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Geology, Geochemistry and Geotectonic Setting of the Pan-African Granites and Charnockites Around Ado-Ekiti, Southwestern Nigeria

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Abstract. The geology, petrology and geochemistry of the coarse-grained and fine-medium-grained gneissic charnockites and the porphyritic biotite-hornblende and medium-grained older granites in the Ado-Ekiti area were studied. Xenoliths of schistose quartzite occur within these charnockitic and granitic rocks. The porphyritic older granite and the coarse-grained charnockite occur in very close association in the field. All these rocks contain monazite, in their mineralogical composition, which indicate crustal input into their original magma. Aluminium-total iron-magnesium (AFM) plot for these rocks indicated that they were calc-alkaline in nature and were formed in a subduction related tectonic setting. Percentage normative corundum versus mol. $A1_2O_3/(Na_2+K_2O+CaO)$ plots for the older granites and the charnockites from the Ado-Ekiti area revealed that their original magma was derived from a mixed source (igneous and crustal). Y+Nb versus Rb plots for the older rare earth granites and the charnockites indicated that they originated from a volcanic arc and within-plate environments. The normalised rare earth elements (REE) patterns showed that these rocks were genetically related, and the feldspar fractionation took place during their formation as revealed by Eu depletion patterns in the REE diagrams. The negative Eu/Eu* (ratio of absolute europium to normalized europium) anomaly and $(La/Yb)_N$ ratios higher than 5 obtained in these rocks indicated that they were emplaced through magmatic fractionation. The mixed magma from which these rocks were derived was formed in a back arc tectonic setting where an ocean slab was subducted into the mantle leading to the generation of magma, which intruded into the earlier formed rocks in a back arc basin. The charnockites and the older granites were the end products of the differentiation of such magma.

Keywords: monazite, xenolith, calc-alkaline, subduction, southwestern Nigeria, geotectonic setting, Pan-African granites, charnockites

Introduction

Nigeria lies within the Pan-African mobile belt in between the West African and Congo cartons (Akande, 1991; Woakes *et al.*, 1987; Odeyemi, 1981). The geology of Nigeria is dominated by the precambrian basement (crystalline and schistose metasediments) and recent-cretaceous sedimentary rocks, almost in equal proportions (Rahaman *et al.*, 1988). There is a high level intrusion of jurassic younger granites into the basement complex in Jos area of central-northern Nigeria. The precambrian basement in Nigeria consists of migmatite-gneissic complex within the muscovite-quartzite schists. In the Ado-Ekiti area, the basement complex, apart from the migmatite-gneissic-quartzite complex, includes granitoid plutons which are mostly older granites and charnockites with other minor granite associations (Fig. 1). These rocks have intruded into both migmatite-gneissic complex and the schists. Older granites and charnockites occur prominently in southwestern Nigeria at Iwo, Akure, Idanre, Ikare, Ikere and Ado-Ekiti (Olarewaju, 1987). According to Dada *et al.* (1989), charnockites also occur at Bena, Makichi, Toro and Zurami in northern Nigeria. The Toro charnockite complex in the north-central Nigeria is Pan-African in age based on a U-Pb-zircon dating, which places the Toro complex in the context of Pan-African granitoid (Dada *et al.*, 1989), making Toro charnockite to be similar in occurrence to those described in the southwestern Nigeria. Recently, Ekwueme (2003) also reported the occurrence of similar Pan-African charnockites in the Oban massives and Obudu plateau in the southeastern Nigeria. On the basis of geochronological and structural evidence, Tubosun *et al.* (1984) and Annor (1995) believe that the emplacemet of granitic and charnockitic complex in southwestern Nigeria took place during the Pan-African tectonic episodes. Olarewaju (1988) suggested on the basis of chemical studies that the Pan-African granites and charnockites in the Ado-Ekiti area are 'magmatic' in origin.

The present study focuses attention on the geology and geochemistry of the older granites and the charnockites in the Ado-Ekiti area with a view to explaining their possible geotectonic origin by comparing the concentration of some index elements in the rocks with those of a pure mantle. Discrimination diagrams, based on the chemical contents of the rocks, have been also used to infer the possible tectonic environment(s) in which their magma originated.

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Materials and Methods

Twelve (12) representative samples each of the older granites and charnockites (making a total of twenty four rock samples) were selected from the fieldwork collections in the Ado-Ekiti area. Petrographic studies were carried out during the fieldwork, as well as in the laboratory, using conventional thin sections of each rock type. Analysis of major elements was carried out on rock glass beads and trace elements on compressed rock powder pellets using X-ray fluorescence (XRF) equipment, which had computer and printer facilities, at the Cardiff University, Wales, UK, by the first author. The detection limits of the XRF used for the analysis of these elements varied from 0.0009% (CaO) to 0.03% (MgO) for the major elements and from 2 ppm (Ni) to 27 ppm (Ba) for the trace elements.

The initial rock sample preparation for the analyses of rare earth elements (REE) was carried out by the first author. This involved selection and pulverising the samples to produce rock powder and transporting them in polythene sample bags. The REE analyses were carried out at the Department of Geology, Royal Holloway and Bedford, New College, University of London, Surrey, UK, using the inductively coupled plasma spectometry (ICPSS) as outlined by Walsh *et al.* (1982). The ICPSS used was a Phillips model OV8210 1.5 5-m, which was capable of evaluating spectral lines and measuring the REE concentration in each sample. Precision level attained was better than 1%.

