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Geochemistry of termite mounds in the sediment-hosted Lead-Zinc Mining District of Yolo, Gongola Sub-basin: A guide for lead-zinc exploration in the Upper Benue Trough, Nigeria

Haruna I. V.*, Ahmed H. A. and Suleiman B. M.

Department of Geology, Modibbo Adama University of Technology, Yola P. M. B. 2076, Yola, Nigeria.

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Yolo lead-zinc mining district is an important area in Gongola Sub-basin of the Upper Benue Trough with paucity of rocks outcrops but abundant termite mounds. The termite mounds and their adjoining surface soils were analyzed for Pb, Zn, Ti, Cu, Sb, As, U, Cr, Zr and Li in an attempt to test their effectiveness in defining favorable areas for lead-Zinc mineralization in the Upper Benue Trough. The result shows a general trend of higher elemental concentration in termite mounds relative to their adjoining surface soils. The ore elements Pb, Zn together with Ti have the highest average concentrations of 503, 2136.5, and 6285 ppb in termite mounds compared to 356, 1662 and 2250 ppb respectively in adjoining surface soils. Biological Absorption Coefficient, calculated to evaluate their degree of concentration, shows 141 values of Biological Absorption Coefficient within enrichment category with only 59 values in the depletion category. The relatively high concentration of the ore elements Pb, Zn and the associated trace elements in termite mounds and the elevated contents of BAC values in the enrichment category together suggest that Pb, Zn and Ti in termite mounds can be effectively used for lead-zinc exploration in the Upper Benue Trough.

Key words: Lead-Zinc, termite mound, Gongola Sub-basin, Upper Benue Trough.

INTRODUCTION

The Upper Benue Trough, like other areas within the tropical and semi-arid regions, is generally covered with thick soil cover in most places. This thick soil cover conceals the rocks outcrops, thereby hampering mineral prospecting in the region. Fortunately, termite mounds of different sizes and shapes are well distributed in the region forming the most conspicuous feature of the

landscape. Most mounds have the shapes of inverted cone with rounded to sub-rounded base ranging in diameter from 0.8 m to over 3.1 m. The heights also vary between about 1 and 2.8 m.

Termites often build mounds with large quantities of earth materials sampled at different depths from sub-surface geological formations (Burgess and Raw, 1967).

*Corresponding author. E-mail: ivharuna@mauctech.edu.ng.

These components of the regolith are mostly brought up from the water table as the termites need the water to maintain high humidity. As a result, the materials commonly contain dissolved minerals and water. Consequently, when the termite mounds are properly sampled and subjected to trace elements determination, geochemical halos which may be related to concealed mineralization are easily detected.

Extensive literatures exist on termite mounds and their structures in the aspects of agriculture (Black and Okwakol, 1997), biology (Jungerius et al., 1999) and paleoclimate (Genise, 1997) (Nagaraju et al., 2012). However, studies on their geological aspect remain scarce and almost limited to India where termite mounds have been utilized in exploration for certain minerals. Notable amongst them are the works of Prasad et al. (1987) which analyzed the significance of termite mounds in gold exploration; Raghu (2007) in a study conducted around Vemula Mine, Kadapa District, India, described termite mound as a bioindicator for the exploration of barite; Chandrasekhar et al. (2012) studied the Physico-chemical characteristics of termite mounds using Byrapur Chromite mining area, Karnataka, as a case study; and Watson (1970) examined the contribution of termites to the development of Zinc anomalies in Kalahari sand. These studies have come out with beautiful conclusions about the use of termite mounds in exploration for certain minerals. However, the conclusions may only hold true for the minerals in question and their locations of studies. This is because most exploration models are commonly dependent on environment of application and the mineral commodity in question; meaning an exploration model that works for one mineral in a particular area may not be directly applicable (without modification) to another mineral in a different environment. The present study sampled and analyzed soils from termite mounds and adjoining surfaces (unaffected by termites) of Yolo mining district in an attempt to test their applicability in the exploration of sediment-hosted Pb-Zn deposits in the Upper Benue Trough.

