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AGE OF BEITAN GNEISS; IMPLICATION FOR LATE PRECAMBRIAN CRUSTAL EVOLUTION IN SOUTH EASTERN DESERT, EGYPT

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ABSTRACT

The gneiss-migmatite rocks of Hodein area, which represents the southeastern extension of Beitan Gneisses, cover about 98 km^2 and trend NW-SE. These rocks are overthrusted by supracrustal cover mainly arc-ophiolite assemblage and granitic rocks. Petrologically, the rocks are divided into biotite-gneisses, hornblende-gneisses, biotite-hornblende-gneisses, garnet-biotite-hornblende-gneisses and augen-biotite-gneisses.

The whole rock Sm-Nd isochron age of the Beitan gneisses yield 889±8 Ma (MSWD=8.5) which is consistent with Rb-Sr age (863±15 Ma, MSWD=9). This rock has initial ϵ^{t}_{Nd} and ϵ^{t}_{Sr}-values (-8.6 and +9.5, respectively) which reveals the age of early Pan-African. Moreover, the Nd-model age (T_{DM}) of these rocks range from 1.46 to 2.65 Ga, negative ϵ^{t}_{Nd} and low ϵ^{t}_{Sr}-values reveal the existence of early Pan-African continental crust. The data are tested against mantlecrust mixing model. It is suggested that these rocks were derived throughout assimilation of about 35—50% Nd-enriched, slightly Sr-depleted lower crust component by a mildly depleted subcontinental mantle source.

INTRODUCTION

The Pan-African thermo-tectonic event originally proposed by KENNEDY, (1964) is now widely accepted to cover a longer lapse of time between 450—550 Ma. The gneiss and migmatites have a limited distribution in the Eastern Desert (*Fig. 1*). Earlier investigators considered these gneisses to be fragmenets of much older continental crustal (HUME 1934). STURCHIO et al. (1983) considered the Meatiq gneisses as one of the classical examples of the famous gneisses in the Eastern Desert, to have formed from sheared and recrystallized felsic igneous rocks at 580—625 Ma accompanying the development of metamorphic core complex. On the other hand, DIXON (1979) HASSAN and HASHAD (1990) believe that the Pan-African basement exposed in the Meatiq area, consists of an infracrustal basement overthrusted by a supracrustal cover. The infracrustal rocks

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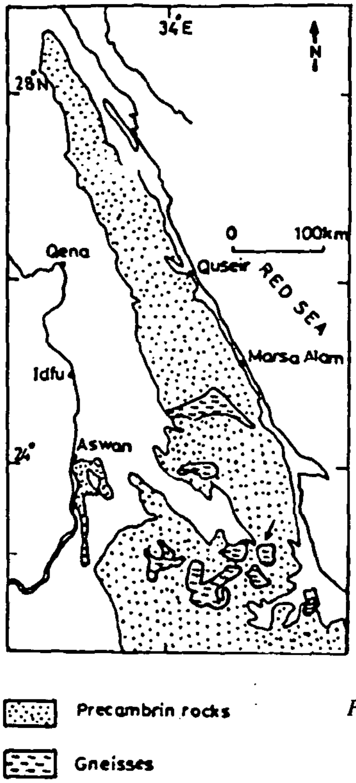

Fig. 1. Distribution of gneisses belts in Egypt, (Arrow denotes the studied area).

developed as a result of Meatiq orogeny, where granitic-gneisses; migmatite-gneisses and migmatized-amphibolites were formed.

EL GABY *et al.* (1988) suggested that the Archaean nucleus located in the southwestern corner of Egypt was fringed by an early Proterozoic continental mass (HARRIS et al. 1984) that extended past Aswan into the Eastern Desert, at least as far as Wadi Sikait on the eastern flank of the Hafafit Swell. The old continent was fringed by an island arc ca.700—800 Ma ago. Around 700 Ma ago, the island arc was swept against the old continent, there by thrusting back-arc ophiolites and the island arc volcanics and volcanoclastics onto the margin of the old continent. Intrusion of subduction-related and mantle-derived magmas induced softening and remobilization of the early Proterozoic continental crust or "infrastructure" around 655 Ma ago.