Results and Discussion

Fieldwork carried out in the Ado-Ekiti area by the authors provided opportunity for studying the rocks in place and collecting fresh samples for the laboratory analyses. Apart from the migmatite gneissic-quartzite basement complex in the Ado-Ekiti area, the older granites and charnockites constituted prominent rock groups in this area. The Pan-African granites are called older granites in order to distinguish them from the non-orogenic, high-level jurassic granite intrusion confined in occurrence to the central-northern Nigeria around the Jos plateau (Falconer, 1911).

Field description and petrography. ***(a) Migmatite-gneissic complex***. In the Ado-Ekiti area, the migmatite-gneissic complex forms the country rock into which the granitoids intruded. This group of rocks is usually low-lying and distinctively made up of three parts. The first part is a pale-coloured quartzo-feldspathic portion composed of quartz, plagioclase and K-feldspar. This portion of the migmatite is texturally medium grained but with relatively coarse crystals of plagioclase. This portion forms the leucosome of the migmatite in Ado-Ekiti area. The melanosome portion of the migmatite in

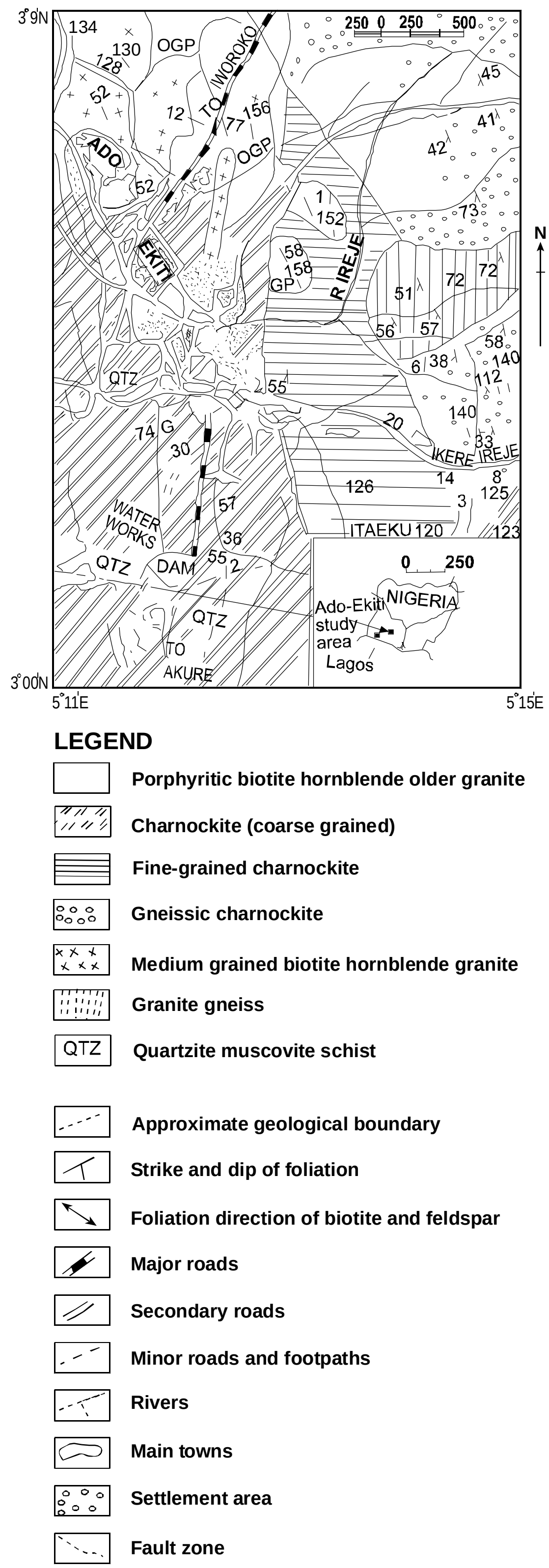

Fig. 1. Geological map of Ado-Ekiti, southwestern Nigeria (after Olarewaju, 1987); G = granite, GP = porphyritic granite, OGP = older granite porphyrite, R = river, QTZ = quartz.

this area is dark coloured and very rich in biotite. Other minerals in the melanosome include hornblende and garnet. Texturally, the melanosome of the migmatite here is medium-coarse grained. The palaeosome portion of the Ado-Ekiti migmatite, which is the third component, has the appearance of an ordinary metamorphic rock (gneiss), which is intermediate in colour between the leucosome and the melanosome. This portion is composed of quartz, plagioclase, biotite, muscovite and hornblende with a medium-coarse grained texture. Strong axial planer foliations, which have been refolded in places, are observed on the migmatite-gneiss complex here. The migmatite-gneiss in the Ado-Ekiti area is a layered type, which can be classified as a stromatite type. A common feature of the migmatite-gneiss here is the layering with quartzo-foldspathic veins, which are deformed into ptygmatic folds. In such folds, synformal and antiformal axes are often very prominent.

The granite gneisses in the Ado-Ekiti area are biotite granite gneisses. These rocks are medium to coarse-grained in texture consisting of quartz, K-feldspar, biotite, muscovite, plagioclase, hornblende, and at times garnet. In places, the biotite granite gneiss may form fresh hilly outcrops, which are quarried for construction purposes. This is a mafic rock which shows a strong mineralogical banding. The biotite-gneiss has also been refolded in places indicating a polycyclic history like the migmatite-gneiss complex, which they are closely associated with.

