large deposit of uranium was discovered 150 meters below the surface at Wollaston,Saskatchewan where the surface soils gave no indication of the element but twigs of black spruce (picea mariana) accurately delineated the deposit (Brooks,1998). Plant analysis has also been used for identification of copper in Zambia, Zaire and South Africa (Brummer J .J. and Woodward G.D., 1999). The sampling of plant materials in phyto-exploration programmes is relatively well developed and accepted **(**Dunn, 2007**),** especially compared with geozoological techniques for mineral exploration.

The study of insects and animals as they interact with their mineral environment is called geozoology (Brooks, 1983). Ants are known to bring grains of rock up to the surface (Ralph, 2003). Anthill prospecting theory was proposed in Zimbabwe in 1965, following assay results of 2.835g gold per tonne of ant heaps built up on overburden Kalahari sand (Ralph, 2003).This unique prospecting method is very different from the conventional approaches aimed at looking for a mineral occurrence. The normal search in the field involves outcrop sampling, float examination, the search of old workings, and tracing known faults. Where valuable minerals lie completely covered by overburden there is little chance of discovery using only these standard visual practices. Kalahari sand covers much of south-central and southern Africa, effectively concealing outcrops (Ralph, 2003). Termitaria have potential to be developed as a mineral exploration sampling medium for the following reasons.

(i) They are widespread and abundant across large regions of semi-arid tropical savannah regions in Africa making them readily available for mineral exploration programmes.
(ii) They result from subsurface burrowing activity of termites and therefore their chemistry may reflect the chemistry of subsurface materials.
(iii) They can be relatively conveniently and easily sampled at the land surface in a manner that minimizes environmental and cultural impact.

Termitaria are utilized at present in mineral exploration programmes in Africa, largely as a result of published accounts of termitaria there hosting indicator minerals such as ilmenite(weakly magnetic titanium-iron oxide) from subsurface mineralization, such as in the Kalahari. Geochemical soil and termitaria sampling in Niger, West Africa, has been used successfully in the search for gold in this arid environment **(**Gleeson and Poulin 1989; Freyssinet et al., 1990; Roquin et al., 1991).

1.1 Anthills (Termitaria)

Anthills are piles of earth, sand or clay found at the entrances of ant colonies (Roja, 2009). Anthills are formed by industrious legions of worker ants for meeting a variety of their needs such as dwelling, mating and storing food. In the construction of a termitaria water and soil are essential.

Figure1: Plate of an anthill

Termites go for water through soft slickensides and along talc-coated vein walls (Ralph, 2003). They chew their way into the easy stuff and carry it to the surface. Ants and termites operate above the water table, in the oxidized zone, where rock alteration has led to softening. They do not actually fracture quartz with their clasping jaws. Natural freeze-thaw cycles, earthquakes, and other invasive events crack vein material over geological eons, permitting the ant to pick up broken pieces from the mother rock (Ralph, 2003). Termites are known to mine passages down to water, carrying the debris back up to the surface. They dig up to 55 meters to water table in some places (Ralph, 2003). Termites build mounds reaching heights of four feet and they are significant agents of ecosystem processes. They can have more biomass than mammals on some African savannas and can remove and digest the majority of plant-originated litter. Termites have the ability to burrow to the subsoil and contribute to the development of soil profiles through bioturbation. Termites and their bioturbation of the regolith during termitaria construction have long been recognized as a significant influence on the chemical and physical properties of soils (Nye 1955**;** Williams 1968, 1978; Lee and Wood 1971; Holt *et al*., 1980; Aspandiar, 2004). This may include chemical additions to surface soils through the upward transport of buried components of the regolith such as key ore indicator minerals. Mound-building activity of termites results in an upward transfer of clay, silts and fine particles to the ground surface (Tooms and Webb 1961; Watson, 1979**;** Surya Prakash Rao and Raju 1984*)***.** Termites also facilitate the upward movement of clays, silt and sand particles as this material is deposited in termitaria, and observed micro-aggregates of kaolinite and quartz derived from the upper saprolite (chemically weathered rock) in the soil surface layer (Freysinnet *et al.,* 1990)**.** Other researchers have noted that the silty material in termitaria is derived from the mottled zone or the top of the saprolite within a 'lateritic' (iron oxide rich) profile (Boyer, 1973). Consequently, termite nest structures have long been used as geochemical and mineralogical sample media for the discovery of ore deposits buried beneath weathered cover and shallow sediments. In this study use of termitaria as sampling media for iron and titanium prospecting is explored.