The radiometric ages obtained from the Feiran gneisses in southern-Sinai yield 682-641 Ma (BENTOR 1985). Gneisses from the Uweinat area in SE-Libya prove a Late-Archaean age as well as a Mid-Proterozoic event (KLERKX and DEUTSCH 1977; HARRIS et al. 1984). The oldest Pan-African rock type in the Nubian Desert Gneisses have their Rb-Sr age of 918±40 Ma (MSWD=34.1, ($^{87}Sr/^{86}Sr)_i$= 0.7167±7), whereas $^{143}Nd/^{144}Nd)_i$= 0.511152 and ϵ^t_{Nd}=-15.8 and T_{CHUR} = 2004 Ma; EL GABY *et al.* 1988). EL GABY et al. (op. cit.) show that negative ϵ^t_{Nd}-value indicates that within the continental plate of NE-Africa during the Pan-African episode involved reworking of pre-existing crust. These isotopic data are suspected to consider that large regions of the south Eastern Desert consist of pre-Pan-African gneisses, and separated by ophiolites. They substantiate the incorporation of some old continental crust at least in parts of the Eastern Desert (EL GABY *et al.* 1988). KRÖNER *et al.* (1988) suspected that no conclusive evidence exists for the presence of pre-Pan-African crust in the Eastern Desert of Egypt. They emphasised that the evolutionary scenario for the Eastern Desert favour the hypothesis of accretion of new crust along a highly irregular active plate margin.

The present paper is aimed to assign age of emplacement of Hodein gneisses to help in regional correlation and geological interpretation of this rock as well as to examine the nature of pre-existing crust in wadi Beitan area.

GEOLOGIC SETTING

The Hodein area is located in the south Eastern desert of Egypt and composed of an assemblage of Precambrian rocks including gneisses and migmatites, supracrustal mainly arc-ophiolite (metavolcanics and volcanoclastic metasediments and metagabbro complex) and Older Granites. The gneisses-migmatites rocks are recorded in elongated low-lying belt, trending mainly NW—SE which parallel to the old structural trend dominated in south Eastern Desert. The gneisses-migmatite belt covers ca. 98 km^2 (ca.22 km in length and ranging between 1—10 km in width.) Moreover, contact between gneisses-migmatites and metagabbro complex is marked by a thin zone (ca.1—3 m width) of schistose, sheared and mylonitized rocks from both rock units developing along a thrust fault trending NW—SE and dip gently toward NE. The contact against the tonalite and granite is sharp and irregular. The gneiss-migmatite rocks are sometimes banded by foliated granite and containing off-shoots and apophysis from granites inside it.

The gneisses under consideration are highly foliated and composed mainly of fine to medium grained biotite-gneisses, hornblende-gneisses, biotite-hornblende-gneisses, garnet-biotite-hornblende-gneisses, augen-biotite-gneisses, para-amphibolites and mylonites.

SAMPLING AND ANALYTICAL TECHNIQUES

At Hodein area four gneiss samples were selected on the basis of both field and petrographic studies. Whole rock samples were analysed for Rb-Sr and Sm-Nd isotopic compositions at the Mineralogical-Geological Museum in Oslo, Norway. The chemistry and mass spectrometry procedures were described by MEARNS (1986). Laboratory total system blanks are typically ≤1ng for both Nd and Sr and are thus negligible for this study. Blank concentrations were measured by isotope dilution using mixed ^{87}Rb-^{84}Sr and ^{149}Sm-^{148}Nd spikes. Rb-Sr were loaded on Ta-Re single filament while Sm-Nd were loaded on the side filament of a double Re filament assembly. Isotopic ratios were measured on a VG 354 fully automated 5-collector peak hopping and static modes. Nd measurements were normalised to yield a ^{146}Nd/^{144}Nd=0.7219. The decay constant used for $\lambda Sm=6.54 \cdot 10^{-12} y^{-1}$ and $\lambda Rb=1.42 \cdot 10^{-11} y^{-1}$. ϵ^{t}_{Nd} and ϵ^{t}_{Sr} values are calculated relative to CHUR with present day ^{147}Sm/^{144}Nd=0.1967, ^{143}Nd/^{144}Nd=0.512647, ^{87}Rb/^{86}Sr=0.0827, and ^{87}Sr/^{86}Sr=0.7045 (ALLÈGRE *et al.* 1983), using Rb-Sr ages to correct for in situ radiogenic ^{143}Nd.

