Rb/Sr Geochronology of Some Gneisses and Felsic Intrusions from Afif-Halaban-Ad-Dawādimī-Ar-Rayn Areas, Saudi Arabia

A.A. ABDEL-MONEM*, A.M.S. AL-SHANTI, A.A. RADAIN
Faculty of Earth Sciences,
King Abdulaziz University,
Jeddah, Saudi Arabia.

ABSTRACT. The earliest recognized older basement rock unit in the eastern region of the Arabian Shield is the Ajal group. It comprises interbedded amphibolite, biotite-schist and para-gneiss. A high grade amphibolite south-southwest of Halaban village gave a Rb/Sr age of $845 \pm 19$ Ma. It is the oldest Rb/Sr age reported from the area, so far. It is interpreted as the age of metamorphism during the Early Najd Cycle. It preceded the Hulayfah group deposition.

The west Al-Quway'iyah (Ad-Dawādimī Province) and Jabal Al-Humayy (Afif Province), are foliated large semicircular granodiorite-granitic complexes. They form negative geomorphologic features surrounded by high circular ridges of slightly metamorphosed Hulayfah and Murdama group rocks. The Rb/Sr ages obtained for Al-Quway'iyah and Jabal Al-Humayy granodiorite-granitic complexes are $725 \pm 10$ Ma and $675 \pm 30$ Ma, respectively. These ages are interpreted as post-Hulayfah as well as post-Abt Formation tectonism (Tuluhah orogeny).

The east Jabal Bitran gneiss belt (Ar-Rayn Province) extends in N-S trend for a distance of 100 km by 40 km, and probably eastwards below the Phanerozoic cover. The gneiss is granodioritic and in places quartz-dioritic and amphibolitic. It was formerly mapped as old fundamental gneiss, but the Rb/Sr age obtained is $584 \pm 14$ Ma suggesting that the gneisses should be considered as post-Murdama. Furthermore, a small pink granite stock cutting the gneiss gave a Rb/Sr age of $492 \pm 12$ Ma, indicating that the tectono-thermal event at 510 Ma recognized in the western parts of the Arabian Shield had also affected this area.

*Present address: Nuclear Materials Authority, P.O. Box 530, Maadi, Cairo, Egypt.
Introduction

The eastern region of the Arabian Shield has been divided into three crustal blocks (Fig. 1), namely from west to east, Alif, Ad-Dawadimi and Ar-Rayn blocks (Defour 1980). These crustal blocks are characterized by tectonic boundaries, the most significant of which is the boundary between the Ad-Dawadimi and Ar-Rayn blocks, which is occupied by Al-Amur-Ihsan fault zone. This zone comprises rocks of orogenic, andesitic and associated lithologies and has been interpreted as a strike-slip zone due to arc-arc collision (Brown and Coleman 1972) or arc-continent collision (Al-Shanti and Mitchell 1976, Naweib 1979, and Schmidt et al. 1979). The boundaries between the other two blocks are represented by large left-lateral strike-slip faults.

Fig. 1. Simplified geological map of a part of the Alif-Halabian-Ad-Dawadimi-Ar-Rayn regions showing sample localities (locality numbers 1-6 from Table 1). locality 7 shows trondhjemite with approximately 2000 Ma inherited zircons (Caban et al. 1983).
In the Ad-Dawādmi block an older basement of unknown age, probably Middle Proterozoic or older, has been designated around Halaban village (Delfour 1979). These rocks are mostly granites of homogeneous composition, strongly sheared, and in places transformed into biotite gneiss. The granite masses are surrounded by Abi Formation and, in places, by ophiolite complexes. Also, Kahr et al. (1972) have mapped large areas covered by gneisses of granodioritic composition as older basement, to the east of Jabal Bizran, Ar-Rayn block. The question of the presence of older Precambrian crust either exposed or underlying the Arabian Shield is important to the petrogenesis and evolution of the Shield.

In this paper, we are presenting new Rb/Sr ages from the above mentioned old gneiss locations in order to know the presence or absence of exposed older Precambrian material in this part of the Arabian Shield. Also, we are presenting Rb/Sr ages of other rock units representing different stages of the geologic evolution in these areas of the shield. The data will be used to discuss the various models proposed for the evolution of the eastern region of the Arabian Shield.

Figure 1, shows the locations of the collected samples. The Rb and Sr concentrations were determined on pressed powder pellets by XRF-spectrometry (Pankhurst and O’Nions 1973). The Sr isotopic compositions were measured using VG-isomass 54E mass spectrometer on separated unspiked Sr by standard ion-exchange methods. The analyses of NBS-987 Sr-standard yielded a mean value of 0.71023 ± 0.00004 (2σ). The measuring errors of Rb/Sr ratios are estimated to be ± 2% (2σ) and that for 87Sr/86Sr ratio is less than ± 0.00020 (2σ).

