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On the Age Dating of the Dyke Swarms of Southwestern Sinai, Egypt

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ABSTRACT. The dyke swarms in Sinai are important in understanding late Precambrian activity in the northern Arabian-Nubian Shield. Fieldwork and K-Ar age dating indicate that these dyke swarms can be described in terms of two major members.

(1) The old (mafic) dykes, mainly consisting of basalts and andesites, which, with minor lamprophyres and plagiophyres, range in age from 586-563 Ma giving a mean age of 574 Ma. They are distinguishable from older 586-577 Ma basalts with a mean of 581 Ma; and younger 570-563 Ma andesites with a mean of 567 Ma. The old dykes crosscut the basement rocks except the Younger granites.

(2) The young (felsic) dykes, comprising dacites-to-rhyolites and quartz porphyries and rang in age from 545-536 Ma with a mean of 541 Ma. They crosscut almost all the basement rocks, the exception being the Younger Granites phase-III.

All the former basement rocks, together with the old and young dyke swarms, are cut by 517-502 Ma (509 Ma mean) late basalt dykes.

These data represent the age of old dykes emplacement and cooling, and place a minimum age of the young dykes probably due to the loss of argon attributable to the influence of the post-extrusion deformation.

Late Precambrian rocks cropping out in the northern Eastern Desert and probably in Sinai were emplaced in an environment of crustal extention. Five principal lithologies dominate the crust of this region (Stern *et al.* 1984). The oldest rocks exposed are *granodiorites,* 680-610 Ma (Stern and Hedge 1985). In Sinai, they range in age from 567-653 Ma (Abdel-Karim and Arva-Sos 1992). Most of the crust exposed in the Northern Eastern Desert formed in the 600-575 Ma interval. Units formed in this event include the *Dokhan Volcanics,* a suite of basalts-to-andesites and rhyolites (Basta *et al.* 1980, Stern and Gottfried 1986). These volcanics has been dated at 594-583 Ma (Stern and Hedge 1985) and are related to the first cycle clastic sediments of *Hammamat Group.* The *pink granites* (609-568 Ma) are the most important intrusives of this event, (Bielski *et al.* 1979, Stern and Hedge 1985, Abdel-Karim and Arva-Sos 1992). *Dyke swarms* are found throughout the Northern Eastern Desert. These range in age from 589-543 Ma (Stern and Hedge 1985). The dykes are compositionally bimodal, consist of melanocratic, aphyric to porphyritic mafic dykes and leucocratic felsic dykes (Stern *et al.* 1988).

In the southwestern part of Sinai, three distinct basaltic phases related to Middle Triassic (233-243 Ma), Middle Jurassic (182 Ma) and Oligo-Miocene (24.8-22.8 Ma) are recorded (Roufaiel *et al.* 1989). Rutig volcanics gave a 587 Ma age for volcanism of andesites (Bielski 1982). El-Aref *et al.* (1988) studied the geology of the basement rocks east of Abu Zenima and arranged some of the present dykes into two main groups, some of those are older and some younger than the pink granites. The older group comprises lamprophyres, granophyres, andesites, plagiophyres and dolerites, while trachytes and rhyolites are grouped as the younger. The dykes in Sinai were studied by Hassan and Azzaz (1990), they classified them petrochemically into three groups: basic (dolerites), acidic (microgranites) and intermediate (andesites). These dykes are of different generations but possibly have a single magmatic origin.

The present work is focussed on the age problems and field observations of the late Precambrian dyke swarms in the southwestern part of Sinai (Fig. 1), and their relation in space and time to granites.

Field Observations and Petrography

The basement rocks of southwestern part of Sinai consist, mainly, of schists, gneisses and migmatites; metagabbro-diorite association, older and younger granites. Table 1 summarizes the main features of field observations and petrography of the intrusive rocks and their relation to the dyke swarms under investigation. Field observations and cross-cutting relationships suggest two components of dyke swarms. The older are mostly mafic in composition and include lamprophyres, basalts, andesites and plagiophyres trending N-S, NNE-SSW and NW-SE. They cut the migmatites, gneisses, rocks of the metagabbro-diorite association and the older granites (Fig. 2). Lamprophyres are crosscut by basalts; subsequently both these dykes were cut by the granite porphyry dykes and the younger granites phase-II (Fig. 1).