Rb-Sr and Sm–Nd Geochronology

The whole rock Rb/Sr and Sm/Nd isotopic data for the samples from Wadi Beitan gneisses are given in Table 1. The slope and intercept were determined using the regression method formulated by YORK (1969). The slope and intercept are given at the 2 sigma (68% confidence level). The four points yield a whole rock Rb-Sr isochron age of 863±15 Ma (MSWD=9, *Fig. 2A*) and initial $^{87}Sr/^{86}Sr$ isotopic ratio of 0.70412±0.00005. The provided age is in agreement with that calculated by Sm-Nd method which assign 889±8 Ma (MSWD=8.5, *Fig. 2B*), with initial $^{143}Nd/^{144}Nd$ ratio 0.51104±0.000002.

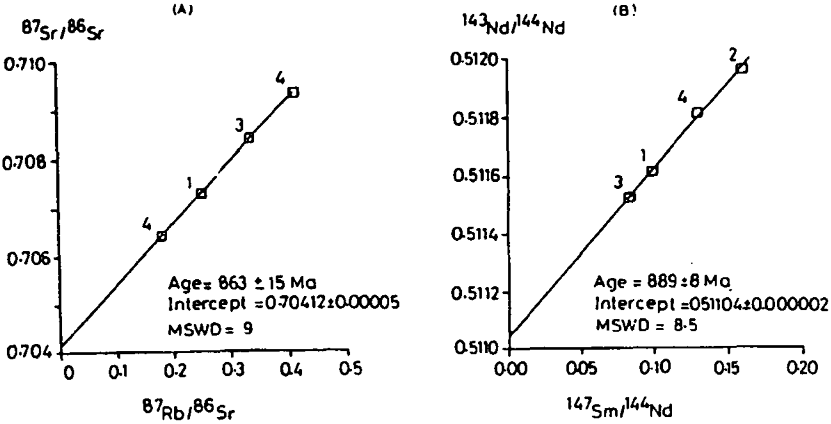

Fig. 2. (A) Rb-Sr and (B) Sm-Nd isochron diagrams for Beitan gneisses.

The assigned age shows that the Wadi Beitan gneisses pertain to the early Pan-African time (near by 863 Ma) similar to other rocks formed during the major magmatic episode affecting the southwestern part of the Eastern Desert between 1000—850 Ma (HASHAD 1980). Neverthless, the calculated initial $^{87}Sr/^{86}Sr$ isotopic ratios of Wadi Beitan gneisses are around 0.7051 (BENTOR 1985). STURCHIO *et al.* (1983) proved that low initial $^{87}Sr/^{86}Sr$ (ca 0.7030) indicate a lack of remelted older continental crust. Therefore, the initial $^{87}Sr/^{86}Sr$ ratios greater than 0.705 are most likely to represent various degrees of contamination by more radiogenic crustal material and/or due to partial melting of the upper mantle or lower crust. A mixing hypothesis of the present rocks is clarified by plotting $^{87}Sr/^{86}Sr$ ratios versus their corresponding 1/Sr values which should bear a linear trend with positive slope among two isotopically and chemically distinct components mixed in various proportions (*Fig. 3*). Although, the Wadi Beitan gneisses have moderately high initial $^{87}Sr/^{86}Sr$-isotopic ratios, they, however lie within the range reported for that of the Eastern Desert of Egypt (HASHAD 1980; BENTOR 1985; STERN 1979). The present initial $^{87}Sr/^{86}Sr$ ratios (0.70412) are too low for rocks to have been derived from old upper sialic crust (0.7369) and higher than the upper mantle (0.70362) range of FAURE and POWELL (1972). Similarly the initial $^{143}Nd/^{144}Nd$ ratios of this gneiss rocks (0.511528—0.511972) are lower than that of CHUR (0.512638; DEPAOLO and WASSERBERG 1976). *Figs. 4* and *5* show the initial $^{143}Nd/^{144}Nd$ ratios relative to the growth line of CHUR which indicate that