2.0 MATERIALS AND METHODS

2.1 Study Areas

Sampling for this study was carried out at Kwale and Tharaka Nithi counties where iron and titanium are known to occur. Mining of titanium is done at Kwale by an Australian company, Base Titanium Limited. The mining area is 50 km south of Mombasa a region within the coordinates 4°10′S 39°27′E. Kwale County is in the former Coast Province of Kenya which is mainly an inland county, but has coastline south of Mombasa. At Tharaka Nithi two locations, Kithiori and Kathwana where iron and Titanium had been mined on small scale were chosen. Tharaka Nithi County is located in the former Eastern Province of Kenya on the coordinates: 0°18′S 38°E; it borders Meru County to the North and North East, Kitui County to the East and South East, Embu County to the South and South West. The rainfall ranges between 200 mm and 800 mm per annum. The county is on the leeward side of Mount Kenya and is dry for better part of the year so it is a semi-arid area. Temperatures in Tharaka Nithi range from a minimum of 11° C to a maximum of 25.9° C.

2.2 Sample Collection

Ten anthills were selected randomly and samples collected from various sections of the termitaria i.e at the bottom, inside, mid-way up an anthill and at the top of an anthill. For control, soil samples were collected 5 metres away from each termitaria picked for sampling. Soil samples were collected in nonmetallic containers to avoid contamination. All samples were labeled by pens containing nonmetallic ink.

2.3 Reagents

All reagents used in this study were of Analytical Reagent (AR) grade. Distilled water was used to prepare all extracting reagents, preparation and dilution of all solutions used. Aqua regia used in digestion was made by mixing nitric acid and hydrochloric acid in the ratio 1:3 by volume. Hydrofluoric acid was used as received from the supplier. 5 M boric acid was made by dissolving 65 g of boric acid crystals in 1 L of water. All reagents were procured from ChemTech Analytical (UK). Stock solutions of commercial standards were used. For titanium Mount Royal Gabbro, rock standard was used, while for iron Syanite rock standard was used. Calibration standard were prepared by serial dilutions of the stock solutions.

2.4 Instrumentation

Acid digested samples were analyzed for iron and titanium using flame atomic absorption spectrometry (FAAS). A Spectra A10 spectrometer was used at the mines and geology laboratory in Nairobi. Hollow cathode lamps were used as excitation sources with resonance lines at 248.2 nm and 364.3nm for iron and titanium respectively. For the determination of iron, air- acetylene fuel system with a flow rate of 1.2 L/min was used. In the determination of titanium nitrous oxide –acetylene with flow rate of 4.5 L/min was used. Lamp intensity and band pass were used as recommended by the manufactures.

2.5 Determination of iron and titanium

The soil samples were oven dried at 110^{o} C for six hours. Large particles including stones and plant remains were removed manually. Dried soils samples were separately pulverized to about 100 µm by use of disc mill pulverizer.

0.10 g of the sample was weighed and transferred to 100 ml plastic bottle. 3 ml of hydrofluoric acid and 1 ml aqua regia was added. The mixture was allowed to stand overnight. 50ml of boric acid was added and mixture allowed to stand for 1 hour. It was then made to volume with distilled water. Dilutions were made using a mixture of boric acid and distilled water (1:1). Iron and titanium were determined using FAAS.

