

Lead Reservoirs and Metallization in Nigeria: Example of a Contrasting Geological Terrains

Silas Dada¹, Onema Adojoh^{2,*}, Adisa Rahaman³, Ibrahim Garba⁴

¹Kwara State University, Department of Geology, Malete, P.M.B 1530 Ilorin, Nigeria

²University of Liverpool, School of Environmental Sciences, Department of Geography, Earth and Ecological Sciences, Roxby Building, Room 805 B, L69 7ZT, UK

³Obafemi Awolowo University, Department of Geology, Ile-Ife, Nigeria

⁴Kano State University of Science and Technology, Department of Geology, P.M.B 3244, Wudil, Nigeria

*Corresponding author: onema.adojoh@liverpool.ac.uk

Received March 29, 2015; Revised April 07, 2015; Accepted April 13, 2015

Abstract Whole rock and mineral extracts from Nigerian goldfields of late Proterozoic age are significantly more radiogenic than those from the much younger Mesozoic lead-zinc mineralization in the Benue Trough, their common formation by hydrothermal processes notwithstanding. Their marked contrasts in lead isotope compositions can be attributed to differences in source reservoirs, structural settings and geological history rather than their age of mineralization. The Mesozoic sulphides have a remarkable uniformly unradiogenic composition for their age, placing the deposits in the lower crustal geotectonic environment that indicate a source of much lower μ . In contrast, mineral extracts from the southwestern and northwestern Nigeria gold deposits show increasingly radiogenic composition and plot in the mixed and upper crustal geotectonic fields respectively, typical of sources enriched in U/Pb and Th/Pb ratios, with clear indication of larger upper crustal reservoir of much higher μ . Therefore, exploration efforts may need to emphasize near-source mineralization prospects of low radiogenic Pb composition for economic deposits.

Keywords: lead reservoirs, metallization, U/Pb and Th/Pb ratios, Benue trough, economic deposits

Cite This Article: Silas Dada, Onema Adojoh, Adisa Rahaman, and Ibrahim Garba, "Lead Reservoirs and Metallization in Nigeria: Example of a Contrasting Geological Terrains." *Journal of Geosciences and Geomatics*, vol. 3, no. 2 (2015): 28-36. doi: 10.12691/jgg-3-2-1.

1. Introduction

Auriferous fields within the Gondwana continental landmass in Nigeria and NE Brazil include Archaean to

Early Proterozoic crystalline cores of the West African and Congo cratons, the Pan-African mobile belt between the cratons and their Phanerozoic cover rocks (Figure 1) (Dada, 1995).

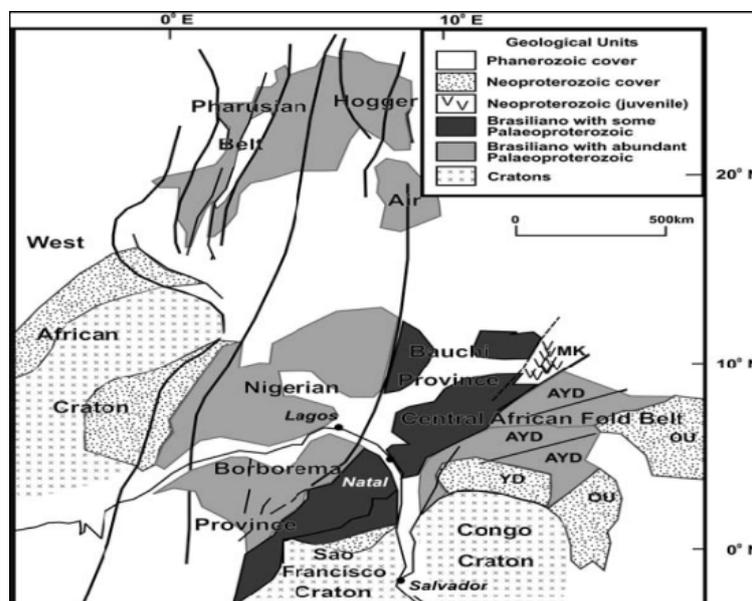


Figure 1. Pre-drift Proterozoic belts and their Phanerozoic cover rocks between the cratons (Dada 2008)

The heterogeneous nature of the late Proterozoic continental collision tectonic event, particularly its all-pervasive structural and metamorphic obliteratory effect on the pre-existing older rocks, has necessitated the deployment of several approaches in the elucidation of its pre-drift evolution (Dada, 1989). Younger Phanerozoic cover rocks also host hydrothermally processed mineralization whose mineralizing fluids are related to deep seated fractures in older crystalline rocks (1995, Dada).

There are no reliable isotopic ages for Nigerian gold deposits but structural correlations suggest that gold mineralizing events are intimately related to the N-S trending semi-ductile to brittle strike-slip faults formed during late Proterozoic orogen-parallel wrenching (Garba, 2000). The kinematics indicate dextral and sinistral movements that are coeval with the formation of sulphide-bearing quartz veins and the late phase Pan-African Sn-Nb-Ta bearing pegmatites. In this study, Plumbotectonics modeling, which appears to be a function of the tectonothermal age of the crust (Rudnick & Goldstein, 1990), is used in constraining the Pb isotopic reservoirs of the diachronous deposits; particularly because the $^{206}\text{Pb}/^{204}\text{Pb}$ and $^{208}\text{Pb}/^{204}\text{Pb}$ ratios are indicative parameters for the source of the metals. The less radiogenic Pb isotopic composition of much younger Mesozoic Pb-Zn deposits of the Benue Trough (Maurin & Lancelot, 1987) contrasts the radiogenic Pb data presented herein from much older Upper Proterozoic metasedimentary terrains.

2. Geological Setting

Overlying the Archaean gneissic complex in Nigeria are widespread Proterozoic metasediments, which include

variable volcanic components, well developed as elongated N-S trending belts in the western half of Nigeria. There are no affirmative ages of formation for metasediments in Nigeria and the Borborema province of NE Brazil. Inferred depositional ages for the Palaeoproterozoic series in these areas straddle from 2.2 to 2.0 Ga and predate the 1.9–1.8 Ga igneous activities (Grant, 1970; Rahaman & Emofurieta, 1983; Rahaman & Lancelot, 1984; Jardim de Sa et al., 1987; Annor, 1995; Neves et al., 2006). In addition to the well developed medium to high grade schists, the Neoproterozoic series of mainly low grade, weakly deformed metasediments occur in association with the thermal aureole of Pan-African granitoids and show upper greenschist to low pressure amphibolite facies metamorphism. More recent work on the same series in NE Brazil (Van Schmus et al., 2003; Neves et al., 2009), their structural relationships with Pan-African granitoids as well as their unequivocal reworking suggest a Neoproterozoic age of deposition. Gold and other metallic deposits occur in these rocks in Brazil and Nigeria and the Pan African is widely accepted as the minimum age of gold and associated mineralization in this belt.