Regional geologic setting of the Upper Benue Trough and location of the study area

The Benue Trough in Nigeria is one of the five mineral belts in the country endowed with rich mineral wealth. Most of Nigeria's lead-zinc occurrences are found within the basin. This is in addition to barite resources and sediment-hosted uranium deposits. The basin is one of the important basins in the country. The Trough is a 1000 km long, approximately 50-150 km wide intra-continental NE-SW trending rift depression in Nigeria (Grant, 1971; Benkhelil, 1982; Maurin et al., 1985; Benkhelil, 1987) genetically related to the opening of the equatorial domain of the South Atlantic (Popoff, 1988; Fairhead

and Binks, 1991). The basin is filled with continental and marine sediments (about 6,500 m in thickness). Geographically, the Benue Trough is divided into three segments: the lower, middle and upper Benue regions (Zaborski, 1998). The Upper Benue Trough is a Y-shape basin bounded to the northeast by the basement rocks of the Hawal Massif, to the south by the Adamawa Massif and to the west by the basement rocks of north central Nigeria (Figure 1). The Upper Benue Trough is further subdivided into three sub-basins: the north-east trending domain to the south, the E-W trending Yola Sub-basin to the east and the N-S trending Gongola Sub-basin to the north. The study area (Figure 2) is located within latitudes 9°31'N to 9°45'N and longitudes 10°45'E to 10°55'E in the Gongola Sub-basin of the Upper Benue Trough.

Geology and mineralization

Extensive literature exists on the Geology and stratigraphy of the Upper Benue Trough (Carter et al. 1963; Offodile, 1976; Benkhelil, 1989; Zaborski, 1997; Tukur et al., 2015), so only a brief summary of the stratigraphy of the Gongola sub-basin will be presented here. The sub-basin, according to Akande et al. (1998), comprises the following stratigraphic succession: the Aptian-Albian Continental Bima Formation, the marine transitional Cenomanian-Turonian Yolde Formation, the marine Turonian-Coniacian Pindiga Formation, the Campanian-Maastrichtian Deltaic Gombe Formation and Tertiary Continental Keri-Keri Formation.

The Continental Albian Bima Sandstone is the oldest Cretaceous sediment and only overlies the Precambrian basement rocks. This formation is overlain by the marine transitional Cenomanian-Turonian Yolde Formation consisting of interbeds of shale, siltstone, sandstone and calcareous mudstone. The Yolde Formation is succeeded by the marine Turonian-Coniacian Pindiga Formation (of mainly shales, intercalated with limestone beds in some areas) and Gongila Formation (consisting of alternating sets of limestone and shale units). Deltaic Campanian-Maastrichtian Gombe Sandstone overlies the Gongila Formation and consists of poorly to moderately sorted sandstone interbedded with argillaceous beds. The Gombe sandstone is capped by the Tertiary continental Keri-Keri Formation. These formations have their lateral equivalents in the Yola sub-basin.

Lead-Zinc mineralization in the area is almost confined to the highly variable Bima Sandstone (Figure 3). Several contrasting models try to explain the processes of formation of lead-zinc deposits in the Upper Benue Trough. These include the magmatic-hydrothermal model which, on the bases of veins morphology and characteristics, suggesting that the mineralizing solutions were derived from intrusive rocks (Farrington, 1952; Orajaka, 1965; Nwachukwu, 1975); the volcanic-

