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

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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 ± 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 ± 10 Ma and 675 ± 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 ± 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 ± 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.

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Introduction

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

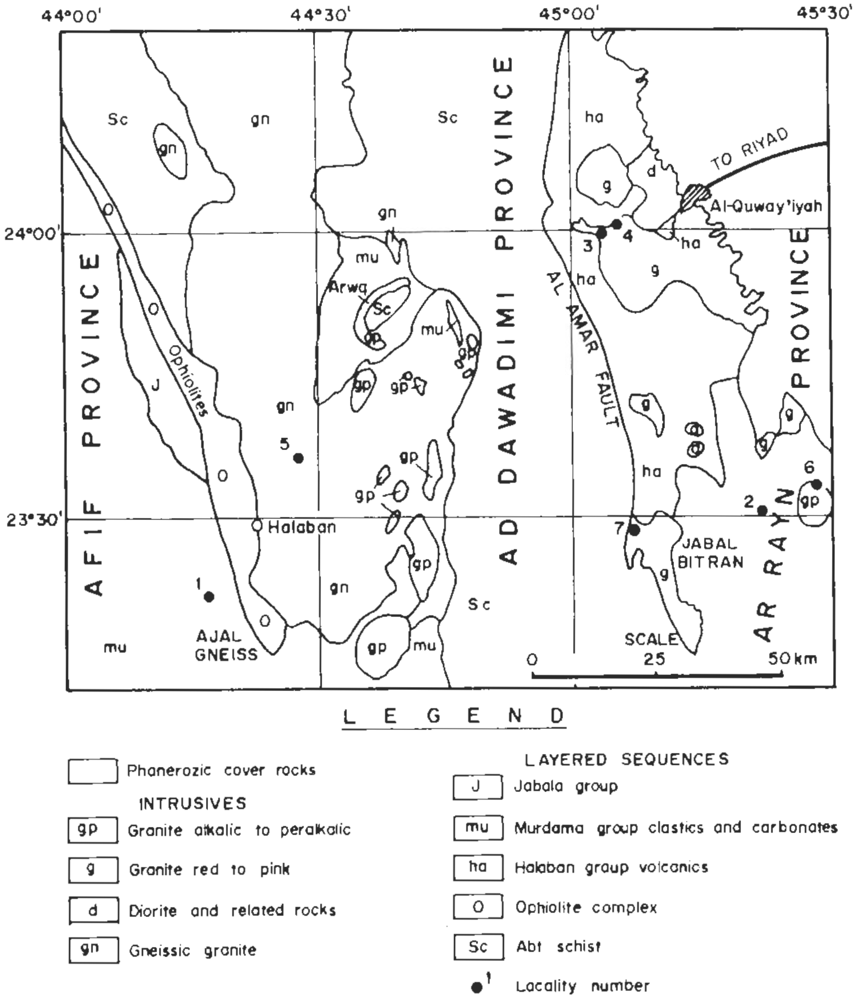

FIG. 1. Simplified geological map of a part of the Afif-Halaban-Ad-Dawādimī-Ar-Rayn regions showing sample localities (locality numbers 1-6 from Table 1). Locality 7 shows trondhjemite with approximately 2000 Ma inherited zircons (Calvez *et al.* 1983).

In the Ad-Dawādimī 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 Abt 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 Bitran, 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 $\pm 2\%$ (2σ) and that for $^{87}Sr/^{86}Sr$ 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 southwards. The belt is 25 km long and its width is 3-1 km. The rocks are essentially composed of alternating fine amphibolite and coarser grained plagioclase-hornblende-biotite gneiss and are tightly folded and migmatized in places. The rock group is later cut by foliated 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 $^{87}Sr/^{86}Sr$ ratio of 0.70293 ± 4. The MSWD value for this isochron is 2.18 (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 Asir 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 Najd 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.

TABLE 1. Rb/Sr data, Halaban-Afif area.

