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Reconnaissance geology of the Al Qasr quadrangle, sheet 27/41C, Kingdom of Saudi Arabia

by

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ABSTRACT

The Al Qasr quadrangle is located in the northeastern part of the Arabian Shield between lat 27°00'N. and 27°30' N., and long 41°00' E. and 41°30' E. Except for a field of Miocene olivine basalt plugs and necks, the quadrangle is underlain by rocks of the shield. Two Precambrian layered rock units were recognized: the Banana formation (less than 735 Ma), which is composed of metabasalt and tentatively correlated with the Hulayfah group, and the Hadn formation (about 613 Ma), correlated with the Shammar group, which consists of rhyolitic ignimbrite flows and cataclastic deposits intercalated with arkosic clastic sediments and minor basalt to andesite flows and sills.

Plutonic rocks dominate the quadrangle and form four main groupings. The oldest grouping is composed chiefly of diorite, quartz diorite, tonalite and granodiorite and is probably associated with the Banana formation. The second grouping consists of cataclastically deformed, foliated, and lineated monzogranites and syenogranites, and represents an episode of regional deformation in the Ha'il region. The most extensive grouping of intrusive rocks are weakly deformed to undeformed biotite ± hornblende granites and granodiorites that form small to major batholiths. The Hadn formation volcanic rocks are the extrusive equivalent of these rocks. The final phase of plutonism was the emplacement of widespread alkali-feldspar and alkali granites, and alkali rhyolite dikes.

The Banana formation and the early dioritic to tonalitic rocks are interpreted to be related to an island arc. The cataclastically deformed and foliated granitic rocks may be related to a major episode of continental collision in the Arabian Shield when the Arabian neocraton formed. Subsequent to initial collision, voluminous intracratonic granites were generated. The intracratonic plutonism culiminated in the emplacement of the alkali granitic rocks, when the Ha'il region underwent regional extension, and major east-striking alkali dike swarms formed.

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No ancient mines or significant mineral occurrences are known within the quadrangle. The only reported mineral occurrences are three fluorite-bearing veins in the Jabal Aja intrusive complex, one of which contains wolframite. Although the mineral potential appears minimal, the possible existence of one or more caldera structures, and the occurrence of an alkali apogranite intrusion and a zinnwaldite(?)-bearing, peraluminous alkali-feldspar granite, indicate a potential for Sn, W, Ta, Nb, Th, REE, Mo, and Au mineralization.

INTRODUCTION

Geographic setting

The al Qasr quadrangle occupies a 2,750 km^2 region of the northeastern part of the Arabian Shield (fig. 1), southwest of the city of Ha'il. Physiographically, the quadrangle is divided by a highlands axis which runs from Jabal Hadn in the southwest to the granite mountains of Jabal Aja in the northeast (see plate). To the east and west of this axis the quadrangle is typically flat pediment with scattered hills and inselbergs. The highlands axis is sufficiently rugged that only a few roads in the central part of the quadrangle allow access between the western and eastern parts (plate). The pediment surface lies at altitudes of about 1100-1200 meters above sea level (a.s.l.), with a maximum elevation on Jabal Hadn of about 1400 meters a.s.l., and on Jabal Aja of about 1500 meters a.s.l.

The quadrangle contains a number of older farming villages such as al Qasr, Mawqaq, and Shuqayq, and new agricultural developments that are expanding rapidly (plate). The al Qasr quadrangle is named for the farming village of Al Qasr that is located in the northeastern quarter of the quadrangle. The name translates literally to the castle or fort, and refers to an old adobe fort in the village.

Previous investigations

The earliest geologic mapping that includes the al Qasr quadrangle is the 1:500,000-scale geologic map of the Northeastern Hijaz quadrangle of Brown and others (1963). The first mineral exploration of the Northeastern Hijaz quadrangle was conducted by Hummel and others (1970). A more detailed mineral reconnaissance of the Ha'il region, including the al Qasr quadrangle, was done by Chevremont (1982). Stuckless and others (in press, b and in press) did geochemical and isotopic investigations of the postorogenic granites of the northeastern part of the Arabian Shield, including the Jabal Aja intrusive complex which partially lies within the al Qasr quadrangle. Ekren (in press) has compiled the geology of the Ha'il 1:250,000-scale quadrangle which includes the al Qasr quadrangle. It should be noted that Ekren (in press) compiled the Ha'il quadrangle using a preliminary version of the present report and that there are some differences in the geology of the al Qasr quadrangle presented in Ekren's compilation as compared to the present report.

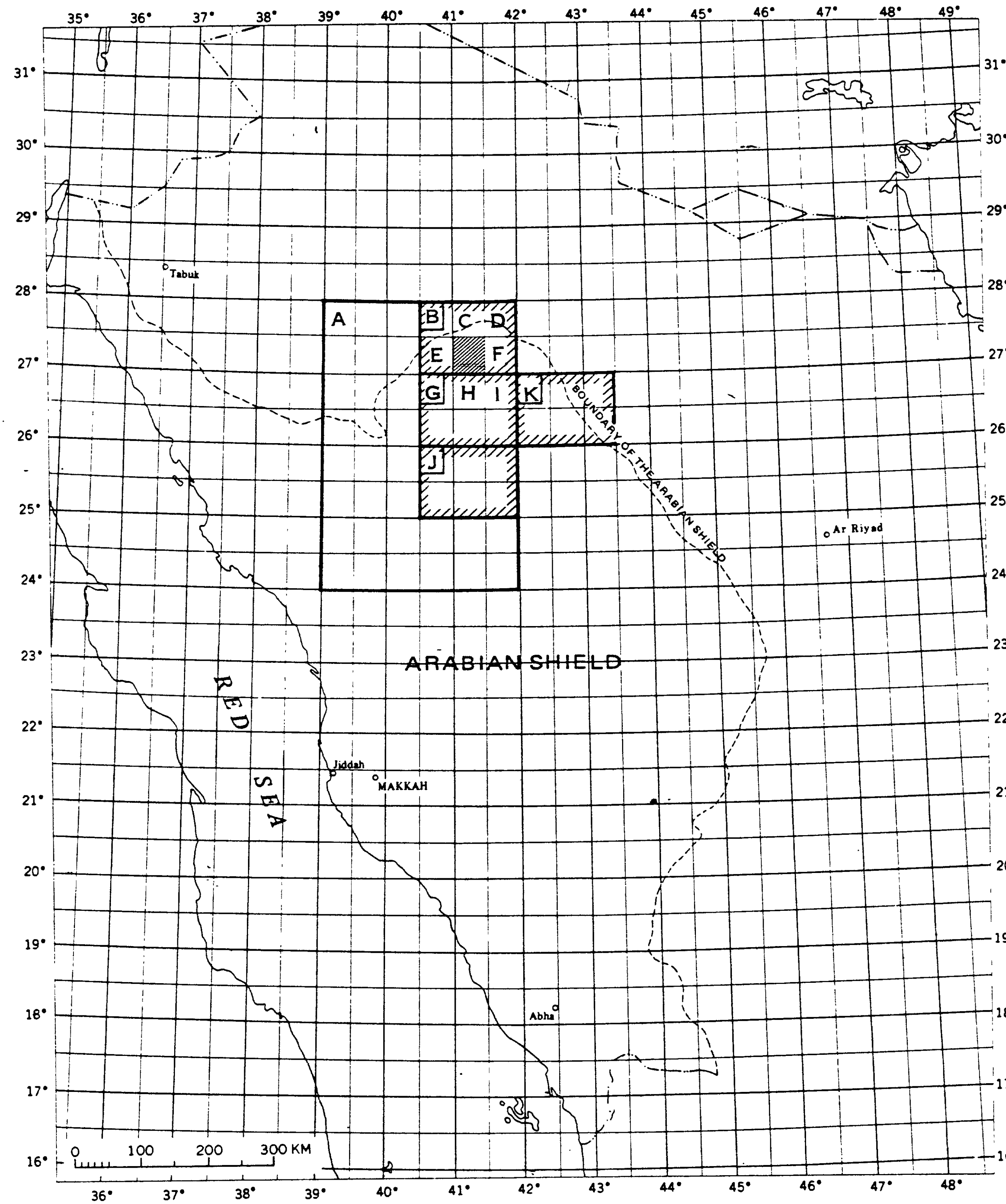

Figure 1.—Index map of Saudi Arabian Shield showing the location of the al Qasr quadrangle (shaded) and other quadrangles refered to in this report: A, Northeastern Hijaz (Brown and others, 1963); B, Ha'il (1:250,000-scale) (Ekren, in press); C, al Hufayr (du Bray and Stoeser, 1984); D, Ha'il (1:100,000-scale) (Kellogg and Stoeser, 1985); E, Jibal Matalli (Ekren, 1984a); F, Gufar (Kellogg, 1983); G, Wadi ash Shu'bah (Quick and Doebrich, in press); H, Ghazzalah (Quick, 1983); I, Al 'Awshaziyah (Leo, 1974); J, Nuqrah (Delfour, 1977); and K, Jabal Habashi (Johnson and Williams, 1984).

Present investigation

The present report is partially based on a regional helicopter-supported reconnaissance of the plutonic rocks of the Ha'il region by Stoeser and Elliott during 1977 and 1978. The results of this reconnaissance have been in part reported in du Bray and Stoeser (1984), Kellogg and Stoeser (1985), Stoeser and Elliott (1980, 1984), and the present report. Work in the al Qasr quadrangle occupied 12 days in October and December of 1977, and 5 days during September and December of 1978. Additional helicopter-supported field work to assist the mapping of the al Qasr quadrangle occurred during 10 days in March, 1979 and 7 days in October, 1983.

Plutonic and volcanic rocks are classified according to the nomenclature of the International Union of Geological Sciences (Streckeisen, 1976, 1979). The term alkali when used as a modifier to a rock name, indicates that the rock contains a sodic pyrobole (usually kataphorite or arfvedsonite amphibole and(or) aegirine or aegirine-augite pyroxene). The presence of these minerals indicates that the rock is geochemically peralkaline. The term apogranite refers to an albitized granite.

Textural terminology in general follows that of Williams, Turner and Gilbert (1954). The textural term hypersolvus is used for granitic rocks which solidified from the melt above the solidus, resulting in one alkali-feldspar forming instead of two feldspars (plagioclase plus potassium feldspar). The characteristic hypersolvus texture consists of a medium- to coarse-grained hypidiomorphic intergrowth of quartz and perthite.

Major and trace element data presented in tables 1 to 4 were performed by The Australian Mineral Development Laboratories (AMDEL), and X-Ray Assay Laboratories, Ltd. (XRAL), Canada. For the AMDEL analyses, the following methods were used with absolute error shown in parentheses. SiO_2: differential color on borate fusion ($\pm$0.2%); Fe_2O_3 as total iron: atomic absorption readings on HF digests plus reading by ICP ($\pm$0.1%); FeO: titration with potassium dichromate on HF digestion ($\pm$0.04%); MnO, MgO, and Na_2O: atomic absorption plus reading by ICP ($\pm$0.01, 0.03, and 0.05% respectively); TiO_2, P_2O_5, Al_2O_3, CaO, and K_2O by ICP ($\pm$ 0.02, 0.01, 1.3, 1.0 and 2.0% respectively; total water by evolution of water at 1150°C ($\pm$0.05%); moisture by loss on drying at 105°C ($\pm$0.02%);and CO_2: combustion in Leco furnace using the infrared measurement ($\pm$0.05%). For the XRAL analyses, all elements were determined by XRF except FeO which was done by wet chemistry (detection limits are 0.01% weight percent for the major elements, 10 ppm for the trace elements and 0.1 weight percent for FeO).

Acknowledgment

This report is in accordance with a work agreement between the U. S. Geological Survey and the Ministry of Petroleum and Mineral Resources of Saudi Arabia.

GEOLOGIC SETTING

Other than two alluvial units and intrusive Tertiary olivine basalts, all of the rock units mapped belong to the late Proterozoic to early Cambrian Arabian Shield. The Tertiary rocks all occur as part of a north-striking field of basalt necks and plugs. The Precambrian units are divided into: (1) sedimentary and volcanic (layered) rocks, and (2) plutonic rocks. A generalized geologic map with named plutons and dike swarms is present in figure 2.

Two layered rock units are recognized: the Banana formation, which is composed of mafic volcanic and hypabysal rocks; and the Hadn formation, which is composed of silicic volcanics intercalated with feldspathic sedimentary rocks. The Banana formation is tentatively correlated with the Hulayfah group, and the Hadn with the Shammar group.

Plutonic rock units dominate the quadrangle and form four main groupings. The oldest grouping is composed chiefly of diorite, quartz diorite, tonalite and granodiorite and are probably associated with the Banana formation. The second grouping consists of cataclastically deformed, foliated and lineated, monzogranites and syenogranites, and represents an episode of regional deformation in the Ha'il region. The most extensive grouping of intrusive rocks are weakly deformed to undeformed, biotite ± hornblende granites and granodiorites that form small to major batholiths throughout the northeastern part of the Shield. The Hadn group volcanics and correlative formations are the extrusive equivalent of these rocks. The final phase of plutonism was the emplacement of widespread alkali-feldspar and alkali granites and alkali rhyolite dikes that are well represented in the al Qasr quadrangle, and occur thoughout the northeastern part of the Shield.

