

# Pb-Pb AND Sm-Nd ISOTOPE STUDY OF METAIGNEOUS ROCKS OF KADUNA REGION: IMPLICATIONS FOR ARCHAEOAN CRUSTAL DEVELOPMENT IN NORTHERN NIGERIA

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## Abstract

The Kaduna Migmatite-Gneiss Complex (MGC) of Northern Nigeria is typical of many Archaean terrains that have undergone polyphase deformation and metamorphism. It is a bimodal association of gneisses and amphibolites; with the latter in form of relicts as possible basaltic precursor material. Available geochronological data put its history back to > 3.5 Ga. New isotopic data presented herein provide some insight into when and how the earliest crust in Nigeria may have formed. Whole rock Pb-Pb and Sm-Nd data yield errochrons that lie on reference isochrons between 3.7 and 3.3 Ga in agreement with  $T^{Nd}$  model ages that average  $3.65 \pm 0.04$  Ga ( $\epsilon_{Nd} = +2.3 \pm 0.3$ ). The sources had near-chondritic rare-earth element (REE) distribution patterns and time-integrated  $^{147}Sm/^{144}Nd$  ratios; features that are characteristic of an undifferentiated mantle about 3.7-3.6 Ga. The differentiation of juvenile crust in the region by partial melting of basaltic sources must be of great antiquity. The data presented here agree with existing U-Pb zircon age of > 3.56 Ga and confirm that the Northern Nigeria lithosphere was isolated from the convecting upper mantle during the early Archaean.

**Key Words:** Archaean, meta-igneous, chondritic, geochron, precursor

## Introduction and Geological Setting

Multiple isotopic studies are of great use in constraining the origin and timing of initial crust formation as well as subsequent tectonometamorphic processes of ancient terrains such as the Kaduna Migmatite Gneiss Complex (MGC). The petrology of the Kaduna MGC has been described in Dada (1989) and Dada et al. (1994). The age and metamorphic history of the gneiss is well constrained by U-Pb analyses on zircons (Bruguier et al., 1994). This complex is within the Pan African mobile belt at the heart of the Northern Nigerian shield (McCurry, 1976) in a transition zone between the mainly supracrustal terrain, the Schist Belt, to the west and a vast vestigial crystalline domain to the east. The MGC is made up of fine to medium grained, variously migmatized, thinly-banded grey gneisses in association with sporadic enclaves of amphibolites. The gneisses vary from trondhjemitic to mainly granodioritic in composition while the amphibolites are meta-tholeiites. The Kabala gneiss has been dated by U-Pb single zircon method at >3.56 Ga (Bruguier et al., 1994) while both multiple and single zircon U-Pb as well as whole rock Rb-Sr studies confirm metamorphic events at 3.1-3.0, 2.8-2.7 and 0.6 Ga (Bruguier et al., 1994, Dada, 1989, Dada et al., 1998).

The present study is aimed at using Pb-Pb and Sm-Nd data to corroborate earlier U-Pb zircon data to constrain the period of formation and early evolution of the Nigerian primitive crust. Because the Kaduna MGC has similar petrologic similarities with other Archaean terrains such as the Amitsoq gneisses, both being dominantly quartz-feldspathic with amphibolite units

(Black et al., 1971); it offers the possibility of comparing similar ancient terrains.

## RESULTS

Isotopic analyses were performed at the Isotope Geochemistry Laboratory, University of Montpellier, using the methods of Manhès et al. (1980) for Pb-Pb and an adaptation of the Sm-Nd method developed by Richard et al. (1976). Line-fittings and age computations were done using the method of Provost (1990) and all regression errors reported in this paper are quoted at the 2 $\sigma$  level.

### Pb-Pb

The whole rock Pb-Pb data (Table 1) show large uncertainties in the calculated ages on the secondary isochron (Fig 2). The scatter about the best-fit isochron exceeds analytical uncertainty and may be related to imperfect initial isotopic homogenisation during emplacement and/or disturbance of the U-Th-Pb systematics including uranium loss during subsequent thermal events, and in particular, the Pan African orogeny. The results define a secondary isochron that corresponds to  $3250 \pm 48$  Ma (Fig 2a). In the Pb-Pb diagram, the gneisses alone yield an errochron that corresponds to an age of  $3780 \pm 380$  Ma (Fig. 2b). The initial isotopic composition ( $^{208}Pb/^{204}Pb=12.24$  and  $^{207}Pb/^{204}Pb=13.70$ ) corresponds to a second stage evolution (Stacey and Kramers, 1975) with a  $\mu$  value of 7.7 subsequent to differentiation about 3.7 Ga, directly comparable to the Amitsoq gneisses (Fig. 2c).