Sample No.	Rb ppm	Sr ppm	$^{87}Rb/^{86}Sr \pm 2\sigma$	$^{87}Sr/^{86}Sr \pm 2\sigma$
1. Ajal Gneiss, SW Halaban				
T-151D	38.2	2466	0.0448 ± .0004	.703748 ± .104
T-152	40.6	596	0.1973 ± .002	.705300 ± .060
T-153	26.7	4576	0.0168 ± .0002	.703142 ± .058
T-154	32.7	3345	0.0281 ± .0003	.703229 ± .084
T-157	38.7	572	0.1961 ± .002	.705313 ± .034
2. Geneiss East of Jabal Bitran				
T-159	20.7	213	0.2817 ± .0028	.704380 ± .132
T-160	15.3	215	0.2051 ± .0021	.703949 ± .038
T-164	29.0	174	0.4840 ± .0048	.706270 ± .050
T-165	75.0	425	0.5112 ± .0051	.706800 ± .084
T-167	39.7	243	0.4735 ± .0047	.705787 ± .078
3. Jabal Al Humayy Granite				
T-223	83.7	1628	0.1487 ± .0015	.704759 ± .106
T-225	101	1072	0.2734 ± .0027	.706554 ± .044
T-227	85.4	1467	0.1684 ± .0017	.705541 ± .048
T-230	110	2023	0.1565 ± .0016	.707009 ± .170
T-231	109	2128	0.1472 ± .0015	.703597 ± .176
4. Granite pluton W. of Al-Quway'iyah				
T-210	52.9	453	0.3379 ± .0034	.706368 ± .034
T-212	36.0	676	0.1539 ± .0015	.704588 ± .030
T-213	43.0	655	0.1900 ± .0019	.704832 ± .104
T-214	32.9	702	0.1354 ± .0014	.704364 ± .114
T-216	52.9	466	0.3284 ± .0033	.706407 ± .074
T-217	51.0	464	0.3179 ± .0032	.706261 ± .036
T-218	47.8	499	0.2771 ± .0028	.705833 ± .092
T-219	54.2	462	0.3393 ± .0034	.706462 ± .148
T-220	45.7	617	0.2141 ± .0028	.705174 ± .166
5. N. Halaban red Granite				
T-117	183	97.5	5.444 ± .054	.743591 ± .004
T-119	191	97.5	5.688 ± .057	.745774 ± .056
T-120	179	90.7	5.731 ± .057	.746812 ± .186
T-121	188	142.0	3.853 ± .086	.733602 ± .142
T-122	202	93.0	6.320 ± .063	.750648 ± .102
T-125	193	173.0	3.242 ± .032	.728252 ± .214
6. Pink-granite intruding Gneiss east of Jabal Bitran				
T-168	87.5	248	1.0196 ± .0102	.710872 ± .042
T-169	87.7	280	0.9067 ± .0091	.710211 ± .096
T-170	97.6	295	0.9588 ± .0096	.710648 ± .066
T-171	80.1	332	0.6982 ± .0070	.708163 ± .110
T-172	75.7	549	0.3990 ± .004	.706590 ± .188
T-173	61.9	611	0.2933 ± .0029	.705823 ± .084
T-176	35.3	547	0.1871 ± .0019	.704621 ± .116