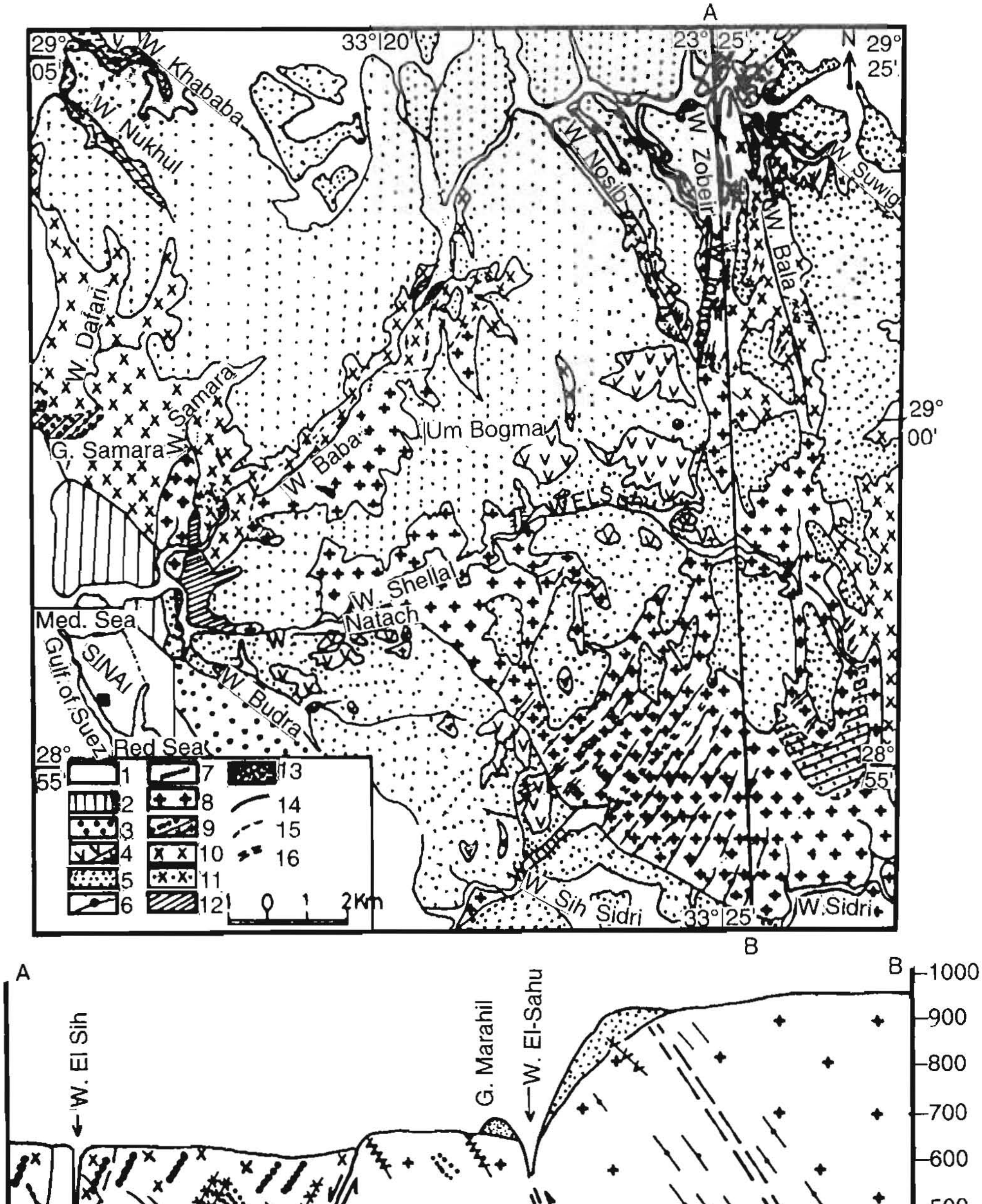

Fig. 1. Geological map of the basement rocks of Southwestern Sinai, Egypt (after Abdel-Karim and Arva-Sos 1992). The mapped area north latitude 28° 57' after El-Aref *et al.* (1988) with modification. AB = Geological section along N-S direction. 1= Wadi deposit, 2= Eocene limestone, 3 =Mesozoic limestone, 4= Latest basaltic sheets and dykes, 5= Cambrian, Ordivician and Carboniferous sandstone, 6= Late basalt dykes, 7= Felsic dykes, 8= Younger granites, 9=Mafic dykes (andesitic and basaltic), 10= Older granites, 1 1=Metagabbro-diorite, 12= Gneiss and schist, 13= Migmatite, 14 and 15 = Continous and discontinous contact, 16= Shear zone.

Table 1. Summary of the main features of the field observations and petrography of the intrusive rocks and their relation to the dyke swarms in the southwestern Sinai

Rock-units	Field observations	Petrographic features
Late basalt dykes	Cut all the basement rock units.	Basalt and dolerite, consist of plagioclase and clinopyroxene with minor olivine and iron oxides.
Younger granites	**Phase III** intrudes all rocks of the basement complex, but cut by late basalt dykes.	Alkali feldspar granite in composition and consist(s)of perthitic K-feldspar, quartz and plagioclase with minor fluorite, topaz and zircon.
