# Metamorphic an magmatic events in the Uweinat – Bir Safsaf Uplift (Western Desert/Egypt)

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With 6 figures and 4 tables


### Zusammenfassung

Die Grundgebirgsschwelle zwischen Gebel Uweinat und Bir Safsaf (Western Desert/Ägypten) war während des Präkambriums durch vier Episoden von Deformation, Metamorphose und Anatexis gekennzeichnet. Die endgültige Kratonisierung erfolgte im Jungproterozoikum im Verlauf eines Pan-Afrikanischen Thermalereignisses. Die während des Jungproterozoikums als Folge großräumiger Intraplattentektonik entstandenen Bruchsysteme wurden während des Phanerozoikums periodisch reaktiviert. Die Platznahme anorogener Magmen erfolgte in mindestens sechs verschiedenen Zeiträumen hauptsächlich entlang dieser Bruchstrukturen.

### Abstract

In the Uweinat – Bir Safsaf Uplift, Western Desert/Egypt, four episodes of deformation and related metamorphism and anatexis occurred until the final cratonisation during the Late Pan-African event was completed. From that time on, probably six independent (Table 4) magmatic episodes can be recognized up to the Quaternary. This anorogenic type of magmatism is mainly related to a fracture system which originated in the Late Precambrian as a result of intraplate block faulting. Periodical reactivation of these older fracture zones throughout the Phanerozoic gave way to the different types of plutonic and volcanic rock assemblages.

### Résumé

Le massif soulevé compris entre le Gebel Uweinat et Bir Safsaf, dans le Désert occidental de l'Egypte, a été le siège de 4 épisodes de déformations avec métamorphisme et anatexie jusqu'à sa cratonisation finale au cours de la Phase Pan-africaine tardive. A partir de ce moment, probablement six épisodes magmatiques indépendants peuvent être reconnus jusqu'au Quaternaire. Ce type anorogénique de magmatisme est principalement en relation avec un système de fractures qui a pris naissance au Précambrien supérieur comme le résultat d'une régime de fracturation intraplaque. La réactivation périodique des ces zones de fractures anciennes durant le Phanérozoïque a conduit à la formation de ces différents types d'associations de roches volcaniques et plutoniques.

### Краткое содержание

Порог основных гор между Gebel Uweinat и Bir Safsaf (западная пустыня. Египет) претерпел во время докембрия 4 деформации, сопровождающиеся метаморфизмом и анатексисом. Окончательная кратонизация произошла только в позднем протерозое в течение некого панафриканского термического события. Возникшая во время позднего протерозоя система разломов, как следствие крупномасштабной межплитовой тектоники, претерпела реактивирование во время фанерозоя. В образовавшихся в этих структурах разломах скопились магмы. Причем такое замещение происходило, по-крайней мере, шесть раз.


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## Introduction

The Dakhla basin of SW-Egypt is filled with Palaeozoic, Mesozoic (Nubian group) and Cenozoic sediments which reach a maximum thickness of 4000 metres in the basin centre (THORWEIHE et al., in press). It is bordered in the south by a basement high which extends from Gebel Uweinat in the west to Bir Safsaf in the east. This basement high, termed by us the Uweinat – Bir Safsaf Uplift, separates the Dakhla basin from the Nubian type sediments of the northern Sudan.

Crystalline rocks are exposed in an area of roughly 37,000 $km^2$ in the Gebel Uweinat – Gebel Kamil region and 3000 $km^2$ in the Bir Safsaf area (Fig. 1). East of Gebel Kamil and west of Bir Safsaf no crystalline rocks are exposed and the probably downfaulted central part of the uplift is covered by Nubian sediments of some 100 m thickness.

## Working methods and Rb/Sr determinations

The area was traversed and fieldmapped in 1980, 1981 and 1982 and the results which are strictly valid for the investigated areas only, were extrapolated with the help of satellite images into adjacent unknown areas. Samples for Rb/Sr whole rock age determinations were taken from three rock units.

