

TRACE ELEMENTS AS PATHFINDERS FOR GEMSTONE DEPOSITS: A CASE STUDY OF JARAWA AND EASTERN PART OF SHERE COMPLEX, NORTH CENTRAL NIGERIA.

A.A. Nyako¹, I. O. Ajigo² and E. C. Ashano³.

¹Upper Niger River Basin Development Authority, Kaduna.

²Unity Geotechnical (Nig.) Limited, km.8 Yakubu Gowon Way, Jos.

³Department of Geology and Mining, University of Jos.

Corresponding author: Tel.:(+234) 8032107038; E-mail: isaacajigo@yahoo.com

ABSTRACT

The Jarawa Younger Granite Complex and the eastern periphery of the Shere Complex, were investigated to ascertain the gem mineral potentials of the study area. Sn, B, Nb, Ta, W, Li, Ni, Cr, V, P, Zn, Ti and Mn in 20 rock samples were analyzed using the Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES). These elements were selected because of their affiliation to hydrothermal fluids, and some of them further play an important role in the formation of some gem stones, in fluids derived from late phase of magmatic crystallization. This will aid to predict the abundance of these elements in the late hydrothermal fluids, and the probable gem potential of the study area. Multiple correlation and regression analyses reveal two major association types: a primary lithologic association explained by the Mn-Cr-Ni-Ti association, and 'secondary', pneumatolitic association exemplified by the B-Nb-Li-W-Sn association which is linked with Fluorine, and typical of the greisenization. The presence of ubiquitous topaz confirms this. In the Younger Granites, this association is linked with Nb-Sn and Gemstone formation. Geochemical data indicate that Sn, Ni, Mn, Ti, Cr and P are more affiliated to early rocks (hornblende-biotite-porphyry and hornblende-biotite-granite), while Nb, B, Li and W show an affiliation to later rocks (Jarawa-biotite-granite, biotite-microgranite and biotite-muscovite-granite) in the area. The higher Sn content of the early rocks suggests that their roof zones could possess greater deposits of topaz and cassiterite, but have not been exposed due to their high resistance to erosion. The presence of B, Li, and F in the late magmatic fluids would have yielded schorl or colored tourmaline under favorable conditions. The minerals of the Columbite-Tantalite Series are alien to the deposits of this area, which could be due to the exclusive association of topaz and cassiterite in pneumatolitic deposits. Sn, not correlating with Nb in the result confirms the total absence of columbite-tantalite series in the deposits of this area. The Low Mn nature of the rocks compared to the background value and the total absence of Ta in the rock suits could also be a contributing factor to this phenomenon.

Key Words: Gemstone, Pathfinder, Trace element, Jarawa, Pneumatolysis, greisen.

INTRODUCTION.

The Jarawa Younger Granite Complex consists of only two major intrusions; an-early hornblende-biotite-granite and a later biotite-granite (Buchanam *et al.*, 1971). Both of these phases are succeeded by closely related biotite-microgranites. The hornblende-biotite-granite defines the eastern and southern perimeter of the Jarawa ring-structure and also forms the two radially arranged masses of the North Jarawa and Fusa Hills. It is closely related

to the Neils Valley granite-porphyry, and the succeeding biotite granite so that the Jarawa cycle appears to have been contemporaneous with part of the early granite cycle of the Jos-Bukuru complex. The Jarawa-biotite-granite constitutes the main part of the well-exposed dissected plateau of the South Jarawa hills with a notably high degree of exposure.

Gemstones are formed in different geological environments in the earth, resulting in various types of deposits including magmatic, pneumatolytic, metamorphic, sedimentary (alluvial),

hydrothermal, pegmatites and greissen gems. For the formation of each kind of gem a specific, and unlikely, combination of five factors are required in their respective environments. These are: temperature, pressure, space, chemical elements, and time. In other words, gems are in general rare but some are rarer than others. For example, silicon and oxygen are the two most abundant elements of the earth's crust and the conditions for the formation of quartz (SiO₂) are relatively common so it is understandable that quartz is found widely, while Axinite on the other hand, which is also a silicate gem requires (in addition to silicon and Oxygen) Ca, Fe, Mg, B, and Al for its formation, this makes such a gem rarer than quartz, (Abaa, 1990).

Gemstone deposits in magmatic environment are formed from late phase of fractional crystallization of acid magma, from residual fluids at the roof zones of fractionally crystallized acid rocks. These fluids are rich in trace elements like Be, B, Zr, Li, F, Nb, W, Sn, Ta, and Cs. The above listed trace elements are found within the rocks of the Younger Granites, which could serve as pathfinders to locating gem mineral deposits. Among these elements are LIL (large ion lithophile) and HFSE (high field strength elements) that are concentrated in fluids of late phase of fractionally crystallized acid magma due to their incompatibility. The abundance of some of these elements, for example F, B and Be in the late phase fluids would yield gems like topaz, tourmaline and beryl respectively, if all other conditions (solution chemistry, T-P and P^H) for their formation are met.