Felsic dyke swarms	Crosscut the metagabbro-diorite, older granite, mafic dykes and younger granite Phase II.	Range from dacite to rhyolite in composition and consist(s) of plagioclase, K-feldspar and quartz, with minor biotite and hornblende.
Younger granites	**Phase II** intrudes all the basement complex and the old (mafic) dykes, but cut by felsic and late basalt dykes.	Ranges from monzogranite tosyenogranite in composition and consists of K-feldspar, plagioclase, quartz and biotite with minor zircon and apatite.
Mafic dyke swarms	Crosscut the metagabbro-diorite complex, older granite, gneiss and migmatite.	Range from basalt to andesite in composition and consist(s) of plagioclase, clinopyroxene ± hornblende, biotite, and chlorite.
Older granites	Intrude the metagabbro-diorite complex, the schists, gneisses and migmatites; but cut by younger granites; mafic and felsic dykes.	Ranges in composition from quartz diorite to tonalite and granodiorite and consists of plagioclase, hornblende, biotite and quartz with minor zircon and apatite.
Metagabbro-diorite complex	Intrudes the schists, gneisses and migmatites but cut by older and younger granites; mafic and felsic dykes.	Ranges from gabbros to diorite in composition and consists of plagioclase, hornblende, pyroxene and quartz with minor biotite, apatite and zircon.