Rb and Sr concentrations and atomic ratios for the Gebel Kamil migmatites and porphyritic granites were determined by X-ray fluorescence spectrometry on 20 gram pellets pressed to 15 tonnes from – 200 mesh powder. The Nusab el Balgum volcanics were analysed by isotope dilution using $^{84}Sr$-enriched and $^{87}Rb$-enriched spikes. Standard ion exchange procedures were employed in the chemical preparation of the samples. Strontium was loaded on single tantalum filaments prepared with phosphoric acid and isotope measurements were made on a 30 cm radius 90° magnetic field sector mass spectrometer operated at 7.1 KV acceleration voltage. Errors are quoted throughout as two standard deviations and the decay constant used in the age calculations is the value recommended by the IUGS Subcommission for Geochronology (STEIGER and JÄGER, 1977) i. e. $\lambda\ ^{87}Rb = 1.42 \times 10^{-11}\ a^{-1}$. Analytical uncertainties are estimated at $\pm$ 0.02 % for $^{87}Sr/^{86}Sr$ and $\pm$ 1.0 % for Rb/Sr. The same errors apply to both XRF and ID determined $^{87}Rb/^{86}Sr$ ratios. During the period of this study the average $^{87}Sr/^{86}Sr$ determined for NBS was 0.71029 $\pm$ 0.00008 (45 analyses) and for Eimer and Amend $SrCO_3$ was 0.70808 $\pm$ 0.00008 (28 analyses).

Regression lines were calculated using a least squares method based on that of YORK (1969). As a measure of the goodness of fit of the regression lines, the mean square of weighted deviates (MSWD) is employed (BROOKS et al., 1972). Where the observed value exceeds the limiting or critical value the scatter of data about the line cannot be entirely accounted for by experimental and sampling errors. The data do not then satisfy the criteria for an isochron, the line is an 'errorchron', and the values for age and initial ratio should be viewed with caution. In some cases it is then appropriate to enhance the errors by mulitplying by $\sqrt{MSWD}$ (YORK, 1966).