These rare conditions in cracks, fractures, faults and shear zones which gemstones are formed make them very rare to find, and so are termed precious. They are used for ornamentation and as jewelries when cut and polished. Some traditions are connected with sentiments, beliefs and superstitions associated with gems, to the effect that some gems carry the power of driving out evil spirits and

providing all sorts of luck or fortunes, (Aga and Ashano, 2008).

This work attempts to highlight some of the gem-related trace elements in the area under study from bed rock samples through geochemical studies. The result will be used to predict the relative gem potentials of the area. Finally, the outcome of this research will serve as a data base for subsequent detailed exploration of the area and future studies.

MATERIALS AND METHOD

A total of (20) samples were selected for analysis, these samples comprise only bedrock samples collected at noted locations. During sampling, care was taken to ensure that weathered rocks were avoided and only fresh rocks were targeted for sample collection using a sledge and geological hammer. Samples were crushed and pulverized at the Nigerian Metallurgical Development Centre (NMDC), Jos, Plateau State, Nigeria. They were crushed to a nominal minus 10 mesh, mechanically split (riffle) to obtain a representative sample and then pulverized to at least 95% minus 150 mesh (106 microns). The crusher and collection materials were vacuum-cleaned after each sample to avoid inter sample contamination. The pulverized samples were stored in sealed and labeled polythene bags. The geochemical analysis was carried out at the advanced Geochemistry Laboratory, Department of Geology and Mining, University of Jos, Plateau State Nigeria, to analyze for trace elements (Li, B, Nb, W, Sn, Cs, Ta, V, Zn, Be, Sb and Cr), and Mn, Ti and P, using complete digestion (extraction) and analysis by Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES) method, (Table 1). Ta, Sb, V and Zn are absent in the analyzed samples, while F could not be analysed for due to lack of standards.

RESULTS AND DISCUSSION.

Table 1: Trace Element concentration of rocks of the Jarawa and part of Shere complex.

Sample name	Cr (ppm)	Mn (ppm)	Ni (ppm)	Ti (ppm)	B (ppm)	Li (ppm)	Nb (ppm)	P (ppm)	Sn (ppm)	W (ppm)
NA1	881.1	111.3	27.89	453	12.89	137.6	52.98	1795	56.4	50.83
NA2	520.5	99.75	19.02	436.5	8.448	16.41	2.725	1738	62.75	14.09
NA3	983.3	385.3	31.57	727.2	11.78	58.51	21.37	1737	49.85	37.27
NA4	992.4	267.5	33.91	1534	13.16	23.7	0	1982	51.3	27.24
NA5	1018	140.7	31.59	571.7	22.34	12.25	0	1717	32.92	18.58
NA6	965.9	165.9	28.74	782.4	17.15	31.3	41.8	1704	18.41	19.47
NA7	971.6	159.8	28.86	519.3	34.42	122.4	94.02	1740	59	26.15
NA8	962.2	574.5	30.36	1919	15.98	26.65	46.13	1791	47.21	25.53

NA9	833.2	240.6	28.21	1928	4.898	26.18	0	2265	45.82	20.63
NA10	957.5	642.9	31.34	3212	10.24	5.435	0	526.4	47.05	7.343
NA11	1356	414.9	38.26	1381	16.63	49.13	60.41	1753	57.99	19.9
NA12	1051	499.7	32.74	1428	9.964	30.67	26.55	1988	41.42	14.92
NA13	907.5	983.2	70.53	9508	4.538	18.11	0	2506	56.4	33.84
NA14	1065	214.2	34.21	859.5	6.598	49.74	27.93	1730	64.44	13.68
AN15	870.2	295.6	30.19	631.7	24.67	57.29	81.77	1794	28.6	29.43
NA16	908.5	373.1	35.54	2021	7.26	20.98	0	2157	72.67	19.11
NA17	860.9	268	29.06	1495	9.67	23.74	0	2468	66.94	19.98
NA18	917.2	684.5	27.03	652.6	32.82	13.34	43.39	1819	61.59	37.93
NA19	1064	88.7	31.56	630.6	20.98	12.65	7.309	1827	41.28	27.09
NA20	858.2	99.41	26.45	474.7	16.71	196.1	45.98	1720	23.83	30.09

Multiple Correlations

Correlation is the measure of the strength of association between two variables measured on a number of individuals, and is quantified using the Pearson product moment coefficient of linear correlation, usually known as the correlation coefficient (r), (Rollinson, 1993). Values of r vary from -1 to +1. When $r = +1$, there is a perfect sympathy between the independent variable (x) and the dependant variable (y). Thus, there is a perfect linear relationship. Where $r = -1$, there is perfect

antipathy between x and y variables. If $r = 0$, there is no relationship between x and y variable at all.