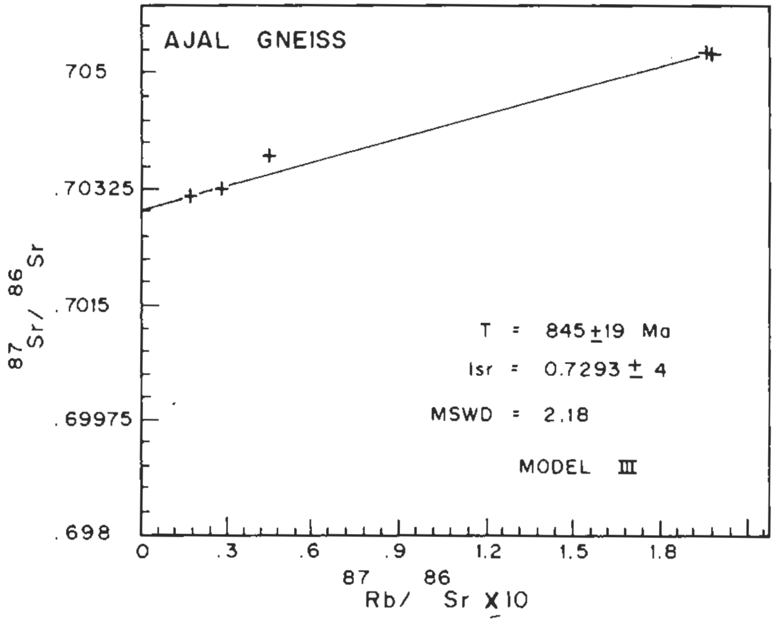

FIG. 2. Rb-Sr isochron diagram for Ajal gneisses. The weighing model III (line fitted with reciprocals of squares of residuals for weights) of York (1969) is used for age calculations.

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. Amphibolitic fine-to-coarse-grained facies are also present. The gneisses are well banded with alternating leucocratic and dark bands. The leucocratic bands aer 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 Nawab 1979). Also, they have been recognized as syntectonic intrusives which cut the Al-Amar group, (Eijkelboom *et al.* 1969, 1971, and Couloumb *et al.* 1981). They occur either as cores of gneiss domes (Nebert 1970) 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 $^{87}Sr/^{86}Sr$ 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 exact 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 mantle around the granite. Also, the age indicates that the Rb/Sr system became closed during this episode.

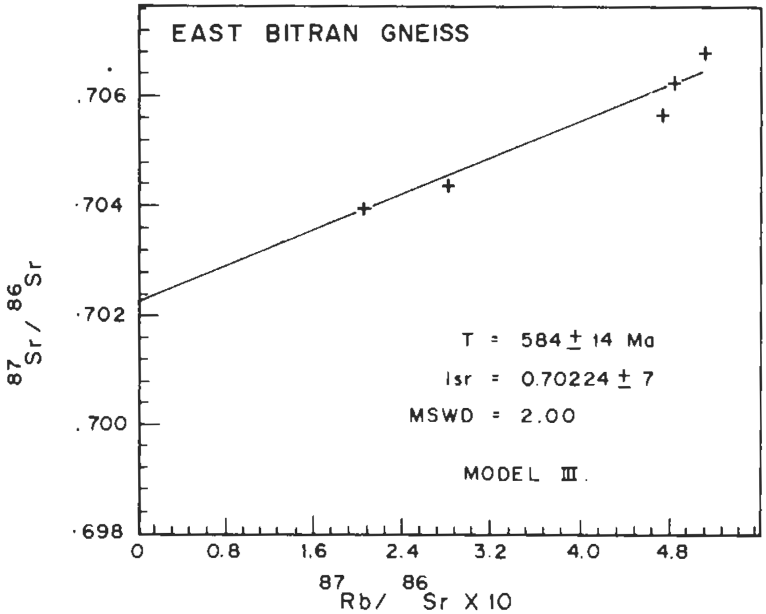

FIG. 3. Rb-Sr isochron diagram for East Bitran gneisses. The weighing model III (line fitted with reciprocals of squares of residuals for weights) of York (1969) is used for age calculations.

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-Humayy (Afif block) and West Al-Quway'iyah granite (Ad-Dawādimī block).

Jabal Al-Humayy 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-Dawādimī Quadrangle. The granitic pluton is a complex comprising quartz-diorite, biotite-granodiorite, foliated biotite-amphibole-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 $^{87}Sr/^{86}Sr$ ratio of 0.70392 ± 10. 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 Letalcnet (1979). He interprets the granite as cutting the Murdama group, hence, younger than 600 Ma age. Our Rb/Sr age suggests that Al-Humayy granite predates the Murdama group.