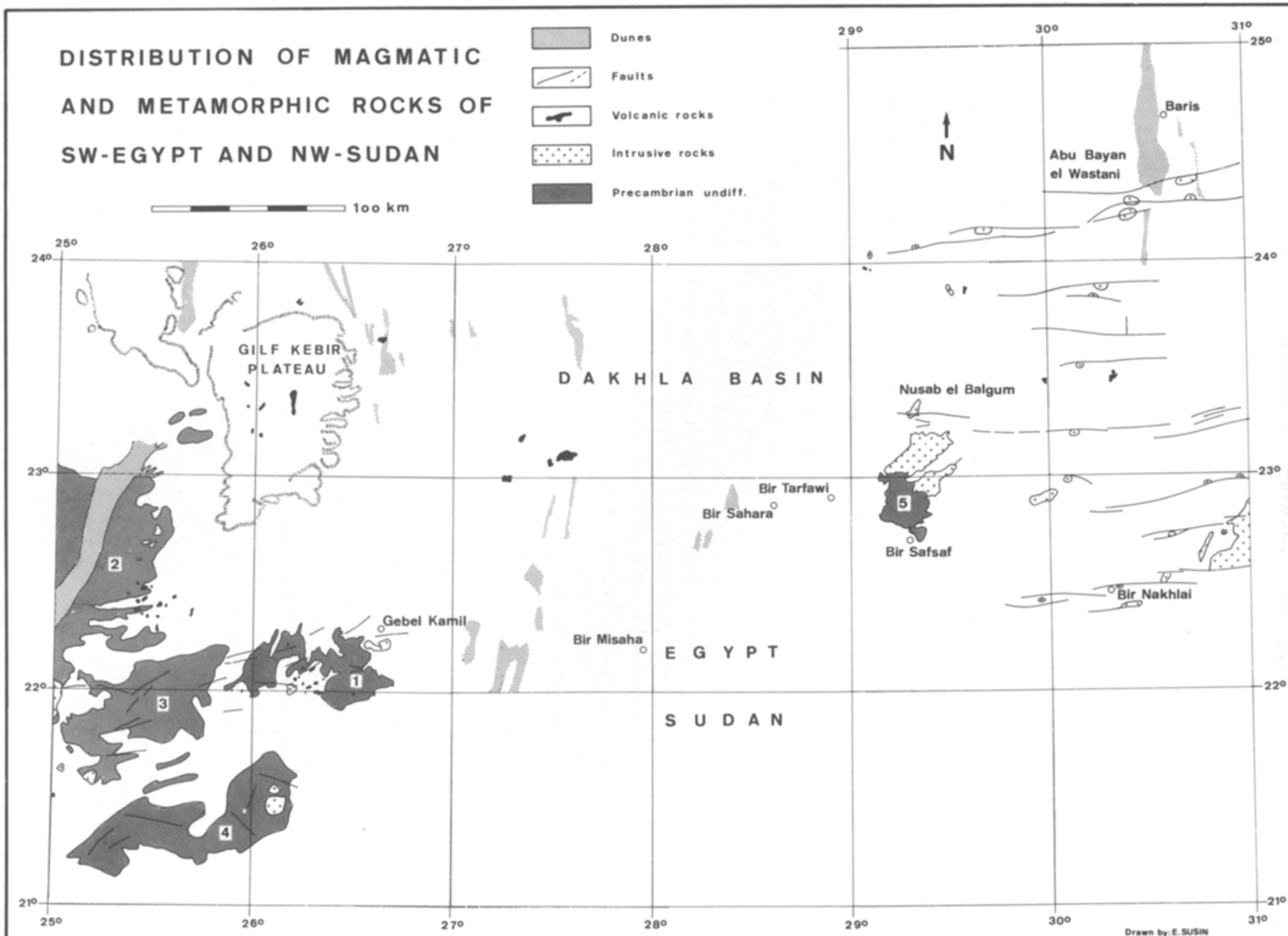


Fig. 1. Distribution of magmatic and metamorphic rocks of SW-Egypt and NW-Sudan. 1 = Gebel Kamil area, 2 = Peneplain area, 3 = East Uweinat area, 4 = NW-Sudan area, 5 = Bir Safsaf area.

## Geological framework

The Uweinat-Bir Safsaf uplift is part of a basement region where the still undefined eastern margin of the postulated East Sahara Craton must be located.

All the basement rocks of the Eastern desert of Egypt, NE Sudan, Ethiopia and Northern Kenya appear to be of late Proterozoic age with no firm evidence of an underlying older basement. ROGERS et al. (1978) postulated an ocean basin between the West-African and Arabian-Nubian shields which was cratonised during and at the end of the Pan-African. However, there is little doubt that in the Uweinat area a pre Pan-African basement exists (KLERKX and DEUTSCH, 1977).

The western margin of the Late Proterozoic Arabian-Nubian shield has to be sought further west than the Sabaloka granulite gneisses at the River Nile (N of Khartoum), which are of Pan-African age (KRÖNER et al., 1983) and west of the Abu Hamed area of Central Sudan where no rocks are older than Pan-African (RIES, 1983). Any NW-SE trending line west of these two locations will pass through the Uweinat-Bir Safsaf uplift.

## Late Archean / Early Proterozoic

The oldest known rocks from the Uweinat area are exposed at the southern border of the Gebel Uweinat ring complex in Libya. These rocks, namely the Karkur Murr series (KLERKX, 1980) consist of biotite-gneisses, diopside-hornblende gneisses, metaquartzites, granulitic gneisses and calcsilicate rocks. The major structural trend of these granulite facies gneisses is E-W to NE-SW. Remnants of recumbent folds with an axial orientation N-S to NNE-SSW were recognized in these rocks. According to KLERKX (1980) these relict folds belong to a tectonic episode which was contemporaneous with the granulite facies metamorphism of the Karkur Murr gneisses.

A nine point Rb/Sr regression line age of 2656 ± 142 Ma $R_i = 0.7019 \pm 0.0030$ (MSWD = 18.45) was obtained for these rocks (CAHEN et al., 1983, recalculated from KLERKX and DEUTSCH, 1977). This age is considered to represent a minimum age for the deformation which accompanied the metamorphism in the granulite facies. A model age from the sample which lies significantly above the line yields 2904 Ma ($R_i = 0.702$) to 2919 Ma ($R_i = 0.700$). This age is considered by CAHEN et al. (1983) to represent a more appropriate approximation to the age of the charnockitic rock. A recalculation using only the seven well-aligned rocks of the Karkur Murr series yields 2632 ± 72 Ma ($R_i = 0.7033 \pm 0.00012$; MSWD = 3.68). This age probably reflects the retrogressive metamorphism of amphibolite facies (CAHEN et al., 1983).