Neoproterozoic granitoids in Nigeria consist of several contemporaneous petrologic groups. Their formation ages are well constrained between 640 and 580 Ma (Tubosun et al., 1984; Dada & Respaut, 1989; Dada et al., 1989; Rahaman et al., 1991). Pb isotope geochemistry on whole rocks and feldspars collected from plutons in north central Nigeria have been used to describe the evolution of the magmatic processes involved in their formation and the Pb reservoirs defined (Dada et al., 1995). The well defined Pan-African deformation pattern in the Nigerian schist belts has been related to gold and associated mineralization.

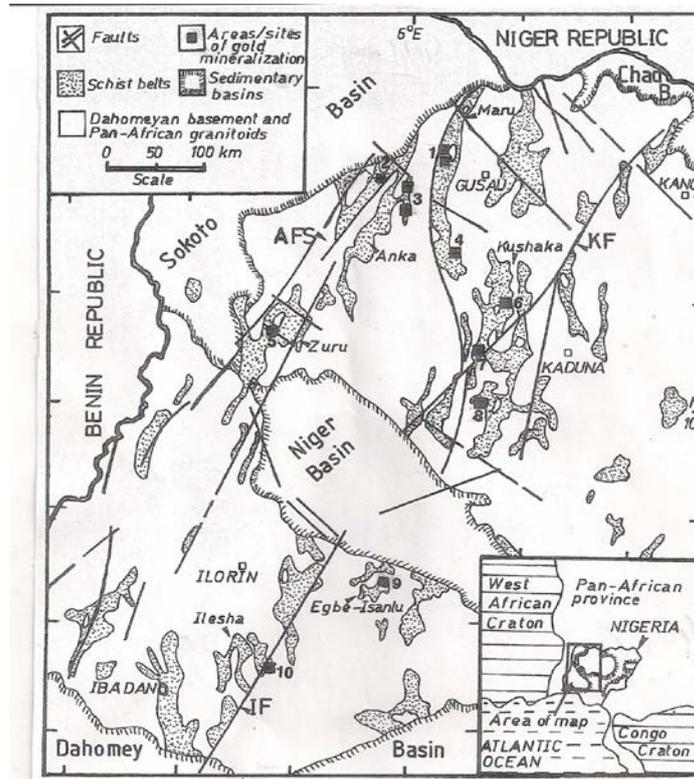


Figure 2a. Major areas of gold mineralization in the schist belts of western half of Nigeria. AFS Anka Fault System, KF Kalangai Fault, IF Ifewara Fault. 1 Maru, 2 Kwali, 3 Anka (Zuzurfa, Kuba), 4 Malele, 5 Bin Yauri, 6 Tshon Birnin Gwari, 7 Kwaga, 8 Gurmana, 9 Okolom-Dogondaji, 10 Iperindo, after (Garba 2003)

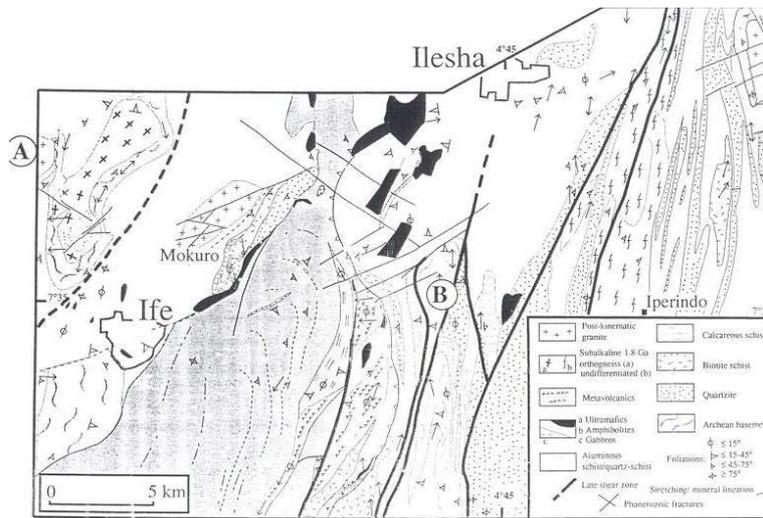


Figure 2b. Geological map of Ife-Ilesha schist belt showing the location of Iperindo goldfield (Caby & Boesse 2001).

2.1. Mesozoic Sediments

Mesozoic sediments of Late Aptian to Maastrichtian age are well developed in the Benue Trough subsequent to the opening of the south Atlantic. The coastal basin that developed in the South America and African landmasses developed a triple junction in the Guinean region with the formation of inland basin along the Benue with lead, sphalerite, brine and other associated mineralization. The origin and material sources of the widespread mineralization has been a subject of intense study and research. Available Pb-Pb isotope data is used in our comparative analysis with similar data from other geological terrains in Nigeria. We discuss our present understanding of metal sources in Nigeria; using new and pre-existing Pb-Pb data of ore pyrite, galena and chalcopyrite of the quartz-sulphide-gold veins from

deposits in the Nigerian schist belts and the galena-sphalerite deposits of the Benue Trough (Figure 2 & Figure 3) in order to constrain the local source rocks of lead, identify the isotopic composition of the main Pb reservoirs, and by analogy, of the mineralization.

3. Methodology

3.1. Isotopic Data

Pb isotope data include recent analyses on sulphides from northwestern Nigerian goldfields carried out at the Canadian Activation Laboratories, existing data of Maurin & Lancelot (1987) on lead-zinc mineralization from the Benue Trough, with comparisons using granitic rocks from northern Nigeria (Dada et al., 1995), Iperindo goldfield (Oyinloye, 2006) and aplites from Ibadan (Oversby, 1975).