Multiple correlation results indicate that Cr/Ni, Mn/Ni, Mn/Ti, Ni/Ti, Ti/B, Ti/Li, Ti/Nb, B/Nb, Li/Nb, Li/W and P/W exhibit correlation significance at 0.023, 0.007, 0.000, 0.000, 0.004, 0.016, 0.007, 0.001, 0.021 and 0.011 levels, with coefficient (r) values of 0.505*, 0.581**, 0.756**, 0.754**, -0.620**, -0.451*, -0.529*, 0.580**, 0.665**, 0.511* and 0.553* respectively, (Table 2).

Table 2: Multiple correlations Tables of Trace Elements in the study area.

		Cr	Mn	Ni	Ti	B	Li	Nb	P	Sn	W	
Cr	Pearson Correlation		1	.290	.505*	.191	.249	.076	.266	-.075	-.076	.033
	Sig. (2-tailed)			.215	.023	.419	.290	.749	.258	.755	.750	.890
	N		20	20	20	20	20	20	20	20	20	20
Mn	Pearson Correlation	.290		1	.581**	.756**	-.238	-.371	-.121	-.100	.303	-.089
	Sig. (2-tailed)	.215			.007	.000	.313	.107	.612	.674	.194	.709
	N	20	20	20	20	20	20	20	20	20	20	20
Ni	Pearson Correlation	.505*	.581**		1	.754**	-.352	-.129	-.226	.198	.145	.131
	Sig. (2-tailed)	.023	.007			.000	.128	.588	.338	.404	.543	.582
	N	20	20	20	20	20	20	20	20	20	20	20
Ti	Pearson Correlation	.191	.756**	.754**		1	-.620**	-.451*	-.529*	-.014	.264	-.243
	Sig. (2-tailed)	.419	.000	.000			.004	.046	.016	.952	.261	.301
	N	20	20	20	20	20	20	20	20	20	20	20
B	Pearson Correlation	.249	-.238	-.352	-.620**		1	.195	.580**	-.158	-.334	.307
	Sig. (2-tailed)	.290	.313	.128	.004			.411	.007	.505	.151	.188
	N	20	20	20	20	20	20	20	20	20	20	20
Li	Pearson Correlation	.076	-.371	-.129	-.451*	.195		1	.665**	.303	-.170	.511*
	Sig. (2-tailed)	.749	.107	.588	.046	.411			.001	.195	.473	.021
	N	20	20	20	20	20	20	20	20	20	20	20
Nb	Pearson Correlation	.266	-.121	-.226	-.529*	.580**	.665**		1	.006	-.272	.372
	Sig. (2-tailed)	.258	.612	.338	.016	.007	.001			.981	.245	.106
	N	20	20	20	20	20	20	20	20	20	20	20
P	Pearson Correlation	-.075	-.100	.198	-.014	-.158	.303	.006		1	.141	.553*
	Sig. (2-tailed)	.755	.674	.404	.952	.505	.195	.981			.554	.011
	N	20	20	20	20	20	20	20	20	20	20	20
Sn	Pearson Correlation	-.076	.303	.145	.264	-.334	-.170	-.272	.141		1	-.028
	Sig. (2-tailed)	.750	.194	.543	.261	.151	.473	.245	.554			.908

	N	20	20	20	20	20	20	20	20	20	20
W	Pearson Correlation	.033	-.089	.131	-.243	.307	.511*	.372	.553*	-.028	1
	Sig. (2-tailed)	.890	.709	.582	.301	.188	.021	.106	.011	.908	
	N	20	20	20	20	20	20	20	20	20	20

Linear Regression

Regression analysis is the traditional method of quantifying the strength of an association defined by the correlation coefficient (r), (McQueen, 2006). The quantification is carried out by fitting a straight line through the data and finding the equation of the line. The equation for a straight line relating variables x (independent) and y (dependant) is, $y = a + b$. The R-square linear, also known as the coefficient of determination is used to evaluate the model fit. It is a term that says how good one term (variable) is at predicting another. The degree to which two or more predictors (independent or x variables) are related to the dependent (y) variable, is expressed in the correlation coefficient (r), which is the square – root of R-square linear.