Gneissose granoblastites and granulitic gneisses are exposed in the western part of the Gebel Kamil area (Fig. 2). These rocks are texturally and mineralogically nearly identical with the gneisses from the Karkur Murr series. The strike of the gneissose layers is NE-SW, dips are mainly to NW and subordinately to SE. The general NE-SW trend could also be observed in the basement gneisses of the NW-Sudan area (Fig. 1, No. 4) and in the southern part of the Peneplain Plateau (Fig. 1, No. 2). There is no evidence in the field or from the interpretation of the Landsat satellite images that there is any marked unconformity between the gneisses of the western Gebel Kamil area and the gneisses of the Karkur Murr

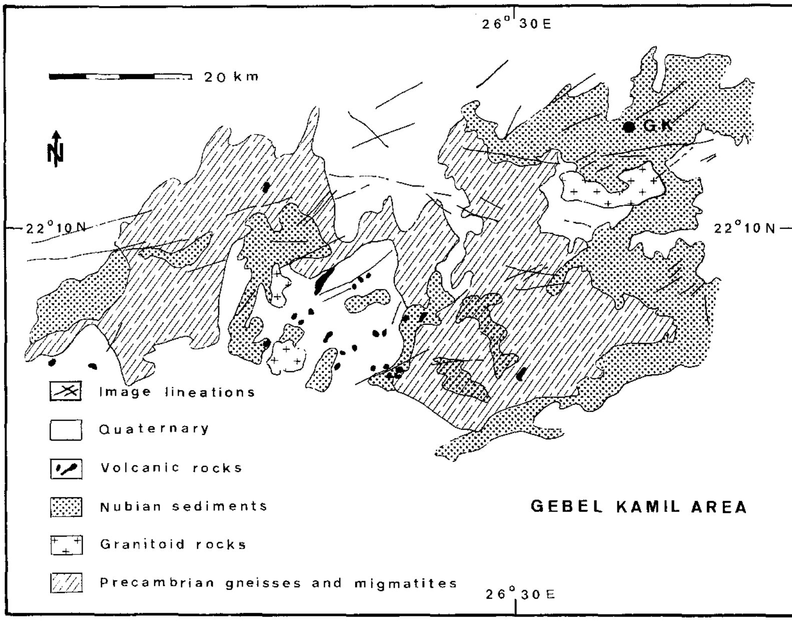


Fig. 2. Geological sketchmap of the Gebel Kamil area; GK = Gebel Kamil.

series. Based on lithological, mineralogical, textural and structural similarities, these rock series are provisionally correlated, until more detailed radiometric work substantiates or opposes this view.

## Middle Proterozoic

The Karkur Murr series is overlain by the Ayn Daw series (KLERKX, 1980), which consists of granitic gneisses, often migmatitic, with local intercalations of amphibolite and diopside – hornblende gneisses. The two series are separated by the mylonitic zone of Il Passo. These mylonites yielded a five point regression line age of 2637 ± 392 Ma ($R_i$ = 0.7002 ± 0.0042; MSWD = 48.5). If one extremely divergent point is rejected, the four others yield 2845 ± 198 Ma ($R_i$ = 0.7006 ± 0.0016; MSWD = 9.25), which may be compared with the above mentioned model age obtained for the charnockitic rock of the Karkur Murr series (CAHEN et al., 1983).

The major trend of the Ayn Daw gneisses is E-W to NE-SW. Relict folds similar to those in the Karkur Murr series are also present in the Ayn Daw series. The gneisses are metamorphosed in the amphibolite facies but probably on a higher crustal level than the Karkur Murr series. The relict folds indicate that they were initially deformed during the same tectonic episode as the Karkur Murr series. The tectonic phase which produced the penetrative NE-SW foliation on the gneisses of the Karkur Murr and the Ayn Daw series was probably accompanied by migmatisation in the Ayn Daw series. From the anatectic zone of Wadi Wahech a Rb/Sr whole rock isochron age of 1784 ± 126 Ma ($R_i$ = 0.7081 ±

0.0014; MSWD = 0.85) was obtained from migmatic gneisses of granitic and tonalitic composition and this age is considered to represent the time of granitisation (CAHEN et al., 1983, recalculated from KLERKX and DEUTSCH, 1977).