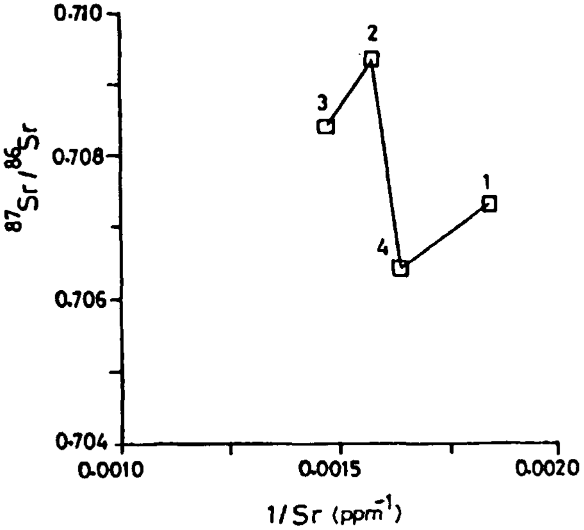

Fig. 3. $^{87}Sr/^{86}Sr$ vs. 1/Sr ratio diagram.

the Beitan gneiss is formed by residual solution derived from the depleted mantle source (FAURE 1986, p.210). They might have mixed source of a depleted upper mantle and lower crustal component.

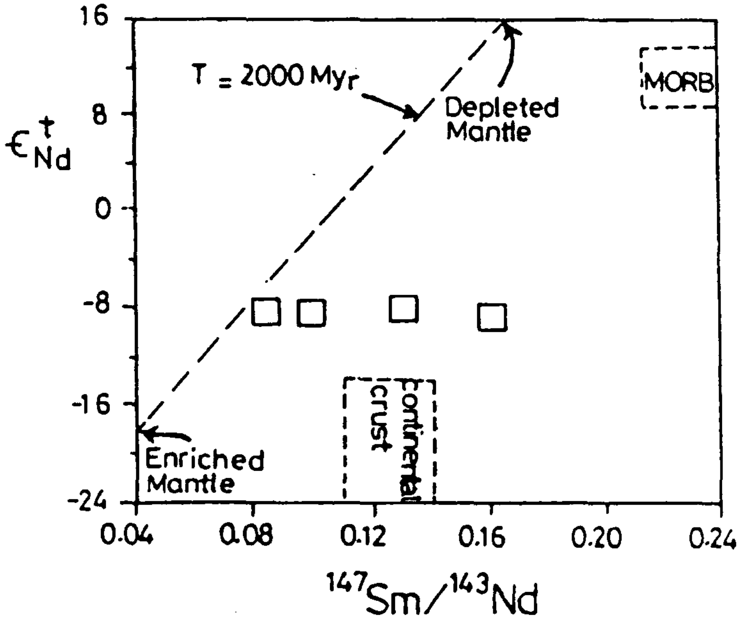

Fig. 4. ϵ^{t}_{Nd} vs. $^{147}Sm/^{144}Nd$ diagram (MCCULLOCH *et al.* 1983) for the studied gneisses.