$r^2 = R - \text{square linear}$

R- square linear assumes values between 0 and 1. If R-squared linear is 1.0, then given the value of one variable, you can perfectly predict the value of the other variable. Values close to 1 are good predictors. If R-squared linear is 0.0, then knowing one term does not help you know the other term at all. Generally, a higher value of R-squared means that you can better predict one variable from the other. From the linear regression plots, the R-square linear values for Ti/Mn, Ti/Ni, Ni/Cr, Ni/Mn, B/Ti, B/Nb, Li/W, Li/Nb, Nb/Ti, W/P are 0.572, 0.568, 0.255, 0.337, 0.384, 0.336, 0.261, 0.443, 0.28, and 0.306 respectively, (Fig. 1a- l), confirming the strength of association defined by the correlation coefficients (r).

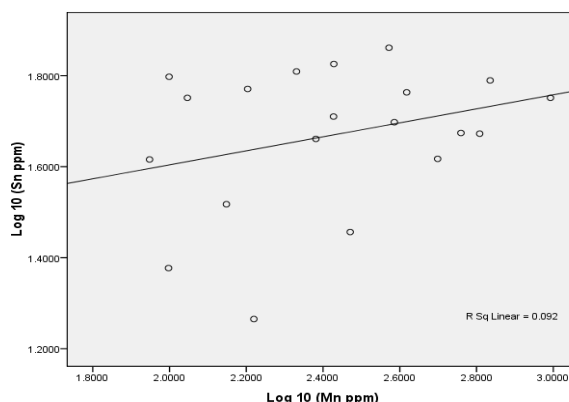


Fig. 1a: Regression chart of Sn/Mn.

R-Square linear=0.092, meaning there is no significant relationship between Sn/Mn. In other words, Sn cannot be used to predict the value of Mn in the study area.

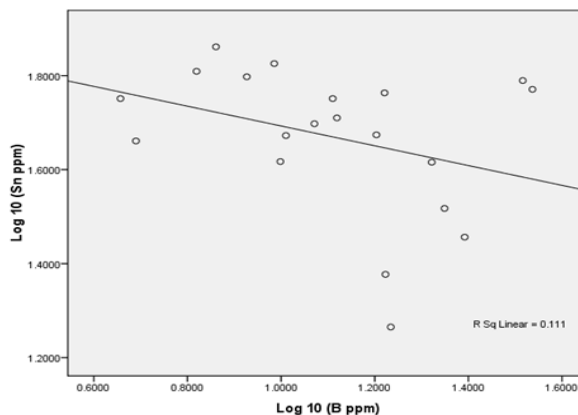


Fig. 1b: Regression chart of Sn/B.

R-Square linear=0.111, meaning there is no significant relationship between Sn/B. In other words, Sn cannot be used to predict the value of B in the study area.

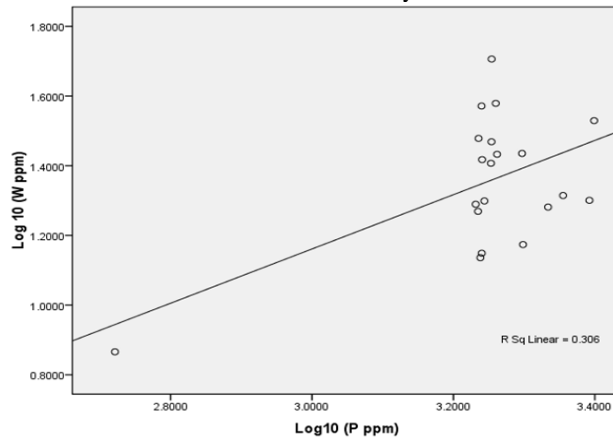


Fig 1c: Regression chart of W/P.

R-Square linear=0.306, meaning there is a significant relationship between W/P. In other words, W can be used to predict the value of P in the study area.

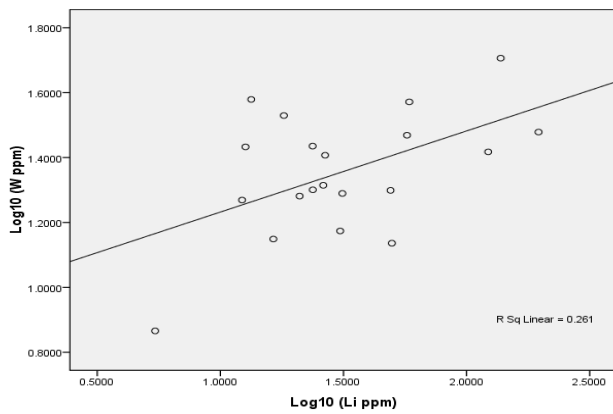


Fig. 1d: Regression chart of W/Li.

R-Square linear=0.261, meaning there is a significant relationship between W/Li. In other words, W can be used to predict the value of Li in the study area.

