DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Precambrian geochronology of part of northwestern Saudi Arabia

Kingdom of Saudi Arabia

by

C. E. Hedge [1/]

Open-File Report 84-381

Prepared for Ministry of Petroleum and Mineral Resources, Deputy Ministry for Mineral Resources, Jiddah, Kingdom of Saudi Arabia

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature.

1/ U.S. Geological Survey Mission
Saudi Arabia

1984

CONTENTS

ILLUSTRATIONS

PRECAMBRIAN GEOCHRONOLOGY

OF PART OF NORTHWESTERN SAUDI ARABIA

by

Carl E. Hedge [1/]

ABSTRACT

Ten plutonic rock units in northwestern Saudi Arabia were dated by U/Pb and (or) Rb/Sr methods. The oldest rocks are diorite and tonalite bodies dated at 725 and 710 Ma. Gneisses, previously interpreted to be the oldest rocks in the area, are syntectonic intrusions and high-grade metamorphic rocks formed 675 Ma. The posttectonic granites were emplaced over the period 575 to 625 Ma.

GEOLOGIC SETTING

The area of this study is along the eastern margin of the Red Sea between latitudes 26° and 28° N. Late Precambrian rocks are exposed in a 50-80 km-wide belt that is bounded on the Red Sea side by Tertiary and Quaternary sediments, and on the northeast by Paleozoic sediments and Tertiary basalts. The exposure of these basement rocks is due to uplift related to the opening of the Red Sea, which is greatest near the coast and diminishes inland.

The units which were sampled for dating occur in the Al Wajh and Al Muwaylih quadrangles. The geology of both quadrangles has recently been compiled by (F. B. Davies, 1983; Davies and Grainger, 1983) who aided in the sample selection and collection. The Precambrian rocks consist of several layered volcanic and sedimentary sequences and a variety of intrusive plutons whose various age relationships are not clear because they are not found in contact with one another or the contacts between them are tectonic. Furthermore, the results of this study show that some of the interpretations of the relative ages of these rock sequences made by Davies (1983) and Davies and Grainger (1983) are in error.

Davies (1983) interpreted a suite of high-grade and deformed metamorphic rocks, called the Usaylah group, as being the oldest rocks in the Al Wajh quadrangle, based on poorly exposed or speculative relationships with adjacent rocks. These rocks occur in antiformal structures, have been metamorphosed to mid-to-upper amphibolite grade, and probably consist of both ortho- and paragneisses. The radiometric age dates determined from this study indicate that the Usaylah group is not the oldest rock sequence in the area, but rather is a mixture of syntectonic plutonic rocks and highly metamorphosed layered rocks.

1/ U.S. Geological Survey Mission
Jiddah, Saudi Arabia

The oldest rocks in the area belong to the Zaam group (Davies, 1983; Davies and Grainger, 1983). This unit consists of mafic to intermediate flows, tuff and volcanolastic sediments interlayered with minor shallow-water sediments. In the Al Wajh quadrangle, the Zaam group is unconformably overlain by rocks of similar lithologies belonging to the Baydah group. Both the Zaam and Baydah groups are comprised of several formations, some of which occur as isolated exposures in the area. The spatial separation and the lithologic similarities of the rocks, combined with disruptions caused by later tectonic and plutonic events, has produced a certain amount of confusion as to the assignment of these rock units. For example, the Silasia formation, which contains economically important jaspilitic iron ore, was originally interpreted by Johnson and Trent (1967) as unconformably overlying metavolcanic rocks, and as such make it correlative with part of the relatively young Baydah group of Davies and Grainger (1983). Harris (1977) and Liddicoat (1977), however, interpreted the contact as being conformable, and Davies and Grainger (1983) assigned the Silasia formation to the older Zaam group, making it one of the oldest rocks in the region.

It is clear that all or parts of the older Zaam and Baydah sequences of volcanic and sedimentary were folded, metamorphosed, and deformed by one or more plutonic episodes, then deeply exposed by a major period of erosion prior to the deposition of the overlying, largely clastic Thalbah group. The plutons which are older than the Thalbah group have compositions in the range of diorite, tonalite, or granodiorite and frequently are somewhat foliated. After the deposition of the Thalbah group numerous plutons, mostly of monzogranite or alkali granite, were emplaced. These late granites were apparently emplaced over a prolonged time span because they both predate and postdate several distinct units in the Thalbah group.