## Late Proterozoic (Pan-African)

Pan-African influence in the working area is still very uncertain since radiometric data neither from basement gneisses nor from intrusive granites and granodiorites are available. The central and southern parts of the Gebel Kamil area are occupied by migmatites and migmatic gneisses (Fig. 2) with intercalations of marbles, sillimanite – garnet – cordierite gneisses and hornblende felses (SCHANDELMEIER et al., in press).

Twenty km south of Gebel Kamil 8 samples of migmatites were taken for Rb/Sr whole rock dating.

If all the data are regressed there is a huge scatter of the points about the line (Fig. 3). This could suggest a very disturbed older (possibly Archean) basement. Point no. 8 from Table 1 which lies far above the regression line yields model ages of 3123 to 2817 Ma if initial Sr ratios of 0.700 to 0.704 are assumed. There is a series of events at 1800 Ma (Uweinat area. KLERKX and DEUTSCH, 1977), at about 1185 Ma, 960 Ma, 800 Ma and finally the 600 Ma Pan-African event (Eastern Desert/Egypt, CAHEN et al., 1983) and if the Gebel Kamil area was part of the Uweinat block, it is conceivable that all these events had some influence on the analysed rocks from the Kamil area. Five out of the 8 points are well-aligned along a line and computation of the regression line yields an age of 673 ± 56 Ma ($R_i$ = 0.7050 ± 0.0004; MSWD = 5.3 enhanced errors). The line is not far from qualifying as an isochron (Fig. 4) and this could suggest a Late Proterozoic resetting within these rocks.

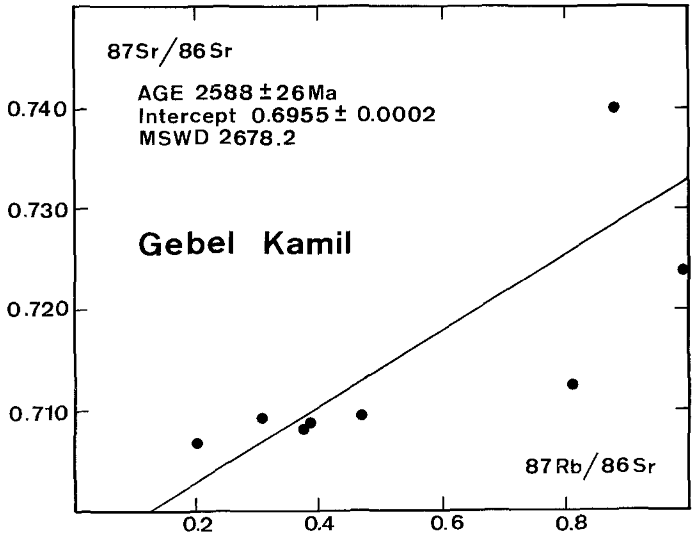


Fig. 3. Rb/Sr whole rock regression line for the Gebel Kamil migmatites.

Table 1. Rb/Sr values for Gebel Kamil migmatites
* Points not considered in regression of Figure 4

| Sample No. | Rb ppm | Sr ppm | $^{87}Rb/^{86}Sr$ | $^{87}Sr/^{86}Sr$ |
|---|---|---|---|---|
| * GK 1 | 58.3 | 547 | 0.3073 | 0.70924 |
| * GK 2 | 115 | 336 | 0.9945 | 0.72387 |
| GK 3 | 98.4 | 351 | 0.8109 | 0.71268 |
| GK 4 | 71.1 | 546 | 0.3766 | 0.70844 |
| GK 5 | 89.9 | 558 | 0.4659 | 0.70963 |
| GK 6 | 90.6 | 681 | 0.3851 | 0.70882 |
| GK 7 | 73.9 | 1051 | 0.2033 | 0.70686 |
| * GK 8 | 87.6 | 290 | 0.8806 | 0.73994 |