(b) Metasediments. Metasediments in the Ado-Ekiti area are represented by quartzites, which occur as ridges and as xenoliths in the granitic and charnockitic rocks. The quartzite ridges vary in length and height. They often contain massive quartz at the crest and quartz veins in places. Elsewhere, pegmatitic bodies may be found in the quartzite ridges. These quartzites are composed mainly of quartz, minor muscovite and zircon. The xenolithic variety of quartzite in Ado-Ekiti is darkish in outlook and highly schistose. They occur as remnants within the older granites and the charnockites. These xenolithic quartzites are fine-grained in texture and are composed of quartz, relatively abundant biotite, muscovite and garnet.

(c) Older granites. There are broadly two major textural varieties of older granites, which are: (i) medium to coarse-grained biotite and biotite-hornblende granite; and (ii) the coarsely-porphyritic biotite-hornblende granite. Microgranite (aplite) occurs as a minor rock intruding the older granites. The biotite hornblende granite occurs as inselbergs all over the Ado-Ekiti area. These inselbergs can be as high as 600 m above the sea-level. It appears as if the older granites exploit the north-south trending regional foliation direction in this area. In places, some of the outcrops of this variety of older granites are covered with sub-angular to rounded boulders and can be very fresh. Elsewhere, they are covered with very thick vegetation, and outcrops may not be visible. Whitish feldspar-dominated pegmatitic bodies are often found associated with the older granites. In thin section, the older granites are composed of quartz, biotite, K-feldspar, monazite, muscovite and hornblende. The porphyritic older granite is the major type of granite in the Ado-Ekiti area. This type of granite occurs as low lying outcrops, which may be flat, forming a table land in places and may form hills in close association with the coarse charnockite elsewhere. This rock type is characterised by large phenocrysts of K-feldspar in a ground mass of fine-grained quartz, biotite and hornblende. In places, the K-feldspar phenocrysts are aligned. Microgranite (aplite) of fine texture, which may be upto 2 m in width, often intrude into the porphyritic older granite outcrop. The microgranite in the older granite may be faulted in places.

The porphyritic older granite is composed of quartz, K-feldspar, biotite, hornblende, plagioclase, monazite, zircon, apatite and opaques.

(d) Charnockites. Although about three textural varieties of charnockites have been reported in literature in the Ado-Ekiti area (Olarewaju, 1987), only two of the three major textural varieties were sampled and have been described here. These are: (i) the coarse-grained charnockite; and (ii) the fine-medium-grained gnessic charnockite. In places, both the charnockite types exist as low lying outcrops, which are exposed. Elsewhere, the coarse-grained chanockite type occurs as hills. The coarse-greenish type often occurs in close association with the porphyritic older granite in the field. The darkish gneissic charnockite outcrops contain angular boulders of rock (charnockite) littering the surrounding. Both the charnockite types were observed as intrusive rocks in the Ado-Ekiti area. Like the older granites, xenoliths of dark schistose quartzite were found within the outcrops of charnockites in many localities in the Ado-Ekiti area. In the boundary areas, where older granites, charnockites and microgranites occur, it was usual to observe on a single outcrop, a section of porphyritic granite intruded by microgranite separating porphyritic older granite from the coarse-grained charnockite. The boundary between the microgranite and the older granite is gradational, but very sharp between the microgranite and the charnockite. The occurrence of the charnockite and the porphyritic older granite together on an outcrop tend to confirm the earlier suggestion by Tubosun *et al*. (1988) and Olarewaju (1988; 1987) that the older granites and the charnockites in the Ado-Ekiti area were formed contemporaneously. In thin section, the charnockites were observed to be composed of quartz, plagioclase and alkaline feldspars, hornblende, biotite, monazite, apatite, zircon, pyroxene and opaques. The occurrence of monazite in all the rocks in the Ado-Ekiti area raises very serious question as to whether these rocks were derived from a magma originating from the primitive mantle. For all intents and purposes, the presence of monazite (Ce, La, Y, Th)PO_4 (as identified and confirmed using a Cambridge 250 scanning electron microscope sport chemical analysis at the Department of Earth Sciences, University of Cardiff, Wales, UK) in an igneous rock indicated crustal or sedimentary input into its original magma.

Geochemistry. ***(a) The older granites.*** The chemical data of major elements for six samples of the porphyritic older granite (ADG1-ADG6) and six samples of the medium-grained biotite older granite (ADG7-ADG12) are shown in Table 1. The major and trace elements data for these granites were similar, with little differences in their respective concentration values. The SiO_2 component of the porphyritic older granite ranged from 74.25%-76.5%, while it ranged in the medium-granied biotite older granite from 73.52-75.63%. The content of $A1_2O_3$ in the porphyritic older granite varied from 13.04-13.69%, while the variation in the biotite older granite was between 13.81% and 14.51%. The oxides, $Fe_2O_{3\,(T)}$, MgO, MnO, CaO and P_2O_5, occurred as minor components of both the older granites. In both granites, K_2O concentrations were consistently higher than the Na_2O component, giving K_2O/Na_2O ratio greater than 1 in both the rocks (Table 1).