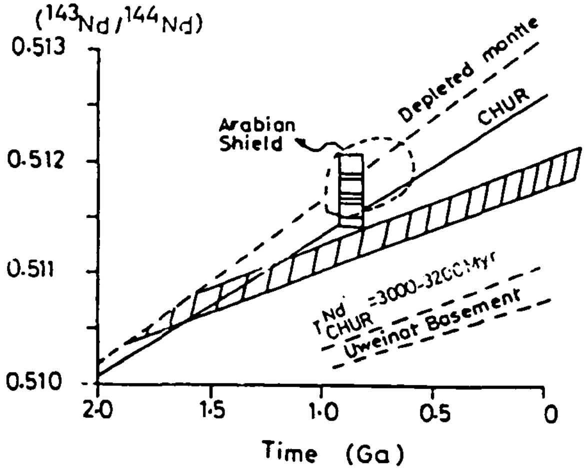

Fig. 5. (^{143}Nd/^{144}Nd)i vs. time variation diagram for the studied gneisses. The stippled region is taken from HARRIS *et al.* (1984). Field of Arabian data taken from DUYVERMAN *et al.* (1982).

It is worth to mention that the full agreement of the assigned age both Rb-Sr and Sm-Nd methods would suggest isotopic homogenization during the above mentioned mixing either during rejuivenation with early Pan-African magmatic crust or else, during a regional metamorphic event as suggested by EL SHAZLY *et al.* (1973), similar to the Abu Swayel metasediments.

Nd and Sr Isotopic Characteristics

The calculated ϵ^{t}_{Nd}-values at 863±15 Ma of the Wadi Beitan gneisses are negative and ranging as low as -8.6 (Table 1). DUYVERMAN *et al.* (1982) show similar range of ϵ^{t}_{Nd}-value for the Darmara granite Saudi Arabia. They considered that these ranges characterise a moderate degree of remobilisation of pre-existing crust. Meanwhile, the narrow range of calculating ϵ^{t}_{Sr}-values (+9.7 to +9.5) suggest again isotopic homogenity at the time formation due to mixing and/or partial melting. However, Wadi Beitan gneisses have ϵ^{t}_{Nd} (-8.6) and ϵ^{t}_{Sr} (+9.5) which favour an enriched mantle source (HARMS *et al.* 1990) and lie near the continental crust on DEPAOLO 1981, Fig.6). It is noted that the low ϵ^{t}_{Nd}-value from the Pan-African samples primarily reflect the age of Pre-existing crust (HARRIS *et al.* 1984).

The calculated Nd-model ages (T_{DM}) relative to the depleted mantle (DEPAOLO 1981) for the Wadi Beitan gneisses yield range from 1.46 to 2.65 Ga (Table 1). This Nd-model ages is comparable with that of magmatic plutonism in the Eastern Desert as described by HARRIS *et al.* (1984). They considered that such isotopic variations reflect derivation of these rocks from mixed source, including both Archean and Pan-African materials. Accordingly, both the calculated model-Nd ages as well as the low ϵ^{t}_{Nd} and ϵ^{t}_{Sr} of the studied gneiss samples reinforces the extraction of the protoliths from mantle material of an early/middle Proterozic crust *(Fig. 6)*.

TABLE 1

Rb/Sr–Sm/Nd isotopic data of Gneiss from Eastern Desert, Egypt.

Rb (ppm)	Sr (ppm)	$(^{87}Rb/^{86}Sr)$ at	$(^{87}Sr^{*}/^{86}Sr)$ + 2σ	$(^{87}Sr/^{86}Sr)$ i**	ϵ^{t}_{Sr}	Sm (ppm)	Nd (ppm)	$(^{147}Sm/^{144}Nd)$ at	$(^{143}Nd^{*}/^{144}Nd)$ + 2σ	$(^{143}Nd/^{144}Nd)_{i}$**	ϵ^{t}_{Nd}	T_{DM} (Ga)
47	542	0.250876	0.707314+10	0.707326	9.5	2.35	15.00	0.098724	0.511613+17	0.511619	-8.5	1.56
90	634	0.410773	0.709361+24	0.709368	9.5	1.70	13.20	0.159219	0.511694+41	0.511972	-8.6	2.65
79	680	0.336145	0.708421+13	0.708415	9.7	3.90	11.42	0.083116	0.511527+29	0.511528	-8.4	1.46
38	610	0.180209	0.706422+20	0.706424	9.6	3.60	18.20	0.129170	0.511812+15	0.511796	-8.1	1.82