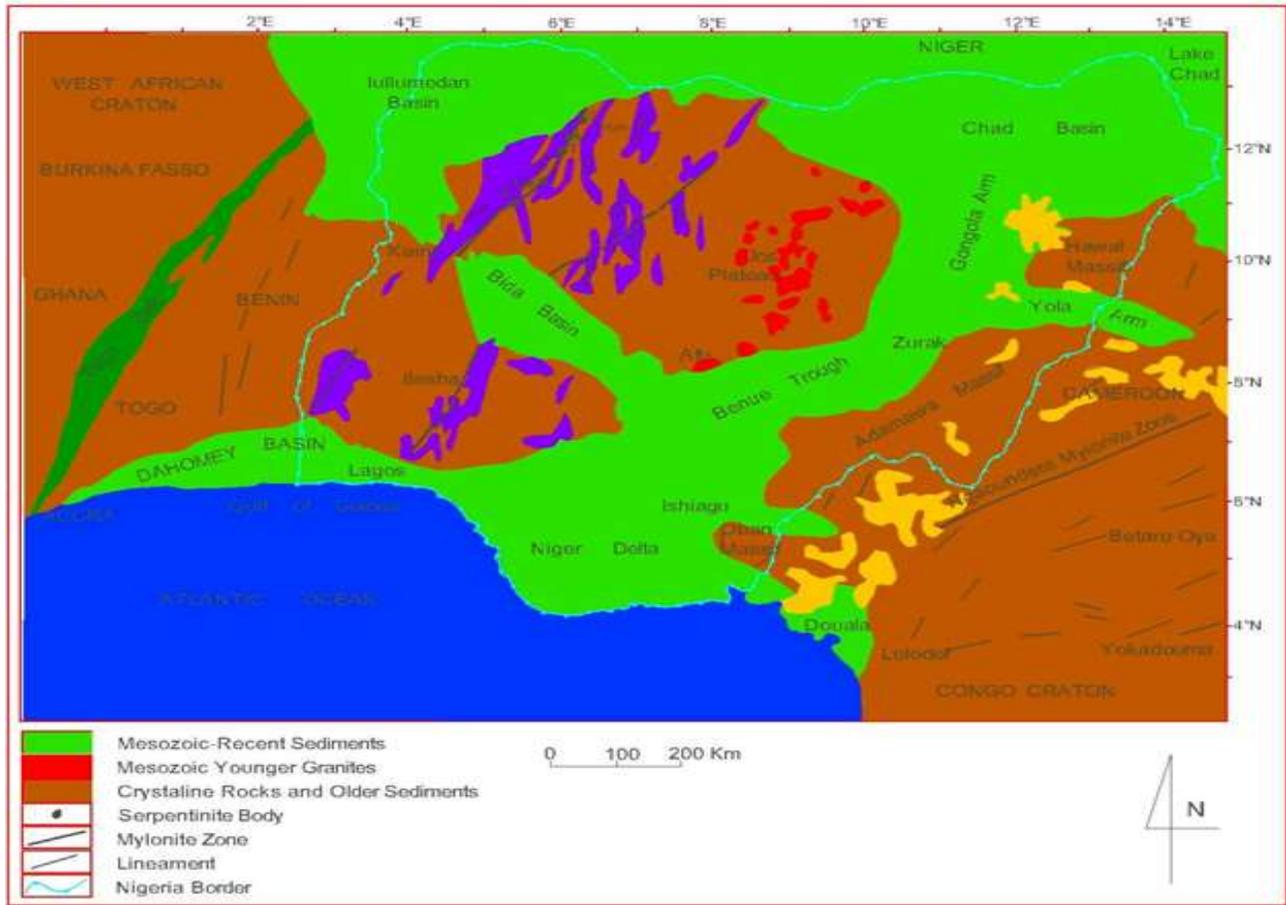


Figure 1. Regional geologic setting of the Benue Trough (modified after Maluski et al, 1995).

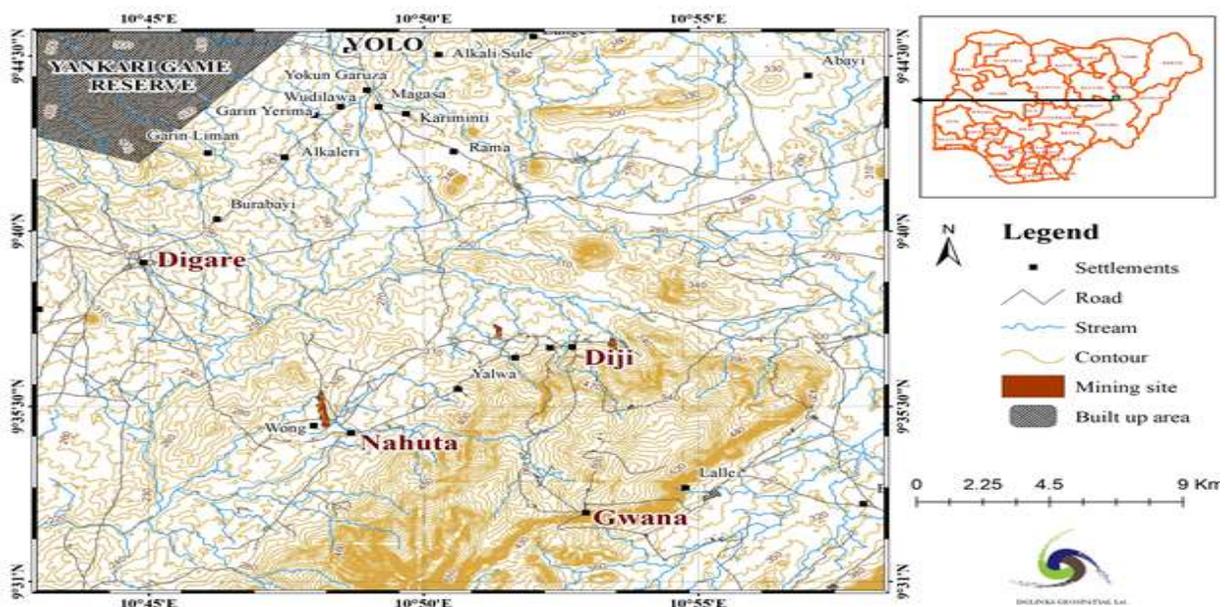


Figure 2. Topographic features and mining sites (sample areas) of Yolo Lead-Zinc Mining District (modified from Federal Surveys, Nigeria, 1975)