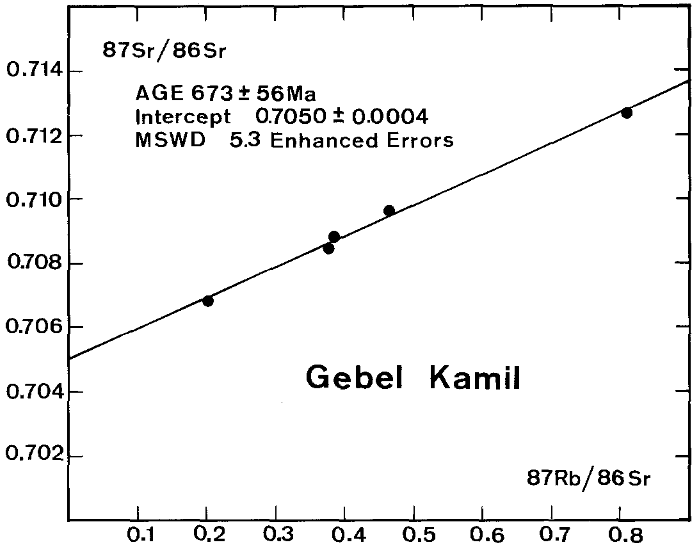


Fig. 4. Rb/Sr whole rock regression line for the Gebel Kamil migmatites after rejection of points 1, 2 and 8 from Table 1.

More conclusive results will have to be postponed until better data are available but the significance of dating these rocks should be briefly mentioned here: According to KRÖNER et al. (1983) and RIES (1983) the eastern margin of the East Sahara Craton must lie further west than previously believed, but still east of Gebel Uweinat where Late Archean/Early Proterozoic rocks are exposed. The continental margin has to be sought within our working area.

The principal question that arises: were the migmatites of the Gebel Kamil area originally of pre Pan-African age and then reworked during the Pan-African or, were they newly generated during the Pan-African and by what mechanism? The presently available data seem to favour the first alternative.

## Palaeozoic

After the Pan-African consolidation of the area, uplift and erosion resulted in the formation of a Late Proterozoic landsurface and Palaeozoic sediments were deposited in the depressions at least from the Ordovician onwards. Sediments of probably Silurian age are still preserved in the vicinity of Gebel Uweinat but are not encountered further east. This indicates that the topographically high position of the Uweinat area and its immediate surroundings is the result of a very young uplift movement possibly related to the intrusion of the Uweinat ring complex at around 45 Ma (KLERKX and RUNDLE, 1976; MARHOLZ, 1968).

In the Gebel Kamil area a number of porphyritic granitic bodies with flow banding textures occur, having very sharp contacts against the surrounding basement gneisses. Four samples from this very homogeneous rock type from the southern Gebel Kamil area define a Rb/Sr whole rock isochron (Fig. 5) of 431 ± 33 Ma with an intercept of 0.7097 ± 0.0007 (MSWD = 0.3). Similar ages and initial Sr ratios of anorogenic complexes are reported from the Air region (KARCHE and VACHETTE, 1976). HUNTING GEOLOGISTS (1974) report a K/Ar whole rock age of 489 ± 12 Ma (recalculated after modern decay constants) for a microgranite from the Gebel Babein (Libya). The intrusions of previously mentioned Ordovician granites in the Uweinat-Kamil area falls in a time span where, after a "quasi-static" interval (Cambrian to Lower Ordovician), a rapid polar wandering of Gondwanaland can be observed (BRIDEN et al., 1973). Although based on rather limited data, there is some indication that Ordovician anorogenic magmatism was more widespread in Northern Africa than has previously been recognized.

Palaeozoic sedimentation continued in the Uweinat area and most likely east of Uweinat until the Permo-Triassic. In the Upper Permean/Lower Triassic, the area between Gebel Uweinat and Bir Safsaf was probably uplifted along zones of pre-existing crustal weakness and these reactivated fractures gave way to the intrusion of basaltic dykes (235 ± 5 Ma; KLERKX and RUNDLE, 1976) and rhyolitic subvolcanic rocks (see below).