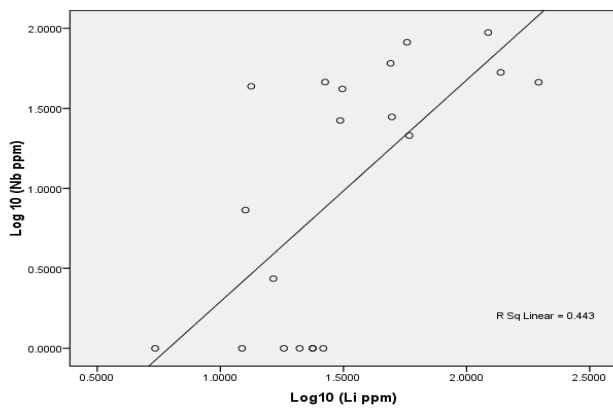


Fig. 1e: Regression chart of Nb/Li.

R-Square linear=0.443, meaning there is a significant relationship between Nb/Li. In other words, Nb can be used to predict the value of Li in the study area.

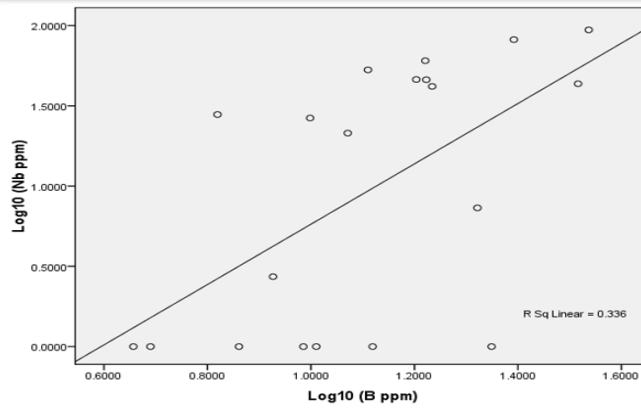


Fig.1f: Regression chart of Nb/B.

R-Square linear=0.336, meaning there is a significant relationship between Nb/B. In other words, Nb can be used to predict the value of B in the study area.

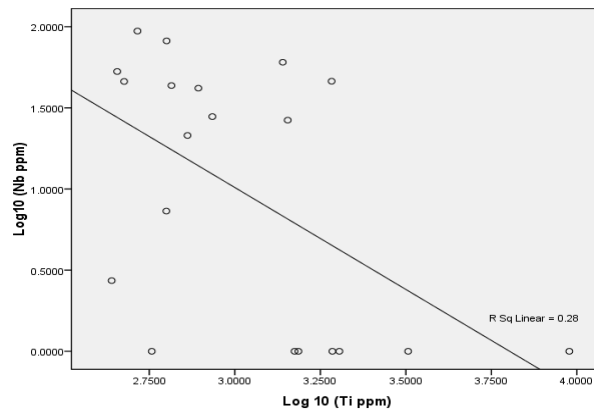


Fig. 1g: Regression chart of Nb/Ti.

R-Square linear=0.28, meaning there is a significant relationship between Nb/Ti. In other words, Nb can be used to predict the value of Ti in the study area.

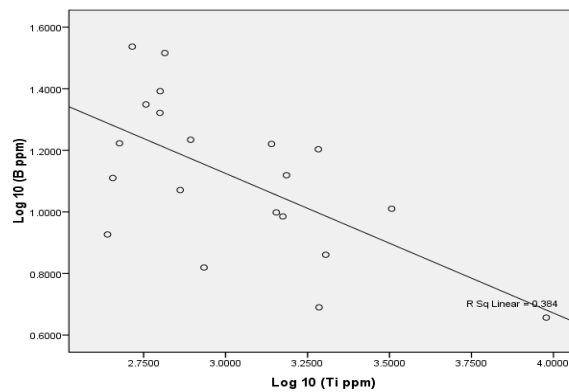


Fig. 1h: Regression chart of B/Ti.

R-Square linear=0.384, meaning there is a significant relationship between B/Ti. In other words, B can be used to predict the value of Ti in the study area.

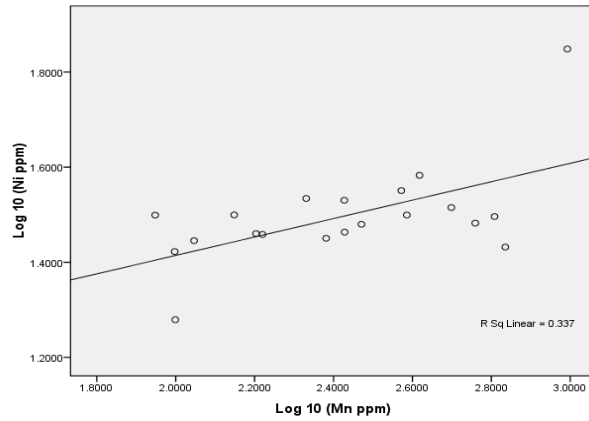


Fig.1i: Regression chart of Ni/Mn.