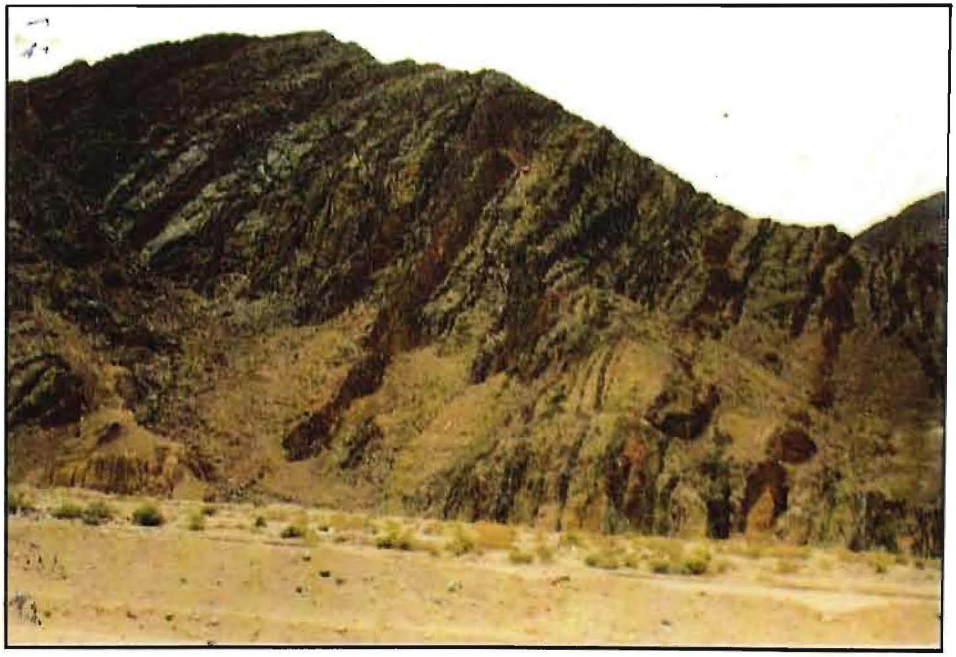

Fig. 2. Swarms of mafic (old) dykes cut the older granites.

Fig. 3. Swarms of felsic (left side) crosscut by late basalt dykes (right side). Both of them cut te younger granites.

The young (felsic) members comprise dacites-to-rhyolites through quartz and granite porphyries trending ENE-WSW and NNE-SSW. They cut the andesite dykes. The felsic dykes are cut by late basalt dykes (Fig. 3). Both the young dykes and the younger (phase II) granites invaded the former basement rock-units (Fig. 1). However, some dacites-to-rhyolites dykes are cut by the younger (phase-III) granites. Therefore, the younger (phase II) granites appear to have separated the older suite of dykes from the younger.

Late basalt dykes cut all the basement rocks (*e.g.*, migmatite and gneiss, metagabbro-diorite and older granite, younger granite together with mafic and felsic dyke swarms).

The old (mafic) dyke swarms mostly range in composition from basalts to basaltic andesites and true andesites. Porphyritic varieties are common and always contain phenocrysts of plagioclase and sometimes clinopyroxene and/or amphibole embedded in basaltic to andesitic matrix of the former minerals together with minor biotite and iron oxides. Plagioclase crystals occasionally exhibit variable degrees of saussuritization; moreover, the clinopyroxene is altered to actinolite and/or chlorite. Lamprophyres range between spessartites and camptonites (El-Aref *et al.* 1988). They consist of fine grained plagioclase and amphibole both or either of which may occur as phenocrysts; minor tremolite and chlorite are recorded.

On the other hand, the young (felsic) members, range from dacites to rhyolites. They comprise phenocysts of variable plagioclase, alkali feldspar and/or quartz embedded in a microcrystalline, graphic and/or granophyric groundmass of the same composition with minor hornblende, biotite and iron oxides.

The late basalt dykes consist of phenocrysts of plagioclase, clinopyroxene and minor olivine embedded in a basaltic groundmass formed of the same minerals together with iron oxides. Fresh olivine is sometimes seen but in places it is altered to serpentine.

Methods

Nine samples selected from the old and young dykes were analyzed for K-Ar age dating at the Institute of Nuclear Research, Debrecen, Hungary. The experimental methods and instrumentation have been employed by Balogh (1985). Ages were calculated using the decay and atomic constants after Steiger and Jaeger (1977). Analytical errors are given at the 68% probability level. K and Ar determinations have been controlled regularly using the Asia 1/65 (Soviet) and G1-o (French) interlaboratory standards. The results are given in Table 2.