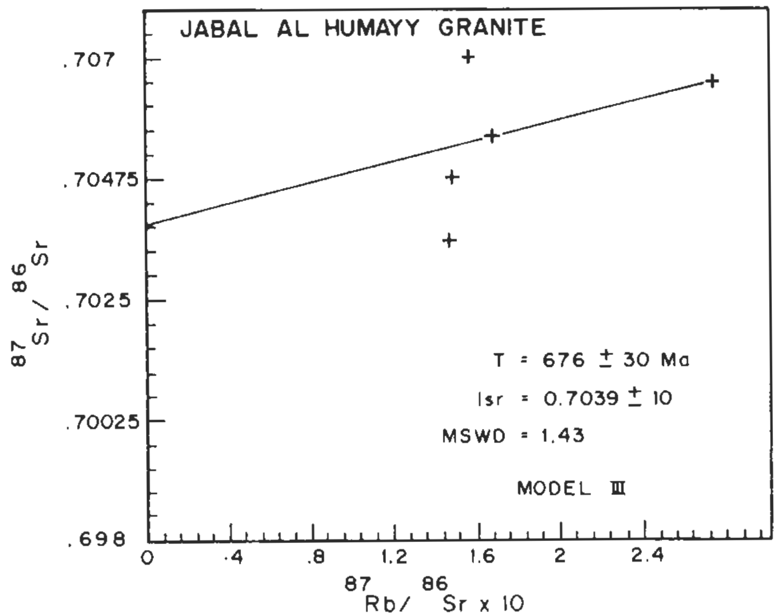

FIG. 4. Rb-Sr isochron diagram for Jabal Al- Humayy granite. The weighing model III (line fitted with reciprocals of squares of residuals for weights) of York (1969) is used for age calculations.

The west Al-Quway'iyah granitic pluton (Ad-Dawādimī) is a semi-circular pluton about 10 km in diameter. It is medium to coarse grained granodiorite-granite complex, and foliated near the boarder 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 $^{87}Sr/^{86}Sr$ ratio of 0.70297 ± 4. The Rb/Sr age postdates the Hulayfah group and predates the Murdama 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 diapiric intrusions associated with contact metamorphic aureols. They are fine to medium grained granitic complexes ranging from per to metaluminous and from calc-alkaline to peralkaline in composition. In the studied areas, two such small pink granitic bodies with well defined intrusive relationships were examined and dated.

A small body at the extreme south end of the Ar-Rukhamah 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

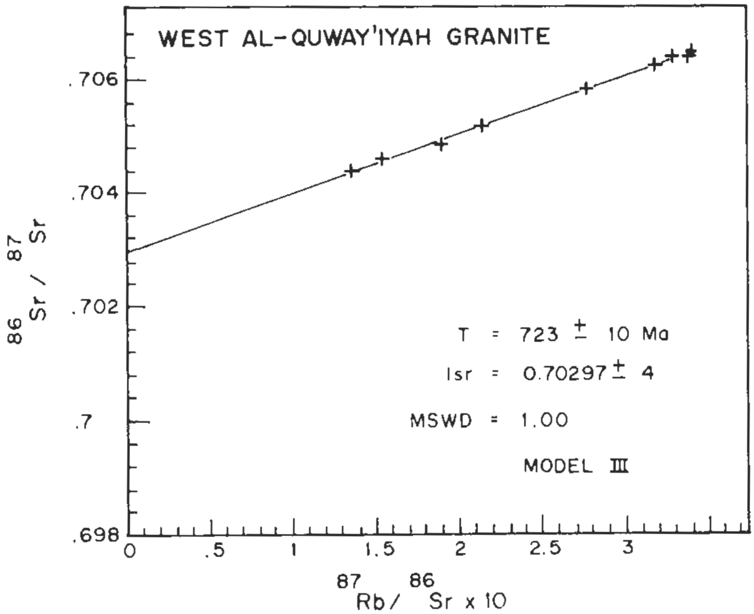

FIG. 5. Rb-Sr isochron diagram for West Al-Quway'iyah granite. The weighing model III (line fitted with reciprocals of squares of residuals for weights) of York (1969) is used for age calculations.

muscovite. A five-point whole rock Rb/Sr isochron produced an age of 510 ± 8 Ma and an initial $^{87}Sr/^{86}Sr$ ratio of 0.70466 ± 8. (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 $^{87}Sr/^{86}Sr$ ratio is higher than usual, if compared with the initial ratios obtained for the older 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 Bitran (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 ± 12 Ma and an initial $^{87}Sr/^{86}Sr$ ratio of 0.70377 ± 8 (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 $^{87}Sr/^{86}Sr$ *ratios* (0.704) are consistent with the suggestion that the post-orogenic granites were generated and emplaced within stable cratonized crust.