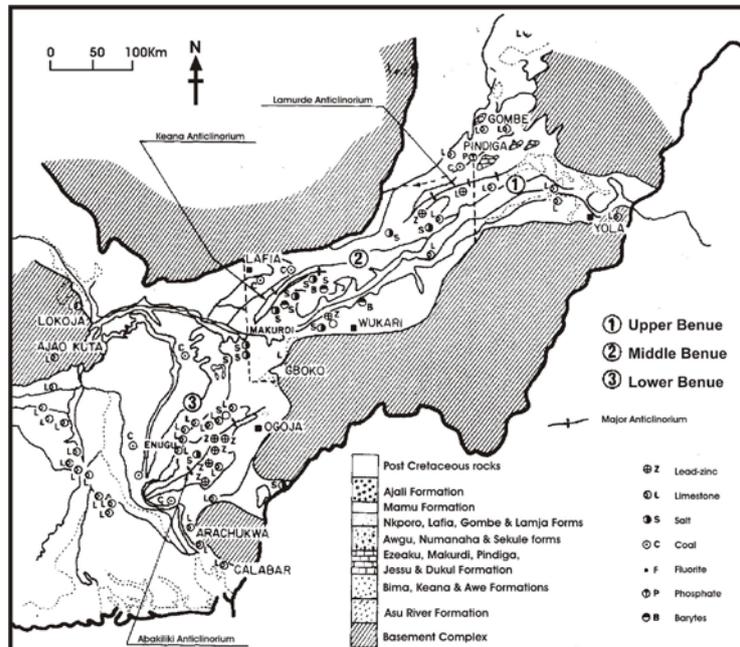


Figure 3. Mesozoic Pb-Zn and related mineralization in the Nigerian Benue Trough, after (Burke et al. 1972)

3.2. Identification of Source End-members

Lead in sulphides of most ore deposits have been derived from underlying basement rocks and they give

information on age and average Pb composition of such underlying basement and their constituents (1990, Rudnick). Nigeria consists of an amalgam of contrasted terrains with well developed metasedimentary rocks known as schist belts to the west and widespread

crystalline, essentially granitic rocks under Mesozoic to Tertiary cover rocks to the east (1984, Rahaman). The entire Nigerian basement has been reworked during thermotectonic Pan-African orogeny (600 Ma), during which prominent strike-slip shears developed along-strike extensions southwards into the Borborema province of northeast Brazil (Dada, 2008). These two provinces obviously have several geological similarities including tectonic, mineralization, age, etc; parameters that are germane to our discussion in this study. Field evidence indicates that both the Proterozoic vein-gold mineralization in the metasediments and the Mesozoic galena-sphalerite and associated vein mineralizations in the Benue Trough are epigenetic (Ogunleye, 2003; Offodile, 1980; Maurin & Lancelot, 1987). Large

mineralized veins are not common in the Nigerian Precambrian and are represented only by far-between quartz-sulphide gold and cassiterite-tantalite-bearing pegmatites and quartz veins that contain scheelite in association with talc schists in central Nigeria. On the other hand, the Nigerian Mesozoic Benue Trough is well endowed with solid minerals of great diversity, including metallic and industrial minerals. In general, there is direct correspondence between the Pb composition of the source rock and the ore deposits. We have therefore used the lead isotope compositions in Pb-Pb isotope diagrams (Figure 4, Figure 5, Figure 6 & Figure 7) of K-feldspars from basement rocks and sulphides from ore deposits to suggest possible geodynamic reservoirs.

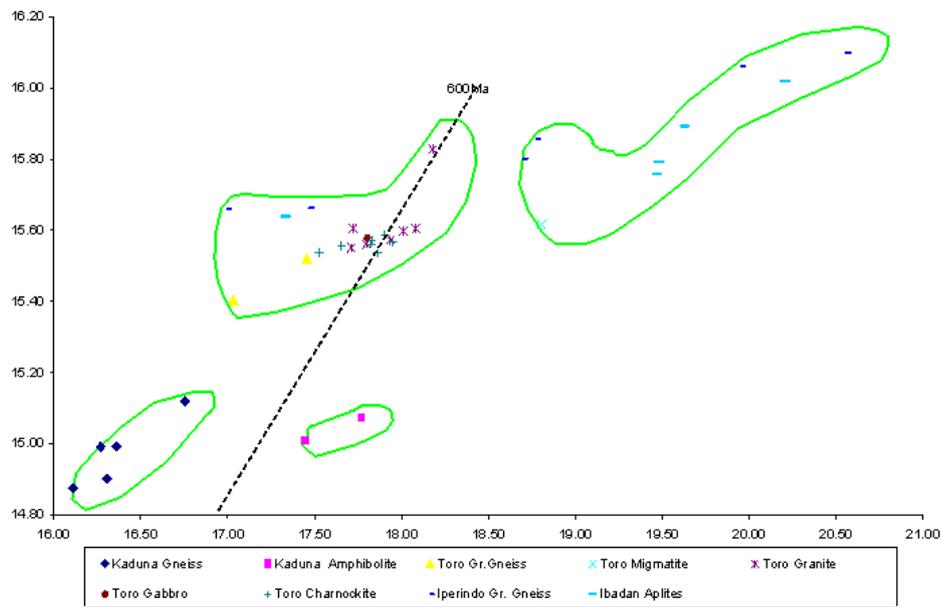


Figure 4a. $^{207}\text{Pb}/^{204}\text{Pb}$ vs $^{206}\text{Pb}/^{204}\text{Pb}$ of various rocks in Nigeria with the 600 Ma reference isochron