Table 2. Whole-rock K-Ar age dating of the dyke swarms in the southwestern Sinai

Rock name	Locality	K (%)	^{40}Ar rad. (ccSTP/g)	^{40}Ar rad. (%)	Age (Ma)
Late basalt	W. el-Lahian	3.331	7.4788×10^{-5}	87.0	501.5 ± 19.0
Late basalt	W. Iqna	1.469	3.4144×10^{-5}	89.8	516.8 ± 19.5
Granite porphyry	W. Abu Tiur	1.147	2.7806×10^{-5}	50.0	536.0 ± 22.7
Rhyolite	W. Baba	3.050	7.5385×10^{-5}	69.4	545.0 ± 21.3
Andesite	W. el-Seih	2.259	5.7946×10^{-5}	83.0	562.8 ± 21.4
Andesite	W. Nasib	3.492	9.0984×10^{-5}	86.6	570.4 ± 21.6
Basalt-andesite	W. el-Lahian	3.490	9.2211×10^{-5}	93.2	577.0 ± 22.0
Basalt	W. Bala	0.771	2.0717×10^{-5}	39.8	585.6 ± 27.2

Table 3. Major element analyses of the dyke swarms in southwestern Sinai

R. type Locality	Old Dykes			Young Dykes		Late Basalt Iqna 6
	Basalt	Andesites		Rhyolite	Gr. Por.	
	Bala 1	Lahian 2	Seih 3	Baba 4	A. Tiur 5	
SiO_2	49.01	62.85	61.20	75.34	74.45	49.90
TiO_2	2.50	0.42	0.50	0.07	0.08	1.75
$Al2O_3$	12.50	14.05	14.20	11.45	12.02	11.81
$Fe2O_3$	3.90	0.95	0.41	1.60	0.80	4.90
FeO	5.71	3.40	4.41	0.42	0.64	4.84
MnO	0.33	0.18	0.08	<0.01	0.03	0.23
CaO	10.93	3.91	4.05	0.59	0.49	9.80
MgO	6.70	2.64	2.92	0.11	0.15	8.04
Na_2O	3.31	4.55	2.41	4.78	3.50	3.07
K_2O	1.31	3.72	3.50	3.92	4.85	1.10
$+H_2O$	1.90	2.10	2.95	0.75	1.10	1.80
$-H_2O$	0.92	0.50	0.37	0.20	0.15	0.89
$-P_2O_5$	0.81	0.15	0.16	<0.01	0.06	0.73
Sum	99.83	99.42	99.96	99.25	98.32	98.86

Six additional samples chosen to encompass the compositional range involved, were analyzed for major elements by standard wet chemical techniques.These analyses were carried out at the Department of Petrology and Geochemistry of Eotvos University, Hungary. The results are listed in Table 3.

Results and Discussion

The chemical analyses show that the old dyke swarms range from 49-62.8% SiO_2 and 1.3-3.7% K_2O. The young dykes range from 74-75% SiO_2 and 3.9-4.8% K_2O which is consistent with the petrographic observations outlined earlier. The studied dyke swarms are mostly calc alkaline. That is apparent from the AFM diagram (Fig. 4) which shows that the old dykes are more enriched in total iron and magnesium and more depleted in alkalis than the young ones. These calc alkaline volcanic suites are enriched in potassium on the K_2O - silica diagram (Fig. 5) (Peccerillo and Taylor 1976).

K-Ar age dating of the present study can be in the context of two distinctive dyke suites (Table 2). *The older dykes* comprise two analyzed basalt samples and two andesite samples. The basaltic dykes yield whole-rock K-Ar ages ranging from 585.6 ± 27.2 to 577 ± 22 Ma and giving a mean of 581 ± 24.6 Ma. This mean indicates that the basalt dykes are older than the andesitic (570.4 ± 21.6 – 562.8 ± 21.4 Ma, a mean of 566.6 ± 21.5 Ma). Most of the old dyke swarms range from 585.6 ± 27.2 to 562.8 ± 21.4 Ma, yielding a mean of 574 ± 23 Ma) appear to overlap with the intrusion of the younger granites (609-568 Ma, a mean of 588 Ma) (Abdel-Karim and Arva-Sos, in press). Therefore, in the field the old dykes cut the basement rock-units except the younger granites. The age of the old dykes (*i.e.* 586-563 Ma) probably represents a close estimation to the age of emplacement and cooling of these dykes. However, some alteration of plagioclase to sassurite and kaolinite and clinopyroxene to actinolite and chlorite can be observed in thin section. This feature may suggest that the old dykes were subjected to a post-emplacement metamorphic event which is most probably associated with the younger granitic intrusions.