Results

Table 1: Concentrations of Iron in mg/g

		1	2	3	4	5	6	7	8	9	10
KWALE	A	23.15±0.01	20.66±0.00	20.64±0.15	20.11±0.00	19.89±0.22	20.92±0.00	20.74±0.10	19.35±0.00	20.11±0.10	20.73±0.00
	B	23.27±0.00	25.84±0.13	23.67±0.00	27.71±0.13	25.43±0.06	24.95±0.15	21.31±0.09	21.43±0.15	21.67±0.15	20.97±0.00
	I	27.92±0.00	28.85±0.11	27.26±0.25	28.82±0.10	26.23±0.16	27.2±0.00	25.63±0.00	25.96±0.20	26.74±0.00	26.59±0.20
	M	19.52±0.14	20.68±0.20	20.27±0.17	24.72±0.11	23.21±0.26	24.45±0.00	24.9±0.09	25.32±0.00	23.78±0.17	23.64±0.16
	T	23.28±0.07	21.98±0.00	23.94±0.00	23.26±0.20	25.62±0.13	24.31±0.08	24.05±0.00	26.37±0.21	25.72±0.00	25.47±0.00
KATHWANA	A	70.5±0.10	95.2±0.16	38.71±0.17	67.41±0.00	109.9±0.00	109.9±0.13	81.2±0.00	142.8±0.17	93.1±0.18	96.6±0.00
	B	140±0.03	110.2±0.09	36.89±0.14	85.33±0.19	95.2±0.00	122.7±0.00	87.5±0.06	90.3±0.06	115.5±0.00	101.5±0.15
	I	107.1±0.13	122.1±0.00	37.73±0.00	80.01±0.14	88.9±0.15	157.5±0.00	83.3±0.00	84±0.18	114.8±0.27	103.6±0.00
	M	88.9±0.00	103.6±0.00	37.92±0.30	134.4±0.13	86.1±0.00	131.6±0.19	88.9±0.08	91±0.00	121.1±0.10	107.8±0.00
	T	108±0.15	107.8±0.18	38.3±0.00	98.7±0.00	88.9±0.21	116.9±0.02	119.7±0.00	88.9±0.17	109.2±0.00	109.2±0.13
KITHIORI	A	63.7±0.11	142±0.21	67.9±0.00	81.69±0.18	81.69±0.11	75.11±0.19	71.33±0.00	87.5±0.00	74.97±0.00	80.39±0.19
	B	71.4±0.00	150.5±0.00	65.8±0.19	85.33±0.00	79.66±0.09	83.44±0.07	85.68±0.00	81.97±0.00	75.39±0.18	88.27±0.16
	I	64.89±0.17	152.6±0.12	84.91±0.00	80.01±0.20	87.29±0.07	60.27±0.21	121.1±0.23	80.08±0.08	76.86±0.02	128.8±0.00
	M	158.7±0.14	98±0.00	65±0.08	67.4±0.15	77.77±0.00	75.18±0.18	68.53±0.00	140.7±0.05	71.54±0.00	79.6±0.24
	T	63.3±0.00	100.1±0.10	82.95±0.0	84.21±0.15	80.36±0.00	81.48±0.07	68.88±0.21	85.8±0.14	144.2±0.00	80.47±0.16

Table 2: Mean Concentrations of Iron in mg/g per study area

	Kwale	Kathwana	Kithiori
A	20.63±0.09	90.53±0.00	82.63±0.22
B	23.63±0.10	98.51±0.22	86.74±0.23
I	27.12±0.06	97.90±0.31	93.68±0.30
M	23.05±0.00	99.13±0.28	90.24±0.03
T	24.40±0.01	98.56±0.10	87.18±0.22
MEAN CONCENTRATION OF ANTHILL	25.3±0.06	98.53±0.29	89.46±0.00

KEY

A: **A**djacent (control) B: **B**ottom of an anthill I : **I**nside of an anthill