(b) The charnockites. Major elements for the six coarse-grained charnockite (CHK1-CHK6) and six fine-grained gneissic charnockite (CHK7-CHK12) are shown in Table 2. Like the older granites, the chemical data of the charnockites were remarkably similar with only slight differences in the concentration values. The SiO_2 content of the coarse-grained charnockite (CHK1-CHK6) varied from 58.60-62.77%, while it varied from 58.8%-62.07% in the gneissic charnockite (CHK7-CHK12). The oxides, $A1_2O$, $Fe_2O_{3(T)}$, CaO, Na_2O and K_2O occurred prominently in both the charnockites. Unlike in the older granites, however, K_2O was consistently lower than Na_2O giving the K_2O/Na_2O ratio lower than 1 in both the charnockites. This might be due to more abundant sodic rock forming minerals like (plagioclase) in the charnokites than was observed in the older granites.

On the plot of aluminium-total iron-magnesium (AFM) diagram, the older granites and the charnockites plotted in the calc-alkaline trend, but in the case of charnockite, samples reached the crest of the curve separating the tholeiitic and

Table 1. Chemical data of major elements (wt, %) for representative samples of the older granites from the Ado-Ekiti area, southwestern Nigeria

Chemical constituent	ADG1	ADG2	ADG3	ADG4	ADG5	ADG6	ADG7	ADG8	ADG9	ADG10	ADG11	ADG12
SiO_2	76.52	75.50	74.25	74.31	74.50	76.52	75.43	75.63	73.52	74.18	75.06	75.24
TiO_2	0.09	0.063	0.13	0.13	0.13	0.10	0.10	0.10	0.13	0.13	0.13	0.01
Al_2O_3	13.69	13.04	14.30	14.45	14.32	13.92	3.67	13.81	14.14	14.51	14.48	13.87
Fe_2O_3(T)*	1.59	1.38	1.30	1.26	1.33	1.61	1.63	1.64	1.27	1.32	1.31	0.18
MnO	0.07	0.01	0.02	0.01	0.01	0.05	1.03	0.07	0.01	0.01	0.01	0.02
MgO	0.05	0.03	0.06	0.06	0.05	0.03	0.06	0.03	0.05	0.70	0.06	0.05
CaO	0.68	0.49	0.51	0.51	072	0.72	0.63	0.62	0.47	0.54	0.53	0.48
Na_2O	2.66	2.38	2.26	2.29	2.24	2.64	2.49	2.48	2.21	2.53	2.31	2.32
K_2O	5.14	6.04	6.95	6.53	7.03	4.96	5.43	5.41	6.83	6.37	6.36	6.28
P_2O_5	0.01	0.02	0.01	0.02	0.02	0.01	0.01	0.01	0.02	0.02	0.02	0.02
LOI	0.39	0.52	0.46	0.97	0.54	0.38	0.30	0.42	1.93	0.20	0.33	0.36
Total	**100.89**	**100.04**	**100.54**	**100.54**	**100.57**	**100.94**	**99.78**	**100.22**	**100.58**	**100.51**	**100.60**	**100.02**
$Na_2O + K_2O$	7.80	8.42	9.21	8.82	9.27	7.60	7.92	2.18	3.09	2.52	2.75	2.71
$MgO/MgO + Fe_2O_{3(T)}$	16	10	16	13	10	17	18	7.89	9.04	8.90	8.67	8.60
K_2O/Na_2O	27	29	26	46	28	42	44	28	31	46	38	38
Y + Nb	0.08	0.02	0.04	0.05	0.04	0.02	0.04	0.01	0.04	0.35	0.04	0.04
Na + K + 2Ca/Al	0.67	0.72	0.72	0.68	0.72	0.7	0.67	0.66	0.69	0.69	0.67	0.69

* = total iron as Fe_2O_3(T); LOI = loss on ignition; ADG1-ADG6 = porphyritic biotite hornblende older granite; ADG7-ADG12 = medium-grained biotite older granite

Table 2. Chemical data of major elements (wt, %) for representative samples of charnockites from the Ado-Ekiti area, southwestern Nigeria

Chemical constituent	CHK1	CHK2	CHK3	CHK4	CHK5	CHK6	CHK7	CHK8	CHK9	CHK10	CHK 11	CHK12
SiO_2	59.20	60.73	62.77	58.60	64.33	61.70	62.07	61.63	59.70	58.80	60.80	60.10
TiO_2	0.16	0.22	0.46	0.19	0.53	0.14	0.42	0.43	0.26	0.37	0.39	0.40
Al_2O3	13.75	14.59	16.45	13.05	14.60	14.35	16.16	15.80	14.10	14.62	16.60	16.89
Fe_2O_3(T)*	4.04	3.93	5.89	6.93	5.99	4.72	5.26	5.71	4.60	4.10	5.60	5.39
MnO	0.15	0.20	0.10	0.22	0.10	0.17	0.79	0.08	0.13	0.20	0.07	0.14
MgO	1.86	3.16	1.80	3.29	1.79	2.10	1.14	1.70	2.50	4.50	1.30	2.59
CaO	8.29	8.04	5.26	8.95	5.40	6.57	6.73	6.14	8.33	9.10	5.18	6.01
Na_2O	5.07	5.60	3.70	4.57	4.74	3.99	4.96	4.78	4.89	2.81	5.15	4.30
K_2O	3.27	2.60	3.41	2.80	2.01	3.41	2.69	3.27	3.60	2.10	3.13	3.10
P_2O_5	2.34	0.55	0.01	2.31	0.09	3.13	0.17	0.07	1.84	2.55	1.01	0.09
LOI	2.40	0.31	0.60	0.11	0.04	0.20	0.60	0.07	0.40	0.60	0.70	0.05
Total	**100.50**	**100.46**	**100.45**	**100.60**	**99.80**	**100.48**	**99.99**	**100.51**	**100.35**	**99.76**	**99.93**	**99.49**
K_2O/Na_2O	0.65	0.46	0.92	0.61	0.42	0.86	0.57	0.68	0.53	0.75	0.60	0.72
$Na_2O + K_2O$	8.34	9.20	7.11	7.37	6.85	7.40	7.65	8.05	8.49	4.91	8.28	7.40
$MgO/MgO + Fe_2O_{3(T)}$	0.32	0.50	0.23	0.32	0.23	0.31	0.18	0.23	0.35	0.52	0.19	0.33
Y + Nb	78	74	74	76	68	74	55	58	77	77	60	70
Na + K + 2Ca/Al	1.81	1.66	1.07	194	1.13	1.43	1.24	1.29	1.78	1.58	1.12	1.5
NCOR	0.11	0.15	1.25	0.21	1 .21	0.24	1.09	1.70	1.68	1.34	1.87	1.33