The younger dykes are represented by two analyzed samples from rhyolite and granite porphyry. They give ages ranging from 545 ± 21.3 – 536 ± 22.7 Ma and yielding a mean of 541 ± 22 Ma, which are mostly lower than the true age, probably due to the rejuvenation of biotite or the alteration of feldspar. These features accompanied by the loss of radiogenic Ar, or K-enrichment or both. In thin section biotite can be seen to have been altered to chlorite and iron oxides; in addition, alteration of the feldspar to kaolinite has occurred in these felsic dykes. Dykes of this swarms cut all the basement rock-units, but only the phase-II (not phase-III) younger granites.

Late basalt dykes (516.8 ± 19.5 – 501 ± 19, a mean of 509 ± 19.3 Ma) are commonly observed to crosscut the former minor and large suites. Consequently, there are two

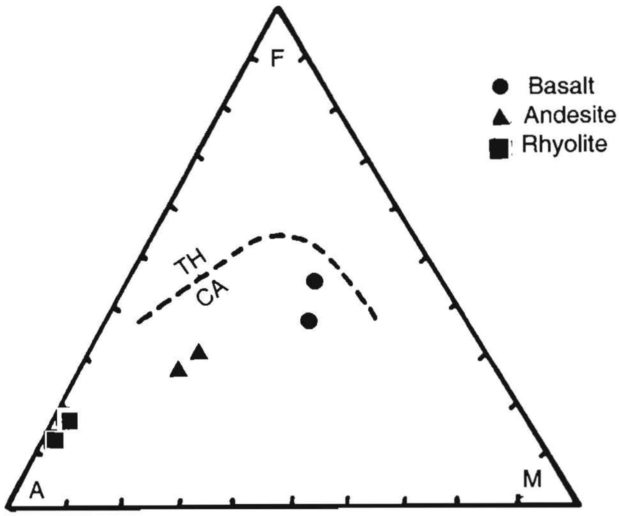

Fig. 4. AFM diagram for the studied dyke swarms.

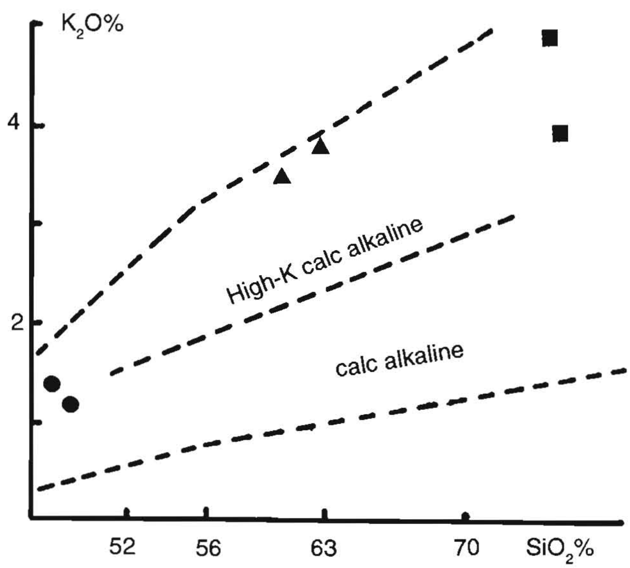

Fig. 5. K_2O-SiO_2 diagram (after Peccerillo and Taylor 1976) for the studied dyke swarms.

main phases of basalt dykes, the first (Late Precambrian) dykes associate with the mafic dyke swarms and the second (Cambrian-Ordivician) dykes represent the late basalt present in the studied area.