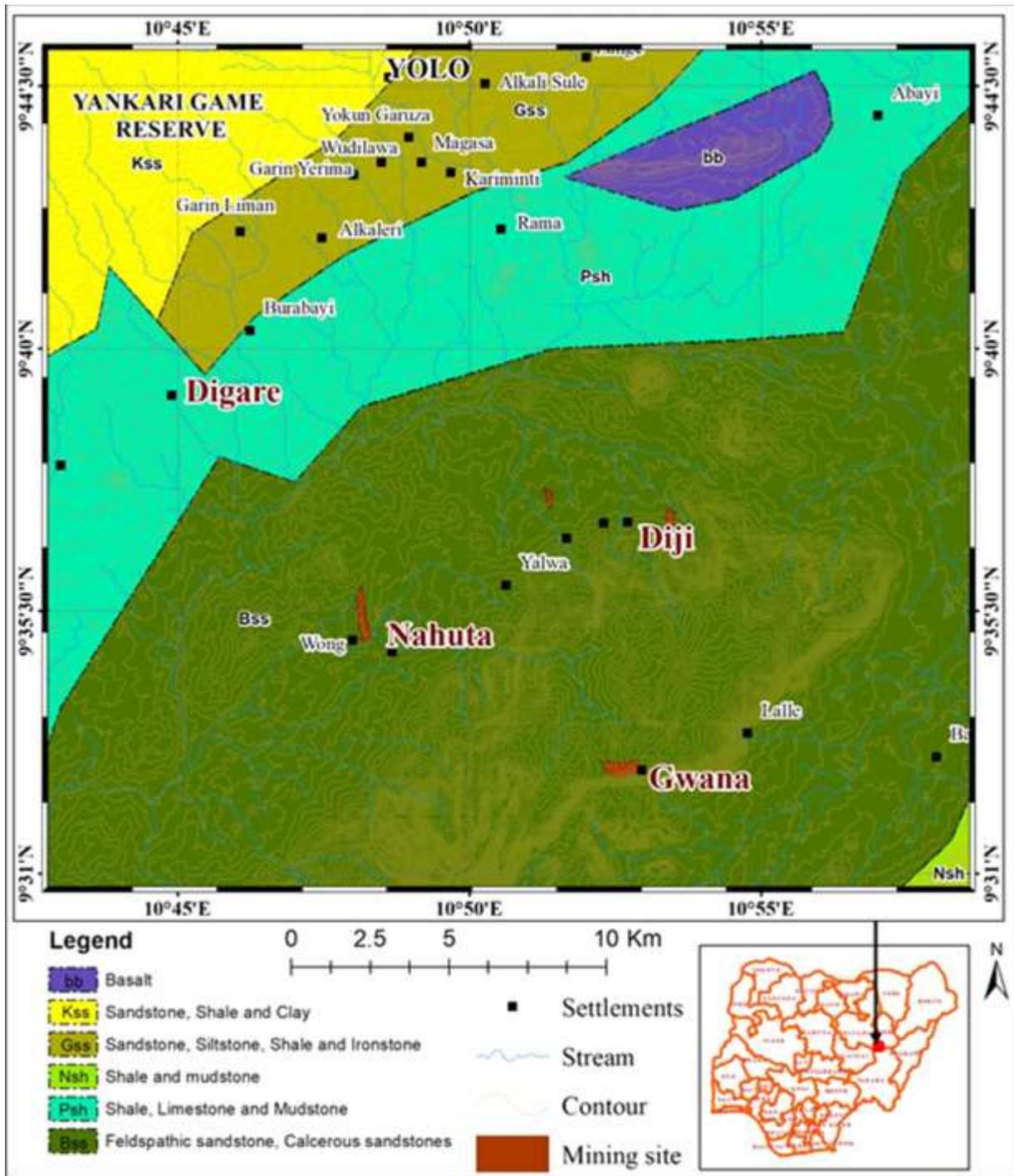


Figure 3. Geology of Yolo Lead-Zinc Mining District.

source model of Reyment (1965) and Orajaka (1972) which was postulated on the basis of close proximity of some lead-zinc deposits to volcanic activities; the Juvenal and connate brine model of Offodile (1976) which proposed interaction between juvenile solutions and

connate brines. The Mississippi Valley-type (MVT) model, on the basis of fluid inclusion data, mode of occurrence and geological settings, suggests connate water circulating in sediments as the ore-forming fluids (Grant, 1971; Olade, 1976; Olade and Morton, 1985). It is most

probable that the lead-zinc deposits in the Upper Benue Trough are Sedimentary Exhalative (SEDEX) Deposit type. Such deposits are localized within sub-basins controlled by syn-sedimentary faults with mineralization characteristically located in the second- or third order fault structures. It is widely accepted that these fault zones provide the main channels for the mineralizing fluids migrating from greater depths, within the basin (Goodfellow et al., 1993).