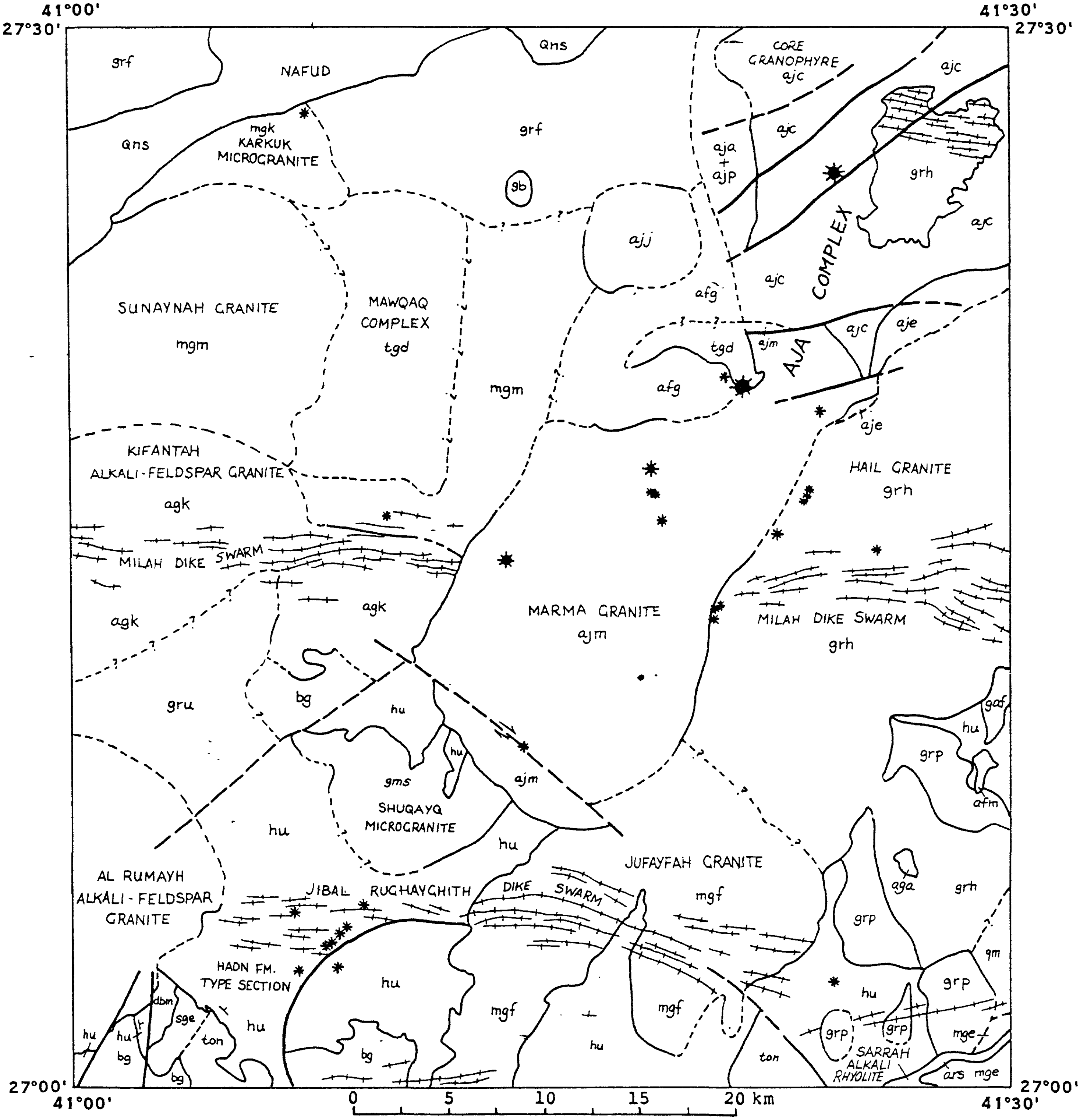

Figure 2.—Generalized geologic map of the al Qasr quadrangle showing named intrusive units. Symbols are the same as plate 1, except that Tertiary olivine basalt plugs and necks are shown with a star symbol.

PRECAMBRIAN SEDIMENTARY AND VOLCANIC ROCKS

Banana formation

The Banana formation (bg) was named by Quick and Doebrich (in press) for a series of metamorphosed mafic volcanic rocks and minor interbedded marble that occurs to the south and southwest of the Al Qasr quadrangle. In an earlier work, Quick (1983) referred to these rocks as the Banana greenstone. The Banana formation also probably correlates with the Nuf formation of Chevremont (1982), and Kellogg (1983).

In the al Qasr quadrangle, the Banana formation consists of volcanic and hypabyssal basalts that are locally intruded by a complex of rhyolitic dikes. These rocks range from unmetamorphosed to metamorphosed in the greenschist facies, and are not noticably deformed. The volcanic rocks consist of very fine grained, quench-textured basalts to fine-grained subophitic pyroxene basalts with a few vesicles. Samples that are somewhat coarser grained and consist of plagioclase phenocrysts as large as 5mm in an ophitic groundmass are interpreted to be hypabyssal intrusions within the volcanic rocks. No olivine was observed in any samples. In the samples which have been metamorphosed the plagioclase is relatively uneffected, but the primary pyroxene has been replaced by a pale-green (actinolitic?) amphibole. The intrusive rocks of the metadiabase unit (dbm) appear to be spacially related to the Banana formation and may represent shallow intrusions into the Banana.

Two major element analyses of Banana metabasalts from the Al Qasr quadrangle are available (table 1). Both are olivine-hypersthene normative subalkaline basalts (fig. 3) whose overall chemistry is similar to ocean floor tholeittic basalt (Carmichael and others, 1974).

Hadn formation

The Hadn formation (hu, hfl, hcg) consists of interbedded rhyolitic welded tuffs and flows with minor basaltic flows, and arkosic sandstone and conglomerate that occur throughout the southern portion of the Al Qasr quadrangle. The Hadn formation is herein named after Jabal Hadn, the most prominent peak within the main outcrop area of the formation, in the southwestern quarter of the Al Qasr quadrangle (fig. 2). This name was originally used in a preliminary version of the map and was subsequently adopted by Chevremont (1982), Kellogg (1983), Quick (1983), du Bray and Stoeser (1984), and Ekren (in press).

The formation occurs in four main outcrop areas within the southern part of the quadrangle. These are, from west to east, (1) the type section in the southwestern part, (2) the section within a semicircular ring fracture in the southwest-central part, (3) the section in the south-central part, and (4) the section in the southeastern part of the quadrangle.

Table 1.—Analyses of Banana and Hadn formation volcanic rocks. All analyses were performed by the Australian Mineral Development Laboratories except for samples 128820, 128823, and 128838 which were done by X-Ray Assay Laboratories, Ltd. of Canada. For details on methods and limits see the "Present investigation" section of the report.

Map unit	Banana fm.	Banana fm.	Hadn fm.	Hadn fm.	Hadn fm.	Hadn fm.
Rock type	basalt	basalt	ignimbrite	ignimbrite	basalt	basaltic andesite
Sample no.	128805	128807	128820	128821	128823	123826
Lat (27°) Long (41°)	01'27" 01'38"	01'00" 01'14"	02'36" 03'43"	02'36" 03'43"	02'36" 03'43"	02'36" 03'43"
SiO_2	48.2	50.6	69.6	73.8	50.7	53.6
TiO_2	0.94	1.30	0.38	0.38	1.22	1.14
Al_2O_3	20.4	15.2	14.4	12.9	15.1	15.1
Fe_2O_3	1.71	2.35	1.47	1.12	4.08	5.51
FeO	5.55	7.67	1.98	1.52	5.50	3.45
MnO	0.13	0.17	0.11	0.28	0.12	0.14
MgO	5.75	7.02	0.11	0.39	5.38	5.40
CaO	12.20	9.60	0.48	0.49	6.66	7.30
Na_2O	2.25	3.24	6.41	2.53	3.98	3.70
K_2O	0.50	0.48	3.51	4.56	1.73	1.16
P_2O_5	0.10	0.13	0.04	0.04	0.24	0.26
CO_2	0.05	0.05	n.d.	0.15	n.d.	0.25
H_2O+	1.70	2.06	--	1.25	--	2.25
H_2O-	0.11	0.06	--	0.11	--	0.19
L.O.I.	--	--	1.16	--	3.85	--
TOTAL	99.8	100.0	99.9	99.7	99.4	99.5
Trace elements (ppm):						
Nb	6	8	--	18	--	8
Rb	17	11	60	85	30	16
Sr	270	310	100	170	620	580
Y	18	26	--	34	--	16
Zr	60	85	390	370	90	110
CIPW Norm:						
Q	--	--	17.58	40.47	--	8.08
C	--	--	--	3.42	--	--
OR	3.02	2.90	21.06	27.45	10.79	7.07
AB	19.47	28.03	55.07	21.81	35.55	32.27
AN	45.09	26.08	0.16	1.24	19.24	21.82
DI	12.82	17.42	1.75	--	11.23	9.45
HY	11.78	17.00	1.40	2.77	13.70	9.64
OL	3.11	2.13	--	--	0.20	--
MT	2.54	3.48	2.16	1.66	6.24	8.24
IL	1.83	2.52	0.73	0.74	2.45	2.23
AP	0.24	0.31	0.10	0.10	0.60	0.63
CC	0.12	0.12	--	0.35	--	0.59

Table 1.-- cont.

Map unit	Hadn fm.	Hadn fm.	Hadn fm.	Hadn fm.	Hadn fm.	Hadn fm.
Rock type	ignimbrite	welded tuff	andesite sill	welded tuff	welded tuff	banded tuff
Sample no.	128829	128831	128834	128835	128837	128838
Lat (27°)	02'37"	02'37"	03'01"	03'01"	03'01"	03'01"
Long (41°)	03'43"	03'43"	05'22"	05'22"	05'22"	05'22"
SiO_2	73.5	72.2	62.3	75.4	69.9	67.9
TiO_2	0.43	0.23	0.97	0.25	0.45	0.55
Al_2O_3	12.6	14.1	15.6	11.4	14.5	14.2
Fe_2O_3	1.32	1.00	1.09	0.52	1.32	1.81
FeO	1.78	1.35	3.27	1.55	1.79	2.44
MnO	0.10	0.06	0.09	0.07	0.06	0.13
MgO	0.49	0.28	1.82	0.22	0.68	0.86
CaO	0.69	0.66	3.72	0.59	1.39	1.28
Na_2O	3.54	4.60	4.35	3.20	5.03	5.52
K_2O	4.31	4.39	3.01	4.56	3.58	3.13
P_2O_5	0.05	0.05	0.13	0.02	0.13	0.15
CO_2	0.05	0.05	0.05	0.52	0.05	n.d.
H_2O+	0.58	0.65	1.60	0.59	0.73	--
H_2O-	0.10	0.11	0.22	0.13	0.07	--
L.O.I.	--	--	--	--	--	1.54
TOTAL	99.7	99.8	99.9	100.0	99.8	99.9
Trace elements (ppm):						
Nb	12	12	12	14	12	--
Rb	80	80	55	75	60	50
Sr	130	100	490	60	190	220
Y	36	24	28	36	24	--
Zr	390	340	230	360	320	310
CIPW Norm:						
Q	34.13	26.73	15.38	38.37	23.01	19.70
C	1.11	0.83	--	1.07	0.25	--
OR	25.76	26.83	18.14	27.20	21.39	18.88
AB	30.30	39.32	37.54	27.33	43.04	47.67
AN	2.81	2.66	14.43	0.39	5.79	4.82
DI	--	--	1.79	--	--	0.55
HY	2.90	2.11	6.24	2.39	3.29	4.29
OL	--	--	--	--	--	--
MT	1.93	1.47	3.82	1.84	1.94	2.68
IL	0.83	0.44	1.88	0.48	0.86	1.07
AP	0.12	0.12	0.68	0.12	0.31	0.36
CC	0.12	0.11	0.12	0.80	0.11	--

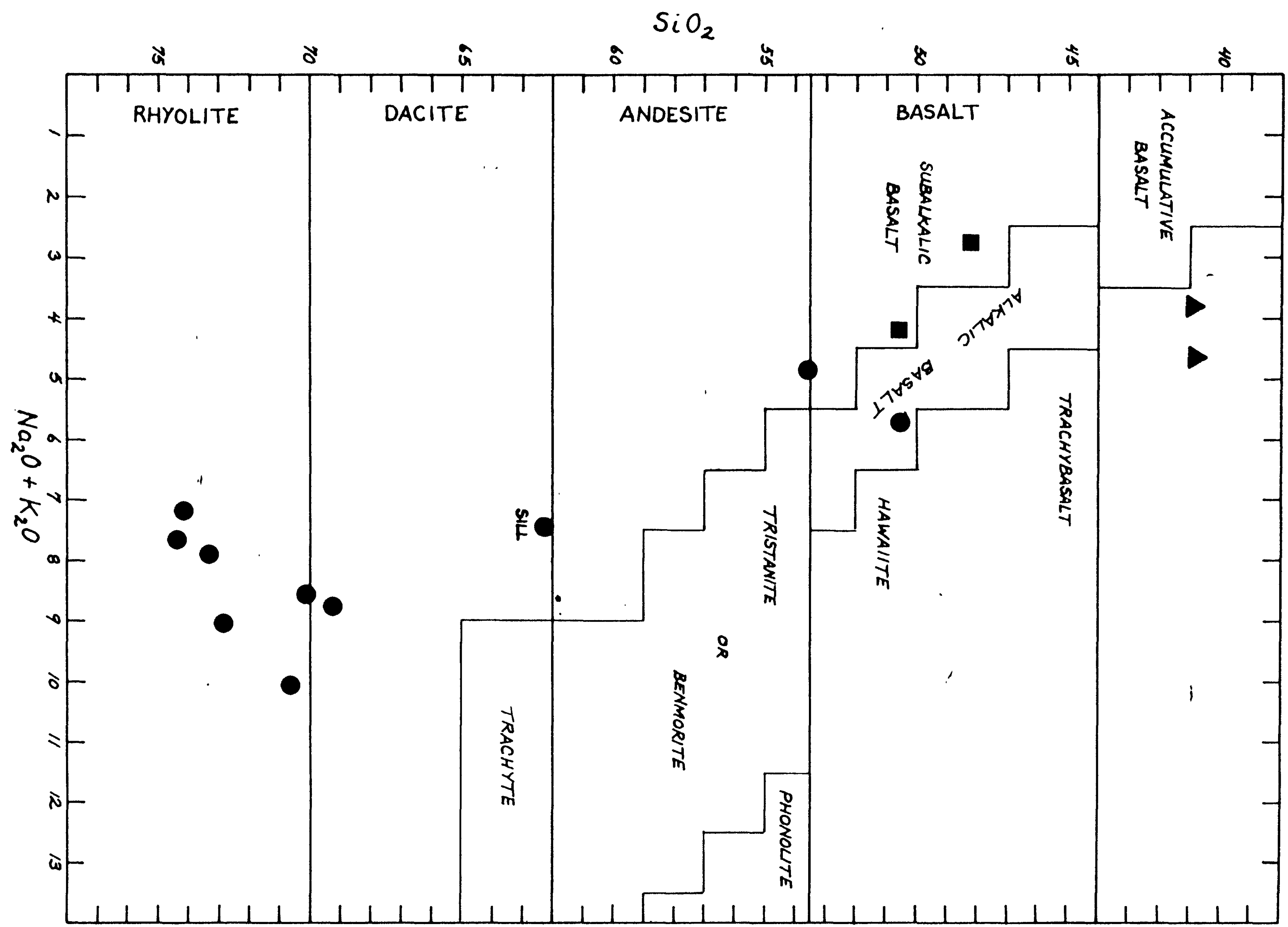

Figure 3.—Silica versus total alkalis binary diagram for all analyzed volcanic rocks of the al Qasr quadrangle. Diagram adapted from Middlemost (1972). Symbols: squares, Banana formation; filled circles, Hadn formation; and triangles, Tertiary olivine basalt.

The Hadn formation within the type section consists of roughly equal amounts of volcanic flow rocks and clastic sediments (figs. 4 and 5). The flow rocks are dominantly welded tuffs (ignimbrite) with feldspar ± quartz phenocrysts and variable amounts of lithic clasts (including pumice, volcanic rocks, and granitic rocks). Fine-grained, well- laminated tuff that are probably air-fall and water-laid ash layers are also locally abundant in the section. Sedimentary rocks include moderately to well-sorted arkose and arkosic sandstone (with some cross-bedding), conglomerate and sparse shaley or argillitic beds. The conglomerates contain a wide variety of volcanic rocks and some granitic clasts. The intraformational conglomerates higher in the section tend to be cannabalistic in that the bulk of the clasts appear to be derived from the Hadn formation itself, plus microgranitic clasts which may be derived from small intrusions or dikes. In the southern part of the type section, the Hadn layered rocks have a consistent north dip in the range 30 to 60 degrees. The section to the north of Jabal Hadn, however, is much more structurally complex, and has been deformed into a series of open folds and intruded by a major dike swarm. The Hadn type section has a minimum thickness of three to four kilometers. Refer to Chevremont (1982) for further information on the Hadn type section .