* = total iron as Fe_2O_3 (T); LOI = loss on ignition; NCOR = normative corundum; CHKl-CHK6 = coarse-grained charnockite; CH7-CHK12 = fine-medium-grained charnockite

calc-alkaline fields (Fig. 2). According to Wilson (1991), this indicates that the magma from which these rocks were formed was calc-alkaline in nature and was totally restricted in occurrence to the subduction-related environment. This, by implication, means that the older granites and the charnockites in the Ado-Ekiti area were derived from a subduction-tectonic environment. Normative values of quartz-albite-orthoclase (Q-Ab-Or) plotted for the porphyritic older granite and the fine-grained older granite showed the rock samples plotting close to the granite minimum point on the liquidus surface and above it (Fig. 3). According to Wilson (1991), igneous rocks whose data plot as discussed above were formed at low H_2O pressure of 1 kb and a temperature of 720 °C. In both the varieties of charnockites, the $Na_2O + K_2O/Al_2O_3$ ratios were greater than 1 (Table 2), which implies that these rocks were paralkaline in nature (Wilson, 1991). In the older granites (both types), the $Na_2O/A1_2O_3$ ratios were less than 1, which means that these rocks were not paralkaline granites according to Wilson (1991). Both the varieties of charnockites studied during the present study showed that all the rocks contained $Na_2O + K_2O + 2CaO/A1_2O_3$ ratios higher than 1, implying that these rocks were not peraluminous in nature, whereas the older granites had $Na_2O + K_2O + 2CaO/Al_2O_3$ ratios that were less than 1, making the older granites in the Ado-Ekiti area peraluminous granites. According to Wilson (1991), peraluminous granites contain crustal or sedimentary materials in their original magma. The $MgO/MgO + Fe_2O_{3(T)}$ ratios in these rocks (0.30 in the charnockites and 0.06 in the granites) were lower than the mean upper mantle values of 0.70 (Wilson, 1991; Tables 1 and 2). This implies that the original magma of these rocks was not from a purely primitive mantle.

A plot of mol. $A1_2O_3$/ ($Na_2O + K_2O$ + CaO) versus percent normative corundum for the classification of igneous rocks is shown in Fig. 4. Majority of the charnockites and older granite samples plotted in the S-type field. This type of plot implies that the original magma from which these rocks were formed contained substantial amount of sedimentary or crustal materials with little mantle component as few samples of both rocks plotted in the I-type field. Histogram of mol. (%) $A1_2O_3/(Na_2O + K_2O$ + CaO) for the charnockites and older granites of the area is drawn in Fig. 5. It was observed that the rock samples plotted in the I-type and S-type fields. However, majority of the charnockite samples plotted in the I-type field, while most of the older granite samples plotted in the S-type field. Nevertheless, few samples of the charnockite plotted in

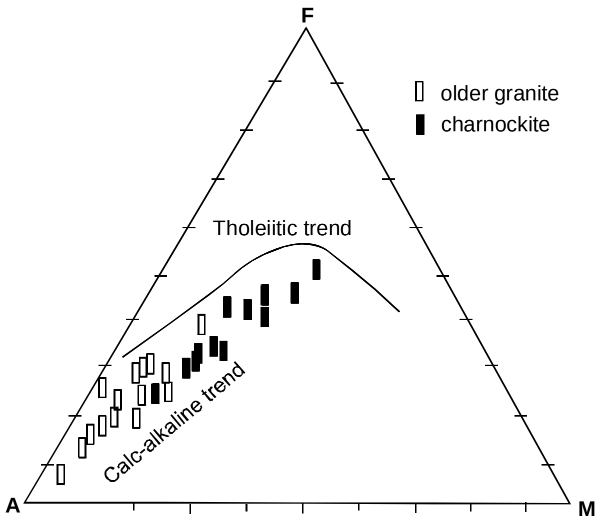

Fig. 2. Aluminium-total iron-magnesium (AFM) diagram showing the tholeiitic and calc-alkaline differentiation trend for the charnockite (CHK) and the older granite (ADG) from the Ado-Ekiti area, Nigeria.

the S-type field and few of the older granite samples plotted in the I-type field (Fig. 5). This implies that while it may be said that the charnockites originated from a mantle source with some crustal or sedimentary contamination in its original magma, the older granites were largely derived from a magma which was highly contaminated by a crustal or a sedimentary source, as is noted in the case of a back arc tectonic setting.