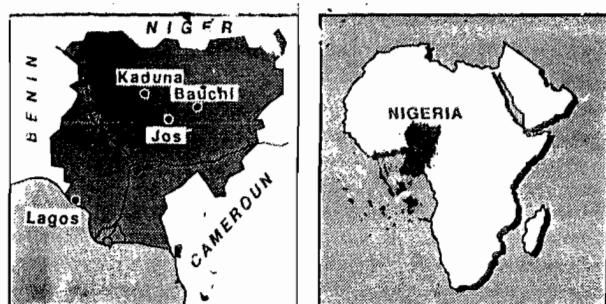
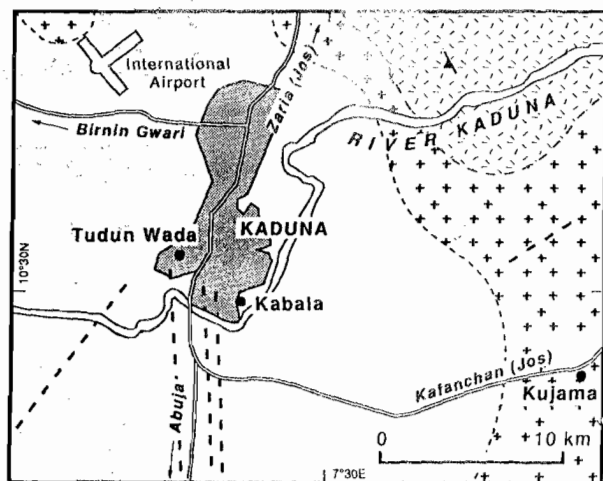


Fig. 1: Geological Map of Kaduna area.

1 - Migmatite Gneiss Complex (gneisses, amphibolites and amphibole schists); 2 - Porphyritic Granite; 3 - Quartz diorite; 4 - Major fractures; 5 - Strike and dip of foliation.

### Sm-Nd

The results of the Sm-Nd isotopic analyses (Table 1) show homogeneity in the  $^{143}\text{Nd}/^{144}\text{Nd}$  ratios and small range in  $^{147}\text{Sm}/^{144}\text{Nd}$  ratios particularly for the gneisses. This makes it difficult to fulfill the conditions for obtaining a precise isochron age. However, the identical Archaean Nd model ages for both units of the Kaduna MGC (gneisses and amphibolites) and their close field relations support the plotting of all data on a single isochron diagram

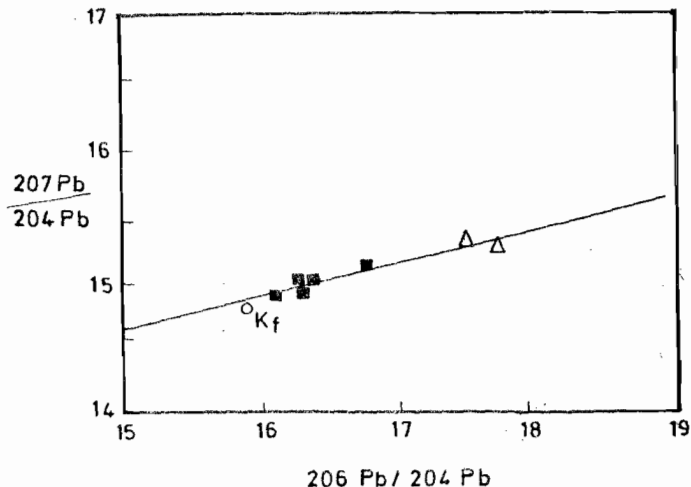


Fig. 2a:

Whole rock Pb isotopic composition of the Kaduna MGC. Solid circles indicate the gneisses, open triangles are amphibolites. K<sub>f</sub> represents the potassium feldspar composition of Kabala gneiss NG 304 dated at 3.56 Ga by Bruguier et al., (1994). All points are considered for age calculations.