Syntectonic Gneisses

Ajal Gneiss

This is represented by a belt of amphibolite and gneisses which extends from the village of Halaban southwest. The belt is 25 km long and its width is 3-1 km. The rocks are essentially composed of alternating fine amphibolite and coarse grained plagioclase-hornblende-biotite gneiss and are tightly folded and migmatized in places. The rock group is later cut by folded biotite granites and veins of aplite granite and migmatite (Delfour 1979).

An outcrop about 3 km south-southwest of Halaban village was sampled. A five-point isochron produced a Rb/Sr age of 845 ± 19 Ma and an initial 87Sr/86Sr ratio of 0.70293 ± 4. The MSWD value for this isochron is 2.16 (Table 1 and Fig. 2). This is the oldest Rb/Sr age reported from the eastern region of the Arabian Shield. Delfour (1979) assigned the Ajal group to the Middle Arar tectonic cycle with an inferred age of ~ 1000 Ma or older. Our reported Rb/Sr age (845 Ma) assigns this Ajal group to the early Nubian Cycle. However, thermal overprints and remobilizations during younger of later tectonic cycles cannot be ruled out which might have affected the Rb/Sr systems. Also, this age indicates that the early episode (900-800 Ma) of the Shield building processes characterized by widespread emplacements of tonalite-trondhjemites was accompanied by regional metamorphism and tectonism. It is also suggested that the Rb/Sr age is in broad agreement with the field observations.
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Gneisses East of Jabal Bitran

These rocks are hornblende-biotite gneisses that comprise a N-S trending belt which extends over an area of 100 km long and 40 km wide along the eastern edge of Jabal Bitran Quadrangle (Kahr et al. 1972). The gneisses are granodioritic in composition but quartz-dioritic in places. Amphibolite fine-to-coarse-grained facies are also present. The gneisses are well banded with alternating leucocratic and dark bands. The leucocratic bands are granodioritic, tonalitic and trondhjemitic, whereas the dark bands are amphibolitic. The gneisses are folded with the dark amphibolitic bands showing flow structures. They have been mapped as older basement complex to the Al-Amar group (Kahr et al. 1972, and Nowab 1979). Also, they have been recognized as syngentic intrusives which cut the Al-Amar group, (Eijkjelboem et al. 1969, 1971, and Couttsam and et al. 1981). They occur either as cores of gneiss domes (Nebert 1979) or as large batholithic complexes as in east Jabal Bitran area.

A five-point whole rock Rb/Sr isochron for the gneisses (Table 1, Fig. 3) produced an age of 584 ± 14 Ma and an initial 87Sr/86Sr ratio of 0.70224 ± 7. The MSWD value for this isochron is 2.00 reflecting the scatter of points around the isochron. This Rb/Sr age is much younger than the geologic assignment suggested by Kahr et al. (1972) for this rock unit. Jabal Bitran post-tectonic granite has been dated by Radain et al. (1984) at 584 ± 3 Ma which is the same age as the gneisses. However, the extra field relationship between the granite and the gneisses is obscured under a cover of Quaternary deposits. The geologic interpretation that these gneisses form the old
basement in the area could be in error. The Rb/Sr age assignment of the gneisses suggests that it must have been metamorphosed syntectonically during the emplacement of Jabal Britran granite, thus representing a gneissic mélange around the granite. Also, the age indicates that the Rb/Sr system became closed during this episode.

![Diagram](image)

**Fig. 3.** Rb-Sr isochron diagram for East Britran gneisses. The weighing model III (line fitted with reciprocals of squares of residuals for weights) of York (1969) is used for age calculations.

**Syn- or Late-Tectonic Granites**

These are represented all over the Arabian Shield by large semicircular plutons, sometimes reaching batholithic sizes. They are exposed as low or negative relief areas surrounded by higher ridges of volcano-sedimentary sequences. In the studied region, two such granitic plutons were sampled for Rb/Sr dating: Jabal Al-Hamayy (Afif block) and West Al-Qawwiyah granite (Ad-Dawadimi block).