R-Square linear=0.337, meaning there is a significant relationship between Ni/Mn. In other words, Ni can be used to predict the value of Mn in the study area.

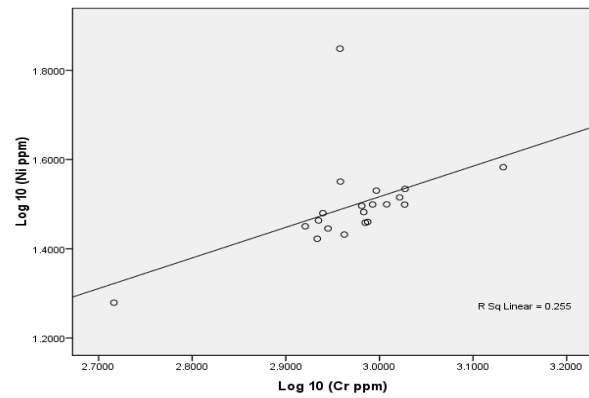


Fig.1j: Regression chart of Ni/Cr.

R-Square linear=0.255, meaning there is a significant relationship between Ni/Cr. In other words, Ni can be used to predict the value of Cr in the study area.

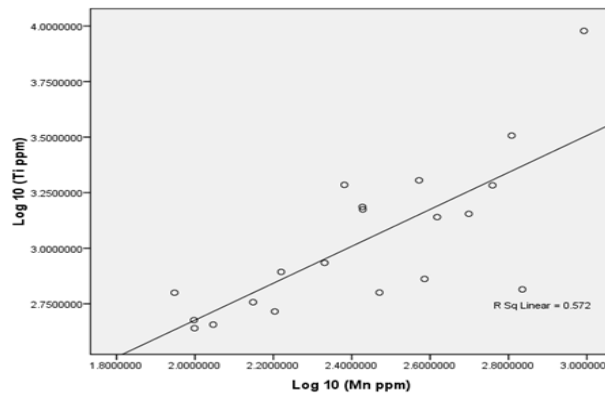


Fig.1k: Regression chart of Ti/Mn.

R-Square linear=0.572, meaning there is a significant relationship between Ti/Mn. In other words, Ti can be used to predict the value of Mn in the study area.

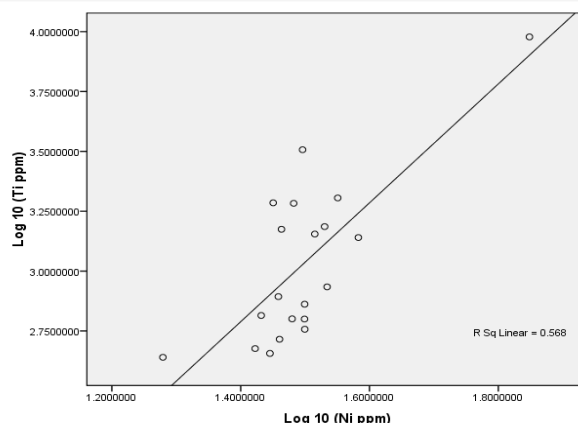


Fig.1/: Regression chart of Ti/Ni.

R-Square linear=0.568, meaning there is a significant relationship between Ti/Ni. In other words, Ti can be used to predict the value of Ni in the study area.

Correlation and regression analyses indicate that there is a sympathy or direct relationship between Ti, Ni, and Mn. This relationship is a function of the lithologic affiliation resulting from a similarity in their small ionic sizes, low ionization energies and positive oxidation states. Ni also exhibits a sympathy or direct relationship with Cr, which is also a transition element. There is antipathy or inverse relationship between Ti and Nb, B, Li, indicating that a progressive enrichment of Nb, B and Li in the rocks of the area was accompanied by depletion in Ti and its related transition metals (Ni, Mn and Cr). This is evident from the geo-chemical results. Ti, Ni, Cr and Mn are more enriched in the early rocks (hornblende-biotite-granite), and depleted in the later rocks (biotite-granite and biotite-microgranite), while Nb, B, W and Li are more enriched in the later rocks (biotite-granite and biotite-microgranite) than in the older rocks (hornblende-biotite-granite and hornblende-biotite-porphry).