M: **M**iddle of an anthill T: **T**op of an anthill

Table 3: Concentration of Titanium in mg/g per study area

		1	2	3	4	5	6	7	8	9	10
KWALE	A	14.02±0.00	13.38±0.17	15.04±0.00	15.24±0.07	13.34±0.22	15.28±0.00	14.52±0.21	16.23±0.00	14.34±0.17	15.81±0.00
	B	14.46±0.06	15.62±0.00	15.24±0.07	16.02±0.00	16.52±0.13	17.21±0.00	16.12±0.17	14.23±0.19	15.76±0.08	14.73±0.00
	I	13.38±0.06	14.26±0.19	15.18±0.15	15.04±0.01	16.63±0.00	15.47±0.16	14.98±0.00	16.81±0.04	16.71±0.00	15.74±0.00
	M	13.14±0.00	12.08±0.21	15.7±0.00	12.68±0.00	13.52±0.19	16.29±0.00	14.11±0.22	12.46±0.00	12.89±0.20	13.63±025
	T	14.04±0.23	16.43±0.00	15.84±0.00	14.14±0.21	16.41±0.00	13.44±0.05	16.38±0.10	15.34±0.00	14.55±0.00	14.22±0.17
KATHWA NA	A	8.94±0.21	22.08±0.00	13.62±0.11	8.74±0.00	10.08±0.27	11.52±0.14	12.36±0.04	12.48±0.00	16.92±0.21	17.04±0.00
	B	8.94±0.00	16.68±0.25	10.9±0.19	9.54±0.05	9.3±0.22	14.76±0.00	5.88±0.00	10.5±0.19	14.28±0.07	12.54±0.13
	I	15.24±0.01	21.12±0.08	7.96±0.00	11.12±0.00	14.82±0.18	12.54±0.00	17.94±0.18	18.54±0.03	11.7±0.00	14.22±0.22
	M	12.66±0.00	14.22±0.00	11.4±0.13	12.17±0.00	18.48±0.00	13.56±0.07	18.12±0.22	14.34±0.10	13.44±0.02	14.46±0.00
	T	20.7±0.00	8.52±0.00	10.2±0.00	8.94±0.12	12.66±0.06	13.44±0.07	14.82±0.00	14.28±0.00	13.5±0.18	13.44±0.17
KITHIORI	A	22.6±0.22	27.0±0.18	10.62±0.17	15.84±0.04	17.04±0.02	23.04±0.11	9.54±0.12	12.0±0.11	11.58±0.00	10.02±0.10
	B	31.86±0.00	19.68±0.11	8.34±0.06	21.6±0.00	18.48±0.00	18.48±0.14	22.32±0.00	12.12±0.22	13.68±0.08	16.86±0.00
	I	14.4±0.07	44.04±0.00	18.84±0.00	16.86±0.00	16.26±0.23	15.06±0.22	12.72±0.21	9.3±0.00	18.18±0.00	12.9±0.07
	M	21.86±0.24	19 .0±0.17	28.04±0.00	20.34±0.07	13.06±0.05	14.82±0.00	26.9±0.06	21.12±0.09	28.36±0.16	26.4±0.20
	T	11.76±0.00	25.4±0.03	17.1±0.09	15.84±0.16	14.4±0.00	12.6±0.19	18.86±0.00	10.7±0.17	16.54±0.24	13.56±0.00

Table 4: Mean Concentrations of Titanium in mg/g per study area

	Kwale	Kathwana	Kithiori
A	14.72±0.00	13.13±0.00	15.93±0.03
B	15.59±0.33	16.91±0.08	18.34±0.07
I	15.42±0.04	13.38±0.01	17.86±0.00
M	13.65±0.02	14.29±0.01	22.00±0.00
T	15.08±0.00	13.5±0.03	15.68±0.08
MEAN CONCENTRATION OF ANTHILL	14.94±0.24	14.52±0.03	18.47±0.03

Discussion of Results

The samples were analyzed in triplicates and the mean values of concentrations calculated. Results were summarized as shown in Tables 1-4. In Kwale the control sample had 20.63±0.09 mg/g of iron while the mean concentration of the termitaria was 25.3±0.06 mg/g, for Kathwana samples the control sample had 90.53±0.00 mg/g of iron while the mean concentration of the termitaria was 98.53±0.29 mg/g, for Kithiori samples the control sample had 82.63±0.22 mg/g of iron while the mean concentration of the termitaria was 89.46±0.00 mg/g. Likewise, titanium levels were found to be higher in termitaria samples than in the control samples. For samples from Kwale the control sample had 14.72±0.00 mg/g of titanium while the mean concentration of the termitaria was 14.94±0.24mg/g, for Kithiori samples the control sample had 15.93±0.03mg/g of titanium while the mean concentration of the termitaria was 18.47±0.03 mg/g, for Kathwana the control sample had 13.13±0.00 mg/g while the mean concentration of the termitaria samples was 14.52±0.03 mg/g of titanium.

The higher iron and titanium content of the soils in termite mounds compared with the surroundings confirm previous findings that soils had been transported from deep subsoil with a high content of the underneath material to build the mounds. (Russel, 1983); (Brady and Weil, 1999) found significantly higher content of clay in termite mound soil compared to surrounding soils. (Gleeson and Poulin 1989) reported that gold content of termitaria is high in soils with gold mineralization.

Conclusion

The focus of this study was to compare the levels of iron and titanium in termitaria soil samples to soil samples collected from near termitaria from Kwale, Kithiori and Kathwana where the two metals are known to occur. Termitaria samples mean concentration of iron was found to be 25.3±0.06 mg/g, 98.53±0.29mg/g and

89.46±0.00 mg/g for Kwale, Kathwana and Kithiori respectively. The control sample concentration of iron was found to be 20.63±0.09 mg/g, 90.53±0.00 mg/g and 82.63±0.22 mg/g. Kwale, Kathwana and Kithiori, respectively. Termitaria samples mean concentration of titanium was found to be 14.94±0.24 mg/g, 14.52±0.03 mg/g and 18.47±0.03 mg/g for Kwale, Kathwana and Kithiori respectively. The control sample concentration of titanium was found to be 14.72±0.00 mg/g, 13.13±0.00 mg/g and 15.93±0.03 mg/g Kwale, Kathwana and Kithiori respectively.