ANALYTICAL PROCEDURES

Rb, Sr, and Pb concentrations were all determined by isotope dilution using ^{87}Rb, ^{235}U and ^{208}Pb as tracers. The concentrations have a precision of $\pm$1% (2 S. D.) and the isotopic compositions are precise to $\pm$0.01% for strontium and 0.1% for lead. The mass spectrometer used for the strontium determinations yielded an average ^{87}Sr/^{86}Sr for the E and A standard of 0.7080. Ages were calculated using the decay constants recommended by the International Subcommission on Geochronology (Steiger and Jager, 1977). Analytical data for U/Pb and Rb/Sr determinations are given in tables 1 and 2, respectively, and the age results are summarized in table 3.

Table 1.--U/Pb data for zircons

Sample Locality number	U ppm	Pb ppm	Atomic Ratios			Ages in Ma		
			$^{206}Pb^{238}U$	$^{207}Pb/^{235}Pb$	$^{207}Pb/^{206}Pb$	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$
1	88.0	9.45	0.10521	0.9206	0.06346	645	663	724
2	112	10.1	.08896	.7722	.06295	549	581	707
3	405	38.1	.09379	.8016	.06199	578	598	674
5	418	41.3	.09566	.8120	.06156	589	604	659
6	574	51.1	.08405	.7015	.06053	520	540	623
7	887	63.6	.06953	.5784	.06033	433	463	615
8	293	24.8	.07818	.6445	.05979	485	505	596

Table 2.--Rb/Sr data for whole-rock samples

Sample Locality number	Rb ppm	Sr ppm	Atomic Ratios $^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	T_m1/	r_i2/
1	4.4	297	0.0433	0.70272	--	0.70227
2	15.7	384	.1183	.70368	--	.70250
3	23.9	244	.2835	.70548	--	.70275
4	63.3	309	.5917	.70827	672	--
5	33.0	432	.2236	.70479	--	.70258
6	97.6	121	2.333	.72361	630	--
7	92.5	81.5	3.294	.73263	638	.70346
8	69.8	303	0.6658	.70834	598	.70265
9A	123	19.6	18.49	.86010	See figure 3	
9B	92.3	22.7	11.86	.80606	See figure 3	
9C	93.9	9.9	28.02	.93412	See figure 3	
9D	110	46.1	6.971	.76564	See figure 3	
10	113	54.8	6.001	.75142	570	--

1/ Model age calculated from $$T_m = \frac{1}{1.42\times10^{-11}} \ln \frac{1+Sr^{87}/Sr^{86}-0.7032}{^{87}Rb/^{86}Sr-0.06293}$$

Only calculated for samples having $^{87}Sr/^{86}Sr=0.708$

2/ Initial $^{87}Sr/^{86}Sr$.

Only calculated for samples having $^{87}Sr/^{86}Sr=0.710$

Table 3.--Summary of age results

Sample locality	Rock type	U/Pb age	Rb/Sr age
1	Tonalite	725±4	---
2	Diorite	710±5	---
3	Gneissic tonalite	676±4	---
4	Gneiss		672±30
5	Granodiorite	660±4	---
6	Alkali granite	625±5	630±10
7	Monzogranite	621±7	638±10
8	Monzogranite	599±5	598±30
9	Quartz syenite dikes	---	575±5?
10	Alkali granite	577±4	570±7

The preferred U/Pb ages, given in table 3, were calculated using a lower intercept of 15±15 Ma as was assumed and tested on similar rocks in Saudi Arabia by Cooper and others (1979). Also, most of the U/Pb results are nearly concordant and as such are insensitive to the time of lead loss.

Some of the late granites have relatively high Rb/Sr ratios. For these rocks, a Rb/Sr age was calculated using the range of initial independently determined $^{87}Sr/^{86}Sr$ ratios. These late granites also tended to give the more discordant U/Pb ages because of relatively high U contents of their zircons; consequently, the agreement between the U/Pb and Rb/Sr ages given in table 3 provides an independent test of our method of treating the data.