Jabal Al-Hamayy is a large semicircular pluton, its half is exposed at the eastern edge of Afif Quadrangle and the second half is exposed at the western edge of Ad-Dawadimi Quadrangle. The granite pluton is a complex comprising quartz-diorite, biotite-granodiorite, foliated biotite-anorthosite-granodiorite with pinkish K-feldspar and coarse grained biotite granite with some xenoliths. A five-point whole rock isochron for this granite (Table 1, Fig. 4) produced an age of 676 ± 30 Ma and an initial 87Sr/86Sr ratio of 0.70392 ± 0.00002. The MSWD value for this isochron is 1.43 reflecting the scatter of points around the isochron line. This Rb/Sr age is not in agreement with the geologic assignment suggested by Letalijic (1979). He interprets the granite as cutting the Murdama group, hence, younger than 680 Ma age. Our Rb/Sr age suggests that Al-Hamayy granite predates the Murdama group.
The west Al-Qaywayyah granitic pluton (Ad-Dawdïmi) is a semi-circular pluton about 10 km in diameter. It is medium to coarse grained granodiorite-granite complex, and foliated near the border contact areas with the surrounding volcano-sedimentary sequences. The pluton was sampled along a profile running in a N-S direction. A nine-point whole rock Rb/Sr isochron (Table 1, Fig. 5) produced an age of 723 ± 10 Ma and an initial 87Sr/86Sr ratio of 0.70797 ± 0.00022. The Rb/Sr age predates the Huayfah group and predates the Mudamina one. It is suggested that these low relief granite plutons were probably emplaced in the cores of large anticlinal structures and were subsequently exposed by deep weathering of the overlying rocks.

Post Orogenic Granites

These are represented by smaller size plutons, and are widely spread in the Arabian Shield. They are circular to oval shaped and mostly emplaced as diapirs intrusions associated with contact metamorphic aureoles. They are fine to medium grained granite complexes ranging from per to metaluminous and from calc-alkaline to peraluminous in composition. In the studied areas, two such small pink granite bodies with well defined intrusive relationships were examined and dated.

A small body at the extreme south end of the Ar-Rukhumah domain and about 5 km north of Halaban village was sampled. It is essentially a biotite granite, fine to medium grained, mostly porphyritic with large K-feldspar phenocrysts in a groundmass of finer crystals of sometimes zoned oligoclase, biotite and occasional
WEST AL-QUWAYYIH GRANITE

$\frac{Rb}{Sr} \times 10$

$T = 723 \pm 10 \text{ Ma}$

MSWD $= 1.00$

MODEL II

Fig. 5. Rb-Sr isochron diagram for West Al-Quwayyih granite. The weighting model III (line labeled with red cross of squares of residuals for weights) of York (1980) is used for age calculations.

muscovite. A five-point whole rock Rb/Sr isochron produced an age of $510 \pm 8 \text{ Ma}$ and an initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of $0.70466 \pm 0.00008$. (Table 1, Fig. 6). The MSWD value for this isochron is 1.99 reflecting some scatter of the points around the isochron. Also, the initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio is higher than usual, if compared with the initial ratios obtained for the other rock units cited above which usually range between (0.702; 0.703). This suggests that such magmas were generated by partial melting within more mature or thickened crust in the area.

The gneissic terrain east of Jabal BIran (Ar-Rayn block) is intruded by a circular pink granite stock which is accompanied by a small diorite arcuate sill along its southwestern edge. The intrusive contact of the granite includes some gneissic xenoliths. Also, parts of the contacts between the granite and the gneisses are characterized by the presence of thin aureoles of hornfels. A five-point whole rock Rb/Sr isochron for this pink granite produced an age of $492 \pm 12 \text{ Ma}$ and an initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of $0.70377 \pm 0.00008$ (Table 1, Fig. 7). The MSWD value for this isochron is 2.95 reflecting a significant scatter of the points around the isochron line.

The two Rb/Sr ages cited above are consistent with the field relationships between the pink granites and the surrounding gneissic terrains. Although such ages were not observed before in the eastern region of the shield, yet similar ages have been reported from the western region. (Kemp et al. 1980). Also, the higher initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratios (0.704) are consistent with the suggestion that the post-orogenic granites were generated and emplaced within stable cratonized crust.
Fig. 6. Rb-Sr isochron diagram for North Halaban granite. The weighting-model III (line fitted with reciprocals of squares of residuals for weights) of York (1969) is used for age calculations.

Fig. 7. Rb-Sr isochron diagram for East Bitran granite. The weighting model III (line fitted with reciprocals of square of residuals for weights) of York (1969) is used for age calculations.
Discussion

The main objective of this study is to investigate the ages of some rock units in the eastern region of the Arabian Shield which were mapped as old basement probably as Early or Mid-Proterozoic as well as the ages of some other rock units relevant to the geologic evolution of the region.