Table 2. Rb/Sr values for Gebel Kamil prophyritic granites

| Sample No. | Rb ppm | Sr ppm | $^{87}Rb/^{86}Sr$ | $^{87}Sr/^{86}Sr$ |
|---|---|---|---|---|
| W 1 | 124 | 492 | 0.7302 | 0.71422 |
| W 2 | 122 | 481 | 0.7361 | 0.71420 |
| W 3 | 108 | 490 | 0.6408 | 0.71370 |
| W 4 | 123 | 332 | 1.0716 | 0.71632 |

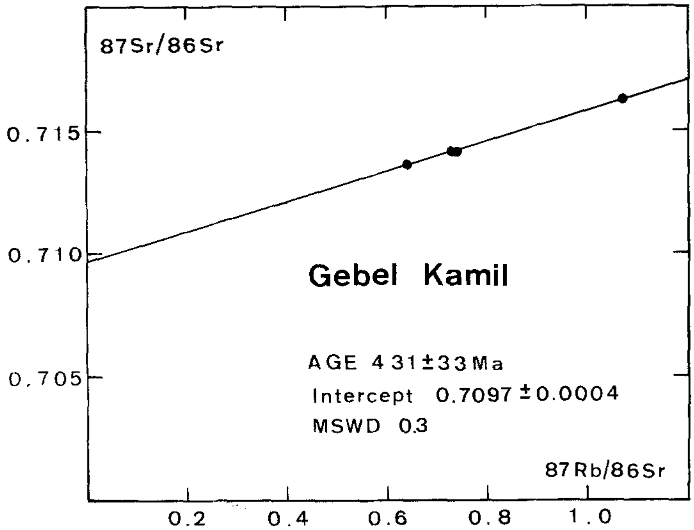


Fig. 5. Rb/Sr whole rock isochron for Gebel Kamil porphyritic granites.

Table 3. Rb/Sr values for Nusab el Balgum subvolcanics

| Sample No. | Rb ppm | Sr ppm | $^{87}Rb/^{86}Sr$ | $^{87}Sr/^{86}Sr$ |
|---|---|---|---|---|
| B 1 | 135 | 17.44 | 22.5553 | 0.774760 |
| B 2 | 232 | 7.82 | 88.0030 | 0.974160 |
| B 3 | 178 | 13.28 | 39.1988 | 0.827050 |
| B 4 | 185 | 8.36 | 65.1246 | 0.906975 |
| B 5 | 118 | 9.46 | 36.5262 | 0.816380 |

The age of the Nusab el Balgum (Fig. 1) rhyolitic subvolcanics (216 ± 5 Ma) was obtained from a 5 point Rb/Sr whole rock isochron with an initial Sr ratio of 0.7054 ± 0.0025 (MSWD = 4.1; enhanced errors) of which the error is too high to make conclusions of the origin of the rocks (Fig. 6).

As a result of the uplift in this area, the sedimentary cover was removed and the eroded material was transported mainly southwards and probably northwards into the present-day Dakhla basin.

## Mesozoic and Cenozoic

With the beginning of the Mesozoic, the basin structure of the Dakhla basin permitted continuous continental sedimentation of Nubian type sediments, the oldest of which are probably Late Jurassic/Lower Cretaceous in age. These basal series are most likely reworked Palaeozoic sediments (FAY and HERRMANN-DE-

Table 4. Relevant age data of the metamorphic an magmatic episodes which occured in the Uweinat-Bir Safsaf uplift
* recalculated from KLERKX + DEUTSCH (1977).

| ERA | Locations and rock types | Metamorphism, magmatism and related structures | Age (Ma) | References |
|---|---|---|---|---|
| | Uweinat-Kamil-Peneplain and Bir Safsaf areas | basaltic plugs and dykes along fracture zones | Quaternary | Almond (1979) |
| CENOZOIC | Gebel Uweinat<br>Gebel Archenu<br>Gebel Kamil area | fracture-bound alkali granites and volcanics | 41 to 48 | Klerkx & Rundle (1976)<br>Marholz (1968) |
| MESOZOIC and PALEOZOIC | Dakhla basin and Uweinat high | Nubian type sedimentation | Late Cretaceous to Early Paleozoic | Klitzsch et al. (1979) |
| | Gebel Uweinat basaltic dyke | | $235 \pm 5$ | Klerkx & Rundle (1976) |
| | Nusab el Balgum alkali subvolcanics | | $216 \pm 5$ | Schandelmeier & Darbyshire (this paper) |
| PALEOZOIC (Permo-Triassic to Ordovician) | | Anorogenic complexes bound to periodically reactivated intraplate fracture systems | | |
| | Gebel Kamil porphyritic granites | | $431 \pm 33$ | Schandelmeier & Darbyshire (this paper) |
| | Gebel Babein microgranite | | $489 \pm 12$ | Hunting Geology & Geophysics Ltd (1974 ,recalculated) |