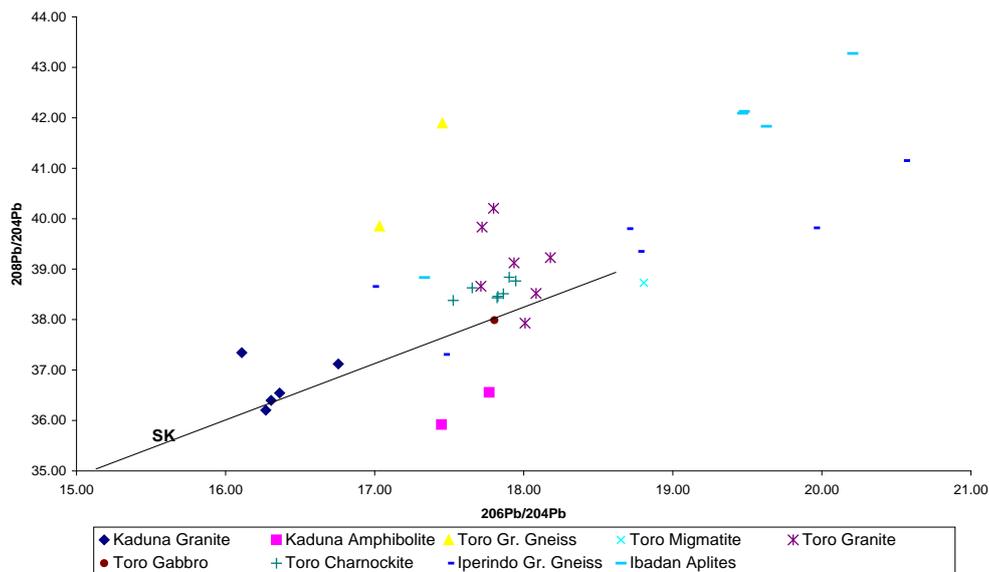


Figure 4b. $^{208}\text{Pb}/^{204}\text{Pb}$ vs $^{206}\text{Pb}/^{204}\text{Pb}$ of various rocks in Nigeria with the average growth curve of Stacey & Kramers, SK (1975)

3.3. Lead Isotope Data

On $^{207}\text{Pb}/^{204}\text{Pb}$ vs $^{206}\text{Pb}/^{204}\text{Pb}$ and $^{208}\text{Pb}/^{204}\text{Pb}$ vs $^{206}\text{Pb}/^{204}\text{Pb}$ diagrams (Figure 4, Figure 5, Figure 6, Figure 7),

the lead isotope data for whole rocks and mineralization plot in a series of echelon clusters along linear arrays. Geographical trends can be contoured (Isoplombs) with increasing radiogenic whole rock lead to the southwest (Figure 4). Apart from those from northwest goldfields, all

mineral extracts including K-feldspars plot along a linear array, regardless of the age of their host rocks. The only exception from northwest gold is the galena sample from Malele. This most probably implies that all other deposits were derived from source rocks of the same age that had initial Pb isotopic compositions similar to that preserved in Pan-African feldspars. When samples from NW goldfields are exempted, the slope of the linear array (0.1785) on the $^{207}\text{Pb}/^{204}\text{Pb}$ vs $^{206}\text{Pb}/^{204}\text{Pb}$ gives an approximate age of 2.01Ga. This is likely to be a crustal residence average mixing age indicative of older source for both sulphide and K-feldspar lead. However the tectonic reservoirs involved have remained undefined. This has implications for exploration.

Table 1. Pb isotope composition of basement rocks from northern Nigeria

Sample (NG)	$^{206}\text{Pb}/^{204}\text{Pb}$	$^{207}\text{Pb}/^{204}\text{Pb}$	$^{208}\text{Pb}/^{204}\text{Pb}$
Kaduna gneisses			
301	16.305	14.901	36.398
304	16.362	14.992	36.543
306	16.109	14.875	37.344
307	16.270	14.992	36.204
309	16.756	15.119	37.121
Kaduna amphibolites			
302	17.769	15.075	36.556
308	17.448	15.009	35.919
Toro granite gneiss			
142	17.454	1.552	41.897
143	17.032	15.405	39.853
Toro migmatite	18.805	15.616	38.730
Toro granites			
123	18.083	15.605	38.520
125	18.009	15.598	37.931
127	17.720	15.606	39.832
131	17.935	15.573	39.123
132	17.713	15.551	38.661
133	17.798	15.562	40.207
135	18.179	15.828	39.228
Toro gabbro (120)	17.803	15.578	37.988
Toro charnockitic diorites			
129	17.527	15.538	38.379
130	17.654	15.556	38.630
140	17.821	15.562	38.432
141	17.827	15.572	38.460
145	17.863	15.536	38.514
136	17.946	15.566	38.764
139	17.903	15.587	38.838

4. Discussion

4.1. Comparative Metallogenesis

Since we are interested in both the nature of the lead source and the identification of probable metal source rocks, the data presented in Table 1 & Table 2 give a comparison of ore-lead and rock-lead. The genetic and prospecting consequences are very obvious, particularly for the epigenetic hydrothermal deposits under study. However, we have decided to compare the ore-lead with the Pb isotopic composition in the feldspars, which unlike the host rock-lead, denotes a phase with low U/Pb (μ) and

Th/Pb (W) ratios; whose isotopic composition will not continue to evolve. The galena samples from the Pb-Zn deposits of Abakaliki and Zurak areas plot in the same field with feldspars of the Pan African granitoids (with μ varying from 9.65 to 10.30). They have a remarkable uniformly unradiogenic composition for their age, although the Zurak group is slightly more radiogenic than the Abakaliki set. This places the deposits in the lower crustal geotectonic environment (Figure 7) of Zartman and Doe (1981), indicating a source of much lower μ . In contrast, mineral extracts from the northwestern Nigeria gold deposits plot distinctively in the upper crustal geotectonic field typical of sources enriched in U/Pb and Th/Pb. This is a clear indication of larger upper crustal reservoir with much higher μ . The pyrite samples from Malele and Tsohon Birnin Gwari are expectedly more radiogenic than the bulk galena/chalcopyrite from Gurmana and the Malele galena extracts. Even taking the galena sample, often taken as representative of their gold deposits (Ayuso et al., 2005), the northwestern Nigeria gold deposits must have derived from highly radiogenic sources as shown in both the uranogenic and thorigenic diagrams (Figure 4 to Figure 7). Examples of geologically related but dissimilar lead-isotope provinces have been identified in the galena-bearing ore deposits of southwestern New Mexico (Stacey & Hedlund, 1983) and western and central Europe (Koeppel, 1984).