There were elevated levels of the two metals in termitaria soils compared to the surrounding soils. Termites are very important bioturbators and are responsible for the higher levels of the metals in termitaria soil samples having brought debris containing the metals from underground. Termitaria sampling can therefore be used as preliminary step in mineral prospecting since they provide an indication of the potential of the positive anomaly, and enables a judgment on the scale of the ore metal accumulation.

Recommendations

It is necessary to carry out analysis of the vegetation in a mineralized area to find out the levels of metals in the plants since termites are known to feed on organic matter which could result in elevated levels of elements in termitaria. In addition, geological survey by systematic boring and prospecting under the subsurface of the proposed promising areas for metal occurrences is recommended. The study further recommends multimedia sampling approach the first step being termitaria sampling where they exist.

REFERENCES

Aaron D. S. and Ravi R. A (2012). Source of anomalous gold concentrations in termite nests, Moolart Well, Western Australia: implications for exploration. Geochemistry: Exploration, Environment, Analysis 12(4): 327-337.

Andersen A, Dawes-Gromadzki T, Jacklyn P.,Morris.I. (2005). Termites of Northern Australia. Barker Press, Darwin.

Aspandiar, M.F, Anand, R.R., Gray, D.J (2004). Mechanisms of metal transfer through transported overburden within the Australian regolith. Explore 125:9–12.

Berkman D.A (2001). Field Geologists' Manual. Australian Institute of Mining and Metallurgy, Monograph, 9.

Bernier M.A, Milner M.W., Myles T.G (1999). Mineralogical and geochemical analysis of cathedral termitaria applied to lode gold exploration in the Roandji alluvial gold fields, Bandas Greenstone Belt, Central African Republic. In: 19th International Geochemical Exploration Symposium Proceedings, poster abstract, Vancouver.

Blake D.H (1978). The Proterozoic and Palaeozoic rocks of the Granites–Tanami region, Western Australia and Northern Territory and interregional correlations. BMR Journal of Australian Geology and Geophysics, 3: 35–42.

Blake D.H.,Passmore V.L.,Mulhing P.C (1977). 1:250 000 Geological Series Explanatory Notes – Billiluna Western Australia. Department of Natural Resources Bureau of Mineral Resources, Geology and Geophysics, Canberra, 28.

Boyer P (1973). Action de certains termites constructeurs sur l'évolution des sols tropicaux I. Annales des Sciences Naturelles Zoologie Paris sér. 12 15, 329-498.

Brooks R. R(1998) Biological Methods of Prospecting for Minerals,NZ BioScience.

Brooks R. R (1983) Biological Methods of Prospecting for Minerals, Wiley- Interscience

Brooks R.R (1982). Biological methods of prospecting for gold. Journal of Geochemical Exploration, 17, 109–122.

Brummer J .J. and Woodward G.D (1999) A history of the ‘Zambian copper flower’ Becium centraliafricanum (B.homblei), Journal of Geochemical Exploration, 65, 133-140

Cannon, H.L (1957) Description of indicator plants and methods of botanical prospecting for uranium deposits on the Colorado Plateau U.S Geological survey 1030M,:399-516

Moon ,Charles J., Michael K.G Whateley and Anthony M. Evans (2006) Introduction to mineral exploration.Blackwell Publishing, Australia.

Dangerfield .J.M, McCarthy T.S and Ellery W.N (1998), The mound-building termite michaelseni as an ecosystem engineer. Journal of tropical ecology 14:507-520.

David Ong’olo (2001) International investment and environmental issues: the case of Kenya’s kwale mineral sands project

Dawes-Gromadzki T.Z (2005). Bugs beneath the surface: the functional significance of soil macro invertebrates to landscape health in Australia's tropical savannas Insect Science, 12, 307–312.

De Bruyn L.A., Conacher A.J (1990). The role of termites and ants in soil modification: a review Australian Journal of Soil Resources, 28: 55–93.

De Paula F.C.F., Abrahao J.R.S (1991). Geochemical prospecting for vanadium and chromium in the Iramaia sheet, Bahia State, Brazil. Journal of Geochemical Exploration, 41: 125–135.