| | | | | |
|---|---|---|---|---|
| LATE PROTERO-*ZOIC* (Pan-African) | Gebel Kamil *migmatites* | migmatization and Pan-African resetting of isotope systems of older rocks | 673 $\pm$ 56 | Schandelmeier & Darbyshire (this paper) |
| MIDDLE *PROTEROZOIC* | Wadi Wahech (Uweinat) anatexites (*Ayn Daw series*) | Amphibolite facies metamorphism and migmatization and refolding of older rocks into *NE-SW trend* | 1784 $\pm$ 126 | Cahen et al. (1983)* |
| EARLY PROTEROZOIC/ ARCHEAN | Karkur *Murr* series (Uweinat) Gebel Kamil series | Retrogressive metamorphism in amphibolite facies | 2656 $\pm$ 142 | Cahen et al. (1983)* |
| | granulitic gneisses; metaquartzites, *grano*-blastites etc. | granulite facies metamorphism relict folds with *N-S* and NNE-SSW trend | 2904 to 2919 | Cahen et al. (1983) |

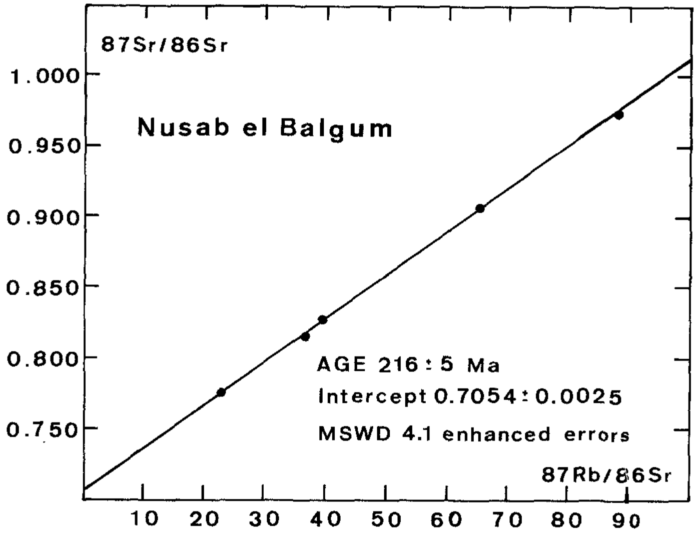


Fig. 6. Rb/Sr whole rock errorchron for Nusab el Balgum subvolcanics.

GEN, in prep.). Intercalated with the continental Nubian sediments are several marine horizons and the whole Nubian sequence is overlain by Lower Maastrichtian/Tertiary marine sediments (KLITZSCH et al., 1979).

From the Upper Cretaceous onwards, intensive reactivation of older zones of crustal weakness gave way to a variety of intrusive and extrusive rocks such as alkali granites, syenites, trachytes, phonolites and basalts. These rocks intrude and include rocks of up to Lower Cretaceous age. The peak of these magmatic activities occurred around 45 Ma (Table 4).

In the Late Tertiary and Quaternary small scale alkali basaltic volcanicity occurs all over the area. Since the eroded cones and lava flows retain remnants of primary morphology, they are regarded younger than the Early Tertiary intrusions (ALMOND, 1979).

## Conclusions

First radiometric results from migmatites of the eastern Gebel Kamil area indicate that these rocks are of pre Pan-African age, but were reworked by a Late Pan-African thermal event. The continental margin of the East Sahara Craton thus must be located east of Gebel Kamil. Anorogenic magmatism seems to be more widespread in the Lower and Upper Palaeozoic than previously recognized. A gap in intrusive and extrusive activities occurred probably between the Silurian and Lower Permian.

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