The volcanic flow rocks are composed primarily of rhyolitic ignimbrites and tuff breccias up to about 100 meters thick, but also include some basaltic and andesitic flows. A few andesite or dacite sills are present in the section. The commonest type of ignimbrite is flow-banded and contains 5 to 20 percent plagioclase phenocrysts, and variable amounts of lithic clasts that are dominantly volcanic or hypabyssal rocks. Less commonly, the ignimbrites contain quartz, plagioclase, and alkali-feldspar phenocysts. Flow breccias are composed dominantly of volcanic clasts up to several centimeters in diameter with lesser amounts of feldspar phenocrysts and crystalline clasts including micrographic granophyres. Well-laminated, waterlain(?) tuffs 2 to 5 m thick occur throughout the section. Other than opaque minerals, no other mafic minerals appear to be preserved in the flow rocks. The volcanic rocks are undeformed and only weakly metamorphosed in the lower greenschist facies. Many of the flows are so heavily oxidized that they are deep- to brick-red in color, and the feldspars have been extensively altered and replaced by very fine sericite(?).

Immediately east of the type section, Hadn formation rocks occur within semicircular fault (fig. 2). Within the core of this circular domain, gently dipping Hadn formation rocks overlie Banana formation. The Hadn here is more metamorphosed than in the type section, and near the base of the section is locally migmatized. The Hadn formation rocks in the core were only reconnaissance-sampled and no attempt was made to examine structures within the core region.

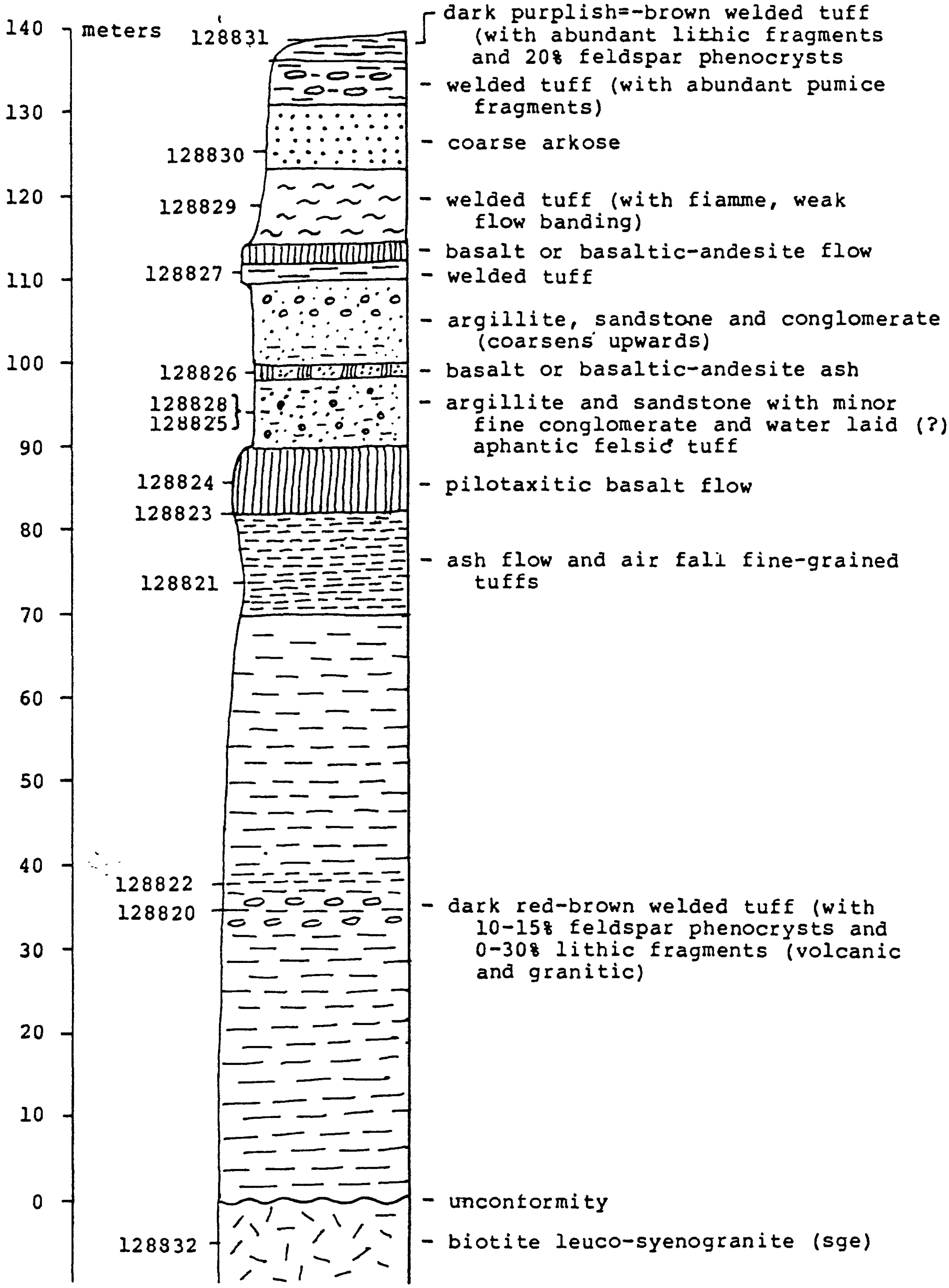

Figure 4.--Partial stratigraphic column for the Hadn formation. Column is based on a traverse on the Hadn type section, the location of which is shown as locality A on plate 1. Thickness are based on visual estimates and are very approximate. Sampled units are indicated by sample number.

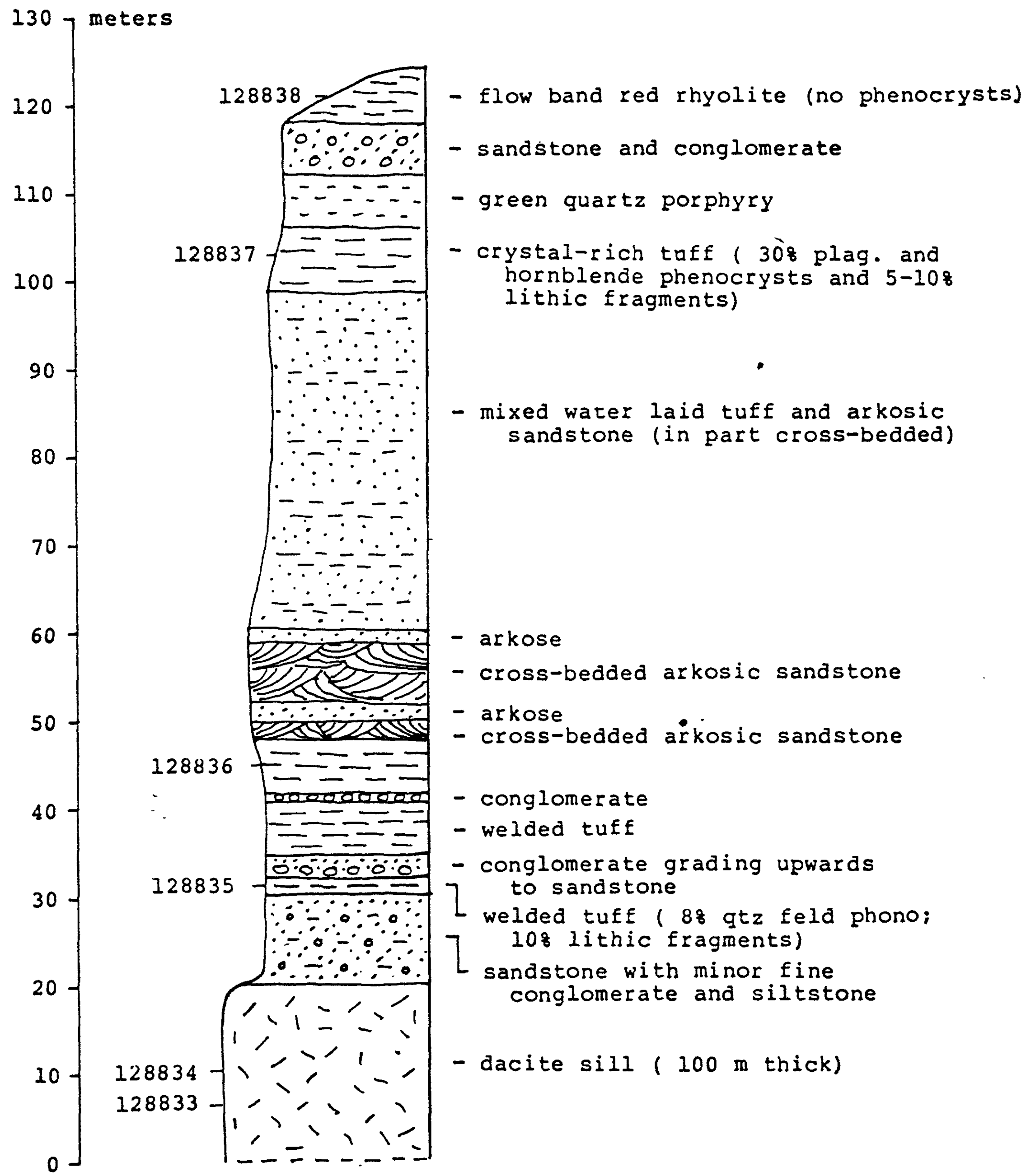

Figure 5.--Partial stratigraphic column for the Hadn formation. Column is based on a traverse on the Hadn type section, the location of which is shown as locality B on plate 1. Thickness are based on visual estimates and are very approximate. Sampled units are indicated by sample number.

The small sliver of Hadn formation southwest of the type section (located at about lat 27°02' N. and 41°02 E.) is somewhat different from the type section. Approximately 110 m of section is preserved, and it consists of four main units (from bottom to top): (1) a fine-grained non-porphyritic basaltic andesite or andesite flow (about 13 m thick), (2) about 40 meters of conglomerate, (3) a trachyandesite sill(?) (about 20 m thick), and (4) about 40 m of conglomerate. Thus the section lacks rhyolitic flow rocks and is rich in coarse clastic sedments, in contrast to the Hadn formation sections further east.

The central and southeastern outcrop areas are composed chiefly of volcanic flow rocks, and sedimentary interbeds are sparse. These sections were not examined in detail. A facies change in the Hadn formation from east to west appears possible in that it changes from to dominantly volcanic (ignimbritic) in the east to mixed volcanic and sedimentary in the southwestern Al Qasr quadrangle to dominantly sedimentary in the southern part of the Jibal Matalli quadrangle of Ekren (1984). Quick and Doebrich (in press) have estabished the Zarghat formation in the western part of the Wadi ash Shu'bah 1:250,000-scale quadrangle, and would include the Hadn formation of the Jibal Matalli quadrangle in their Zarghat formation (Quick, oral commun., 1984). The Zarghat formation consists of clastic sedimentary rocks intercalated with basic and felsic volcanic rocks (rhyodacite, dacite and quartz keratophyre), and may have been deposited in a shallow marine basin. To the east, Kellogg (1983) also maps felsic volcanic rocks which he assigns to the Hadn formation. To the southeast, Leo (1984) has mapped a series of rhyolitic to dacitic tuffs, flows and fragmental rocks intercalated with clastic sediments, which he has named the Al 'Awshaziyah formation. The Al 'Awshaziyah is almost certainly correlative with the Hadn formation. The above regional distribution of facies suggests a volcanic highland with one or more eruptive centers in the vicinity of the southeastern Al Qasr, Qufar, and Al 'Awshaziyah quadrangles and with a shallow sedimentary basin to the west (Quick and Doebrich, in press).

Ten major element analyses are available for the rocks of the Hadn formation. These analyses are presented in table 1, and the stratigraphic position of the samples is presented in figures 4 and 5. Seven analyses of Hadn felsic flows show that they are rhyolite except for one sample which was marginally dacitic (fig. 3). The flows have normal to high Na_2O/K_2O ratios such that several are properly classified as quartz keratophyre (fig. 6). The occurrence of such rocks in the section suggests chemical alteration and that some of the flows may have been deposited under marine conditions rather that subaerially. If this is correct, the type section must lie on the eastern margin of the Zarghat basin and was probably near sea level. Insufficient data are available on the contemporaneous plutonic rocks to allow any significant comparision of their chemistry with that of the Hadn formation volcanic rocks.

Two analyses are available for basic flow rocks within the Hadn type section (fig. 4). One is a hypersthene- normative alkali basalt, and the other a quartz-normative basaltic andesite. The sill in the type section (fig. 5) is subakaline and compositionally borderline between andesite and dacite. Its phenocryst assemblage of plagioclase and amphibole without quartz suggests an andesitic affinity.

PRECAMBRIAN INTRUSIVE ROCKS

Metadiabase

The metadiabase unit (dbm) consists of several small hypabyassal intrusions in the Banana formation. The two samples examined in thin section consist of metamorphosed clinopyroxene-hornblende diabase with average grain sizes in the range 2-3 mm. Hornblende is the dominant mafic mineral (about 30-40 percent), with only a few percent of clinopyroxene. In both samples, the pyroxene and hornblende had been extensively replaced by a pale-green (actinolitic?) amphibole. Accessory minerals are abundant opaques and apatite.

Mawqaq complex

This unit (tgd) consists of a poorly exposed intrusive complex of plagioclase-rich granitoid and dioritic rocks that form a series of small isolated jabals in the west- central portion of the quadrangle. Rock types include are hornblende-quartz diorite, hornblende-biotite monzodiorite, hornblende and biotite-hornblende tonalite, biotite granodiorite and monzogranite. The quartz diorites and tonalites are closely related and either grade into each other or pervasively intrude each other. The granodiorite and monzogranite appear to be somewhat younger, but the overall intrusive relationship of the various rock types is not clear. These rocks are cut by a series of basalt dikes which also appear to be related to the intrusive complex. The rocks of this unit have been pervasively metamorphosed in the greenschist facies and are locally cataclastically deformed.

Tonalite

The tonalite unit (ton) is correlated with both the tonalite (ton) and and biotite-hornblende granodiorite (gd) units of Quick (1983) in the Ghazzalah quadrangle. It is mapped in two places along the southern border of the Al Qasr quadrangle. The unit consists of biotite-hornblende tonalite and leucotonalite which are cut by dikes of basalt and biotite-hornblende quartz diorite. The unit tends to form a low terrane of greenish-gray outcrops that have smooth, rounded-weathering surfaces.