The ages of the present dyke swarms (586-502 Ma) are consistent with that given by Stern and Hedge (1985) for the mafic and felsic dyke swarms (589-543 Ma) from the Northern Eastern Desert and by Bielski (1982) for the Rutig andesites (587 Ma) from the southwestern Sinai.

Conclusions

The present work has revealed that the dyke swarms in southwestern Sinai may be divided into an older (mafic) and younger (felsic) dyke suites.The old dykes consist of basalts and andesites, together with minor lamprophyres and plagiophyres, the trends of which are almost parallel to the Gulf ofAqaba. The young dykes range from dacites to rhyolites, trending parallel to the Gulf of Suez.

Based on the age dating and cross-cutting relationships, the old dyke swarms were intruded at 586-563 Ma with a mean of 574 Ma. They are distinguishable from 586-577 Ma basalts with a mean of 581 Ma and 577-563 Ma andesites with a mean of 567 Ma. They can not be distinguished in terms of age from younger granites in the same area. Therefore, the intrusion of both old dyke swarms and younger granites are chronologically contemporaneous. The age of the old dykes (*i.e.* 586-563 Ma) most probably represents the age of their emplacement and cooling.

The young dykes (545-536 Ma, a mean of 540.5 Ma) are believed to be having age contemporaneous with or sligthly lower than the younger granites, and can be situated between phase-II and phase-III on the basis of the field observation. Both these basement rocks and dyke swarms of the studied area are crosscut by a 517-502 Ma age late basalt dykes.

The lower ages of the young dykes are mostly represented by the minimal age values of these rocks due to the loss of Ar and/or k enrichment, probably attributed to the effect of deformation and/or alteration processes.

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يختص البحث بتقدير العمر المطلق لمجموعات الجدد بجنوب غرب سيناء بمصر لما لها من أهمية في فهم أحداث عصر ماقبل الكامبري المتأخر بالدرع العربي الأفريقي . وقد تم تقدير عمر تلك الجدد بناء على المشاهدات الحقلية لمعرفة العمر النسبي لها وكذلك الدراسة المعملية باستخدام طريقة البوتاسيوم أرجون لتحديد العمر المطلق لها . وقد أثبتت الدراسة أن مجموعة الجدد تتكون من مجموعتان أساسيتان أقدم وأخرى ثانوية أحدث .

المجموعة الأولى وتمثل الجدد القاعدية القديمة والتي تتكون أساسًا من البازلت والانديزيت وبعض اللامبروفير والبلاجيوفير وتلك المجموعة يترواح عمرها المطلق مابين ٥٨٦ و٥٦٣ مليون سنة بمتوسط عمر ٥٧٤ مليون سنة ويمكن التمييز ما بين جدد تلك المجموعة بجدد البازلت الأقدم والتي يتراوح عمرها مابين ٥٨٦ و٥٧٧ مليون سنة بمتوسط عمر ٥٨١ مليون سنة وجدد الانديزيت الأحدث والتي يتراوح عمرها مابين ٥٧٠ و٥٦٣ مليون سنة بمتوسط عمر ٥٦٧ مليون سنة وقد وجد أن جدد تلك المجموعة قاطعة لكل صخور القاعدة ماعدا صخور الجرانيت الحديث .

المجموعة الثانية وتمثل الجدد الفلسية الحديثة والتي تتكون من الداسيت والرايوليت والكوارتز البورفيري ويتراوح عمره ما بين ٥٣٦ و٥٤٥ مليون سنة وتلك المجموعة وجد انها قاطعة لكل وحدات صخور القاعدة ماعدا الطور الثالث من الجرانيت الحديث والمجموعة الثالثة من الجدد والقاطعة لكل صخور القاعدة والصخور الرسوبية التي تعلوها ووجد أن عمرها المطلق ٥٠٢ و٥١٧ مليون سنة وتلك الأعمار تمثل الحد الأدنى لعمر الجدد القديمة والحديثة وذلك احتمالاً لفقد عنصري البوتاسيوم والأرجون أو اياً منهما نتيجة لتأثير العمليات اللاحقة على تلك الجدد .