ϵ^{t}_{Nd} and T_{DM} are the deviation from the value expected in a chondritic reservoir (CHUR) at time T (863 Ma) and is defined by DEPAOLO (1981).
($\lambda^{87}Rb = 1.42 \cdot 10^{-11}$ yr^{-1} $(^{87}Rb/^{86}Sr)^{o}_{UR} = 0.0816$, $(^{87}Sr/^{86}Sr)^{o}_{UR} = 0.7045$, $\lambda^{147}Sm = 6.54 \cdot 10^{-12}$ *yr*$^{-1}$, $(^{147}Sm/^{144}Nd)^{o}_{CHUR} = 0.1967$,
$(^{143}Nd/^{144}Nd)^{o}_{CHUR} = 0.512638$

* Errors refer to least significant digits and are 2σ mean.
** i = initial ratio

From the combined ϵ^t_{Nd}-ϵ^t_{Sr} diagram (*Fig. 6*) it is clear that the Beitan gneiss occupies an area bounded by ϵ^t_{Nd}-values of -8.6 to -8.1 and ϵ^t_{Sr}-values +9.5 to +9.7, and fall in range of ϵ^t_{Nd}-values (+7.5 to -10.3). It characterises Pan-African rocks of NE-Africa (HARRIS *et al.* 1984) and to that reported by HARMS *et al.* (1990) (-8.8 to -5.3). Meanwhile, the negative ϵ^t_{Nd} and positive ϵ^t_{Sr}-values offered by the present gneisses simply the presence of old basement beneath the southern Eastern Desert, which strongly supports the role of assimilation of enriched, continental crust by basaltic magma derived from a depleted subcontinental mantle source (*Fig. 6*, HARMS *et al.* op. cit.).

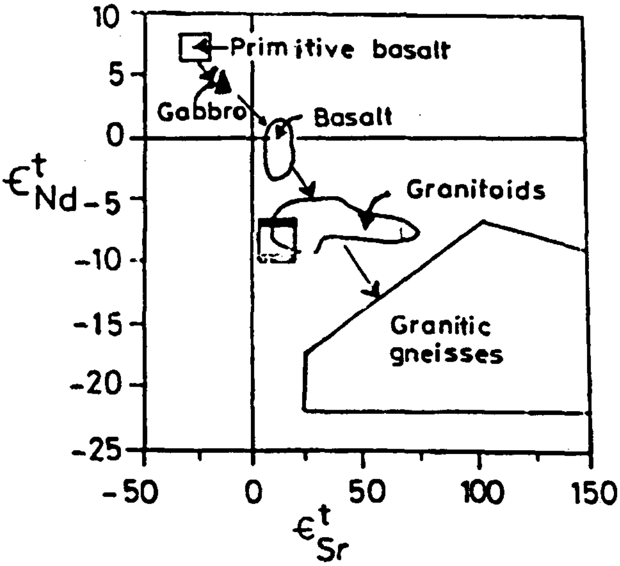

Fig. 6. ϵ^t_{Nd} vs. ϵ^t_{Sr} variation diagram shows Nd isotope characteristics of gneisses and granitoids, from southern Egypt and northern Sudan. Curve are indicating probable paths of mixing of mantle and crustal rocks. Fields are taken from HARMS *et al.* (1990).