The tonalite is medium grained with average grain sizes in the range 4 to 7 mm. The rock has a distinct texture in which plagioclase (as large as 1 cm) forms subhedral to euhedral crystals with quartz and the mafic minerals in the interstices. Except for mild to moderate deformation of the quartz, the unit in general does not appear to be significantly deformed. The chief mafic minerals (approximately 8-18 percent) are hornblende and biotite that occur in the approximate ratio of 2:1 to 3:1. Although the hornblende is typically only mildly altered, the biotite is invariably completely replaced by chlorite. Accessory minerals include opaques, apatite, sphene and rare zircon.

Two analyses of the western tonalite pluton (which is unconformable beneath the Hadn formation) are presented in table 2. Chemically, they are low-alumina tonalites (fig. 6) with a low femic content.

Pendant tonalite

The pendant tonalite (tnp) occurs as a large 6 by 8 km roof pendant within the core of the Jabal Aja intrusive complex. Although the unit may correlate with the Ha'il granite, its lithology appears to be distinct from any other unit in the quadrangle. The pendant tonalite is intruded by an intense series of east-striking rhyolite dikes some of which are porphyritic granophyres similar to the host granophyre of the roof pendant. Three of the five samples examined in thin-section are deformed biotite and hornblende-biotite tonalites, one is a cataclasitic leucoalkali-feldspar granite, and one is oxidized granitoid whose feldspars are so altered they could not be identified. The feldspars in the tonalites are so oxidized and altered that the presence of primary potassium feldspar cannot be determined, but it is clear that plagioclase is the dominant if not the only feldspar present.

Jadid syenogranite

The Jadid syenogranite (jsg) is represented by a single outcrop, on the north-central border of the quadrangle, that is the southern extention of the Jadid syenogranite mapped and defined by du Bray and Stoeser (1984) in the Hufayr quadrangle to the north. The Jadid syenogranite is pervasively cataclastically deformed which resulted in a distinct, shallow eastwards-plunging lineation due to mineral streaking. Only one sample was examined in thin section. Although cataclastically deformed, it is still possible to see that the original rock was medium grained with an average grain-size of about 3-4mm. The cataclastic texture consists of coarser-grained relics of alkali-feldspar and plagioclase (in places rimmed with crush zones) in a monomineralic matrix of fine-grained quartz. Locally, the rock is cut by very fine grained mylonitic seams of crushed quartz and feldspar. The only significant mafic mineral is less than five percent fine-grained biotite that is clearly not primary but formed as a secondary (metamorphic) mineral during deformation. Accessory minerals include sparse opaques, allanite, and zircon.

Foliated syenogranite

The foliated granitoid (grf) consists of isolated inselbergs in the northern and northwestern portions of the quadrangle. The unit probably correlates with the syenogranite unit of du Bray and Stoeser (in pres) in the Hufayr quadrangle. A few outcrops of cataclastic to toliated hornblende-biotite monzogranite and granodiorite that occur as inselbergs in the Nafud immediately north of Jabal Jarkuk were also included in this unit.

Table 2.—Major and trace element analyses for pre-Aja suite plutonic rocks. All analyses were performed by the Australian Mineral Development Laboratories except for samples 128803 and 128841, which were done by X-Ray Assay Laboratories, Ltd. of Canada. For details on methods and limits see the "Present investigation" section of the report.

Map unit	Tonalite	Tonalite	Syenogranite	Jufayfah granite	Jufayfah granite	Jufayfah granite
Sample no.	128796	128803	128715	128839	128841	128843
Lat (27°)	00'20"	00'55"	01'29"	02'02"	00'39"	03'10"
Long (41°)	06'06"	04'24"	03'15"	13'36"	13'04"	13'53"
SiO_2	66.3	67.9	75.1	74.7	72.8	75.2
TiO_2	0.54	0.43	0.14	0.20	0.22	0.16
Al_2O_3	15.1	14.3	12.1	12.8	13.4	12.7
Fe_2O_3	2.05	2.39	0.82	0.87	0.90	0.75
FeO	2.25	1.60	1.11	0.80	0.90	0.70
MnO	0.08	0.07	0.03	0.04	0.03	0.05
MgO	1.70	1.33	0.04	0.27	0.30	0.19
CaO	4.57	3.78	0.55	0.90	1.22	0.68
Na_2O	4.25	4.64	3.60	3.83	4.00	4.10
K_2O	1.12	1.22	5.20	4.83	4.87	4.67
P_2O_5	0.14	0.09	0.02	0.06	0.05	0.05
CO_2	0.05	n.d.	0.35	0.05	n.d.	0.05
H_2O+	1.63	--	0.37	0.44	--	0.37
H_2O-	0.13	--	0.18	0.15	--	0.15
L.O.I.	--	1.77	--	--	1.39	--
TOTAL	99.9	99.8	99.7	99.9	100.2	99.8
Trace elements (ppm):						
Nb	4	--	50	44	--	14
Rb	22	20	170	260	210	140
Sr	290	300	24	80	150	65
Y	10	--	60	44	--	24
Zr	140	150	420	180	170	200
CIPW Norm:						
Q	25.77	27.64	33.82	31.96	28.40	32.08
C	--	--	0.41	--	--	--
OR	6.74	7.38	31.02	28.73	29.16	27.79
AB	36.64	40.16	30.75	32.62	34.29	34.94
AN	19.17	14.92	0.39	3.49	4.28	2.47
DI	2.15	2.88	--	0.24	1.25	0.23
HY	5.01	2.43	1.29	1.06	0.75	0.86
MT	3.03	3.55	1.20	1.27	1.32	1.10
IL	1.04	0.84	0.27	0.38	0.42	0.31
AP	0.34	0.22	0.05	0.14	0.12	0.12
CC	0.12	--	0.80	0.11	--	0.11

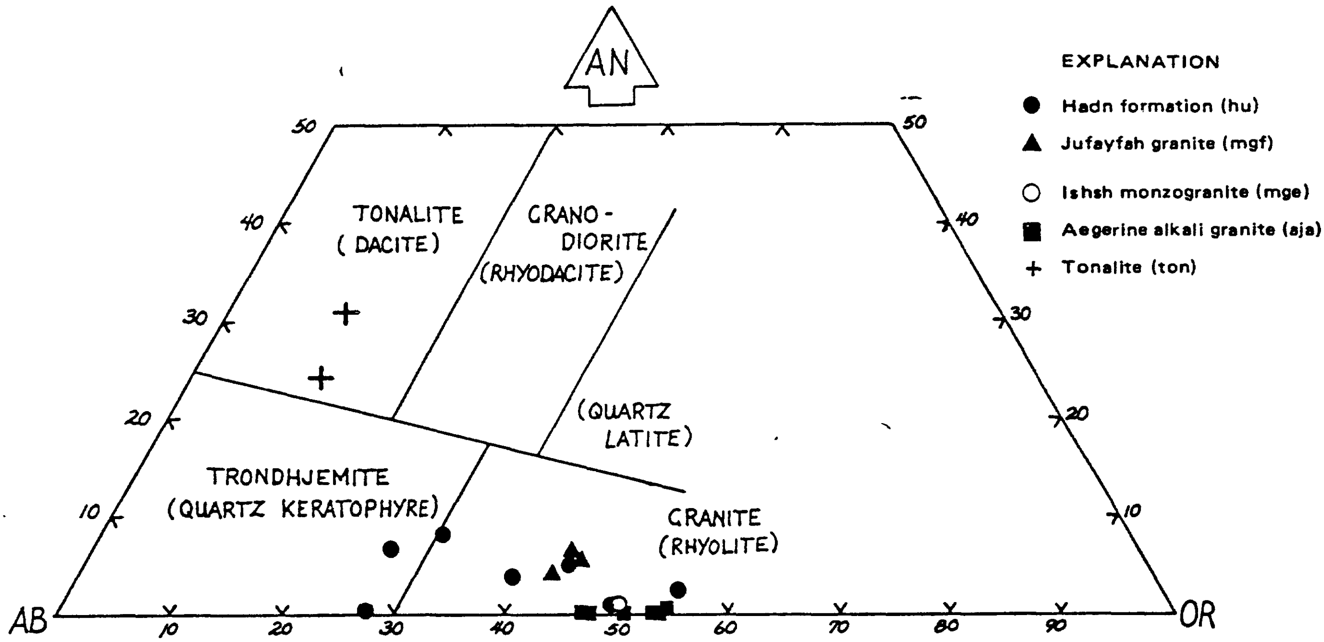

Figure 6.—Normative albite (AB)-orthoclase (OR)-anorthite (AN) ternary diagram, for rocks with excess silica, showing the propotion of normative feldspars for Hadn formation rhyolites and granitoid plutonic rocks of the al Qasr quadrangle (data from table 1-3) (after O'Conner, 1965).

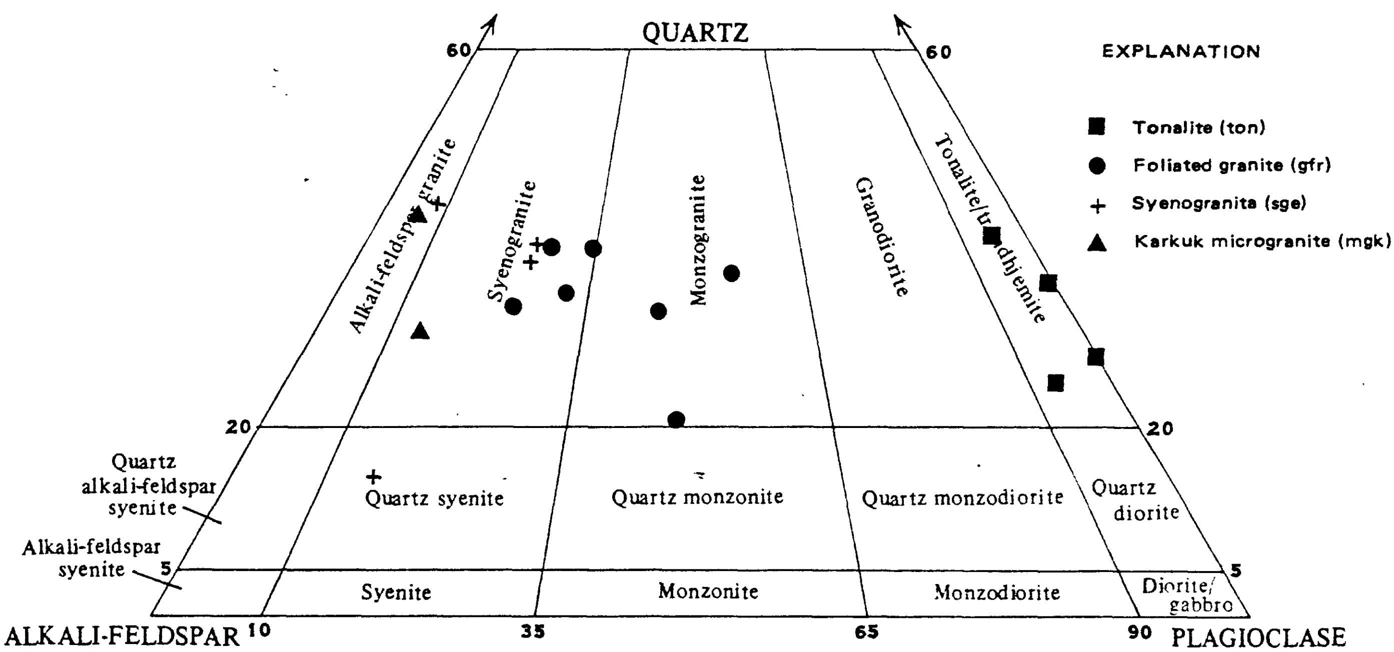

Figure 7.—Quartz-alkali feldspar-plagioclase ternary diagram for stained slab modal analyses of pre-Hadn formation plutonic rocks.

The unit chiefly consists of a light-pink cataclastically deformed biotite leucosyenogranite to leucomonzogranite (fig. 7) that had an original grain size of approximately 3-5mm. Although the foliated granitoid generally shows a well- to poorly developed foliation in outcrop, it lacks the distinctive intense lineation of the Jadid syenogranite. The degree of cataclasis ranges from mild to intense. Where well-developed, the texture consists of coarser relic clasts of feldspar in a fine-grained, highly sutured, annealed matrix of quartz and feldspar with minor amounts of biotite, chlorite, and opaque minerals. Mafic minerals consist of less than five percent (and generally less than 2%) biotite and/or chlorite (hornblende was observed in one sample). Accessory minerals include opaque minerals and sparse allanite, sphene, apatite, and zircon.

Jarkuk microgranite

The Jarkuk microgranite (mgk) is informally named here for Jabal Jarkuk, a large inselberg in the northwestern part of the quadrangle, which forms the main body of this unit. No contact relations with other units were observed. The unit is assumed to be pre-Hadn formation on the basis of mild deformation observed in outcrop, and the occurrence of clasts of Jarkuk-like micro-granites in Hadn formation conglomerates to the north in the al Hufayr quadrangle (du Bray and Stoeser, 1984).

Three samples of this unit were examined in thin section. The lithologies are biotite graphic microgranite, hornblende-biotite alkali-feldspar microgranite, and hornblende-biotite syenogranite porphyry. Two stained slab modal analyses showed similar results (fig. 7). The first two rocks are very similar and consisted of 10-20% alkali-feldspar and quartz phenocrysts (as large as 3mm in diameter) in a very complex, fine-grained, micrographic to myrmekitic groundmass of quartz, feldspar, and mafic minerals. The third sample consists of alkali-feldspar and plagioclase phenocrysts (as much as 6mm long) in a fine-grained inequigranular (but not graphic) groundmass with an average grain size of about 0.1-0.2mm. The ratio of phenocrysts to groundmass is about 6:4. Modally, the unit is probably a leucosyenogranite. Fine-grained hornblende and biotite constitute less than 3 modal percent of the samples. Accessory minerals include sphene, opaque minerals, apatite and zircon. The sphene is secondary, and extensively rims and replaces the primary opaque minerals

Syenogranite

The syenogranite unit (sge) consists of three small plutons of syenogranite which outcrop in the southwestern quarter of the quadrangle. Two of them lie on the border with and extend into the Ghazzalah quadrangle of Quick (1983), where they are mapped as part of his magnetite syenogranite unit (sgm). The northern unit of the syenogranite unit is unconformably overlain by the rocks of the Hadn formation and the unconformity is fairly well exposed for a length of over a half a kilometer.

The unit consists of a brownish-red weathering granite which forms jabals of moderate relief. Three samples were examined in thin section and all were medium-grained biotite leucosyenogranites with an average grain-size of 3-6 mm. Stained slab modal anaylses of four samples indicate that the unit includes alkali-feldspar granite and quartz syenite (fig. 7). In general, the unit is only weakly deformed, although a mylonite seam was seen in thin section in one sample. The alkali-feldspar is a string-to patch-perthite with lengths up to about 1 cm. The only mafic mineral is less than two percent late interstitial biotite that has largely been decomposed to a fine-grained mixture of chlorite, opaque mineral, and minor epidote. Accessory minerals include sparse opaque minerals, allanite, and zircon. A major element analysis for one sample of this unit is presented in table 2 and figure 6.