DATA DISCUSSION

The oldest age obtained in this study was 725 Ma (locality 1, fig. 1 and table 1) for a small body of diorite that intrudes the Zaam group. The Zaam group is therefore older than 725 Ma.

A slightly younger age of 710 Ma (sample 2) was obtained on a sample from a large tonalite-granodiorite body called the Duba complex by Davies and Grainger (1983). This body intrudes the Zaam group, but its relationship to the overlying Baydah group is not clear.

Sample 3 is a tonalitic, locally migmatitic gneiss from the Baladiyah complex of Davies (1983). Davies assigned this complex to the Usaylah suite which he interpreted to be the oldest rock in the area. Although the rock exhibits some development of migmatite, its generally uniform character combined with the presence of metapelitic xenoliths suggests that it is an orthogneiss. Davies (1983) states that the relative age of the Baladiyah complex is uncertain because its contacts are deformed. However, the relationships illustrated in his detailed sketch map of the complex (fig. 2; Davies, 1983) seem to require that the gneissic rocks of the complex be intrusive into the Baydah group. If this interpretation is correct then the Baydah group at this locality is older than the gneissic tonalite which was dated at 676 Ma.

Sample 4 is from the Qazaz complex (Davies 1981), which was also assigned to the Usaylah suite. The complex is exposed in an isoclinal anticline comprised of quartzofeldspathic schist and gneiss interlayed with amphibolite. The sample from the quartz-feldspathic gneiss yielded no zircons and does not have a favorable Rb/Sr ratio. Based only on the severely limited range in initial $^{87}Sr/^{86}Sr$ ratios observed in other samples, the sample probably is about the same age as the gneissic tonalite sample 3.