Dunn C.E (2007). Biogeochemical mineral exploration, Elservier Amsterdam

Dunn C.E. (2001). Biogeochemical methods in the Canadian Shield and Cordillera. In McClenaghan M.B., Bobrowsky P.T., Hall G.E.M. & Cook S.J (eds) Drift Exploration in Glacial Terrain, 151–164, spec. publ. 185. Geological Society, London.

Eggleton R.A. Aspandiar M.F (2004). Mechanisms of metal transfer through sedimentary overburden. In: Eggleton R.A. (ed.) Extended Abstracts, Minerals Exploration Seminar. AMEC-CRC LEME, Adelaide, SA, 22–25.

Freyssinet, P., Lecomte,P . and Edio, F., (1989). Dispersion of gold and base metals in the Mborguene lateritic profile, East Cameroun.J.Geochem Explor., 31:99-116

Freyssinet. P. (1993).Gold dispersion related to ferricrete pedogenesis in South Mali: application to geochemical exploration. Chronique de Recherche des mines 510:25-40

Gambogi, Joseph (2003).Titanium, in Metals and minerals: U.S. Geological Survey Minerals Yearbook 2001, v. I, p. 79.1-79.16.

Gleeson, C. F. and Poulin, R. (1989). Gold exploration in Niger using soils and termitaria. Journal of Geochemical Exploration, 31: 253-283.

Hawkes, H. E (1957). Principles of geochemical prospecting: U.S. Geol. Survey Bull. 1000-F, p. 225-355.

Hodge R.A (2011). Mining's contribution to economic and social development. In:The commonwealth Heads of Government meeting , Australia, 28-30 October 2011

Holt, J.A. (1998) Microbial activity in the mounds of some Australian termites. Applied Soil Ecology, 9:183-187.

Horsnail . R. F (2001). "Geochemical prospecting", in AccessScience@McGraw-Hill,
http://www.accessscience.com, DOI 10.1036/1097-8542.285700

http://www.atlascopcoexploration.com/1.0.1.0/354/TS3 Accessed on 17 November 2012.

http//www.epzakenya.com/UserFiles/files/Gemstonekenya Accessed on 19 November 2012.

Jason S. Ogola , Winnie V. Mitullah and Monica A. Omulo (2002). Impact of Gold Mining on the Environment and Human Health: A case study in the Migori Gold belt, KENYA Environmental Geochemistry and Health 24: 141–158

Jouquet, P., Lepage, M. & Velde, B. (2002). Termite soil preferences and particle selections: strategies related to ecological requirements. Insectes Sociaux, 49:1-7.

Krupadam R. J, Smita. Pand Wate S. R (2006). Geochemical fractionation of heavy metals in sediments of the Tapi estuary Geochemical Journal, 40: 513-522

Lee, K. E. and T. G. Wood (1971). "Physical and chemical effects on soils of some Australian termites, and their pedobiological significance." Pedobiological 11: 376-409

Maria Balcerzak (2002). Sample Digestion Methods for the Determination of Traces of Precious Metals by Spectoscopic Techniques.Journal of Analytical Science 18: 737

Moon. J., Michael K.G.W and Anthony M. E (2006) Introduction to mineral exploration.Blackwell Publishing, Australia.

Nkoane B (2003). Analysis of copper and Nickle in soils and plants from mineralized areas Ph.D. Thesis University of Botswana

Ralph .E. P (2003). A unique prospecting method .Prospecting and mining journal,vol 72 No.8

Roquin, C., Dandjinou, T.,Freyssinet,P., and Pion, J.C.,(1989). The correlation between geochemical data and spot satellite imagery of lateritic terrain in Southern Mali. J.Geochem Explor., 32:149-168

Roquin, C., Freyssinet, P., Zeegers,H. and Tardy,Y.,(1990). Element distribution patterns in laterites of in Southern Mali: consequence for geochemical prospecting and mineral exploration. Appl.Geochem., 5:303-315

Roja(2009)."How to get rid of anthills". http//www.freeuniquearticles.com Accessed on 15th October, 2012

Surya P.K.R and Raju S.V (1984) Geochemical analysis of termite mounds as a prospecting tool for tin in Bastar,MP- a preliminary study Earth science 93(2): 141-148.

Tooms J.S and J.S Webb (1961), Geochemical Prospecting in the Northern Rhodesia copper belt Economic Geology 56:815-846