'Ishsh monzogranite

The 'Ishsh monzogranite (mge) is mapped in one area at the extreme southeastern part of the quadrangle. The unit is interpreted to be an extension of the 'Ishsh monzogranite from the Qufar quadrangle, and the name and symbol is adopted from Kellogg (1983). It is described by Kellogg as being composed of medium-grained, allotriomorphic-equigranular, biotite-hornblende monzogranite that grades locally into granodiorite.

Ha'il granite

The Ha'il granite (grh) of Kellogg (1983) is poorly exposed throughout a broad flat pediment region in the east-central portion of the quadrangle. Although the stratigraphic position of the Ha'il granite relative to the Hadn formation cannot be defined in the Al Qasr quadrangle, Kellogg has indicated that it is at least in part older than the Hadn formation in the Qufar quadrangle. The Ha'il granite is very similar in outcrop appearance and weathering style to the Jufayfah granite to the south and the actual contact between them has not been observed. The contact between them has been selected on the basis that there are more dikes within the Ha'il granite and slight color differences observed in Landsat imagery of the region.

The Ha'il granite exhibits mild to moderate deformation in thin section as indicated by strained and mosaiced quartz and calaclasis. In the Al Qasr quadrangle, the Ha'il granite consists of a rather leucocratic granodiorite to granite with 3 to 5 percent biotite (and less than 2 percent hornblende in some samples). In the Qufar quadrangle, Kellogg (1983) indicates that the typical mafic mineral of the Ha'il granite is a sodic hornblende, but that does not appear to be true for the Al Qasr quadrangle. Accessory minerals include opaque minerals, apatite, sphene, and zircon.

Granodiorite megabreccia

A small area of granodiorite megabreccia (gvd) is mapped on the eastern margin of the quadrangle and is an extension of a large area of the unit in the Qufar quadrangle of Kellogg (1983). The unit name and symbol is taken from Kellogg. He describes the unit as consisting of a megabreccia composed of blocks up to tens of meters across of rhyolitic volcanic rocks (Hadn formation?) in a granodiorite to monzogranite matrix. The unit was not sampled in the al Qasr quadrangle, and its boundaries were inferred from interpretation of aerial photography.

Biotite quartz monzonite

The biotite quartz monzonite unit (qm) occurs in one pluton on the southeastern margin of the quadrangle and extends into the Qufar quadrangle. The unit name and symbol is taken from Kellogg (1983). Only one sample of the unit was examined in thin section. It is a medium-grained, seriate, biotite quartz monzonite with an average grain size of about 2 mm. Modally, it is composed of 40 percent plagioclase, 40 percent orthoclase, 17 percent quartz and 3 percent biotite. The plagioclase is a zoned, partly sericitizied oligioclase that tends to be coarser than the other minerals (as large as 7 mm). The alkali feldspar is a weakly perthitic orthoclase. Olive-brown biotite is paragenetically early and formed euhedral crystals up to 1.5 mm. The biotite is extensively replaced by chlorite. Accessory minerals are opaque oxide minerals, apatite and zircon. At the sample site, the quartz monzonite is cut by a dike of leucocratic biotite micrographic rhyolite porphyry that has phenocrysts of quartz and plagioclase.

Undifferentiated granitoid

The undifferentiated granitoid unit (gru) was recognized in an area containing a few small, widely separated outcrops, in the southwestern part of the quadrangle south of the Kifantah alkali-feldspar granite. The unit was sampled at only one locality near its contact with the Kifantah granite. Here it is an undeformed, medium-grained biotite leucomonzonite with an average grain size of about 3 mm. The rock is composed of 41 percent quartz, 34 percent perthitic potassium feldspar, 22 percent oligioclase and 3 percent biotite. Sparse accessory minerals are opaque oxide minerals, and sparse apatite, fluorite, allanite, and zircon.

Gabbro

Olivine-clinopyroxene gabbro (gb) occurs as a single 1-1/2 by 2 km pluton in the north-central portion of the Al Qasr quadrangle. Only one sample was examined in thin section. The sample was metamorphosed such that approximately 40 to 50 percent of the rock had been replaced by fine-grained chlorite, epidote and amphibole. A good equigranular relic texture is preserved with an original average grain-size of 2mm. Its primary mineralogy consisted of less than 5 percent olivine and approximately 30 to 40 percent each clinopyroxene and plagioclase. It intrudes rocks of the foliated syenogranite unit. The relative age of the gabbro is unclear, but the degree of metamorphism suggests that it is older than the alkali-feldspar granite units and may be older than the Hadn formation.

Granite porphyry

The granite porphyry (grp) consists of a group of four plutons in the southeastern quarter of the quadrangle. At least one of the plutons is intrusive into the Hadn formation.

The rocks of this unit are texturally highly variable, and range from seriate to porphyritic with average grain sizes in the range 3 to 5mm. Five stained slab modal analyses show that the unit is modally variable from low quartz granodiorite to granite (fig. 8). The coarse-grained to phenocrystal minerals are alkali-feldspar, plagioclase and hornblende. One sample is cataclastically deformed and contained porphyoblastic alkali-feldspar. Biotite (less than 5 percent) occurs in all samples, and hornblende (less than 5 percent) occurs in most samples and is the dominant mafic mineral in one sample. Accessory minerals include opaque minerals, apatite, zircon, and in one sample allanite.

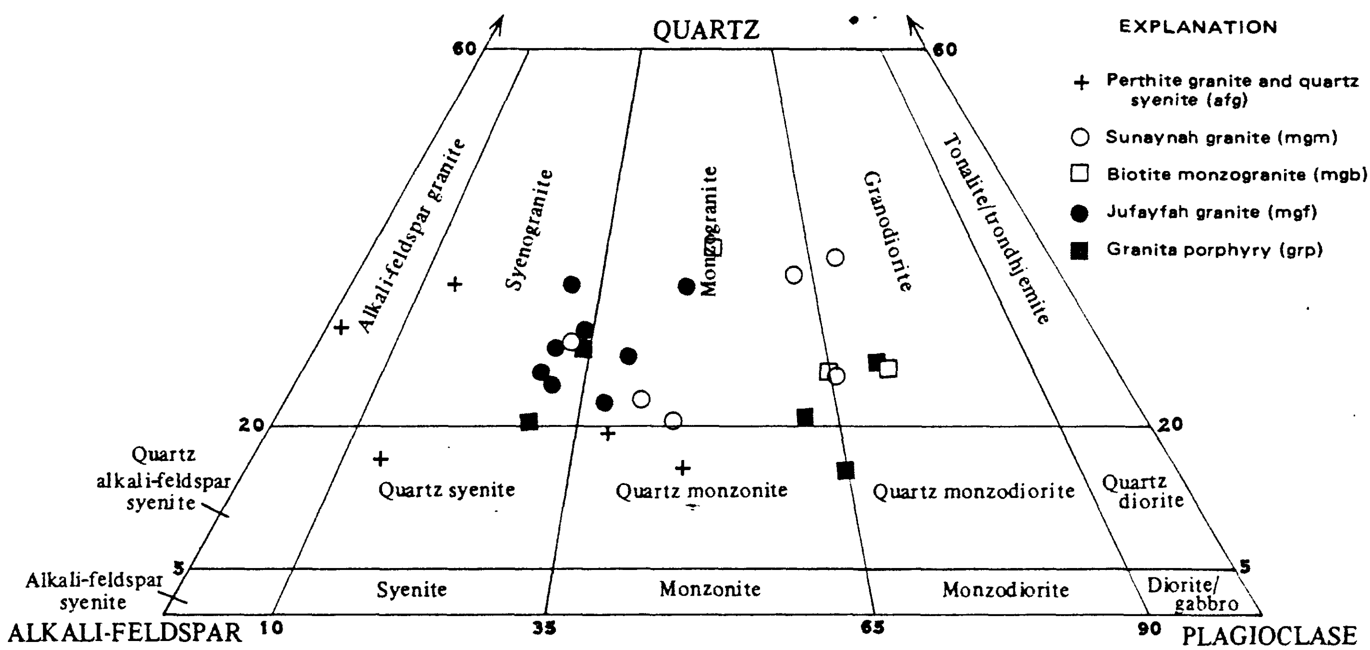

Figure 8.—Quartz-alkali feldspar-plagioclase ternary diagram for stained slab modal analyses of post-Hadn formation pre-dike swarm plutonic rocks.

Shuqayq microgranite

The Shuqayq microgranite (gms) is here informally named after the village of ,as Shuqayq which is located at the southwestern margin of the pluton. It occurs as a series of well-exposed brownish-pink outcrops of moderate relief. The relative age of the Shuqayq microgranite is poorly defined by contact relations but it intrudes the Hadn formation and is intruded by the Marma granite of the Jabal Aja intrusive complex.

Two samples of the Shuqayq microgranite were examined in thin section. One is a very fine grained, porphyritic granophyre with about five percent plagioclase phenocrysts (less than 1 mm long). The other sample is a fine-grained porphyritic biotite microgranite that consists of approximately 10 percent plagioclase and quartz phenocrysts (less than 3 mm) in a fine-grained groundmass. The groundmass consists of euhedral to subhedral plagioclase and perthitic alkali feldspar enclosed in subpoikilitic quartz. The overall proportions of quartz, plagioclase and alkali feldspar are 24:43:34. The feldspars have experienced extensive sericitization. The rocks also contains about two percent fine-grained, brown biotite that has been extensively altered to chlorite, and very fine grained opaque minerals. The only observed accessory minerals are apatite, opaque oxide minerals, and sparse zircon. Both samples contain a small amount of interstitial calcite.

Jufayfah granite

The Jufayfah granite (mgf) is herein informally named for the small farming village of Jufayfah that is located in the south-central portion of the quadrangle. The Jufayfah granite extends southwards into the Ghazzalah quadrangle of Quick (1983). It intrudes the Hadn formation and is diked by the Jibal Rughayghith dike swarm (fig. 2).

It is a biotite syenogranite to monzogranite (fig. 8) with an average grain size of 1 to 3mm. Some samples have been mildly deformed as indicated by strained quartz and minor cataclastic zones. It contains perthitic alkali-feldspar, plagioclase, biotite (less than 3 percent), and in a few samples hornblende (less than 2 percent). Accessory minerals include sphene, opaque minerals, allanite, zircon, and fluorite. Three major element analyses are presented for this unit in table 2 and figure 6.

Hypabyssal rhyolite

Brick-red hypabyssal porphyritic rhyolite (ryh) occurs in three small sill-like bodies in the Jufayfah granite in the central portion of the quadrangle. No samples of this unit have been examined in thin section.

Biotite monzogranite

Two occurrences of this unit (mgb) were mapped in the quadrangle, both as roof pendants within the Jabal Aja intrusive complex. One sample from each unit was examined in thin section. Both are leucocratic medium-grained (average grain size 3-4 mm) monzogranites that have been thermally metamorphosed such that their feldspars are oxidized and the mafic minerals largely decomposed. One also shows minor cataclasis. Three stained-slab modal analyses indicate two monzogranites and a granodiorite. Accessory minerals are opaques, sphene, and apatite.

Sunaynah granite

The Sunaynah granite (mgm) is represented by two poorly exposed granite plutons that occur in the northwestern quarter of the quadrangle. Few contacts with neighboring units are exposed but a relatively young age for this unit is indicated by the lack of deformation and alteration.

The western pluton extends into the Jibal Matalli quadrangle of Ekren (1984) (fig. 1). Within the Al Qasr quadrangle, the pluton has maximum width of about 10 km and a length of 14 km. The bulk of the outcrop of this pluton occur as small, flat surfaces that are flush with the surrounding pediment surface. The two areas of Sunaynah granite are separated by a large area of Mawqaq complex rocks which may represent roof pendants above a single Sunaynah pluton.

The pluton is composed of medium- to coarse-grained biotite granodiorite to alkali-feldspar granite, with the characteristic rock being a coarse-grained monzogranite (fig. 8). Feldspars consist of perthitic orthoclase and sodic oligioclase. The granite typically has an anhedral inequigranular texture with average grain sizes in the range 4 to 10mm. The rock is leucocratic with less than 3 percent biotite. Accessory minerals include opaque minerals, apatite, allanite, sphene, and zircon.

Biotite syenogranite and quartz syenite

The biotite syenogranite and quartz syenite unit (sy) is represented by one small pluton that is located on the eastern margin of the quadrangle. It extends into the Qufar quadrangle of Kellogg (1983) and his unit name and symbol have been adopted in this report. Kellogg reports for the pluton which extends into the al Qasr quadrangle that it "is a brick-red, medium-grained, hypidiomorphic-equigranular quartz syenite containing about four percent hornblende, 2 percent augite, and 1 percent biotite." Only one sample of this unit from the al Qasr quadrangle was examined in thin section. It is a hornblende-biotite alkali-feldspar microgranite that has an anhedral seriate texture consisting of medium-grained quartz and alkali-feldspar

(1-3 mm) in a fine-grained groundmass. The rock contains approximately 60 percent, 30 percent quartz, 5 percent plagioclase (albitic?), 3 percent biotite, 1 percent hornblende, and 1 percent opaque and other accessory minerals. Accessory minerals include magnetite, ilmenite, apatite and zircon.

Biotite alkali-feldspar granite

The biotite alkali-feldspar granite (afb) is represented by only one small xenolithic block in the western rim granite of the Jabal Aja intrusive complex. Although not deformed,the granite has been thermally metamorphosed such that the feldspars are extensively sericitized. The rock is a typical hypersolvus granite with an average grain size of about 3 to 4mm. Several percent of biotite has been altered to chlorite. The only observed accessory mineral is fluorite.

Perthite granite and syenogranite

The perthite granite and syenogranite unit (afg) occurs on the southwestern margin of the Jabal Aja intrusive complex and probably represents a single pluton. It appears to contain a large roof pendant of Mawqaq complex (tdg), and is intruded by small bodies of the biotite-hornblende quartz diorite unit (di) and the Marma granite (ajm).

Seven samples of this unit were examined in thin section. These consist of coarse-grained, biotite-hornblende, leucocratic, hypersolvus perthite, alkali-feldspar granite, syenogranite, and quartz syenite (fig. 8) with an average grain size in the range 5-8 mm. They are undeformed and unmetamorphosed. Mafic minerals consitute less than five percent in all samples. Hornblende is present in all samples, biotite in all but one, and clinopyroxene is present in two samples. Accessory minerals include opaque minerals, allanite, and zircon.

Biotite-hornblende quartz diorite

The biotite-hornblende quartz diorite unit (di) consists of a small hypabyassal intrusions located in the north-central portion of the quadrangle. Many of these bodies are too small to show on the plate. They are late in the stratigraphic sequence, and intrude most of the plutonic units of the quadrangle except the late alkali-feldspar granites and the alkali granites.

Three samples of this unit were examined in thin section. All consist of a equigranular fine-grained diorite or quartz diorite with an average grain-size of about 0.2mm. No potassium feldspar is observed, but due to the fine-grain size it would be difficult to detect small amounts. One sample contains no quartz, whereas two contain 10-20 percent quartz. The rocks are mafic rich with about 40-50% biotite (7-8%) and hornblende. A few percent of clinopyroxene is observed in one sample. Accessory minerals are abundant magnetite, ilmenite, and apatite.