SAMPLING AND ANALYSIS METHODS

A total of forty samples were collected from two closely separated areas (Diji and Nahuta) within the Yolo mining District. In each area a total of 20 samples (in 10 pairs of termite soil samples (Ts) and adjoining surface soil samples, Ss) were collected. Termite soil samples were collected from 5-7 separate spots from different parts of the termite mounds and combine to form a composite sample. For each termite sample collected, corresponding spot samples of their adjoining surface soil (unaffected by termite activity) occurring within a radius of 10 m were collected. Both samples were dried in special room kept above 40°C then disaggregated, sieved and shipped to Activation Laboratory, Canada where trace elements were determined by Inductively Coupled Mass Spectrometry (ICP-MS) technique under Enzyme Selective Extraction (ESE) analytical package. The Enzyme Selective Extraction analytical package is designed for detection of blind mineralization and therefore determines elements in parts per billion (ppb) instead of parts per million (ppm). It is within ActLabs standards to ensure that analyses are conducted with adequate control on precision and accuracy of the results obtained. The quality control is usually done through analysis of standards, blanks and duplicate samples, done under the same conditions with the samples submitted. All these were done by ActLabs, Canada and submitted along with the analytical results. The standard comparison is excellent, making the results to be reliable and in conformity with highest industry standards.

RESULTS

Analytical results of the termite mounds samples (Ts) and adjoining surface soil samples (Ss) for the selected chemical elements are presented in Table 1. From the table, it is clear that the concentration of elements in termite mound samples is, in most cases, higher than their concentration in samples collected from adjoining surface soils. Three elements, Zn, Pb and Ti have the highest average concentration in termite samples relative to their corresponding surface soils. Ti has the highest average concentration of 6285 ppb in termite mound samples as compared to its 2250 ppb in the adjoining surface soil sample. The element has its respective maximum and minimum values of 21700 ppb and 12300 ppb in termite soil samples as against 600 and 200 ppb in adjoining surface soil samples. Zn, with a maximum content of 23200 ppb and minimum value of 120 ppb in termite mound samples has 18200 and 80 ppb as its respective maximum and minimum samples in its corresponding surface soil samples. Zn content averages

2136.5 ppb in termite mound samples and 1662 ppb in samples collected from adjacent soils. This is closely followed by Pb average content of 503 and 356 in termite mound and surface soil samples respectively within a maximum range of 4130 and 1690 ppb in termite mounds and just 42 ppb and 51 ppb minimum in surface soils.

Other elements, Cu, Sb, As, U, Ti, Cr, and Zr, Li have their average, maximum and minimum concentrations in termite mounds and surface soil samples as indicated in the table. To give a clear pictorial view of the analytical results, plots of the elements versus average concentrations were graphically presented in Figure 4. A close look at the table reveals generally high values of the elements in samples 9 to 11 and 15 to 17 of both the termite mound and surface soil samples. In each of these samples, the concentrations of elements were found to be higher in the termite mounds samples than their adjoining counterparts. This is particularly clear for Zn, Pb, Ti, Cr, Zr, Li, and Cu.

Intensity of elemental concentration was also evaluated using Biological Absorption Coefficient (BAC), defined by Prasad et al. (1987), as the ratio of concentration of the element in termite mound (C_{TS}) to that of its adjoining surface soil (C_{SS}). BAC is mathematically represented as $BAC = C_{TS}/C_{SS}$.

Using the above formula, the BAC values of the termite mounds for all the elements have been calculated and presented on Table 2. From this table, Pb averages 1.523 ppb with respective minimum and maximum values ranging between 0.190 and 5.096 ppb; Zn with a minimum value of 0.047 ppb and maximum value of 10.545 ppb has an average of 2.268 ppb. Ti has an average value of 4.867 ppb with minimum and maximum values of 0.760 and 15.500 ppb respectively. All other elements, Cu, Sb, As, U, Cr, Zr and Li have their average, minimum and maximum values as indicated.

DISCUSSION

Enrichment or otherwise of elemental concentration in termite mounds and adjoining soils is best discussed within the framework of Biological Absorption Coefficient. Prasad et al. (1987), grouped termite mounds into different levels of enrichment and depletion based on Biological Absorption Coefficient. This grouping has been adopted for trace elements of the Yolo lead-zinc mining district (Table 3).

The BAC value of unity (1) is taken as a datum line between enrichment and depletion. Different intensities of enrichment are contained between BAC values of more than unity to more than 5.94. Similarly, BAC values of less than 1.00 and 0.11 encompass different levels of depletion. Applying this to the present study, 141 BAC values fall within different intensities of the enrichment category with less than half of this number within the

Table 1. Concentrations of trace elements (in ppb) in termite mounds (Ts) and adjoining surface soil (Ss).