The age obtained in this study for the Ajal gneiss (845 Ma), is the oldest Rh/Sr age reported in the eastern region so far. It is similar to the ages reported for plagio- greites, trondhjemites, and tonalite batholithic size intrusions encountered in various parts of the Arabian Shield (Calvez et al. 1983, Fleck et al. 1980, and Kemp et al. 1981). These ages have been assigned to a tectonic cycle, designated as the island-arc stage (Stoeser 1986) is the longest in the geologic history of the Shield (between ~900-775 Ma with a peak at 825 Ma). The metamorphism of the gneissic rocks examined probably took place syntectonically during this tectonic cycle. The rock types developed during this stage dominantly showed acetic character or were direct addition from the mantle. The low initial 87Sr/86Sr ratios may be taken as an evidence. However, the presence of gneissic rocks, which is a mixture of ortho- and para-gneissoes where regionally metamorphosed during this tectonic cycle, could also be taken as an evidence for the presence of older crustal material. Isotopic evidence for the presence of older crustal material as well as the involvement of such material in the evolution of the Arabian-Nubian Shield was presented by many workers. (Abdel-Moaty and Hurley 1979, Harris et al. 1984, Stacey and Hedge 1984, Stacey and Stoeser 1984). The presence of ~2000 Ma zircons (Calvez et al. 1983, Fig. 1, Locality 7) in a younger trondhjemite associated with the Al-Amar fault and U-Pb zircon upper intercept age of 1628 ± 200 Ma from Jabal Khida granodiorite (Stacey and Hedge 1984, Thirum 1988, Stoeser and Stacey 1988) also supports the presence of an older age basement in the eastern region of the Shield.

The island-arc stage was ended by suturing into collision between the series of island-arcs present at that time. Stoeser and Carpenter (1985) suggested at least 5 such arcs. The isotopic age for the collision or suturing event was presented by Caiazzo et al. (1984), who reported (Sm-Nd) model ages of 743 ± 24 Ma and 752 ± 38 Ma for Jabal Al-Wank and Jabal El-Salih ophiolite, respectively. They also suggested that these formation ages provide maximum limits of possible subduction. The syntectonic plutonites occurring throughout the Arabian Shield have ages ranging between 740 and 610 Ma. They are peraluminous, calc-alkaline and highly depleited in (LIL)-elements, which are the characteristics of subduction related granite magmas. It is suggested here that the syntectonic plutonic rocks such as Jabal Al-Hamry (676 Ma) and West Al-Qasray'ah pluton (723 Ma) were emplaced during the suturing or orogenization stage.

The post-orogenic granite plutons were emplaced during the final stage of stabilization of the crust, where the suturing and collision lead to thickening and supercrustal material reached depths of partial melting. During the period 600-500 Ma, numerous granite plutons, such as red granite north of Halaben, (510 Ma) and the granite stock cutting the east of Jabal Bitrani gneisses, were emplaced. They range
from peraluminous to metaluminous, from calc-alkaline to peralkaline, and slightly to highly enriched in (LIL) elements.

The slight increase in the initial $^{143}$Sm/$^{147}$Sm ratio from 0.702 to 0.704 observed in the post-orogenic granites is consistent with the evolutionary model of plutonism in the Shield suggested above (Stoos 1986). However, the consistent low $^{143}$Sm/$^{147}$Sm ratios observed in the Arabian Shield lead some investigators to believe that the Shield developed solely within ensimatic environment and considered all plutonic rocks to be fresh additions from the mantle. Dyreyman et al. (1982) based on Nd-isotopic data suggested that most of the magmas were derived from upper mantle sources and any inferred crustal sources for other magmas could not be older than 1200 Ma indicating the rapid accretion in the Arabian Shield. However, evidence has been presented above for the presence of older basement underrath the Shield and its possible involvement in its development. Also, it is now realized that low $^{143}$Sm/$^{147}$Sm ratios are not unique indicators for direct derivation from the mantle (Peterman 1979, Moorbath and Taylor 1981). They do indicate either upper mantle sources or lower crustal material with low $^{143}$Sm/$^{147}$Sm ratios and a short time residence in the crust. We suggest that remobilization and material cycling played some role in the evolution of the Shield.

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References


السياق الجيولوجي بارزة وبارزة يبرز في هذه المقالة، حيث يشتمل على عدة عناصر رئيسية:

- محاور الأيض السوط في البحار الحمراء.
- التغيرات المناخية التي تؤثر على الإDidChangeات الجيولوجية.
- التغيرات في سطح البحر.

ويستعرض المقال أحداثًا جيولوجية مهمة، بما في ذلك:

- تغيرات في سطح البحر خلال العصور الجليدية.
- التغيرات في المناخ على مر العصور.
- التغيرات في سطح البحر خلال العصور الجليدية.

ويتناول المقال أيضًا أوجه أخرى تتعلق ببارزة وبارزة، بما في ذلك:

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