Table 2. Pb isotope composition of mineral extracts from various Nigeria geological terrains. ML are data from Maurin et Lancelot, 1987

Sample (NG)	$^{206}\text{Pb}/^{204}\text{Pb}$	$^{207}\text{Pb}/^{204}\text{Pb}$	$^{208}\text{Pb}/^{204}\text{Pb}$
K-feldspars			
Kaduna gneiss	15.825	14.863	35.732
Toro granite	17.420	15.620	37.950
Toro charnockitic diorite	16.890	15.510	37.880
Bauchi monzonite	17.420	15.560	37.770
Jada granite	17.640	15.603	37.708
Jada granite	17.629	15.601	
Jalingo granite	17.887	15.631	38.072
Mika granite	17.796	15.569	37.848
NW Nigeria goldfields			
Tsohon B/Gwari pyrite	19.880	16.980	41.050
Malele pyrite	19.930	16.960	41.090
Malele galena	19.300	16.090	39.050
Gurmawa galena/chalcopyrite	19.940	16.770	40.220
GALENA (Abakaliki) ML			
1	17.979	15.574	38.337
2	17.966	15.561	38.287
3	17.996	15.589	38.384
4	18.001	15.599	38.413
5	17.992	15.592	38.387
6	17.982	15.591	38.394
GALENA (Zurak) ML			
1	18.074	15.633	38.473
2	18.113	15.654	38.580
3	18.085	15.638	38.504
4	18.132	15.670	38.634
5	18.133	15.682	38.673
6	18.094	15.662	38.575

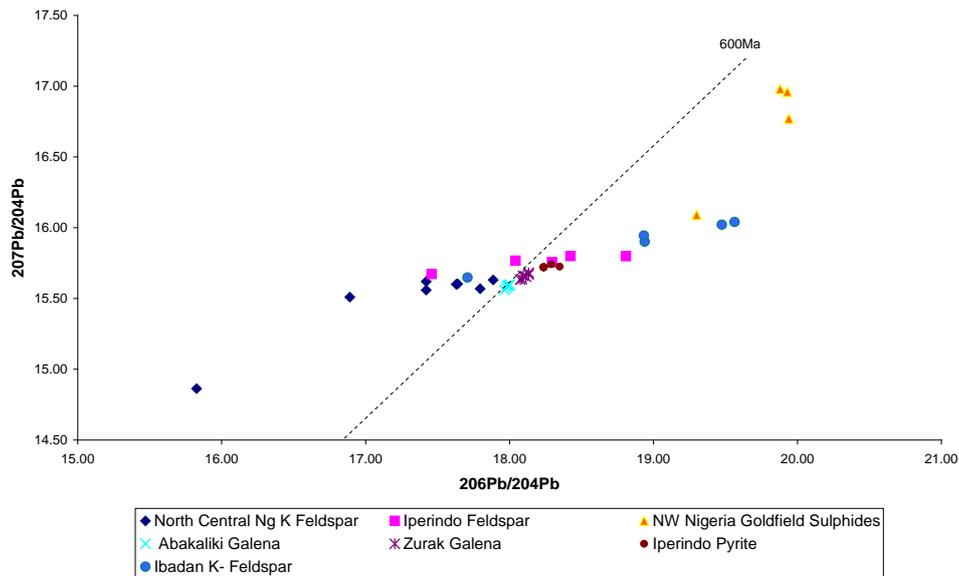


Figure 5a. $^{207}\text{Pb}/^{204}\text{Pb}$ vs $^{206}\text{Pb}/^{204}\text{Pb}$ of various mineral extracts in Nigeria with the 600 Ma reference isochron

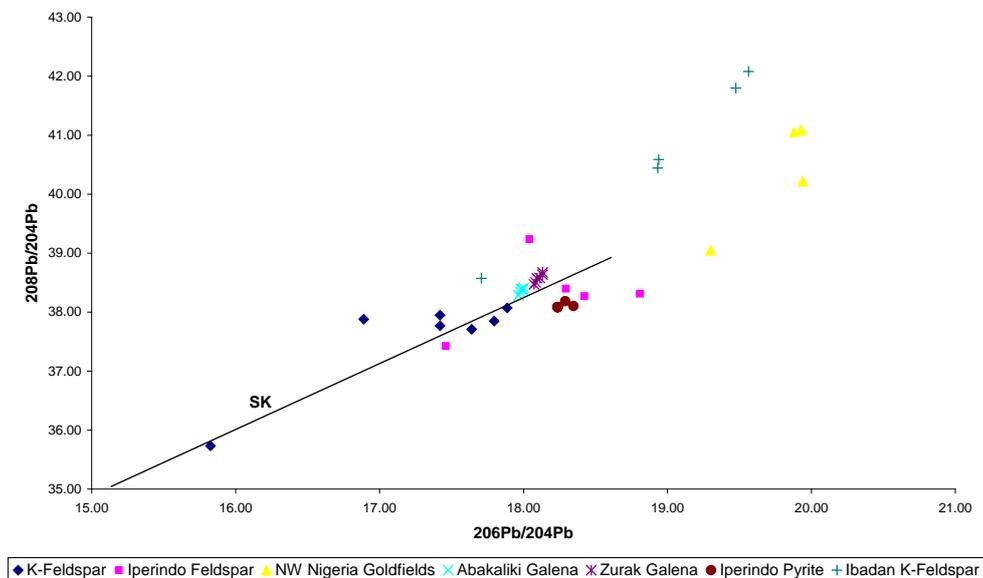


Figure 5b. $^{208}\text{Pb}/^{204}\text{Pb}$ vs $^{206}\text{Pb}/^{204}\text{Pb}$ of various mineral extracts in Nigeria with the average growth curve of Stacey & Kramers, SK (1975)

4.2. Constraints on Mineralizations

Sulphide ores containing galena, sphalerite, pyrite, and chalcopyrite that commonly preserve the initial, primitive isotopic composition of the ore fluid occur in both Proterozoic metasedimentary rocks of the Nigerian schist belts and in Cretaceous sediments of the Benue Trough. We infer the provenance of ore metals in precious (gold) and base (lead-zinc) metal deposits from lead isotope data from the Proterozoic schist belts and the Cretaceous of the Benue Trough. Our data on sulphides (Table 1 & Table 2) from Proterozoic goldfields of NW Nigeria show that their Pb compositions are much more radiogenic ($^{206}\text{Pb}/^{204}\text{Pb}=19.30-19.94$, $^{207}\text{Pb}/^{204}\text{Pb}=16.09-16.98$, $^{208}\text{Pb}/^{204}\text{Pb}=39.05-41.09$) than those of K-feldspars from Pan African granitoids (Dada et al., 1995). This precludes the establishment of a direct genetic connection with the Pan African granitoids. In comparison, pyrite from Iperindo goldfield in southwestern Nigeria have less

radiogenic Pb composition ($^{206}\text{Pb}/^{204}\text{Pb}=18.24-18.35$, $^{207}\text{Pb}/^{204}\text{Pb}=15.72-15.74$, $^{208}\text{Pb}/^{204}\text{Pb}=38.09-38.18$). On the