(Hamilton et al., 1980; McCulloch and Compston, 1981). The 7-point whole rock data distribute on a 3.7 Ga reference isochron and define an age of  $3702 \pm 332$  Ma with an initial  $^{143}\text{Nd}/^{144}\text{Nd}$  ratio of  $0.50797 \pm 0.00026$  (Fig. 3). The scatter in the data (MSWD=6) is insufficient to render age discussions and interpretations ambiguous. The initial ratio is that of an undifferentiated chondritic mantle at 3.55 Ga. This is in agreement with Nd model ages (Table 1) and existing U-Pb zircon crystallisation age of Bruguier et al. (1994). If we exclude NG 302, the 6-point whole rock data align and define an age of  $3.35 \pm 0.17$  Ga with an initial ratio of  $0.50820 \pm 0.00010$  (MSWD = 1.7).

### ARCHAEOAN CRUSTAL DEVELOPMENT IN NIGERIA

The Pb isotopic compositions plot to the left of the geochron and confirm the unradiogenic composition of the source. The alignment of the experimental points on the reference isochron and on the single stage model (Stacey and Kramers, 1975), in

Table 1 Whole rock isotopic data for gneisses and amphibolites of the Kaduna MGC. NG304Kf represents the alkali feldspar from Kabala gneiss dated at 3.56Ga from U-Pb on zircons by Bruguier et al. (1994). All quoted errors are 2σ. Pb isotope ratios are relative to NBS 981 International Standard, which yields  $^{206}\text{Pb}/^{204}\text{Pb}=16.92$ ,  $^{207}\text{Pb}/^{204}\text{Pb}=15.46$ ,  $^{208}\text{Pb}/^{204}\text{Pb}=36.60$  (n=9) on CAMECA TSN 2065.  $^{143}\text{Nd}/^{144}\text{Nd}$  ratios are normalised to  $^{146}\text{Sm}/^{144}\text{Nd}=0.7219$ . JMC 361 Standard yielded  $0.511140 \pm 0.000016$  (n=14).

Sample No	208Pb/ 204Pb	207Pb/ 204Pb	208Pb/ 204Pb	143Nd/ 144Nd	147Sm/ 144Nd	Sm (ppm)	Nd (ppm)	T(DM) Ga	ENd (Ga)
Gneisses									
NG 304Kf	15.825	14.863	35.732						
Error +/-	0.006	0.006	0.054						
NG 301	16.305	14.901	36.398	0.510593	0.10691	3.4	19.2	3.65	2.41
Error +/-	0.002	0.002	0.005	0.000027					
NG 304	16.362	14.992	36.543	0.51065	0.10688	3.3	18.5	3.57	2.59
Error +/-	0.004	0.004	0.01	0.000022					
NG 306	16.109	14.875	37.344	0.510567	0.10806	10.3	57.5	3.72	2.16
Error +/-	0.002	0.002	0.005	0.00003					
NG 307	16.27	14.992	36.204	0.510464	0.1016	3.8	22.8	3.65	2.39
Error +/-	0.005	0.004	0.087	0.000014					
NG 309	16.756	15.119	37.121	0.510724	0.11475	3.3	16.1	3.73	1.34
Error +/-	0.004	0.003	0.009	0.000009					
Amphibolites									
NG 302	17.769	15.075	36.556	0.511382	0.13292	8.3	37.6	3.37	3.21
Error +/-	0.004	0.003	0.008	0.000023					
NG 308	17.448	15.009	35.919	0.511572	0.15123	7.6	30.4	3.86	1.86
Error +/-	0.001	0.001	0.002	0.000014					