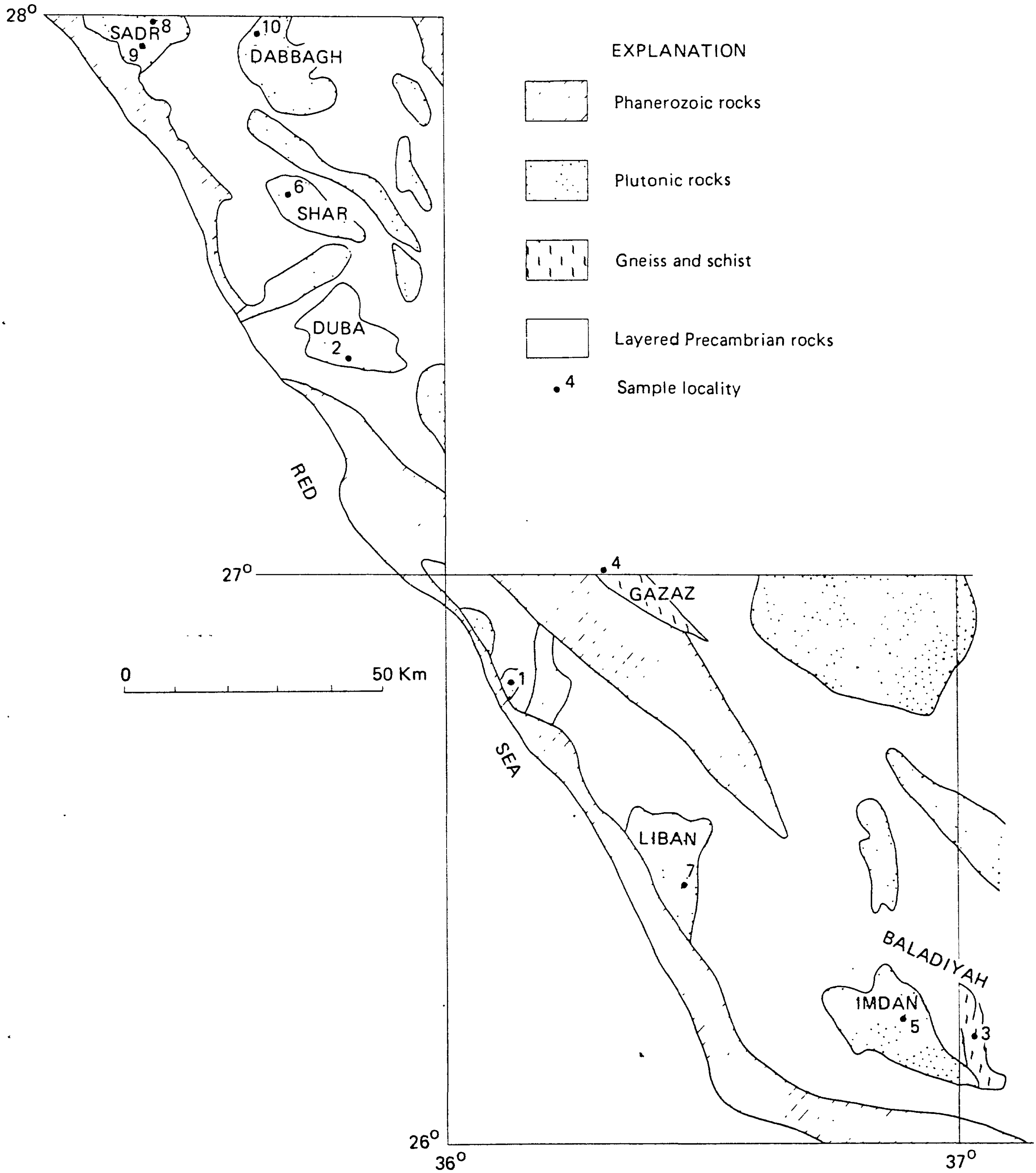

Figure 1.--Geologic sketch map showing sample locations.