ORIGIN AND SOURCE OF MAGMA

The narrow range of the initial ϵ^t_{Nd} and moderate initial ϵ^t_{Sr} values of the studied gneiss samples emphasis some constraints on the possible source region and the processes which may have been involved in the formation of this rock. The data simply preclude a single mantle or crustal source.

The source of the gneiss and granitoid rocks in the Arabian-Nubian Shield are still a matter of debate (HARRIS *et al.* 1984; HARMS *et al.* 1990, SULTAN *et al.* 1990). Some workers consider the Arabian Shield had been originated from juvenile mantle-derived oceanic and intra-oceanic island arc (DUYVERMAN *et al.* 1982; STERN and HEDGE 1985; HARRIS *et al.* op. cit.). The available combined isotopic data on the studied gneisses, show strong negative initial ϵ^t_{Nd} (-8.1 to -8.6) and low ϵ^t_{Sr} (+9.5 to +9.7) narrow ranges. These obviously reflect the role of crustal contamination during their petrogenesis. This also was confirmed by the $^{87}Sr/^{86}Sr$-1/Sr binary plot which enhanced the role of crustal contamination during the evolution of the studied gneisses (*Fig. 3*). However, the well-defined isochrons shown by most of the studied gneiss rocks (*Fig. 2*) imply that the magmas were isotopically homogenous after interaction with the crustal material. In this approach a mixing model (DEPAOLO 1981) by assimilation of upper and lower crustal rocks (UC and LC, respectively; FAURE 1986) in basaltic magma derived from mildly depleted mantle source (M. FAURE op. cit.) are included in *Fig. 7* with hypothetical mixing trends (M-UC and M-LC). Also, the gneisses (A; sample no. Nd-G6) from SW-Egypt (HARMS et al. 1990) are used as Pan-African crustal end member to construct the mixing trends (M-A, *Fig. 7*). The values of weight percent of the crustal contamination in mafic melt are indicated on the curves shown in *Fig. 7*.

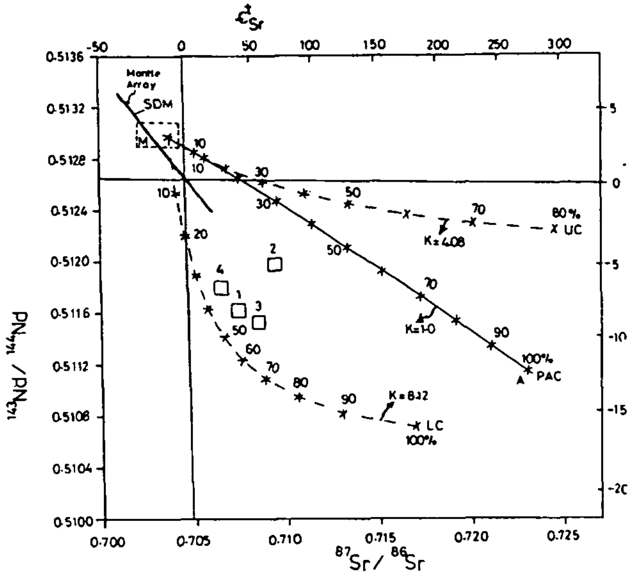

Fig. 7. Isotopic composition of initial Nd and Sr ratios among the analyzed gneisses. Solid line "Mantle Array" (ALLÉGRE *et al.* 1983, O'NIOS *et al.* 1977). The degree of crustal contamination is marked with intervals of 10%. SDM: The strongly depleted source of MORB ($^{87}Sr/^{86}Sr$=0.7025, $^{143}Nd/^{144}Nd$=0.5132) (DEPAOLO 1981); M: a mildly depleted mantle average Colombia River Basalt ($^{87}Sr/^{86}Sr$=0.70362, $^{143}Nd/^{144}Nd$=0.5130)(CARLSON *et al.* 1981); UC: upper crust, average of Paleozoic granitic rocks from Berridale, southereastern Australia ($^{87}Sr/^{86}Sr$=0.7369, $^{143}Nd/^{144}Nd$=0.51212) (MCCULLOCH and CHAPPELL 1982); LC: Lower crust, average of early Precambrian granulites from the Fyfe Hills, East Antarctica ($^{87}Sr/^{86}Sr$=0.7107, $^{143}Nd/^{144}Nd$=0.51071) (DEPAOLO *et al.* 1982); A: average of granitic gneisses, southeastern Egypt, sample no.ND-G6 ($^{87}Sr/^{86}Sr$=0.72304, $^{143}Nd/^{144}Nd$=0.511152) (HARMS *et al.* 1990); PAC: Pan-African Crust and K: Degree of curvature.