Trace elements. The elements Ba, Rb, Sr were highly concentrated in the charnockites. These elements recorded lower concentrations in the older granites (Tables 3 and 4). This might be due to the presence of more plagiodase in the charnockite, which harbours Ba. Barium also substitutes for K in the biotite in the charnockites and in the older granites. Strontium and rubidium are anomalous in the charnockites due to substitution of these elements for Ca in plagiodase and hornblende, which are abundant in the charnockites but either absent or low in the older granites. The concentrations of Ni, Cr, Co and V though higher in the charnockites than in the older granites, are by far lower than those for rocks that originated from the primitive mantle sources, which are in hundreds of ppm. This suggests again, that the magma of these rocks cannot be from a pure primitive mantle source (cf. Wilson, 1991).

The plot of Y + Nb versus Rb for these rocks shows that the older granites plotted in the volcanic arc granite (VAG)-field (Fig. 6), while the charnockite samples plotted in the ‘within plate granite (WPG)-field’. This implies that these rocks were formed in a volcanic arc tectonic environment, and the movement of plates was important in the generation of their magma.

Rare earth elements (REE). Table 5 shows the REE data for the charnockites and the older granites from the Ado-Ekiti area. The charnockites contained higher absolute REE concentrations than the older granites, which might be due to the presence of high values of light rare earth elements (LREE). This implicates REE concentrating minerals (especially, monazite,

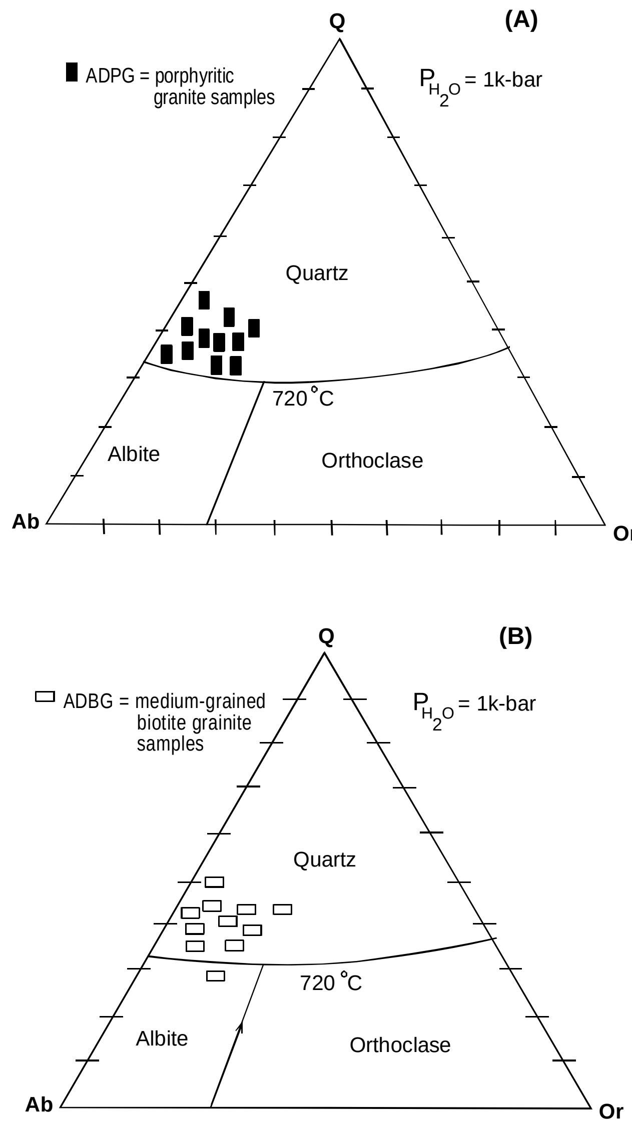

Fig. 3. Normative albite (Ab)-orthoclase-(Or)-quartz (Q)-H_2O system for the: (**A**) porphyritic granite (ADPG), and (**B**) biotite granite (ADBG) from the Ado-Ekiti area, southwestern Nigeria (P_{H_2O} = 1k-bar = pressure equivalent of water = 1 kilobar).

which contains LREE in the rocks), indicating that their original magma had crustal input. When the REE values for normalized chondrite were plotted for these rocks (Fig. 7), all showed similar stepped relationship. However, the charnockites showed slightly stepped patterns with very little Eu depletion in the coarse-grained charnockite and relatively marked Eu depletion in the gneissic charrnockite variety (Fig. 7). The charnockites contained higher LREE than heavy rare earth elements (HREE) as in the older granites. The older granites showed slightly more marked stepped patterns than the charnockites and more pronounced Eu depletion (Fig. 7), implying higher feldspar fractionation in this rock group than in the charnockites.

The charnokites and the older granites showed negative normalized Eu/Eu* (ratio of absolute Eu to normalized Eu) anomaly as well as high $(La/Yb)_N$ ratios. According to Feng

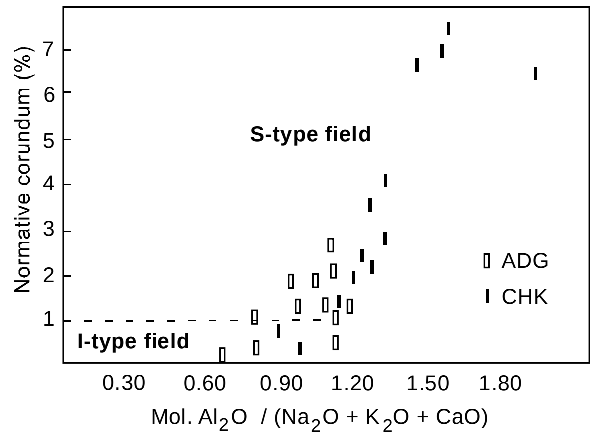

Fig. 4. Normative corundum versus mol. Al_2O_3/ (Na_2O + K_2O + CaO); ADG = porphyritic biotite hornblende Ado-Ekiti older granite; CHK = fine-medium grade charnockite.