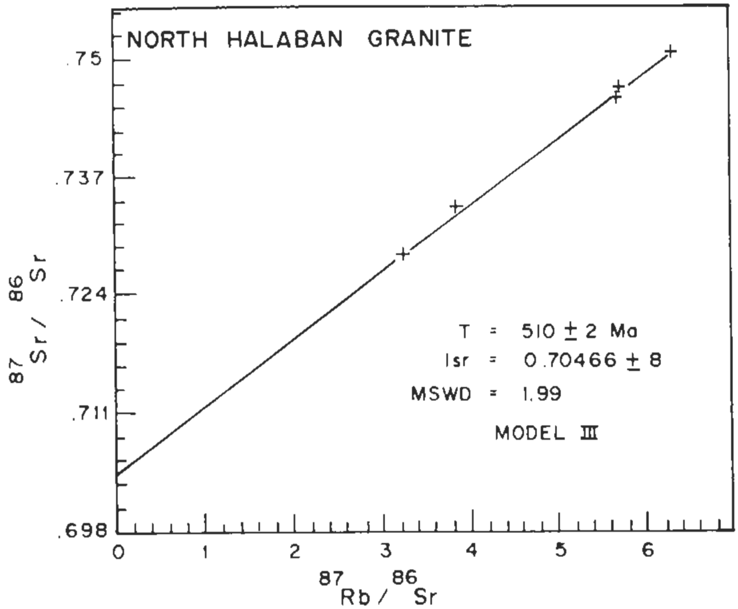

FIG. 6. Rb-Sr isochron diagram for North Halaban granite. The weighing model III (line fitted with reciprocals of squares of residuals for weights) of York (1969) is used for age calculations.

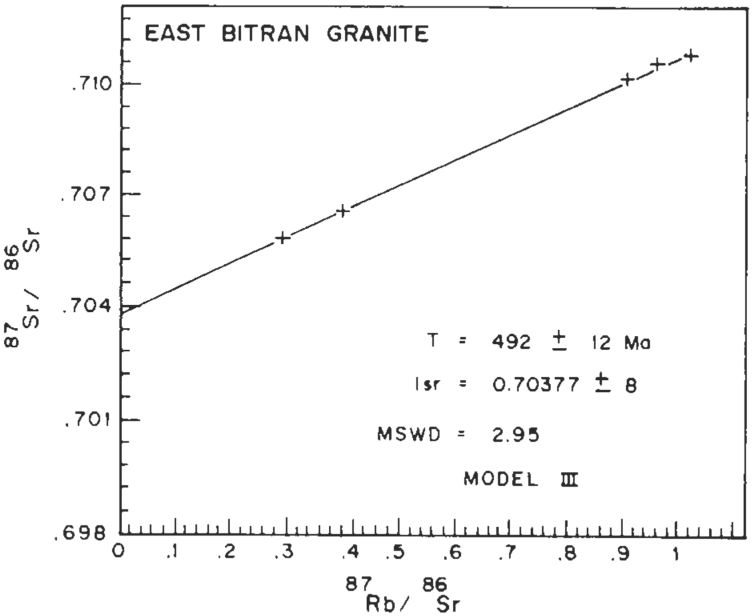

FIG. 7. Rb-Sr isochron diagram for East Bitran granite. The weighing model III (line fitted with reciprocals of square of residuals for weights) of York (1969) is used for age calculations.

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 Rb/Sr age reported in the eastern region so far. It is similar to the ages reported for plagiogranites, 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.* 1980). 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 oceanic character or were direct addition from the mantle. The low initial $^{87}Sr/^{86}Sr$ ratios may be taken as an evidence. However, the presence of gneissic rocks, which is a mixture of ortho- and para-gneisses 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-Monem 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, Thieme 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 and collision between the series of island-arcs present at that time. Stoeser and Camp (1985) suggested at least 5 such arcs. The isotopic age for the collision or suturing event was presented by Claesso *et al.* (1984), who reported (Sm-Nd) model ages of 743 ± 24 Ma and 782 ± 38 Ma for Jabal Al-Wask and Jabal Ess 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 760 and 610 Ma. They are peraluminous, calc-alkaline and highly depleted in (LIL)-elements, which are the characteristics of subduction related granitic magmas. It is suggested here that the syntectonic granitic plutons such as Jabal Al-Humayy (676 Ma) and West Al-Quway'iyah pluton (723 Ma) were emplaced during the suturing or cratonization stage.