The plots of Wadi Beitan gneisses lie within a limited area bounded by $^{143}Nd/^{144}Nd$ (0.511528—0.511972) and 87Sr/86Sr (0.706424—0.709368). The sample plots also lie close to the M-LC trend which correspond to contamination of mantle derived magma by crustal rocks of low ϵ^t_{Sr} in the Late-Proterozoic time. Hypothetical mixing model M-LC trend suggests that the Wadi Beitan gneisses have experinsed about 35—50% crustal contamination.

The calculated amount of crustal component involved during the formation of the present gneisses proofs a limited Sr-contribution from the crust and assumes assimilation of Sr-poor crustal rocks or mixing with Sr-poor anatectic melt. The high plagioclase stability as a residual phase and extensive fractionation of potash feldspar may explain the low content of Sr in crust derived melt. Nd concentration on the other hand, are unaffected during the fractionating phases. The $^{147}Sm/^{144}Nd$ of the studied samples (Table 1) retain typical gneiss values of 0.083 to 0.159. Accordingly the negative ϵ^{t}_{Nd} of the studied gneisses confirm their dependence on the degree of contamination. Contrasting inference from different isotopic systems (Sr, Nd and Pb) was also described by SULTAN *et al.* (1990) for some granitic rocks in the Nubian Shield. They reported low initial $^{87}Sr/^{86}Sr$ ratio (0.7029) for approximately 20% crustally contaminated Aswan granites. This feature is explained by overshadowing of the Nd and Sr isotopic composition of the older crustal component by more primative material.

CONCLUSIONS

1. The studied part of Beitan gneisses (98 km^2) forms NW-SE trending belt and consist of gneisses-migmatites. The rocks are overthrusted by arc-ophiolite assemblage as well as granitic rocks.
2. Both Rb-Sr and Sm-Nd dating are compatible indicating early Pan-African age; whole rock isochron assign Sm-Nd 889±8 Ma (MSWD=8.5) and Rb-Sr 863±15 Ma (MSWD=9).
3. The calculated initial ratios for both $^{87}Sr/^{86}Sr$ (0.70412± 0.00005) and ($^{143}Nd/^{144}Nd$ (0.51104·0.000002) are generally higher than rocks which have been derived from mantle and lower than that of older upper sialic crust. Meanwhile, the negative ϵ^{t}_{Nd} (-8.1 to -8.6) as well as narrow range o fϵ^{t}_{Sr} (+9.5 to +9.7), suggest a mixed source of a depleted upper mantle and lower crust components. The well defined isochrons of the studied gneiss imply that they were isotopically homogeneous after the above mentioned mixing.
4. The relatively high values of initial $^{87}Sr/^{86}Sr$ ratio and low $^{143}Nd/^{144}Nd$ as well as negative value of ϵ^{t}_{Nd} as compared with CHUR, all together favour essential para-origin of Beitan gneiss (Para-gneisses).
5. The Beitan gneiss plots lie close to the mantle-lower crust trend (M-LC) which correspond to contamination of mantle derived magma by crustal rocks. Hypothetical mixing model (DEPAOLO 1981) suggests that Beitan gneisses have experinsed ca. 35—50% crustal contamination.
6. The assigned age of Beitan gneisses would represents the data of homogenization which had took place during rejuvenation of early-Pan-African crust.

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