S/N	Zn		Pb		Cu		Sb		As		U		Ti		Cr		Zr		Li	
	Ts	Ss	Ts	Ss	Ts	Ss	Ts	Ss	Ts	Ss	Ts	Ss	Ts	Ss	Ts	Ss	Ts	Ss	Ts	Ss
1	260	350	353	448	41	37	0.9	1	8	5	2.2	0.8	1400	1600	40	50	28	36	24	22
2	650	80	174	51	107	46	0.7	0.3	15	2	2.3	0.7	1400	200	70	20	74	7	8	3
3	180	350	154	196	52	69	0.7	0.3	9	4	0.6	0.4	600	200	40	20	29	7	11	3
4	470	730	349	694	91	73	0.8	1.4	6	9	1.8	1.7	1900	2500	50	70	51	68	12	21
5	420	750	194	1020	55	56	0.9	1	8	7	1.3	3.7	2400	700	70	40	73	59	28	16
6	750	260	312	245	87	43	1	0.3	17	3	4.5	1.9	3100	500	120	30	109	24	56	9
7	480	350	204	262	75	46	0.7	0.3	9	4	4.1	1.4	5000	600	120	30	144	24	75	10
8	1590	530	199	127	102	183	0.6	0.7	8	13	1.2	1.1	3100	1200	90	50	93	47	94	59
9	23200	2200	1370	732	265	191	1	0.5	9	11	7.2	1.7	13200	1500	690	90	525	64	478	172
10	8360	3230	4130	1690	563	302	0.9	0.6	14	15	8.4	2.8	12300	4300	290	120	386	126	181	60
11	860	18200	258	427	98	75	0.6	0.8	7	5	4.7	2.4	8300	2800	170	70	210	71	104	53
12	120	150	85	59	55	26	0.5	0.3	7	4	2.2	0.9	2400	1200	50	40	59	31	23	25
13	190	2290	99	206	31	33	0.3	0.4	4	6	2.3	5.2	2100	800	70	30	59	33	43	22
14	580	830	323	320	91	48	0.6	0.2	8	4	6.9	3.2	4700	1800	110	50	122	51	58	30
15	1230	380	617	131	152	46	1	0.4	9	5	8.8	1.1	13700	1100	330	40	354	29	166	17
16	2390	360	958	188	217	49	1.2	0.4	13	5	16.4	3.1	21700	1400	560	40	625	35	295	20
17	350	1440	121	125	102	44	0.6	0.2	8	4	6.6	3.6	8800	800	220	30	195	26	124	11
18	170	190	62	62	68	77	0.4	0.4	5	5	7.6	4.9	7200	8400	170	180	170	190	90	99
19	220	330	65	89	78	105	0.4	0.5	6	7	6.9	8.8	9400	12300	200	290	228	318	101	159
20	260	240	42	52	91	31	0.3	0.1	8	3	3.7	1.8	3000	1100	80	40	84	31	37	18
Ave.	2136.5	1662	503	356	121	79	0.71	0.51	8.9	6.1	4.985	2.56	6285	2250	177	66.5	180.9	63.85	100.4	41.45
Max.	23200	18200	4130	1690	563	302	1.2	1.4	17	15	16.4	8.8	21700	12300	690	290	625	318	478	172
Min.	120	80	42	51	31	26	0.3	0.1	4	2	0.6	0.4	600	200	40	20	28	7	8	3

Ave = Average; Max. = Maximum; Min. = Minimum.

depletion category. Within the Enrichment Category, twenty seven values of Zn, As, U, Ti, Cr, Zr and Li fall within the Very Intensive Enrichment class; only 2 within the narrow Intensive Enrichment class; and 25 values of all the elements except as, within the Very Strong Enrichment category. Strong Enrichment category

recorded 60 BAC values while Moderately Strong Enrichment has only 27 values. Within the depletion class, 46 BAC values fall within the range of less than 1.00 and 0.58 corresponding to Moderately Weak Depletion, while only 9, 2 and 2 BAC values respectively fall within the Moderately Weak Depletion, Weak Depletion and Very Weak

Depletion classes. In summary, the high concentrations of chemical elements in termite soils could be attributed to sampling of geochemical halos (primary, secondary or both) at depth resulting from mineralization. This result agrees with similar studies conducted by Nagaraju et al. (2012) and Chandrasekhar (2014). Nagaraju