The post-orogenic granitic plutons were emplaced during the final stage of stabilization of the crust, where the suturing and collision lead to thickening and supracrustal material reached depths of partial melting. During the period 600-500 Ma, numerous granitic plutons, such as red-granite north of Halaban, (510 Ma) and the granitic stock cutting the east of Jabal Bitran 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 $^{87}Sr/^{86}Sr$ 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 (Stoeser 1986). However, the consistent low $^{87}Sr/^{86}Sr$ 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. Duyverman *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 underneath the Shield and its possible involvement in its development. Also, it is now realized that low $^{87}Sr/^{86}Sr$ 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 Rb/Sr 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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التأريخ الجيولوجي بطريقة الروبيديوم-استرنشيوم لبعض صخور النَّيس والتداخلات الفِلْسِية من مناطق عفيف - حلبان - الدوادمي - الرَّيْن بالمملكة العربية السعودية

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مستخلص . تعتبر مجموعة عجال (الحجل) أقدم وحدات صخور الأساس المعروفة في المنطقة الشرقية من الدرع العربي . وتشمل طبقات متبادلة من الأمفيبولَيْت - الشِّسْت البيوتيتي والنَّيس ذي الأصل الرسوبي . ويعطي أمفيبوليت عالي التحول ، يقع جنوب غرب قرية حلبان ، عمرا بطريقة الروبيديوم - استرنشيوم مقداره ٨٤٥ ± ١٩ مليون سنة . وهو بهذا يعتبر أقدم عمر سُجِّل بهذه الطريقة من تلك الناحية حتى الآن ، ويُفسَّر بأنه عمر التحول خلال دورة نجد المبكرة والتي سبقت ترسيب مجموعة حُلَيْفَة .

أما القُوَيعية غرب (ناحية الدوادمي) وجبل الحمى (ناحية غفيف) فيشغلهما معقدات كبيرة شبه مستديرة من صخور الجرانوديوريت - جرانيت المتورق مكونة تضاريس منخفضة نسبيًا ومحاطة بأعراف عالية دائرية من صخور مجموعات حُلَيْفة ومردمة ذات رتبة تحول بسيطة . ويعطى معقدى القويعية وجبل الحمى أعمارًا بطريقة الروبيديوم - استرنشيوم مقدارها ٧٢٥ ± ١٠ مليون سنة و ٦٧٥ ± ٣٠ مليون سنة على الترتيب . تُفسَّر هذه الأعمار على أنها تلى ترسب حُلَيْفة ومتكون العبط (حركة طلوحة التجبلية) .

أما حزام النَّيس شرق جبل بطران (ناحية الرَّيْن) فيمتد في اتجاه شمال - جنوب لمسافة ١٠٠ كم بعرض ٤٠ كم مع احتمال الامتداد شرقًا تحت الغطاء الفانيري . وللنيس تركيب جرانوديوريتي ، وفي بعض المواضع يكون كوارتز - ديورَيْتي أو أمفيبولَيْتي . وقد وُضع في معظم الخرائط السابقة على أنه نَيْس الأساس القديم ، ولكن عمره بطريقة الروبيديوم - استرنشيوم والمقدر بـ ٥٨٤ ± ١٤ مليون سنة يوحى بأنه يلي مجموعة مردمة في التكوُّن . كما يوجد تداخل جرانيتي أحمر صغير يقطع النَّيْس يعطى عمرًا بنفس الطريقة مقداره ٤٩٢ ± ١٢ مليون سنة ، مبينا أن الحدث الحراري التكتوني عند ٥١٠ مليون سنة والمعروف في الأجزاء الغربية من الدرع العربي قد ترك بصماته أيضًا على هذه المنطقة .