Kifantah alkali-feldspar granite

The Kifantah alkali-feldspar granite (agk) is here informally named after Jabal Kifantah which forms the westernmost outcrops of the unit on the western margin of the quadrangle (plate). It occurs as a series of major inselbergs throughout the west-central region of the quadrangle. It intrudes the undifferentiated granitoid unit (mgu), and is intruded by the Milah dike swarm and the Marma granite of the Jabal Aja intrusive complex.

Only one pluton is assigned to this unit (agk), which occurs as large widespread jabals separated by alluvium in the west-central portion of the quadrangle. It is intruded by one of the central east-striking dike swarms. The bulk of the pluton consists of an alkali-feldspar granite with a typical hypersolvus texture and average grain sizes in the range 4 to 8 mm. The chief pyrobole is hornblende (ferroedenite) or kataphorite, but biotite or aegirine-augite occurs in some samples. Based on the pyroboles, it appears that granite of the pluton varies from metaluminous to weakly peralkaline. Accessory minerals include opaque minerals, zircon, allanite, fluorite, and sphene (in one sample).

Hornblende alkali-feldspar granite

The hornblende alkali-feldspar granite (afh) consists of a small area of outcrop within the western rim of the Jabal Aja intrusive complex. It is assumed to be a roof pendant within the rim complex but could be intrusive into the rim. The unit was not examined in the al Qasr quadrangle, but was described by du Bray and Stoeser (1984) in the adjoining al Hufayr quadrangle to the north. They describe it as a medium-grained hornblende alkali-feldspar granite which contained a trace amount of biotite in some samples. Accessory minerals included opaque oxides, zircon, apatite, and flourite.

Al Rumayh alkali-feldspar granite

The al Rumayh alkali-feldspar granite (agl) occurs as a single large pluton in the al Qasr, Jibal Matalli and Zarghat quadrangles (fig. 1). The pluton was informally named by Ekren (1984) after Jibal al Rumayh, which forms one of the prominent ridges along the northern margin of the pluton in the Jibal Matalli quadrangle. The al Rumayh alkali-feldspar granite is well exposed throughout, and typically consists of light-brownish-gray-weathering outcrops of considerable relief.

Ekren (1984) reports that in the Jibal Matalli quadrangle that the pluton is zoned such that it has a peralkaline outer northwestern margin and a metaluminous to peraluminous core. All samples from the Jibal Matalli quadrangle were amphibole bearing (hornblende to arfvedsonite). Two samples from the pluton in the al Qasr quadrangle were examined in thin section, one from the northern margin and one from the core. Both are hypersolvus, clinopyroxene-hornblende, alkali-feldspar granites, with average grain sizes in the range 3 to 4 mm. Feldspar from the sample from the northern margin consists solely of finely exsolved string perthite, whereas the other sample consisted of string- to patch-perthite and considerable late albite along grain boundaries and replacing the perthite. The hornblende (ferroedenite) from the northern sample is pleochroic olive brown to deep olive green, and in the other sample pale olive green to dark medium green. A weakly pleochroic yellow-green to emerald-green clinopyroxene (either ferrohedenbergite or aegirine-augite) occurs in both samples, although pyroxene is more abundant in the core sample. Accessory minerals include abundant opaque oxide minerals, zircon, allanite, sphene, and apatite. The overall mineralogy suggests that the rock is transitional between metaluminous and peralkaline and possibly the amphiboles have outer zones of kataphorite (soda-amphibole).

The al Rumayh pluton is clearly late relative to other plutons of the region. Its relationship to the Jibal Rugnayghith dike swarm is not clear. Ekren notes that although the pluton is not diked by the swarm as such, that a few dikes of the swarm intrude the northwestern margin of the pluton, which suggests that the swarm and the pluton are approximately contemporaneous.

Dikes

Sampling of dikes within the quadrangle was insufficient to allow classification, and all dikes have been included in one unit. The available sampling indicates, however, that the great majority of dikes are felsic and that only rare diabase and basalt dikes occur. In particular, basic dikes are present within the older units (bg, di, tgd, ton, tng). Dacitic to rhyolitic dikes with plagioclase ± quartz phenocrysts characterize the granodiorite to monzogranite plutons (grf to mgm units in the description of map units of plate). The most notable feature of the dikes of the al Qasr quadrangle is the occurrence of two major east-striking dike swarms whose dominant rock is an aegirine alkali rhyolite to microgranite (Ekren, 1984a, in press). A third east-striking dike swarm is also preserved in the large roof pendant within the Jabal Aja intrusive complex. The dikes within the pendant swarm are "normal" red rhyolite porphyrys. The formation of these late east-striking dike swarms is discussed further below.

Sarrah alkali rhyolite

The Sarrah alkali rhyolite (ars) occurs as a large arcuate dike that forms a prominent ridge in the Qufar (Kellogg, 1983), Ghazzalah (Quick, 1984), and southeastern al Qasr quadrangles (fig. 2). The Sarrah alkali rhyolite is herein informally named after Jabal Sarrah which forms the most prominent part of the ridge formed by the rhyolite in the Qufar quadrangle (Kellogg, 1983; Ekren, 1984). The dike at its maximum width is over 500 m and is over 30 km long.

In the Qufar quadrangle, Kellogg (1983) describes the Sarrah rhyolite (his red syenogranite and rhyolite prophyry dikes unit, rh) as consisting of brick-red to maroon granophyric syenogranite to rhyolite porphyry that contains euhedral phenocrysts of quartz and alkali-feldspar and as much as 1 percent sodic amphibole. One sample of the dike from the al Qasr quadrangle consists of an alkali rhyolite porphyry with about 15 percent alkali-feldspar and 10 percent quartz phenocrysts in a very fine grained groundmass. The groundmass contains about 8 percent pleochroic dark-olive-green to dark-gray-green amphibole (katophorite or arfvedsonite) (0.1-0.8 mm). Accessory minerals include fluorite and sparse opaque oxides. Texturally, the rock is very similar to the comendite porphyry of the Jabal Aja intrusive complex in the Ha'il quadrangle (Kellogg and Stoeser, 1985).

Muscovite-biotite alkali-feldspar granite

The muscovite-biotite alkali-feldspar granite (afm) occurs as one small poorly exposed pluton of about 1 and 1/2 km^2 that intrudes the Hadn formation and the granite porphyry unit near the east-central margin of the quadrangle. Only one sample of the pluton was examined in thin section. It is a medium-grained, muscovite(?)-biotite, leucocratic, alkali-feldspar granite with a somewhat seriate anhedral granitic texture and an average grain size of about 1 to 1 1/2 mm. The potassium feldspar is a patch perthite and the plagioclase is either albite or sodic oligioclase. Three distinct micas appear to be present. The most abundant (about 1 percent) is a highly altered pale brownish-green mica (less than 1.5 mm) which is assumed to be altered biotite. A second primary mica as large as 1.5 mm in diameter, is moderately pleochroic clear to pale grayish green which may be muscovite or zinnwaldite. The third mica is disseminated secondary muscovite or smectite (less than 0.2 mm) that largely replaces feldspar. Accessory minerals are very sparse fluorite and opaque oxide minerals. Some interstitial calcite is also present. Based on its mineralogy the sample is almost certainly peraluminous in composition.

Although the relative age of the muscovite-biotite alkali-feldspar granite is uncertain on the basis of field relations alone, such granites are known to occur late in the plutonic sequence of the northeastern part of the Shield and are typically contemporaneous with the alkali granites (Stuckless and others, *in press*). The unit is assumed to be approximately contemporaneous with the alkali granites of the quadrangle on this basis as well as the lack of deformation or significant metamorphism .

Alkali apogranite

The alkali apogranite (aga) occurs in one small pluton of about 1 and 1/2 km^2 in the east-central portion of the quadrangle, where it intrudes the Ha'il granite. Two samples (one unaltered, one altered) were examined in thin section. Both consist of medium-grained equidimensional quartz (less than 3 mm; 30-45 percent) in a fine-grained matrix of albite (average about 0.1 mm; 50-70 percent). The albite also occurs as numerous inclusions within the outer margins of the quartz, in many places in the form of annular rings of albite inclusions. This texture is typical of alkali apogranites found elsewhere in the northern part of the Shield (Drysdall and others, in press). The unaltered sample also contains about 6 percent very pleochroic arfvedsonite (light olive green, slate gray blue, dark indigo blue) and no accessory mineral (including opaque oxides). The altered sample contains about one percent altered biotite(?) and fayalite(?). No accessory minerals were observed in the altered sample.

Aja suite

The Jabal Aja intrusive complex consists of a 35 by 85 km complex of coarse-grained hypersolvus peralkaline granite to micrographic porphyritic granophyre and rhyolite. The name is taken from Jabal Aja, a long high ridge of granite west of the city of Ha'il. The intrusion was first named the Jabal Aja granite complex by Stoeser and Elliott (1980). Kellogg (1983), and Kellogg and Stoeser (1985) refer to the batholith as the Jabal Aja complex or Jabal Aja intrusive complex and the latter usage is followed here. In addition, du Bray and Stoeser (1984), and Kellogg and Stoeser (1985), refer to the Aja suite. The authors also recognize a Aja suite that includes the rocks of the Jabal Aja intrusive complex, and several other alkali granite intrusions in the vicinity of the complex (one of which occurs in the al Qasr quadrangle). The relationship of the Aja suite to other alkali granites of the al Qasr region is discussed in a later section of this report.

Alkali-feldspar granophyre and alkali granite

The alkali-feldspar granophyre and alkali granite unit (ajj) occurs in a single pluton immediately west of the Jabal Aja intrusive complex (fig. 2). It is assigned to the Aja suite because of its proximity to the complex, lacking of diking, and being in part an alkali granite. Five samples from this pluton were examined in thin section and the results indicate that the pluton is zoned such that it has a hornblende-biotite alkali-feldspar granophyre core and an aegirine-arfvedsonite alkali-granite rim.

The core granophyre was examined in three thin sections and consisted of a leucocratic fine-grained alkali-feldspar microgranite with a granophyric texture and 20 to 50 percent medium-grained alkali-feldspar and quartz phenocrysts. Mafic minerals consisted of three to four percent brown biotite and euhedral hornblende. Accessory minerals included sphene, opaque minerals, zircon, and sparse apatite.

The rim granite was examined in two thin sections and consisted of medium-grained alkali-feldspar granite with about five percent aegirine and arfvedsonite. One of the two samples was strongly albitized. Accessory minerals included zircon, ilmenite, and elpidite.

Jabal Aja intrusive complex

Arfvedsonite-aegirine alkali granite: The light-brown to light-greenish-brown arfvedsonite-aegirine alkali granite (age) forms the eastern rim granite of the Jabal Aja intrusive complex (plate). It is typically a medium- to coarse-grained hypersolvus granite. Some samples include a few percent late albite that occurs along the margins of the earlier perthic alkali-feldspar or partially replaces it. The pyroboles are variable and include aegirine, ± arfvedsonite or katophorite, which are paragenetically later than the felsic minerals, and fill interstices between the feldspar and quartz grains. The accessory mineral suite is highly variable and includes zircon, fluorite, opaque oxides (chiefly ilmenite), and in some samples aenigmatite. One major element analysis of a sample from this unit is presented in table 3. See Kellogg (1983), and Kellogg and Stoeser (1985), for more information on this unit.

Aegirine alkali granite: The aegirine alkali granite (aja) forms the western outer rim of the Jabal Aja intrusive complex in the Al Qasr quadrangle. The rock outcrop has a distinct grayish-green cast when viewed from a distance. This unit tends to weather with very positive relief. The unit extends into the al Hufayr quadrangle of du Bray and Stoeser, and the same unit name and symbol is used here.

The unit consists of a rather uniform, arfvedsonite-aegerine, alkali-feldspar granite (fig. 9) with an average grain-size of about 4 or 5mm. The aegerine (4 or 5 modal percent) is non-pleochroic and is typically partially replaced by the arfvedsonite. The arfvedsonite (1 or 2 modal percent) is pleochroic from gray green to bright green. Accessory minerals are sparse, and mainly consist of opaque minerals and a late unidentified interstitial brown mineral. One analysis of a sample from this unit is included in table 3.

Porphyritic alkali granite: The porphyritic alkali granite (ajp) forms an inner rim unit (ajp) of the Jabal Aja intrusive complex between the aegirine alkali granite (aja) outer rim and the core granophyre (ajc). The unit extends into the al Hufayr quadrangle of du Bray and Stoeser (1984), and the same unit name and symbol is used here. It consists of a porphyritic aegirine-augite katophorite (or possibly arfvedsonite) porphyritic alkali microgranite (fig. 9) with phenocrysts of alkali-feldspar. The groundmass has an average grain-size of about 1 mm. Accessory minerals include aenigmatite, opaque minerals, fluorite, and apatite. One major element analysis of a sample from the porphyritic alkali granite is included in table 3.

Pendant granophyre: The pendant granophyre (ajg) consists of two large roof pendants of pale-red granophyre that are hosted by the pink core granophyre (ajc). The rock of the two blocks is very similar to that of the pink core granophyre, but are clearly subsided blocks within it. Unlike the pink core granophyre, the pale-red granophyre has a well-developed layering (plate) on the scale of tens of meters. The origin of this layering is unclear, but it may represent multiple quench units. All samples consist of a fine-grained, micrographic, porphyritic granophyre with 20 to 50 percent quartz and alkali feldspar phenocysts. Stained slab modal analyses (fig. 9) indicate that the pendant granophyre has a low quartz content and that some samples are quartz syenite. Quartz has probably been underestimated due to the fine grain size. The chief mafic silicates are biotite and/or arfvedsonite or katophorite. Accessory minerals include opaque minerals, fluorite, and in some samples allanite and zircon.