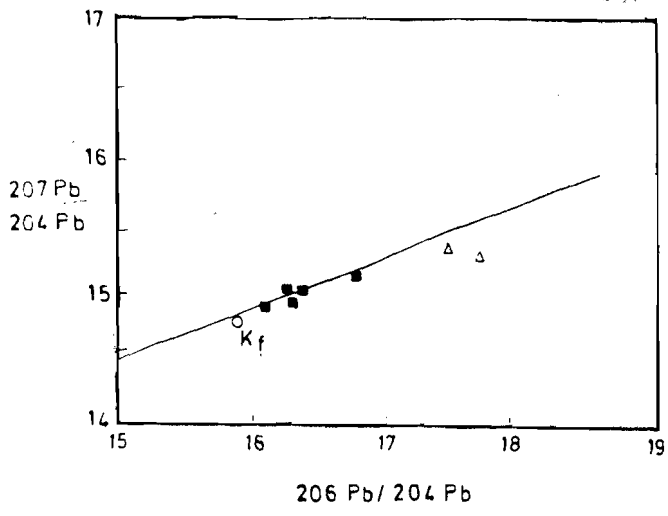


Fig 2b  
Whole rock Pb isotopic composition of the Kaduna MGC. Legend is as in Fig. 2a above. The amphibolites have not been considered for age calculations.

alignment with the Amitsoq gneisses and parallel to the Isua supracrustals (Fig. 2c) is consistent with their initial derivation from undifferentiated mantle ( $\mu=7.7$ ) or lower crustal sources shortly after differentiation from the former. We also interpret the alignment of the amphibolites with the gneisses on the Sm-Nd and the Pb-Pb 3.7 Ga reference isochrons as pointing to the dominant role of basaltic underplating as an important crustal growth process since Archaean times.

The age estimations from the Pb-Pb and Sm-Nd isotopic data (3780 +/- 380 Ma and 3702 +/- 332 Ma) are within their error margins in agreement with the Nd model ages and with existing U-Pb zircon crystallisation age (Ekwueme and Kroner, 1993; Bruguier et al., 1994). This coherence shows that the differentiation that led to the emplacement of these primitive rocks took place relatively rapidly. They also show that equilibration of the Sm/Nd and Pb/Pb of the whole rock occurred 3.7-3.5 Ga ago. The homogeneity of the  $^{143}\text{Nd}/^{144}\text{Nd}$  compositions and low fractionation of the Sm/Nd, in particular for the gneisses confirm that the Sm-Nd system has not been disturbed by post-magmatic fractional crystallisation.

The Archaean history of the basement in Northern Nigeria therefore appears to record a period of substantial juvenile addition in its early stage. The development of tholeiitic basalts and granites in the formation of new crustal materials now preserved as amphibolites and gneisses respectively is notable. Sm-Nd data presented herein indicate a mean mantle separation age of 3.64 +/- 0.04 Ga and coincides with the oldest measured zircon crystallisation age of 3.56 Ga by Bruguier et al. (1994).

The tectonic processes of new crustal additions during the Archaean enjoys little agreement but it surely appears more rapid than at present (Hoffman and Bowring, 1984). The relatively small proportion of basaltic rocks (amphibolites) associated with acid intrusives (granodioritic gneisses) suggest that the Kaduna MGC experienced a period of crustal thickening and melting during which anatectic melting of the previously accreted rocks occurred. U-Pb zircon data indicate the latter events to be at 3.1-3.0 Ga and 600 Ma (Bruguier et al., 1994) while Rb-Sr systematics record metamorphic events at 3.1-3.0 and 2.8-2.7 Ga