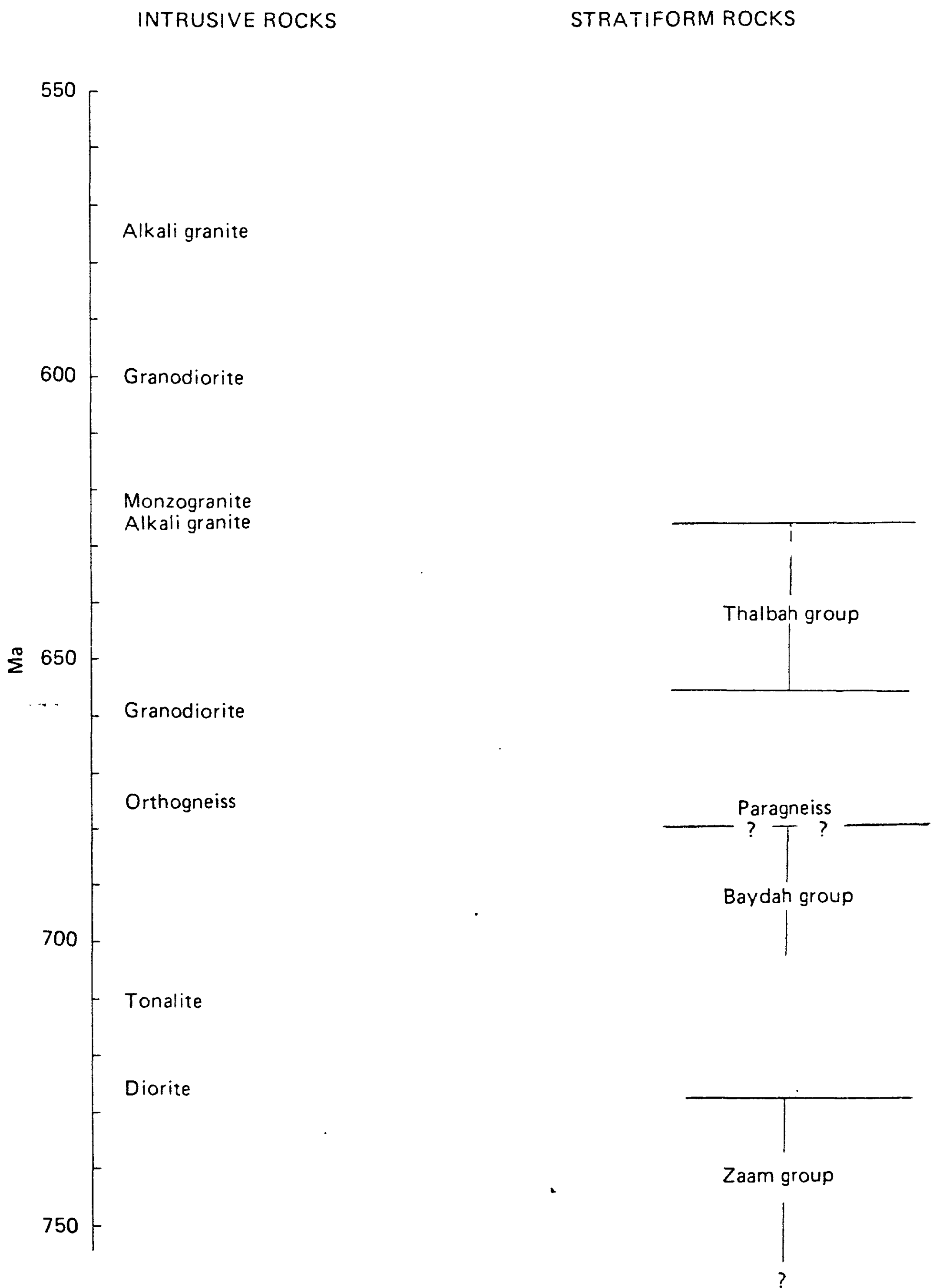

Figure 2.--Summary diagram of age assignments.

The Imdan complex (Davies, 1983) is a large body of massive to weakly foliated diorite to granodiorite that intrudes the Zaam group just west of the Baladiyah complex. The rocks having an age of 660 Ma were emplaced late in a major magmatic-tectonic event of which the Baladiyah complex represents an earlier phase. Clasts from the Imdan complex have been recognized within the basal conglomerate of the Thalbah group (Davies, 1983).

The Shar complex (locality 6) is an ovoid body of alkali granite from which Aldrich (in Aldrich and others, 1978) reported a K/Ar age of 1190 Ma for hornblende collected from Jabal Shar. The body was resampled as part of the present study and an age of 625 Ma was obtained. An essentially identical age of 629 Ma was reported by Kemp and others (1980) for a granite body located about 30 km to the southeast. Davies (1983) indicated that the relatively young Shar granite intruded both the Zaam and Thalbah groups.

The Liban complex (Davies and Grainger, 1983) is a zoned pluton of monzogranite partially surrounded by a rim of syenogranite. Sample 7 was collected from near the center of this pluton and has an age of 621 Ma.

The results from sample 8 present some problems. The sample, intended to represent the granodiorite of the Sadr complex (Davies and Grainger, 1983), is a monzogranite, and its age, 599 Ma, is atypical for granodioritic rocks in the region. Either the sample represents a small younger intrusion within the complex or else the Sadr complex is significantly younger than expected. The complex is cut by numerous felsic dikes of approximate quartz syenite composition. Samples 9A, 9B, 9C and 9D were collected from the dikes to determine whether they represent a late phase of this pluton or are related to later granite bodies. The resulting Rb/Sr isochron is reasonably good (fig. 3), but the resulting age of 575 Ma must be suspect because the initial $^{87}Sr/^{86}Sr$ ratio (0.709) is much higher than any other value found in the area. Dike rocks can easily pick up some radiogenic ^{87}Sr as they are being emplaced, but in this case the immediate wall rocks would not be a suitable source.

Assuming that the age for the dikes is correct, it would make them contemporaneous with the Dabbagh complex just a few kilometers to the east (locality 10). Rb/Sr results from this body indicate an age of 570 ± 7 Ma. and John Aleinikoff (written commun., 1983) has analyzed four zircon fractions and obtained a value of 577 ± 4 Ma. The complex has a core of biotite monzogranite that is surrounded by a rim of alkali granite. Sample 10 is from the alkali granite.