Table 3. Chemical data of trace elements (ppm) for representative samples of older granites (ADG1-ADG12) from the Ado-Ekiti area, southwestern Nigeria

	ADG1	ADG2	ADG3	ADG4	ADG5	ADG6	ADG7	ADG8	ADG9	ADG10	ADG11	ADG12
Ba	211	239	251	147	166	236	173	265	272	154	199	153
Ni	10	13	11	9	11	11	10	9	1.0	11	11	11
Cr	8	6	7	8	9	10	11	10	9	8	7	10
V	8	6	5	5	4	10	8	11	9	4	3	10
Co	68	73	70	58	59	72	57	73	71	60	53	50
Rb	182	162	182	190	180	195	185	186	181	174	160	199
Sr	148	183	170	158	159	172	157	172	171	160	167	158
Y	19	19	18	27	23	25	28	22	24	30	30	23
Zr	121	135	113	128	137	148	169	132	131	148	134	161
Nb	8	10	8	19	15	17	16	6	7	16	8	15
Th	42	58	52	29	30	31	32	22	45	34	41	29
Ta	1.93	2.54	3.08	2.85	3.14	1.88	2.18	16	16	12	14	13

Table 4. Chemical data of trace elements (ppm) for representative samples of the charnockite (CHK1-CHK12) from the Ado-Ekiti area, southwestern Nigeria

	CHK1	CHK2	CHK3	CHK4	CHK5	CHK6	CHK7	CHK8	CHK9	CHK10	CHK11	CHK12
Ba	1450	1399	1490	1290	1480	1440	1550	1100	1250	1050	1440	1241
Ni	18	20	24	24	16	24	30	24	29	20	30	34
Cr	11	14	20	16	20	11	26	11	20	29	24	32
V	20	24	26	24	14	24	22	20	40	46	41	24
Co	13	29	30	38	12	18	24	29	34	49	39	42
Rb	165	154	175	153	100	162	180	183	180	147	186	178
Sr	172	187	148	208	239	230	232	193	245	249	298	355
Y	40	42	48	50	24	39	29	26	49	41	31	44
Zr	34	40	56	47	52	46	24	50	54	32	85	75
Nb	38	32	26	26	34	35	26	32	28	36	29	26
Th	17	18	20	15	30	24	23	17	18	17	11	21
Ta	8	9	10	4	5	6	7	9	17	10	4	6

and Kerrich (1990), negative Eu/Eu* anomaly and $(LA/Yb)_N$ ratios higher than 5 in an igneous rock are indications of magmatic differentiation. The implication of this for the magma of the charnockites and the older granites here is that even though the magma might have originated from a mixed source (mantle and crust), differentiation was important in the formation of these rocks.

Conclusion. The geological, petrological and geochemical results described here revealed that the charno-ckites and the older granites were genetically related and were formed in the same environment. Presence of monazite in the mineralogy of the charnockites and the older granites from the Ado-Ekiti area indicated crustal or sedimentary input into the original magma of these rocks. The AFM plot (Fig. 2) for both the rocks

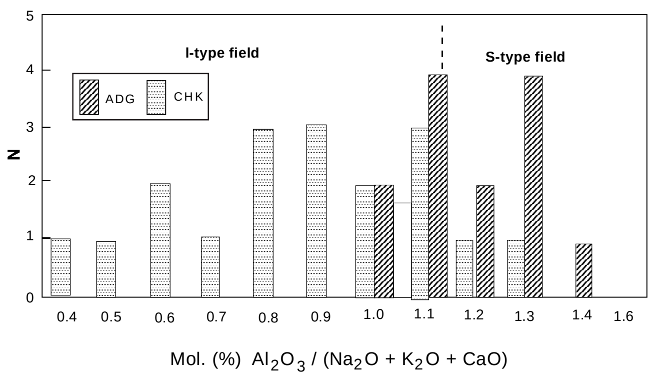

Fig. 5. Histogram of mol. (%) $Al_2O_3/(Na_2O + K_2O + CaO)$; CHK = charnockite samples; ADG = Ado-Ekiti older granite; methods of classification of igneous rocks after Vivallo and Rickard (1990); N = frequency; bar value is 2 on N column.

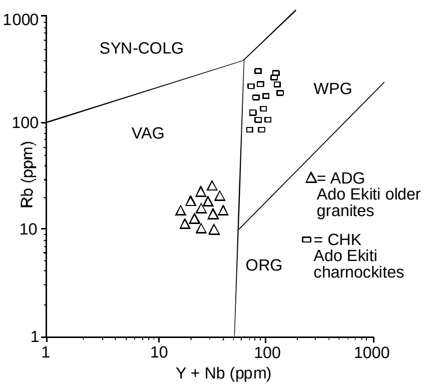

Fig. 6. The Y + Nb versus Rb discrimination diagram for the Ado-Ekiti charnockite (CHK) and older granites (ADG); SYN-COLG = syn-collision granite; ORG = ocean ridge granite; WPG = within plate granite; VAG = volcanic arc granite (after Pearce *et al.*, 1984).