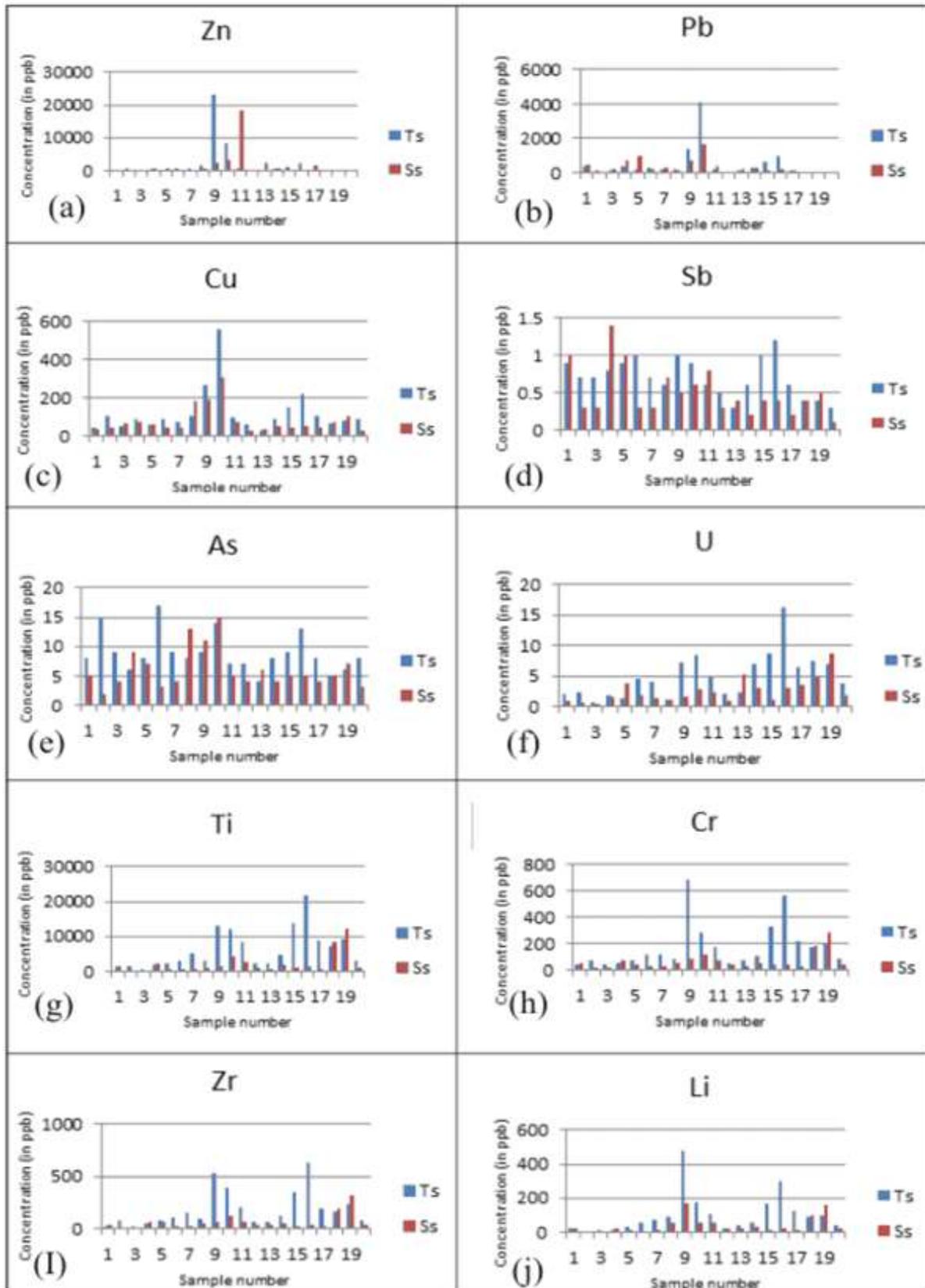


Figure 4. Plots of concentrations of selected elements against samples

Table 2. Biological Absorption Co-efficient (BAC) Values for ore elements Pb, Zn and some associated trace elements.\