From field investigation, the only gem mineral found in the Jarawa Complex currently mined within the Jarawa-biotite-granite is topaz, (Appendix 1&2). It is exclusively associated with cassiterite and large quartz crystals, hosted in greisens, which are weathered and irregular masses of clay, silica and large feldspar grains up to 20cm in size buried through time underneath alluvium from surrounding rocks. The chemical environment of the fluid from late magmatic crystallization was conducive for the simultaneous formation of topaz and cassiterite. The abundance of topaz in the area suggests that the fluid was very rich in F and Al, which favored the formation of topaz deposits. This fluid is believed to be of pneumatolytic origin, since the association of cassiterite with topaz indicates

pneumatolytic deposits, while cassiterite in association with tantalite-columbite, indicates pegmatite deposits and associations of cassiterite with sulfides indicate hydrothermal deposits (A.Ye Fersman, 1939). F being an agent of mobilization of high-field-strength-elements (HFSE) such as Sn, W, Ti and Zr (Shao-Yong, *et al*, 2004) would have aided the transportation or mobility of Sn from the granitic magma during crystallization, to the pneumatolytic fluid. This relationship between F and Sn explains why topaz and cassiterite are in coexistence as deposits of the area. Further evidence of this relationship is the high Sn content of the Younger Granite Rocks of the area, ranging from 18.41 ppm in latter rocks to 72.67 ppm in earlier rocks, which is much higher than the average crustal abundance value in granitic rocks (Sn=3ppm. Levinson, 1974). Thus, a higher enrichment of Sn is noticed in the early rocks (hornblende-biotite-porphry and hornblende-biotite-granite) than in the later rocks (Jarawa-biotite-granite and biotite-microgranite), (Appendix 3&4).

The present erosion surface of the Jarawa-biotite-granite is exposed close to the roof of the intrusion, which has been facilitated by its low resistance to weathering and erosion (Buchanam *et al*, 1971). As a result, a high degree of mineralization with cassiterite and topaz is revealed from the deposits. From the study, geochemical analysis and field investigation suggest that the roof zone of the early rocks (hornblende-biotite-granite) would probably possess greater deposits of topaz and cassiterite, but have not been exposed due to their high resistance to erosion. The reason Sn does not show a significant relationship with the other minerals, most importantly with the incompatible

elements (B, Li, W, and Nb) is probably because the parameters that affected its mobility in the pneumatolytic process did not affect the others in the same manner.

Pneumatolitic deposits are characterized by metasomatism, with the formation of minerals containing volatile compounds like H₂O, F and B (Smirnov, 1969). The B and Li contents of the Jarawa-biotite-granite and biotite-muscovite-granite in the study area are above the background value or average crustal abundance value (B=15ppm and Li=30ppm. Levinson. 1974). These anomalies in addition to the high F content in the area, and other anomalies like high Al and Cr content would have yielded schorl and other colored tourmaline supposing pressure, temperature and P^H conditions were favorable.

The minerals of the Columbite-Tantalite Series are alien to the deposits of topaz, quartz and cassiterite found in the Jarawa Complex deposits. This is probably due to their not being associated with cassiterite in pneumatolytic deposits (A.Ye Fersman, 1939) with respect to their varying response to the factors of mobility in this system, or due to the complete absence of Ta, and low content of Mn below the average crustal abundance value (Mn=500ppm. Levinson. 1974), though Nb in the biotite-granites occur in concentrations far above the background value in granites (Nb=20ppm, levinson 1974).

There is a high content of W in the rocks, which is well above the background value (W=2ppm. Levinson. 1974). W has a higher content in the later rocks (Jarawa-biotite-granite, biotite-microgranite and biotite-muscovite-granite) than in the early rocks, this is why wolframite is found as an associated mineral with the cassiterite and topaz deposits of the study area.

The rocks in the study area though successively emplaced at different times, yet originated from the same parent acid magma and had varying emplacement conditions. This is evident from the similarities in total absence of Ta, Sb, V and Zn content in the rock suits. The area is noticed to have experienced post-genetic events of metasomatism and tectonism, prior the emplacement of the dikes (Rafin jaki granite porphyry and dolerite).

Ti, Ni, Cr and Mn are more enriched in the early rocks (hornblende-biotite-granite), and depleted in the later rocks (biotite-granite and biotite-microgranite), while Nb, B, W and Li are more enriched in the later rock (biotite-granite and biotite-microgranite) than in the older rocks (hornblende-biotite-granite and hornblende-biotite-porphyry). Sn was used as a reference or pathfinder element because the deposits of topaz in the area are exclusively associated with cassiterite, and was discovered to show no significant relationship with any of the other elements in multiple correlation and regression analyses. Rather, it exhibits a very weak positive trend towards Ti, Ni and Mn. The gem deposits in the area are believed to be pneumatolytic because of the association of topaz and cassiterite, and because minerals like columbite and tantalite are not found in association with cassiterite in the deposit. This is probably the reason why Sn does not correlate with any of the elements analyzed.