Table 5. Data (in ppm) of absolute rare earth elements (REE) for the charnockites and the older granite from the Ado-Ekiti area, southwestern Nigeria

Elements	CHK(1)	CHK(2)	CHK 2	ADK (1)	ADK(2)	ADK (2)
La	520	750	580	400	280	320
Ce	840	1240	980	280	220	230
Br	87	130	110	200	180	170
Nd	300	455	365	160	110	120
Sm	36	60	40	60	40	50
Eu	12	9	9	20	15	15
Gd	37	26	22	25	20	20
Dy	12	22	14	10	10	10
Ho	2	4	3	6	8	6
Er	6	10	6	8	5	6
Yb	3	6	3	2	2	2
Lu	0.40	0.80	0.50	0.20	0.20	0.20
Total	**1855.40**	**2712.80**	**2132.50**	**181.20**	**930.21**	**949.21**
LREE	1795	2644	2084	1150	885	905
HREE	60.40	68.80	48.50	51.20	45.21	44.21
LREE/HREE	29.72	38.43	43.96	22.07	19.58	20.47
Eu/Eu*	0.36	0.34	0.35	0.24	0.22	0.20
$(La/Yb)_N$	91	132	122	129	115	117

HREE = heavy rare earth elements; LREE = light rare earth elements; Eu/Eu* = normalised Eu/Eu* anomaly (ratio of absolute Eu to normalized Eu); $(La/Yb)_N$ = normalised La/Yb; CHK(1) = coarse charnockite; CHK(2) = gneissic charnockite; ADK(1) = porphyritic hornblende-biotite granite; ADK(2) = medium-grained biotite granite

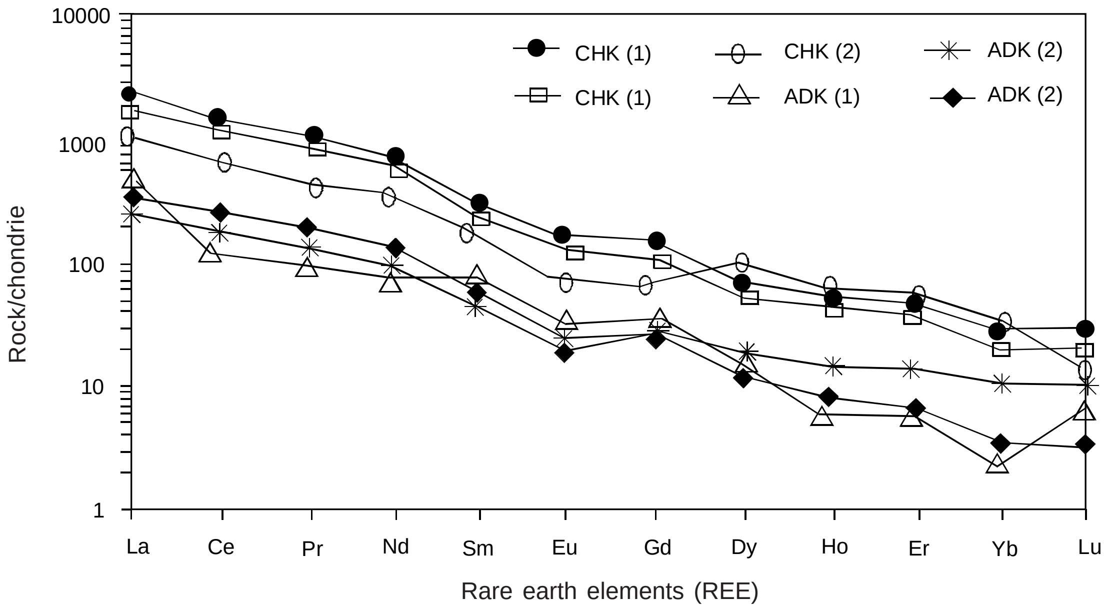

Fig. 7. Chondrite normalised rare earth elements (REE) patterns for the charnockite and older granites from the Ado-Ekiti area, southwestern Nigeria; CHK (1) = coarse-grained charnockite; CHK (2) = fine medium-grained gneissic charnockite; ADK (1) = porphyritic biotite hornblende older granite; ADK (2) = medium grained biotite older granite.

revealed that these rocks were calc-alkaline, typical of a subduction tectonic environment. The percentage corundum versus mol. $A1_2O_3/(Na_2O + Ka_2O + CaO)$ and the histogram of molecular (%) $A1_2O_3/(Na_2O + K_2O + CaO)$ indicated that the charnockites and the older granites were derived from a mixed source of crustal and mantle materials. The Y + Nb versus Rb discrimination plot for both the rocks showed that these rocks were derived from a volcanic arc and 'within plate tectonic environments'. The charnockites and the older granites from the Ado-Ekiti area contained high REE, indicating REE concentrating minerals, especially the LREE, whose hosts are known to be crustal in origin. The similarity in patterns of the normalised $(La/Yb)_N$ and Eu/Eu* data for both rocks (charnockites and older granites), indicated that feldspar fractionation and magmatic differentiation were responsible for the formation of these rocks. Generally, the geochemistry of these rocks did not implicate either a purely mantle or crustal source, exclusively. Rather, the geology, petrology and geochemistry implicated a mixed magmatic source of subduction-type geotectonic environment. This type of environment is most likely to be the one in which an ocean slab (with crustal materials) had been subducted into the mantle as in a back arc environment.

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