S/N	Zn	Pb	Cu	Sb	As	U	Ti	Cr	Zr	Li
1	0.743	0.788	1.108	0.900	1.600	2.750	0.875	0.800	0.778	1.091
2	8.125	3.412	2.326	2.333	7.500	3.286	7.000	3.500	10.571	2.667
3	0.514	0.786	0.754	2.333	2.250	1.500	3.000	2.000	4.143	3.667
4	0.644	0.503	1.247	0.571	0.667	1.059	0.760	0.714	0.750	0.571
5	0.560	0.190	0.982	0.900	1.143	0.351	3.429	1.750	1.237	1.750
6	2.885	1.273	2.023	3.333	5.667	2.368	6.200	4.000	4.542	6.222
7	1.371	0.779	1.630	2.333	2.250	2.929	8.333	4.000	6.000	7.500
8	3.000	1.567	0.557	0.857	0.615	1.091	2.583	1.800	1.979	1.593
9	10.545	1.872	1.387	2.000	0.818	4.235	8.800	7.667	8.203	2.779
10	2.588	2.444	1.864	1.500	0.933	3.000	2.860	2.417	3.063	3.017
11	0.047	0.604	1.307	0.750	1.400	1.958	2.964	2.429	2.958	1.962
12	0.800	1.441	2.115	1.667	1.750	2.444	2.000	1.250	1.903	0.920
13	0.083	0.481	0.939	0.750	0.667	0.442	2.625	2.333	1.788	1.955
14	0.699	1.009	1.896	3.000	2.000	2.156	2.611	2.200	2.392	1.933
15	3.237	4.710	3.304	2.500	1.800	8.000	12.455	8.250	12.207	9.765
16	6.639	5.096	4.429	3.000	2.600	5.290	15.500	14.000	17.857	14.750
17	0.243	0.968	2.318	3.000	2.000	1.833	11.000	7.333	7.500	11.273
18	0.895	1.000	0.883	1.000	1.000	1.551	0.857	0.944	0.895	0.909
19	0.667	0.730	0.743	0.800	0.857	0.784	0.764	0.690	0.717	0.635
20	1.083	0.808	2.935	3.000	2.667	2.056	2.727	2.000	2.710	2.056
Average	2.268	1.523	1.737	1.826	2.009	2.454	4.867	3.504	4.610	3.851
Maximum	10.545	5.096	4.429	3.333	7.500	8.000	15.500	14.000	17.857	14.750
Minimum	0.047	0.190	0.557	0.571	0.615	0.351	0.760	0.690	0.717	0.571

Table 3. Termite mounds distribution at Yolo on the basis of Biological Absorption Co-efficient (BAC) for selected elements.

Category	Class interval	BAC range	Zn	Pb	Cu	Sb	As	U	Ti	Cr	Zr	Li	Total
Enrichment	Very intensive enrichment	>5.94	3	-	-	-	1	1	7	4	6	5	27
	Intensive enrichment	5.17-5.94	-	-	-	-	1	1	0	0	0	0	2
	Very strong enrichment	2.99-5.17	2	3	2	5	-	3	2	3	3	2	25
	Strong enrichment	1.73-2.99	2	2	7	5	8	8	7	8	6	7	60
	Moderately strong enrichment	>1.00-1.73	2	5	5	3	4	4	0	1	1	2	27
Datum Line ----		--BAC=1--											
Depletion	Intermediate depletion	<1.00-0.58	6	7	5	6	6	1	4	4	4	3	46
	Moderately weak depletion	0.58-0.33	2	2	1	1	-	2	-	-	-	1	9
	Weak depletion	0.33-0.19	1	1	-	-	-	-	-	-	-	-	2
	Very weak depletion	0.19-0.11	2	-	-	-	-	-	-	-	-	-	2

et al. (2012) conducted a biogeochemical study of termite mounds from Tummalapalle area of Andhra Pradesh, India and found out that, among the BAC values, Cu showed the highest factor values indicating more Cu concentration in termite mounds than the adjacent surface soils and thus concluded that the BAC values of termite mounds, rather than absolute values, are more significant biogeochemical parameter. Chandrasekhar

(2014) carried out similar study in the chromite mining area of Karnataka, India and attributed the higher BAC values of Cr and other elements in termite mounds to the influence of chromite mineral zone in the study area. He therefore concluded that termite mounds are useful indicator of Cr mineralization and can find application in mineral exploration.

The high concentration of chemical element in termite

mounds could therefore be explained in terms of geochemical halos (zones), surrounding metalliferous ore bodies. These zones are enriched in chemical elements, as a result of the introduction or redistribution of elements during the process of ore formation or supergene destruction (Krauskopf, 1976). This enrichment is lacking in the adjoining surface soils (unaffected by termite soils) which are probably in their background level in terms of trace elements content. Since geochemical halos are composed of elements which are typomorphic for ore bodies (Beus and Grigorian, 1977), analysing termite soils and comparing the results with that of their adjoining surface soils may directly indicated the present of lead-zinc ore bodies in the Upper Benue Trough.

Conclusion

The sediment-hosted lead-zinc deposits of Yolo mining district display high concentrations and wide geochemical halos for Pb, Zn and Ti. The investigation also revealed elevated content of BAC values in the enrichment category with reference to depletion category and good density of termite mound distribution in the region. The high concentration of the ore elements Pb, Zn, Ti and the associated trace elements in termite mounds compared to their adjoining surface soils; the elevated contents of BAC values (totaling 141) in the enrichment category of the BAC classification as against the low values (only 46) in the depletion category and the good density of termite mounds distribution in the Gongola sub-basin of the Upper Benue Trough show that termite mounds can be effectively used for Lead-Zinc exploration in the region. Consequently, application of Pb, Zn and Ti as indices in termite mounds is proposed for defining the most favorable areas for lead-Zinc mineralization in the Upper Benue Trough.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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