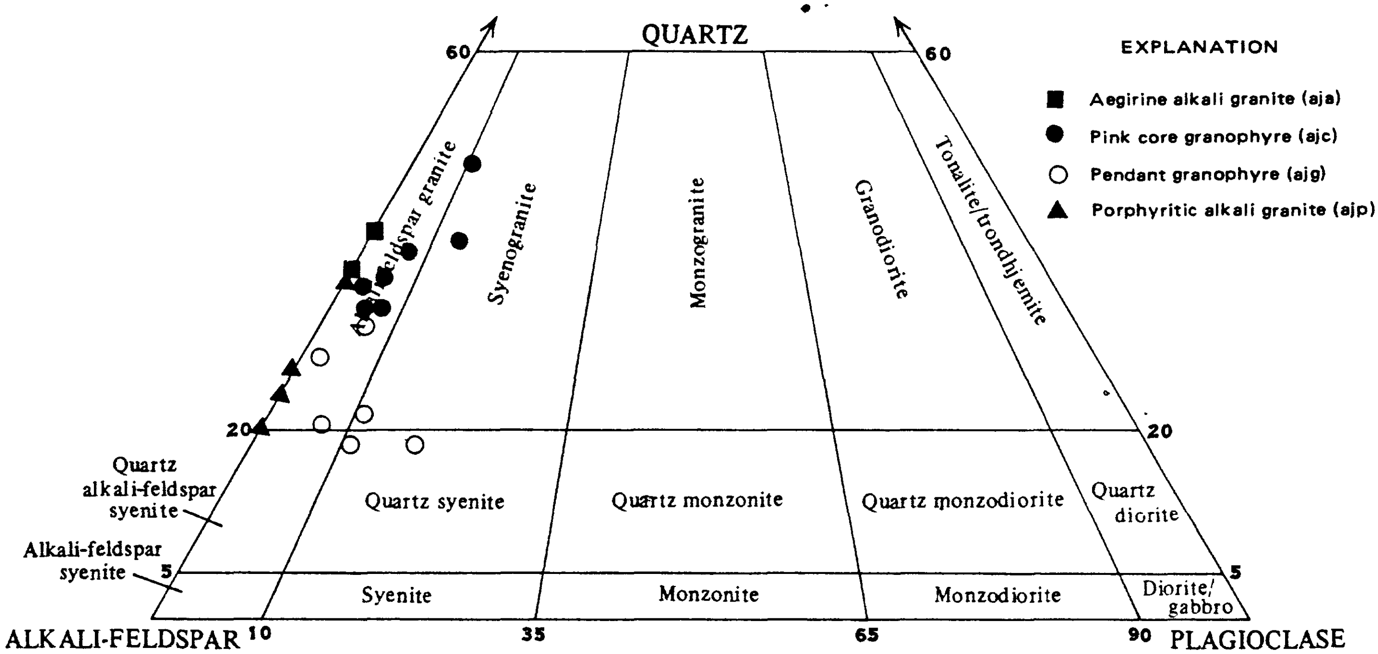

Figure 9.—Quartz-alkali feldspar-plagioclase ternary diagram for stained slab modal analyses from the Jabal Aja intrusive complex.

Table 3.—Major and trace element analyses for Aja suite intrusive rocks. All analyses were performed by the Australian Mineral Development Laboratories except for samples 128811 and 128814, which were done by X-Ray Assay Laboratories, Ltd. of Canada. For details on methods and limits see the "Present investigation" section of the report. At the bottom of the table, "A.I." stands for alkalinity index which gives value of the ratio $(Na_2O+k_2)/Al_2O_3$, where a rock is peralkaline if this ratio is greater than 1.0

Map unit	Pink core granophyre (ajc)	Pink core granophyre (ajc)	Arf.-aeg. alkali gr. (aje)	aegirine alkali gr. (aja)	porphy. alkali gr. (ajp)	porphy. rhyolite (ajr)
Sample no.	128811	128812	128814	128815	128816	128819
Lat (27°)				24'23"	24'23"	22'47"
Long (41°)				20'55"	20'55"	22'20"
SiO_2	75.2	75.7	73.1	74.3	76.4	76.0
TiO_2	0.14	0.16	0.50	0.37	0.27	0.13
Al_2O_3	11.8	11.7	10.1	10.2	10.6	11.8
Fe_2O_3	0.74	1.05	1.96	1.52	1.25	0.64
FeO	1.00	0.86	2.64	2.05	1.69	0.87
MnO	0.03	0.04	0.10	0.07	0.06	0.02
MgO	0.09	0.13	0.08	0.11	0.09	0.08
CaO	0.49	0.61	0.89	1.26	0.35	0.69
Na_2O	4.28	3.98	3.90	3.61	3.79	3.65
K_2O	4.85	4.71	4.80	4.78	4.66	4.78
P_2O_5	0.02	0.03	0.01	0.03	0.01	0.02
CO_2	n.d.	0.15	n.d.	0.75	0.10	0.25
H_2O+	--	0.31	--	0.37	0.33	0.53
H_2O-	--	0.13	--	0.20	0.11	0.14
L.O.I.	0.77	--	0.47	--	--	--
TOTAL	99.6	99.6	99.0	99.8	99.8	99.8
Trace elements (ppm):						
Nb	--	32	--	80	75	60
Rb	190	150	150	150	170	190
Sr	n.d.	28	n.d.	12	7	24
Y	--	34	--	80	85	50
Zr	280	520	910	980	1100	290
CIPW Norm:						
Q	31.39	33.96	31.94	34.51	36.05	35.60
C	--	--	--	--	--	--
OR	29.05	28.08	28.92	28.52	27.74	28.55
AB	34.15	33.97	25.72	26.10	28.79	31.22
AN	--	0.15	--	--	--	1.72
NS	0.02	--	0.32	--	--	--
AC	2.18	--	5.77	4.17	3.10	--
DI	2.04	1.47	3.87	1.17	0.86	0.01
HY	0.85	0.11	2.47	2.90	2.40	1.09
MT	--	1.54	--	0.13	0.27	0.94
IL	0.27	0.31	0.97	0.71	0.52	0.25
AP	0.05	0.07	0.05	0.07	0.05	0.05
CC	--	0.34	--	1.72	0.23	0.57
A.I.	1.041	0.995	1.149	1.089	1.064	0.947

Pink core granophyre: The pink core granophyre (ajc) is the chief unit within the core of the Jabal Aja intrusive complex. It is generally well exposed and forms massive pink to pale-red, smooth, rounded outcrops and jabals with considerable relief. In the field, it is clear from local internal contacts and sharp color differences that there are multiple units within the core granophyre, but these were not not mapped due to their complexity.

The pink core granophyre in thin section is porphyritic with a fine-grained miarolitic micrographic groundmass. The phenocrysts consist of approximately 30 to 50 percent quartz and alkali feldspar (less than 4 mm maximum length) in about equal amounts. Stained slab modal analyses indicate the unit is modally an alkali-feldspar granite (fig. 9). The chief mafic silicates are biotite and/or arfvedsonite. Minor amounts of aegerine-augite are also found in some of the arfvedsonite-bearing samples. On the basis of their mineralogy, the composition of these rocks presumbly ranges from metaluminous (biotite only) to peralkaline (arfvedsonite-bearing). Accessory minerals include opaque minerals, fluorite, and zircon.

The overall texture of the core granophye suggests that it was an alkali feldspar-quartz crystal mush whose mesostasis was quenched to form the graphic groundmass. The presence of multiple similar granophyres within the core granophyre suggests that it may have formed by multiple pressure quenches due to venting at the surface above the complex. Gas streaming is also suggested by the pervasive occurrence of miarolitic cavities throughout the core complex. The core granophyre also appears to have has been pervasively effected by subsolvus deuteric alteration. The chief effects of this alteration were to completely oxidize and destroy the mafic silicates in some samples, and to oxidize the iron within the alkali feldspars such that they appear to be heavily dusted with submicroscopic particles, presumably hematite. The oxidation of the feldspars gives the unit its pink to red coloration.

Marma granite: The Marma granite (ajm) occurs as a southern lobe to the Jabal Aja intrusive complex. The unit is similar in overall appearance to the core granophyre unit and may be directly related to it. No contact between the southern red granite and the core granophyre has been observed, and they may grade into each other. For that reason a dashed line contact is shown between the two units. The Marma granite is also very similar to the biotite alkali-feldspar granite (ajb) of the Aja complex in the Ha'il quadrangle (fig. 1), where the biotite alkali-feldspar granite occurs along the outer margin of the core granophyre.

The southern red granite pluton is fairly homogeneous throughout and tends to form very massive, smooth, rounded-weathering faces. In outcrop, it is typically dark- pinkish-red to brick-red and miarolitic. In thin section, it is an alkali-feldspar granite with an anhedral inequigranular seriate texture with subphenocrystal alkali- feldspar forming larger grains (3 to 8 mm) in a finer groundmass. Grain sizes are in the range 2-4 mm. Biotite is the only mafic silicate in most samples, but hornblende occurs in some samples, and arfvedsonite was found in one sample. The most common accessory minerals are opaque minerals and fluorite. Zircon and sphene are observed in a few samples.

Alkali micrographic granite: The alkali micrographic granite (ajd) is represented by a single, large, grayish-green dike, approximately 50-100 meters wide, that is located along the western flank of one of the granophyric roof pendants (ajg). Only one thin section was examined, and the rock is an aegirine-arfvedsonite micrographic granite, with alkali-feldspar and quartz phenocrysts (as much as 3 mm in diameter) in a fine-grained micrographic groundmass. The alkali-feldspar is only partially exsolved. Accessory minerals include opaque minerals, zircon, aenigmatite, and fluorite.

Red granophyre: The red granophyre unit (ajy) is represented by four small, pink to dark-red granophyric intrusions in or near the Jabal Aja intrusive complex. The unit is defined in order to recognize these late small intrusions, but no definite relationship between them is implied. Only two of the intrusions were sampled. The body at the extreme northeastern part of the quadrangle is an extension from the Qufar quadrangle (Kellogg, 1983) of a major granophyric dike in the Aja core complex. The al Qasr sample of this unit is a biotite leucogranophyre. The other sampled locality is a small "plug" in the arfvedsonite-aegirine alkali rim granite west of the village of al Qasr. The sample from this body is a fine-grained, hornblende-biotite, monzogranite granophyre.

Porphyritic rhyolite: The porphyritic rhyolite (ajr) represents widespread sills within the core of the Jabal Aja granite. The unit consists of brick-red, biotite rhyolite porphyry that contains 5 to 40 percent quartz and alkali-feldspar phenocrysts (as large as 5 mm in diameter) in a miarolitic, very fine grained, graphic to myrmekitic groundmass. Minor amounts of biotite (less than 2 percent) occur as a late interstitical mineral, which is generally partially replaced by chlorite. Hornblende was found in one sample. The only common accessory minerals are magnetite, ilmenite, and fluorite (which is abundant in some samples).

TERTIARY OLIVINE BASALT

The Tertiary olivine basalts (Tba) occur as a field of volcanic pipes and necks that appear throughout the 27/41 one-degree quadrangle, but are concentrated in the al Qasr quadrangle. Twenty seven of these intrusions have been mapped within the quadrangle . The majority occur on along a broad N. 30° E. axis from the southwest to the north corners of the quadrangle. They range in size from a few tens of meters to 0.9 kilometer in diameter.

Eight samples from eight different intrusions were examined in thin section. All are very similar and consist of very fresh intergranular basalts with average groundmass grain sizes in the range 0.01 to 0.12 mm, and contain 10 to 20 percent fresh euhedral olivine phenocrysts (one sample has approximately 5 percent olivine phenocrysts). Brown spinel inclusions in olivine were observed in only two thin sections. Two samples also contain about 3 to 5 percent euhedral augite phenocrysts which are highly zoned in one sample. A few percent devitrified glass was observed in one sample; the rest were holocrystalline. One plug was observed to contain lherzolite xenoliths up to a few centimeters in diameter (locality 128845 of table 4).

Major element analyses are available samples from two of the larger plugs (table 4). Both are very similar chemically and are picritic alkali olivine basalt (basanite). The low silica content (41 percent) reflects both the degree of undersaturation of the rock, and the relatively high olivine content (fig. 3).

Preliminary whole rock K/Ar age dates on the two samples which were chemically analyzed gave ages of 19.3 Ma (sample 128844) and 15 Ma (sample 128845). These ages are somewhat younger that the 23.4 ± 0.2 Ma K/Ar whole rock age obtained by Kellogg (1983) for a basalt flow remnant in the Qufar quadrangle (fig. 1). These data suggest one or more episodes of Miocene age basaltic volcanic activity in the Ha'il region along the axis of the Ha'il arch (Greenwood, 1974); the products of the activity have been largely removed by erosion.

Table 4.—Major and trace element analyses for Tertiary olivine basalt plugs. Analyses were performed by the X-Ray Assay Laboratories, Ltd. of Canada. For details on methods and limits see the "Present investigation" section of this report.

Sample no.	128844	128845
Latitude	27°25'59"	27°14'57"
Longitude	41°24'24"	41°13'51"
SiO_2	40.8	40.9
TiO_2	2.68	2.53
Al_2O_3	11.4	11.9
Fe_2O_3	4.83	4.54
FeO	7.80	8.60
MnO	0.19	0.19
MgO	11.40	11.10
CaO	11.80	11.20
Na_2O	3.34	2.72
K_2O	1.20	1.09
P_2O_5	0.81	0.37
L.O.I.	0.93	1.47
TOTAL	98.1	98.2
Trace elements (ppm):		
Cr	290	320
Rb	20	30
Sr	920	750
Zr	300	240
CIPW Norm:		
Q	--	--
C	--	--
OR	7.37	6.74
AB	2.69	7.23
AN	13.07	17.83
NE	14.46	9.13
DI	33.61	27.84
OL	14.40	17.37
MT	7.28	6.89
IL	5.17	5.03
AP	1.99	1.98

QUATERNARY SURFICIAL DEPOSITS

Eolian sand

The southern margin of the An Nafud, the second largest dune field of the Arabian Peninsula, occurs in the northern part of the quadrangle (plate, fig. 2) (Whitney and others, 1983). In the Al Qasr quadrangle, pale yellowish-orange sand (Qns) of the Nafud occurs as large barchanoid dunes that are approximately 50 to 100 meters high. These barchanoid dunes are largely stabilized by sparse vegetation, but local areas of active dune sand are present.

Alluvium

Unconsolidated alluvium and colluvium (Qal) occurs primarily in wadi channels, and as a widespread veneer over rock pediment surfaces that are widespread throughout the eastern, western and northwestern parts of the quadrangle. In the vicinity of Jabal Aja, the unit also includes alluvial fan deposits originating from wadis draining the Jabal Aja intrusuve complex. These sediments are predominantly composed of moderately to well-sorted sand-sized particles, but includes silt, and pebbles in wadi channels.

STRUCTURE AND METAMORPHISM

The metamorphic state of the Banana formation in the al Qasr quadrangle is difficult to generalize, due to the limited exposures and to the limited work on the unit. The Banana formation in the quadrangle is remarkably well preserved, however, given its early stratigraphic position. In the several samples examined it has only been metamorphosed in the lower greenschist facies, and has not been significantly deformed. Quick and Doebrich (in press) report higher degrees of metamorphism and deformation for the Banana formation to the south, and observations in this quadrangle may be somewhat anomalous.

The early granitoid plutonic rocks of the quadrangle such as the Mawqaq complex do show considerable deformation and recrystallization in the greenschist facies, such that, in the more mafic members, primary hornblende has been replaced by actinolite and chlorite. The medium-grained primary textures have been largely obliterated in some samples, and fine-grained mineral assemblages developed in their place. The most notable deformations of the granitoid rocks are the weak to well-developed foliation or lineations in the foliated granitoid units (jsg, grf), and indications of cataclasis in other older units (mgk, grh, sge, mge, etc.). The occurrence of these effects points to an episode of regional deformation, and similar rocks are reported in the Qufar (Kellogg, 1983), Ha'il (Kellogg and Stoeser, 1985), and al Hufayr (du Bray and Stoeser) quadrangles. The possible origin of this deformation is discussed in the next section.