other hand, Pb isotope compositions of sulphides from the younger Cretaceous Pb-Zn mineralization in the Benue Trough are even more significantly unradiogenic ($^{206}\text{Pb}/^{204}\text{Pb}=17.98-18.13$, $^{207}\text{Pb}/^{204}\text{Pb}=15.56-15.68$, $^{208}\text{Pb}/^{204}\text{Pb}=38.29-38.67$) and compare with K-feldspars from Pan African granitoids (Maurin & Lancelot, 1987). This led the authors to conclude for lead derived from a source strongly depleted in uranium such as detrital feldspars eroded from basement of Pan African age. The remarkable difference in isotopic compositions of the diachronous deposits cannot be explained by their age differences alone. In fact, crustal influences generally increase in younger ore associations (Bielichi & Tischendorf, 1991) in many geological settings and it would appear more logical for Cretaceous mineralizations to contain more radiogenic Pb than those of the Proterozoic. The nature of the sources for the deposits and

probably the character of the ore-forming processes require further elucidation. While mineralizing fluids were mostly derived from devolatilization of the Pan African collisional upper crustal slabs, the higher radiogenic character of the lead in sulphides of the goldfields would suggest a source of upper crustal affinity. This reinforces the stable isotope (^{34}S , ^{13}C , ^{18}O) evidence for an upper crustal reservoir for the metals (Garba, 2000). Available U-Pb, Sm-Nd and Rb-Sr studies have revealed that NW Nigeria is underlain by Archaean basement (Bruguier et al, 1994, Dada, 1998) and their metasedimentary rocks contain a high proportion of Archaean-derived material. Such involvement of older rocks as source rocks for gold in Nigeria that was subsequently implicated in the Pan African thermotectonic event and mineralization is not in doubt.

4.3. Tectonic Environments and Implications for Exploration

Figure 6 & Figure 7 show the distribution of isotopic composition values (Table 1 & Table 2) in the curves for average Pb isotope evolution in the four Plumbotectonic domains of Zartman & Doe (1981). It is evident that the sulphides from northwestern goldfields and the K-feldspars from Ibadan aplites have a large component of ancient upper crustal material in the make-up of their rocks and mineralization; and rocks of Archaean age have been reported in both areas (Oversby, 1975; Bruguier et al, 1994, Dada, 1998). Further south in the southwestern Iperindo gold district, the data plot well below those of the NW goldfields and therefore indicates a much smaller involvement of older sialic material. The Iperindo sulphides plot below the Stacey and Kramers (1975) curve (SK) in Figure 5b and since the SK curve corresponds to the average orogene curve of Zartman & Doe, they can at best be regarded as have derived from a mixture between upper mantle and crustal leads.

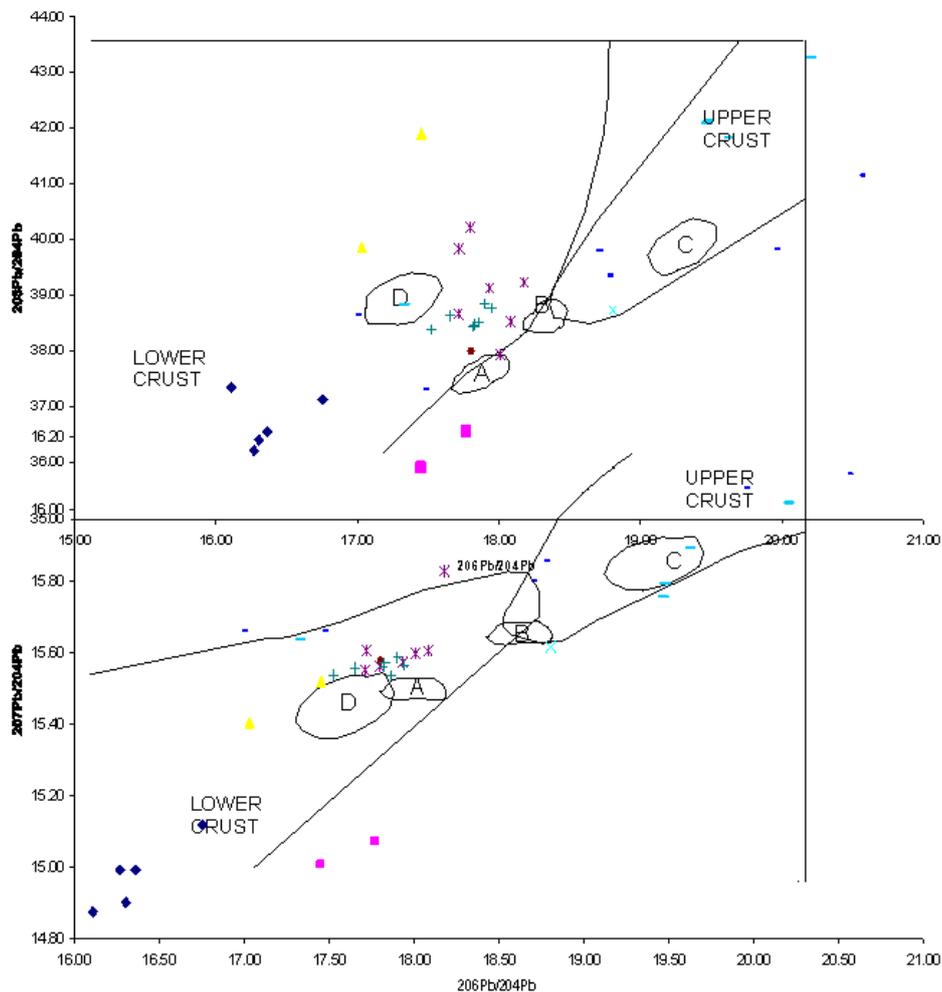


Figure 6. Plot of Pb isotopic composition of various rocks as in Figure 4. in the global geotectonic environments (Zartman & Doe, 1981). A=mantle, B=orogen, C=upper crust, D=lower crust

Data from the galena samples from the Abakaliki and Zurak Pb-Zn mineralization indicate a much smaller older basement component. The assertion of Maurin & Lancelot (1987) is corroborated by the isotopic evidence of Dada et al. (1995) and the contrasting evidence on Figure 7 that indicate upper mantle origin of subsequent evolution in the lower crust, without significant contribution from Archaean sources. Plutonic rocks responsible for mineralization in several geological terrains have been

shown to have similar lead isotopic composition to that of the least sulphides in such regions (Stacey & Hedlund, 1983); with the consequence that the least radiogenic leads are often favourable indicators for large ore deposits (Doe & Stacey, 1974; Zartman, 1974). Exploration in Nigeria should therefore target and emphasize such near-source deposits of low radiogenic lead where erosion has not removed significant sedimentary and metasedimentary cover rocks.