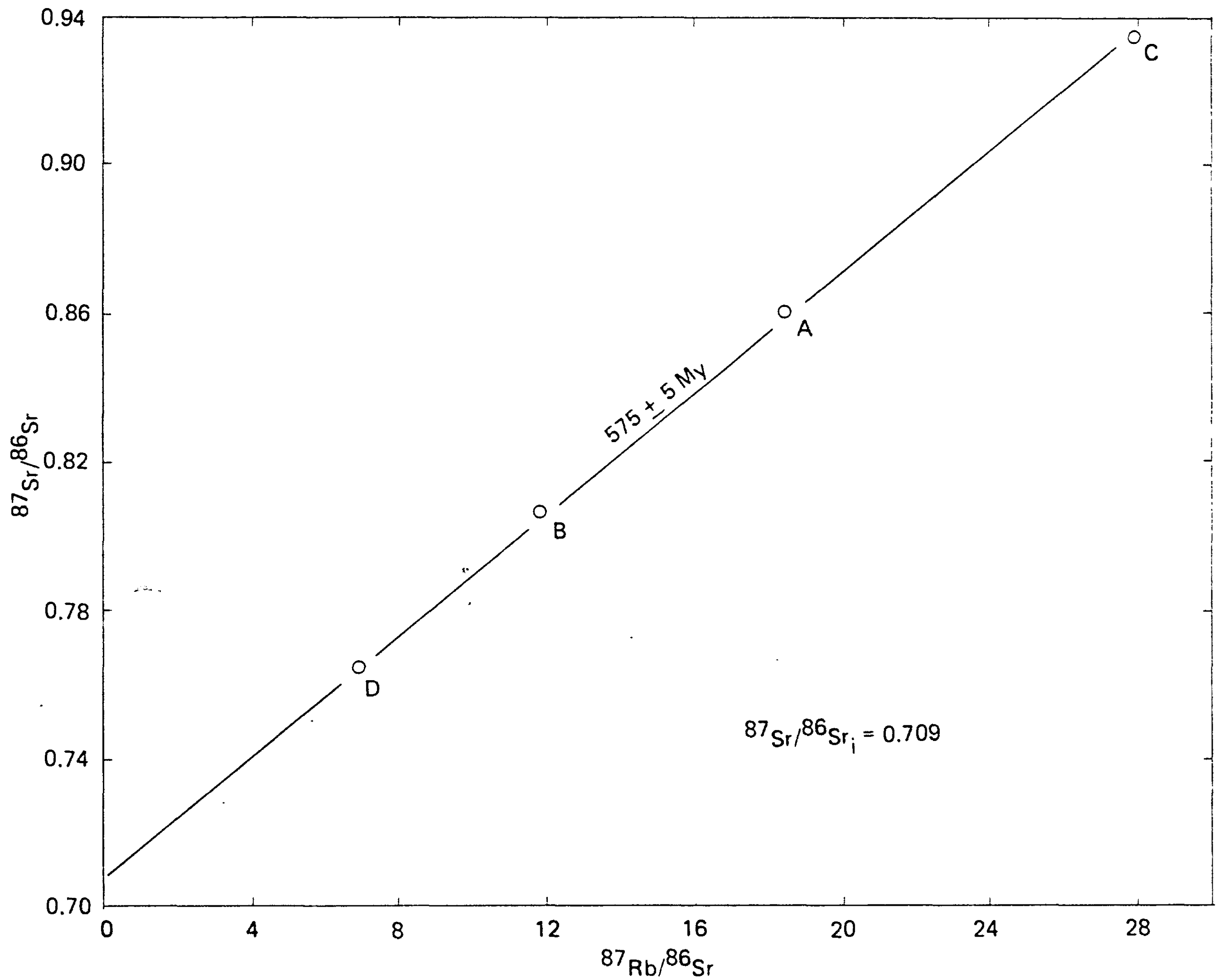

Figure 3.--Rb/Sr isochron diagram for dike samples of quartz syenite from locality 9.

Figure 2 summarizes the results of this study. The Zaam group of metavolcanic and metasedimentary rocks clearly predate 725 Ma., but by how much is problematical. It can be argued that since the old diorite pluton that intrudes the Zaam group is chemically primitive (0.28 percent K_2O and 4.4 ppm Rb) it was probably formed early in the evolution of this terrain and, therefore, the Zaam group rocks may not be much older.