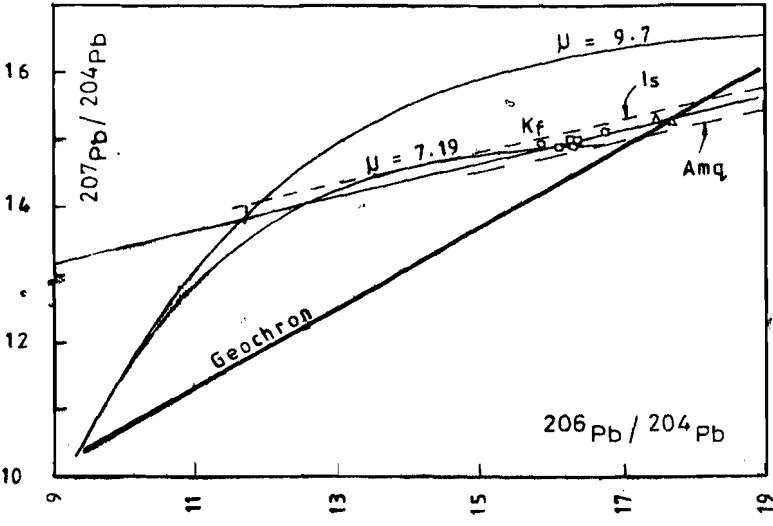


Fig 2c.  
Whole rock Pb isotopic composition of the Kaduna MGC (gneisses and amphibolites) on model growth curve of Stacey and Kramers (1975). First ( $\mu=7.19$ ) and second ( $\mu=9.74$ ) stage curves are indicated. Isochron for Kaduna MGC compares with Isua Supracrustal Iron Formation (Is) and Amitsoq gneisses (Amq) isochrons indicated in broken lines.

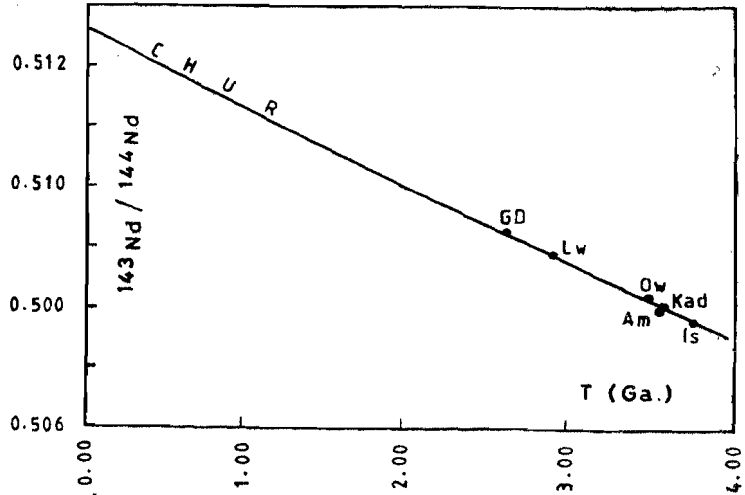
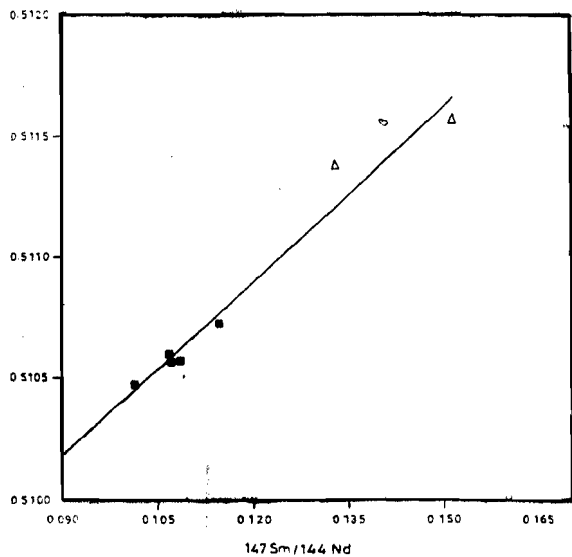


Fig 4: Location of Kaduna MGC (gneiss/amphibolite) chondritic evolution isochron. The Kaduna MGC isochron is parallel to the Amitsoq gneisses and between Onverwacht and Isua

(Dada et al., 1998). The average positive  $\epsilon Nd_7$  value of  $+2.3 \pm 0.3$  for the rocks indicates that their protolith had a time-integrated  $^{147}Sm/^{144}Nd$  ratio higher than that of the average chondrite of 0.1967. This rules out the possibility of a major time interval between the formation of the precursors of the MGC and its emplacement and firmly establishes the presence of continental crust in Northern Nigeria in the early Archaean. The amphibolites retain above average HREE enrichment. This was followed by remelting of the complex at 3.1-3.0 Ga, 2.8-2.7 Ga and 600 Ma. This scenario is comparable to the evolution of the Toijottamanselka terrain in Northern Finland (Jahn et al., 1987). The Kaduna Migmatite Gneiss Complex falls on the Chondritic Uniform Reservoir and with an initial  $^{143}Nd/^{144}Nd$  ratio of 0.50797 it is placed adjacent to the Amitsoq gneisses and between Onverwacht and Isua spercrustals (Fig. 4).

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