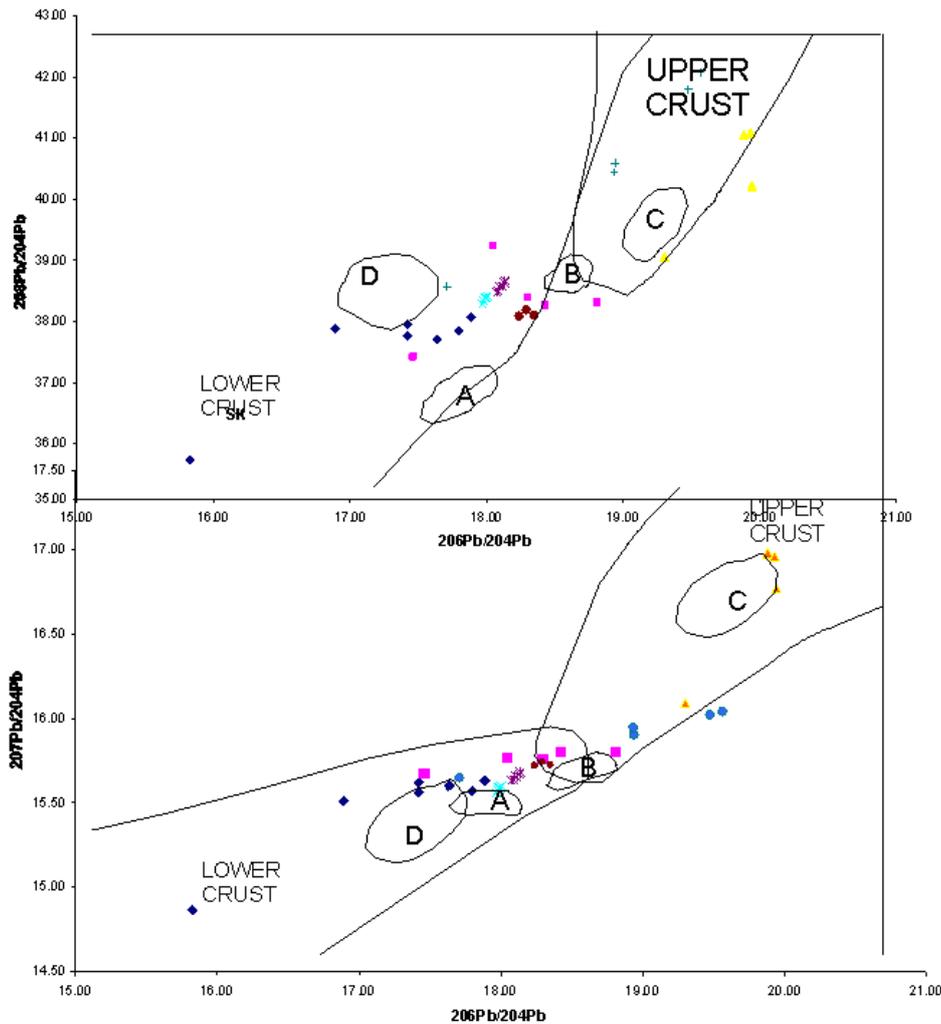


Figure 7. Plot of Pb isotopic composition of mineralisation as in Figure 5 in the global geotectonic environments (Zartman & Doe, 1981). A=mantle, B=orogen, C=upper crust, D=lower crust

5. Conclusions

The development and evolution of the Nigerian crust from Archaean took place in several stages with the reworking of the older crust throughout the Proterozoic. Existing Sm-Nd, U-Pb, Rb-Sr and Pb-Pb data (Dada, 1998, 2008) indicate that a significant greater component of older material was incorporated into the metasedimentary pile in the western half of the country than into the eastern part during ancient subduction processes. Unradiogenic sources in the mantle but preferably in the lower crust have been inferred for the formation of Pan-African granitoids (Dada et al., 1995); and represent the most probable source reservoir for the less radiogenic Mesozoic Pb-Zn mineralization in the Benue Trough (Maurin & Lancelot, 1987). The reworked late Pan African pelites and phyllites of the upper crustal Younger Metasedimentary suite, that host the mineralized vein-quartz, are hereby interpreted as the ultimate source for the more radiogenic Pb of the western auriferous terrains. The isotopic characteristics of mineralization in Nigeria therefore have no direct relationship with age of formation but to structural settings and geological history. Pb-Pb isotope systematics suggests that metal sources are essentially from the crust implicated in well-defined

structural discontinuities by hydrothermal processes during both the Pan African and Mesozoic. The correlation between radiogenic factor in Pb and size of deposit remains to be confirmed in the light of the low level of exploration activity.

Acknowledgments

Several people have contributed to this study, notably the Isotope Research groups at the University of Science and Technology (USTL), Montpellier and University of Paris 6 & 7 (IPGP) as well as Nigerian colleagues, including AOO (UNAD) with whom we had useful and stimulating discussions.

References

- [1] Annor AE (1995) U-Pb zircon age for Kabba-Okene granodiorite gneiss: implication for Nigeria's basement chronology. *African Geoscience Review* 2 101-105.
- [2] Ayuso RA, Wooden JL, Foley NK, Seal RR, Sinha AK (2005) U-Pb Zircon Ages and Pb Isotope Geochemistry of Gold Deposits in the Carolina Slate Belt of South Carolina. *Economic Geology* 100 no. 2; p. 225-252.
- [3] Bielicki KH, Tischendorf G (1991) Lead isotope and Pb-Pb model age determinations of ores from Central Europe and their