The positioning of the Baydah group in figure 2 is even more problematical. If my interpretation, that Baladiyah rocks represent a deep-seated intrusion is correct, then the Baydah group is older than 676 Ma. The Baydah group is younger than the Zaam group, and it would be reasonable to presume the unconformity between the two groups was produced during the 710-725 Ma intrusive episode.

The Thalbah group can be bracketed between 660 and 625 Ma because clasts from the 660 Ma granodiorite are found in its basal conglomerate and it was intruded by granite at 625 Ma.

Davies (1983) and Davies and Grainger (1983) discuss several other units of dominantly conglomerates and silicious volcanic rocks, which both pre- and post-date the various late granites. These units could easily be accommodated on figure 2 because the results of this study require at least three episodes of granite emplacement in the region.

CONCLUSIONS

The Zaam group of volcanic and sedimentary rocks was deposited before the oldest dated intrusive rocks that were emplaced 725 Ma. The Baydah group, which is lithologically similar to, but rests unconformably on the Zaam group, was probably deposited prior to 657 Ma and most likely after 710 Ma. The Thabah group of dominantly clastic sediments was deposited after 660 Ma and prior to 625 Ma. Several local units of rhyolites and conglomerates were deposited in the interval from 625 to 575 Ma. This latter interval also included three episodes of granite emplacement.

DATA STORAGE

Data file USGS-DF-04-15 (Hedge, 1984) has been established for the storage of field and laboratory data used in this report. No MODS entries have been made.

ACKNOWLEDGMENTS

The work on which this report is based was performed in accordance with an agreement between the Saudi Arabian Ministry of Petroleum and Mineral Resources and the U.S. Geological Survey (USGS).

REFERENCES

Aldrich, L. T., Brown, G. F., Hedge, C., and Marvin, R., 1978, Geochronologic data for the Arabian shield, Sec. 1- Radiometric age determinations of some rocks from the Arabian shield, by L. T. Aldrich: U.S. Geological Survey Saudi Arabian Project Report 240, 20 p; also 1978, U.S. Geological Survey Open-File Report 78-75.

Cooper, J. A., Stacey, J. S., Stoeser, D. B., and Fleck, R. J., 1979, An evaluation of the zircon method of isotopic dating in the southern Arabian craton: Contributions to Mineralogy and Petrology, v. 68, p. 429-439.

Davies, F. B., 1981, The reconnaissance geologic map of the Wadi Thalbah quadrangle, sheet 26/36 A, Kingdom of Saudi Arabia: Saudi Arabian Deputy Ministry for Mineral Resources Geologic Map GM-42, scale 1:100,000, with text, 32 p.

Davies, F. B., 1983, Geology of the Al Wajh quadrangle, sheet 26B, Kingdom of Saudi Arabia: Saudi Arabian Deputy Ministry for Mineral Resources Open-File Report DGMR-OF-03-8, 81 p.

Davies, F. B., and Grainger, D. J., 1983, Geology of the Al Muwayliyah quadrangle, sheet 27A, Kingdom of Saudi Arabia: Saudi Arabian Deputy Ministry for Mineral Resources Open-File Report DGMR-OF-03-07, 61 p.

Harris, N. B. W., 1977, Geology of the northern halves of Wadi as Surr and Al Muwaylih quadrangles (27/35 A and B), northwestern Hijaz, Kingdom of Saudi Arabia: Saudi Arabian Directorate General of Mineral Resources Open-File Report 608, 41 p.

Hedge, C. E., 1984, Supporting data for a study of the Precambrian geochronology of part of northwestern Saudi Arabia: Saudi Arabian Deputy Ministry for Mineral Resources Data-File USGS-DF-04-15.

Johnson, R. F., and Trent, V. A., 1967, Geologic map of the Wadi as Surr area: Saudi Arabian Directorate General of Mineral Resources Mineral Investigations Map MI-5, scale 1:100,000, with text.

Steiger, R. H., and Jager, E., 1977, Subcommission on geochronology; convention on the use of decay constants in geo- and cosmochronology: Earth and Planetary Science Letters, v. 36, p. 359-362.