The sole gem minerals in the area are topaz and quartz, which is exclusively associated with cassiterite and they are found in greisens so are termed pneumatolitic deposits. The fluid that gave rise to these minerals had a chemical and physical environment that favored the mobility of F and Sn together. The high B, Li, Al and Cr content, together with the aforementioned pneumatolytic conditions in the area, would have yielded schorl and other colored tourmaline.

SUMMARY AND CONCLUSION

APPENDIX



Plate 1: A picture showing the local underground mining (loto mining) of topaz in Zabir-Nabar, a part of the study area within the Jarawa-biotite-granite.



Plate 2: Local underground mining (loto mining) of topaz and cassiterite within the Jarawa-biotite-granite alluvium at Zebir-Nabar.

REFERENCES

1. Abaa, S.I. (1990): Hydrothermal fluid Responsible for the Formation of Precious Minerals in the Nigerian Younger Granite province. Mineral Deposits, Spring-Verlag. Vol.26, pg 34-39.
2. Adriano D.C. (2001). Trace Elements in Terrestrial Environments: Biogeochemistry, Bioavailability and Risks of metals. Geochemical Exploration. Environment. Analysis. Vol 2.
3. Adubok A.S (2008): Evolutionary Trend of the Jarawa Younger Granite Ring Complex, Jos Plateau Central Nigeria. Science World Journal Vol.3.
4. Aga, T and Ashano, E. C (2008) Enhancing the Value of Nigerian Gems through Lapidaries. Continental J. Earth Sciences vol.3: 71 – 76.
5. Buchanan, M. S., Macleod, W.N. Turner, D.C. Berridge, N. G. & Black, R. (1971). The Geology of the Jos Plateau Younger Granites Complexes, Bull. Geol. Survey of Nigeria, 2 (32): 67-106.
6. Charles, B. Boss and Kenneth J. Fredeen. (1997). Concepts, Instrumentation and Techniques in Inductively Coupled Plasma-Optical Emission Spectrometry, Second Edition. North Carolina State University. 44 pp.
7. Clifford, R. Stanley (2006). Geochemical Exploration. Environment. Analysis. Numerical Transformation of Geochemical Data; 1. Maximizing Geochemical Contrast to Facilitate Information Extraction and Improve Data Presentation. Vol 6. Part1. Pg 69-96.
8. Ekwueme, B.N. (1993). An Easy Approach to Igneous Petrology, University of Calabar Press pp. 19-153.
9. Hawkes, H.E. and Webb, J.S., (1962). Geochemistry in Mineral Exploration. Harper and Row, New York.
10. Howarth, R.J. and Earle S.A.M. (1979). Application of a Generalized Power Transformation to Geochemical Data. Mathematical Geology. Vol. 11. Pg 45-62.
11. Imoekparia, E.G. (1985). Geochemical Evolution of the Jarawa Younger Granite complex, Geological Magazine 122 (2):163-173, Printed in Great Britain.
12. Levinson, A.A (1974): Introduction to Exploration Geochemistry. Wilmette. Illinois, Allied Publishing Ltd, 614 p.
13. McQueen, K.G. (2006). Identifying Geochemical Anomalies. Department of Earth and Marine Sciences, Australian National University, ACT 0200.
14. Ntekim, E.E, Orazulike, D.M. and Ashano, E.C. (2007). Statistical Analysis of Trace Element Concentration in Shale-Carbonate Sediments from Northeastern Nigeria. Global Journal of Geological Sciences vol. 6 No 2 2008. Pg 95-104.
15. Nyambok, I.O. and Davies T.C. (1993) Geosciences and the Environment. Nairobi University Press.
16. Rollinson, H., (1993). Using Geo-chemical Data: Evaluation, Presentation, Interpretation. Longman, Essex, pg 1-36.
17. Shao-Yong Jiang, Ru-Cheng Wang, Xi-Sheng Xu and Kui-Dong Zhao (2005). Mobility of high field strength elements (HFSE) in magmatic-, metamorphic and submarine-hydrothermal systems. State Key Laboratory for Mineral Deposits Research, Department of Earth Sciences, Nanjing University, Nanjing 210093, China.
18. Simonet, C. S. and Okundi, P. (2000) Masai General setting of gemstone deposits in the Mozambique Belt of Kenya Preliminary considerations. Rockland Kenya Ltd.
19. Smirnov, V.I. (1969). The Great Soviet Encyclopedia, 3rd Edition.
20. Turner, D.C. (1989). Structure and Petrology of the Younger Granite Ring Complexes. In C.A. Kogbe (Ed). Geology of Nigeria. Second Revised Edition-Rock View Ltd. Jos. Pp 175-190.
21. Ye Fersman, A, (1939). Geochemical and Mineralogical Methods of Prospect for Mineral Deposits. Chapter 5, Special Methods of Prospecting. Geological Survey Circular 127.