- metallo-genetic interpretation. Contributions to Mineralogy and Petrology 106 4 440-461.
- [4] Bruguier O, Dada S, Lancelot JR (1994) Early Archaean component (>3.5 Ga) within a 3.05 Ga orthogneiss from northern Nigeria: U-Pb zircon evidence. *Earth and Planetary Science Letters* 125 89-103.
- [5] Caby R, Boesse M (2001) Pan African nappe system in southwest Nigeria: the Ife Ilesha schist belt. *Journal of African Earth Sciences* 33 211-225.
- [6] Dada SS, Respaut JP (1989) La monzonite a fayalite de Bauchi (bauchite): Nouveau emoin d'un magmatisme syntectonique pan-africain au nord du Nigeria. *Compte Rendus Academie des Sciences de Paris* 309 (II) 887-892.
- [7] Dada SS, Lancelot JR, Briquieu L (1989) Age and origin of the annular charnockitic complex at Toro, Northern Nigeria: U-Pb and Rb-Sr evidence. *Journal of African Earth Sciences* 9 2 227-234.
- [8] Dada, S.S., Briquieu, L. Harms, U., Lancelot, J.R. & Matheis, G. (1995) Charnockitic and monzonitic Pan-African series from north central Nigeria: Trace-element and Nd, Sr, Pb isotope constraints on their petrogenesis. *Chemical Geology (Isotope Geoscience)* 124 233-252.
- [9] Dada S S (1998) Crust-forming ages and Proterozoic crustal evolution in Nigeria: a reappraisal of current interpretations. *Precambrian Research* 87 65-74.
- [10] Dada SS (2008) Proterozoic evolution of the Nigeria-Boborema province. Geological Society, London, Special Publications 294 121-136.
- [11] Doe BR, Stacey JS (1974) The application of lead isotopes to the problem of ore genesis and ore prospect evaluation: *Economic Geology* 69 757-776.
- [12] Garba I (2000) Origin of Pan-African mesothermal gold mineralization of Bin Yauri, Nigeria. *Journal of African Earth Sciences* 31 2 433-449.
- [13] Grant NK (1970) Geochemistry of Precambrian basement rocks from Ibadan, southwestern Nigeria. *Earth & Planetary Science Letters* 10 29-38.
- [14] Jardin De Sa EF, Wacedo WH, Legrand JM, McCreath L, Galindo A, SA, JM (1987) Proterozoic granitoids in a polycyclic setting: the Serido region, northeast Brazil; In: International Symposium on Granites and Associated Mineralization, Salvador, Brazil, Extended Abstracts 103-110.
- [15] Koeppel V (1984) Lead Isotopes as Tracers of the Origin of Metals in Ore Deposits and of the Evolution of Continental Crust: Examples from Western and Central Europe. Proceedings of the 27th International Geological Congress in Metallogenesis and Mineral Ore Deposits 12 53-82.
- [16] Maurin JC, Lancelot JR (1987) Origine des mineralisations de Pb-Zn de la Vallee de la Benoue (Nigeria) d'apres la composition en Pb des galenes de l'encaissant. *Mineralium Deposita* 22 99-108.
- [17] Neves PS, Bruguier O, Vauchez A, Bosch D, Rangel Da Silva JS, Mariano G (2006) Timing of crust formation, deposition of supracrustal sequences, and Transamazonian and Brasiliano metamorphism in the East Pernambuco belt (Borborema Province, NE Brazil): Implications for western Gondwana Assembly. *Precambrian Research* 149 197-216.
- [18] Neves SP, Bruguier O, Rangel Da Silva, JM, Bosch D, Alcantara VC, Lima CM (2009) The age distributions of detrital zircons in metasedimentary sequences in eastern Borborema Province (NE Brazil): Evidence for intracontinental sedimentation or orogenesis? *Precambrian Research* 175 187-205.
- [19] Offodile ME (1980) A mineral survey of the Cretaceous of the Benue Valley, Nigeria. *Cretaceous Research* 1 101-124.
- [20] Ogunleye PO, Ike EC, Garba I (2003) Geochemistry of the niobium-rich arfvedsonite granites of the northern Nigerian anorogenic ring-complexes. Annual Conference of the Nigerian Mining & Geosciences Society, Itakpe, 39.
- [21] Oversby VM (1975) Lead isotopic study of aplites from the Precambrian basement complex rocks near Ibadan, Southwest Nigeria. *Earth and Planetary Science Letters*, 27, 177-180.
- [22] Oyinloye AO (2006) Metallogenesis of the lode gold deposit in Ilesha area of southwestern Nigeria: inferences from lead isotope systematics. *Pakistan Journal of Scientific & Industrial Research* 9 1 1-11.
- [23] Rahaman MA, Lancelot JR (1984) Continental crust evolution in SW Nigeria: Constraints from U/Pb dating of pre-Pan-African gneisses. In: Rapport d'activite 1980-1984. Document Travaux Centre Geologie et Geophysique, Montpellier, II 4 41.
- [24] Rahaman MA and Emofurieta WO (1983) The potassic granites of the Pan-African Belt in Southwestern Nigeria. *Precambrian Research* 22 75-92.
- [25] Rahaman M.A, Tubosun IA, Lancelot, JR (1991) U-Pb geochronology of potassic syenites from southwestern Nigeria and the timing of deformational events during the Pan-African orogeny. *Journal of African Earth Sciences* 13 387-395.
- [26] Rudnick RL, Goldstein SL (1990) The Pb isotope compositions of lower crustal xenoliths and the evolution of lower crustal Pb. *Earth Planetary Science Letters* 98 192-207.
- [27] Stacey JS, Hedlund DC (1983) Lead-isotopic compositions of diverse igneous rocks and ore deposits from southwestern New Mexico and their implications for early Proterozoic crustal evolution in the western United States. *Geological Society of America Bulletin* 94 43-57.
- [28] Stacey JS, Kramers JD (1975) Approximation of terrestrial lead isotope evolution by a two-stage model. *Earth Planetary Science Letters*. 26 206-221.
- [29] Tubosun IA, Lancelot JR, Rahaman MA, Ocan O (1984) U-Pb Panafrican ages of two charnockite-granite association from southwestern Nigerian. *Contributions to Mineralogy and Petrology* 88 188-195.
- [30] Van Schmus WR, Brito Neves BB et al. (2003) The Serido Group of NE Brazil, a late Neoproterozoic pre-to syn-collisional basin in West Gondwana: insights from SHRIMP U-Pb detrital zircon ages and Sm-Nd crustal residence (T_{DM}) ages. *Precambrian Research* 127 287-327.
- [31] Zartman RE (1974) Lead isotope provinces in the Cordilleran of the western United States and their geology significance. *Economic Geology* 69 901-942.
- [32] Zartman RE, Doe BR (1981) Plumbotectonics. The model Tectonophysics 75 135-162.