The post-Hadn formation plutonic rocks of the quadrangle, and in part including the Hadn formation, show little evidence of metamorphism and are only locally deformed (see Chevremont, 1982; Quick, 1983; Quick and Doebrich, in press). The Hadn formation at its type section is not significantly deformed and has a homoclinal dip of 30 to 60 degrees north throughout. Immediately to the north of the type section, however, the Hadn has been compressed into a series of east-striking open folds with roughly horizontal fold axes. This deformation may be related to the emplacement of the Shuqaq microgranite immediately to the north of the disturbed Hadn.

The occurrence of several kilometers of ignimbritic felsic volcanic flow rocks in the southern portion of the al Qasr quadrangle strongly suggests the existence of a related caldera. Several geologists have already discussed this problem and identified a number of structures which might be indicate a possible Hadn caldera. In an early version of the present report it was proposed that the circular structure immediately to the east of the Hadn type section might represent such a structure. Ekren (1984) has discussed this proposal and, although not rejecting it,has noted a number of problems to the structure being related to a caldera for the Hadn formation. His objections centered on the amount of Banana formation exposed within the circular structure. The higher degree of metamorphism within the structure supports the proposal, and the fact that the Jufayfah granite appears to cross-cut the structure suggests that it is older that the granite and therefore may be of Hadn age. Another aspect of the structure is that, because the base of the Hadn formation is exposed in the structure,it is clear that the core of the structure is upthrown relative to the Hadn to the west of the structure and therefore the caldera would have to be resurgent. Whether related to a caldera or not, it seems likely that the circular structure is likely to represent the roof of an underlying pluton.

Kellogg (1983) proposed that the granodiorite megabreccia (gdv) was related to a caldera structure. Ekren (1984) went further and suggested that the arcuate Sarrah dike outlined a portion of a caldera. The megabreccia may be related to a caldera, but there is no good structural evidence for this at present. The Sarrah rhyolite dike can be eliminated as a source for the Hadn volcanic rocks because it post-dates the Al Rughayghith and Milah dike swarms and, being an alkali rhyolite, clearly belongs with the later alkali granites.

The Shuqaq microgranite could possibly be considered as potentially related to the Hadn volcanic rocks. It occurs within an 8- to 10-km diameter circular structure and the microgranite pervasively intrudes the Hadn formation within the structure. One of the chief problems in trying to identify the source of the Hadn volcanic rocks is that the present level of reconnaissance mapping is inadequate, and considerably more work will be required to resolve the problem.

The emplacement of the alkali rhyolite-bearing, east-striking dike swarms is an important feature in the regional structural evolution of the northeastern part of the Arabian Shield figure 10, shows a generalized map of these dike swarms, other dikes with similar trends, and all the late alkali-feldspar granites and alkali granites of the Ha'il region. Such swarms do not occur further south. The discontinous nature of the dike swarms is due in part to extensive cover in some parts of the area mapped. The Jabal Rughayghith dike swarm (Ekren, 1984a, in press; fig. 10) potentially can be traced for about 180 km. The Milah swarm is shorter and its apparent extension through the Salma complex is questionable since in the al Qasr quadrangle the chief rock type is alkali rhyolite whereas in the Salma portion of the swarm it is diabase. It is impossible to determine the length the Ha'il and northern Ha'il swarms (informally named herein) due to the Paleozoic cover rocks.

The swarms are highly generalized in figure 10, and on the ground they consist of hundreds of dikes in many places only a few meters apart. One suprising aspect of the swarms is that they appear to consistantly dip northwards in the Jibal Matalli (Ekren, 1984a), and al Qasr quadrangles (plate). These swarms presumably represent regional extension during the period when the alkali granites of the region were being emplaced. The dip on the dikes suggests that the Ha'il region was being extended northwards away from the Shield to the south. The Aja and Salma complexes notably have north-northeast axes sharply divergent and roughly at right angles to the trend of the swarms. The pre-dike alkali granites vaguely trend north, but this is difficult to define, in part due to their generally highly irregular outlines (fig. 10).

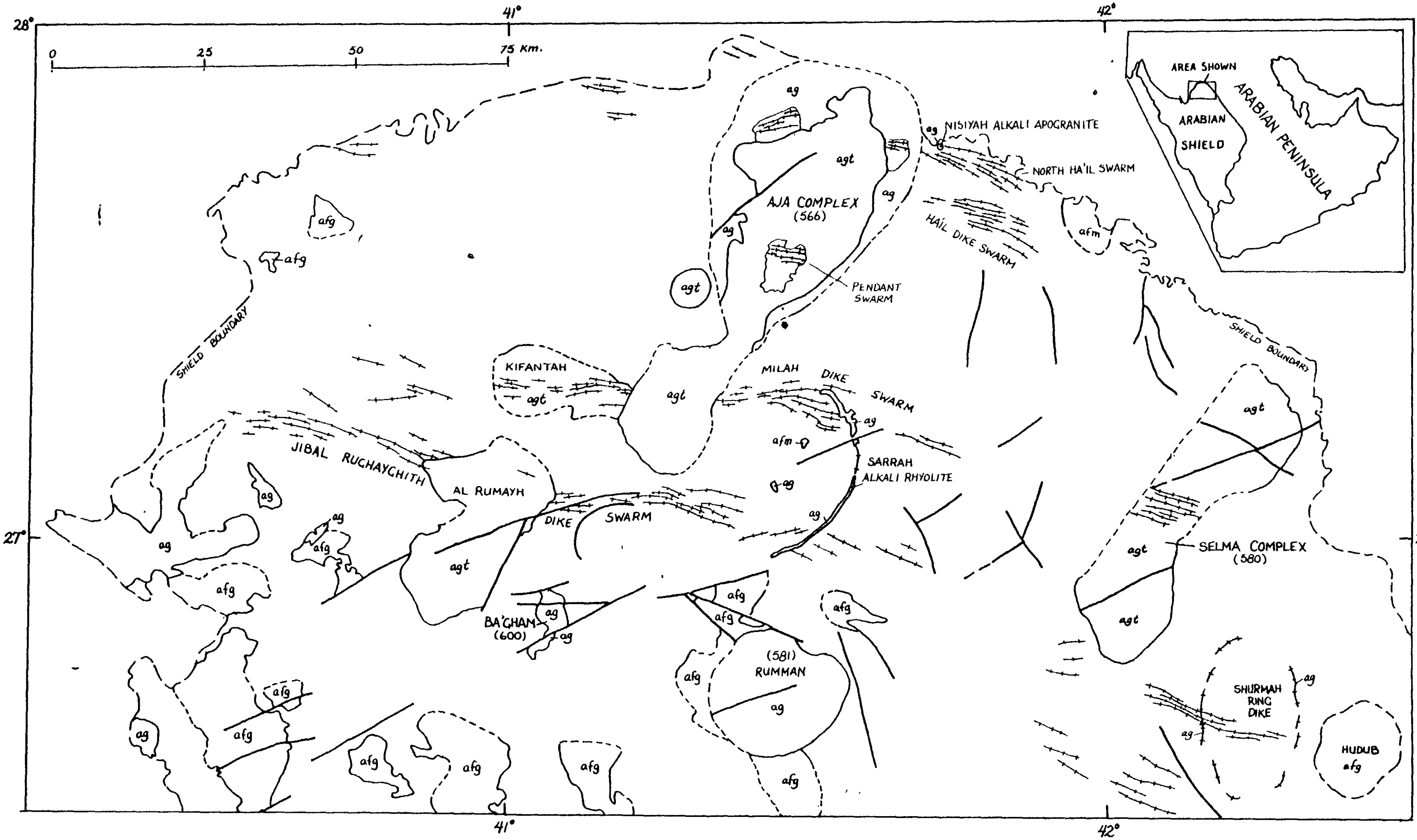

Figure 10.—Geologic map of the Ha'il region showing the distribution of post-orogenic alkali rhyolite dike swarms, metaluminous alkali-feldspar granites (afg), peraluminous alkali-feldspar granites (afm), transitional granite pluton which include both metaluminous and peralkaline granite (agt), and alkali granites (ag). Pluton and dike swarm names are also shown.

PRECAMBRIAN GEOLOGIC HISTORY AND GEOCHRONOLOGY

The earliest known rocks of the al Qasr quadangle are the mafic volcanics and hypabyssal rocks of the Banana formation. Ekren (1984) correlates these rocks with the Hulayfah group of Delfour (1977), and Quick and Doebrich (in press) tentatively support the idea that they may at least be coeval. The Hulayfah group in the Nuqrah region is reported to consist of andesite, dacite, quartz keratophyre and subordinate marble (Delfour, 1977; Calvez and others, 1983). The lithology of the Banana is similar (Quick and Doebrich, in press). The Banana formation also probably correlates with the Nuf formation of the Qufar quadrangle which consists of metabasalt, metaandesite, sparse marble and associated ultramafic rocks (Chevremont, 1982; Kellogg, 1983).

The age of the Banana formation, and that of the Hulayfah group, is very poorly constrained. Hedge (written communication, reported in Quick and Doebrick, in press; and in Ekren, 1984) has obtained an age of 735±10 Ma for a granodiorite that intrudes the Banana in Ghazzalah quadrangle. Further south, in the Nuqrah region, Calvez and others (1983) report an age of 720±10 Ma on a tonalite that intrudes the Hulayfah group, and two ages of 839±23 Ma and 821±48 Ma for quartz karatophyres of the Hulayfah group. The data suggest that the rocks of the Banana formation are older than 720-735 Ma, and may be considerably older. The Hulayfah group is not yet well defined in its type area and all regional correlations with it must be considered very tentative.

In any case, the lithologies of the Banana and Nuf formations suggest a very primitive crust of an ensimatic character (Calvez and others, 1983). Several geologists have interpreted the rocks of the Hulayfah group, including the Banana and Nuf formations, as being of island arc origin (Frisch and Al-Shanti, 1977; Kellogg, 1983, 1984; Stoeser and others, 1984; Stoeser and Camp, in press), whereas Ekren (1984) prefers an origin in a back-arc rifting environment. It is perhaps significant that clastic sediments appear to be rare in both the Banana and Nuf formations, suggesting the lack of an close highlands source area to generate significant amounts of sedimentation.

Possible support for an island arc formation of the early rocks of the al Qasr and surrounding quadrangles is the occurrence of diorite, quartz diorite, tonalite, and granodiorite plutons and complexes (such as the Mawqaq complex of the al Qasr quadrangle). The rocks are the type which should form in the core zones of island arcs. No geochronologic data are available for these rocks yet, and their association with the Banana formation, and that all of these rocks represent an island arc assemblage, can only be inferred. Similar rocks of the Laban complex to the southeast in the Jabal Habashi quadrangle have given a U/Pb zircon age of 646±6 Ma (Cole and Hedge, personal commun. cited in Williams and Johnson, 1984).

An episode of regional deformation is evidenced by widespread early cataclastic and foliated monzogranite to syenogranites that occur in the Qufar, Ha'il, al Hufayr and northern al Qasr quadrangles. Their relative age is poorly constrained, except that they clearly predate the Hadn formation. Pre-Hadn formation granitic rocks in the southern al Qasr quadrangle and further south in the Wadi ash Shu'bah quadrangle do not appear to be deformed and either the event did not affect this region or these rocks have not yet been identified there. The foliated granitoid rocks are likely older that 730 Ma, based on the ages of the later undeformed granitic rocks of this part of the Shield .

The amount of evolved granitic magmatism that occurred throughout the region (Stoeser and Elliott, 1980; Stuckless and others, in press ; Ekren, in press) is one of the most notable aspects of the al Qasr quadrangle, as for the whole of this part of the Arabian Shield. Current geochronologic studies indicate that this episode of granitic plutonism began about 630 Ma and continued until at least 570 Ma. A marked evolution of magma types is also indicated, with monzogranite and granodiorite being dominant in the early stages, grading to syenogranite and alkali-feldspar granites (630-600 Ma), and finally ending with widespread alkali granite (600-570 Ma).

Preliminary whole rock Rb/Sr isochron dating of 14 samples from the Hadn formation taken from its type section gave a preliminary age of 613 Ma (R. J. Fleck, written commun.). This suggests that the Hadn formation rocks are the effusive volcanic rocks normally associated with the earlier granites. Volcanic rocks of the Al 'Awshaziyah formation in the Al 'Awshaziyah quadrangle (Leo, 1984), and the Hibshi formation (632±6 Ma, U/Pb zircon age; Johnson and Williams, 1984) of the Habashi quadrangle (fig. 1), are probably approximately coeval with the Hadn and related to this episode of felsic magmatism. These rocks as a whole are part of the Shammar group felsic volcanic rocks that occur throughout the northeastern part of the Arabian Shield (Delfour, 1981).

The post-Hadn plutonic rocks can be subdivided into two groupings, pre- and post-alkali dike swarms. The pre-dike swarm plutonic rocks chiefly include monzogranite, syenogranite, and metaluminous to peralkaline alkali-feldspar granites, of which the latter appear to be the youngest members. The post-dike grouping of plutonic rocks is represented by the Aja suite of metaluminous to peralkaline alkali-feldspar granites and granophyres. The ages of the comendite-bearing dike swarms and of the pre-dike alkali-feldspar granites is fundamental. If the older granites are in fact significantly older than those of the Aja suite then it would appear to be more rational to recognize them as belonging to an older but similar suite rather than include them with the Aja suite. In the al Qasr vicinity, three U/Pb zircon ages are available for the later alkali granites: 581±5 Ma for the ar Rumman alkali granite of the Ghazzalah quadrangle (Stuckless and others, in press); 580±5 Ma for the Salma granite complex of the Rak quadrangle (Stuckless and others, in press;, and 566±4 Ma for the arfvedsonite-aegirine alkali granite of the Jabal Aja intrusive complex (Aleinikoff and others, 1985). Similar alkali granites to the southwest in the Nuqrah area (Delfour, 1977) are notably significantly older than the Aja suite (630-605 Ma) (Stuckless and others, in press).

Stuckless and others (in press) tentatively conclude that the postorogenic granites within the Najd fault zone are somewhat older (630 to 595 Ma) than similar granites to the north of the northern Najd boundary fault (580 to 565 Ma). In the al Qasr region, four of these plutons have been dated (Jabal Aja intrusive complex, Jabal Salma, Jabal ar Rumman, and Bagham). The Bagham alkali granite of the Ghazzala quadrangle was not included in the study of Stuckless and others (in press) but in a separate study (Stuckless and others, in press). The Jabal Salma and Aja granites are known to be younger than the east-west dike swarms of the Ha'il region, and the Jabal ar Rumman alkali granite pluton contains few dikes. The Bagham alkali granite, on the other hand, hosts a number of dikes including one east-striking swarm (Quick, 1983). Stuckless and others (in press) have estimated the age of the Bagham granite at 600 Ma, thus putting it into the older group of postorogenic granites. The authors feel it is premature to assume a fundamental difference in the age distribution of the postorogenic alkali-feldspar granites of the northern part of the Shield until the ages of the older (i.e. pre-dike) members of these granites have been determined.

Schmidt and others (1979), Stoeser and others (1984), and Stoeser and Camp (in press) have suggested that the formation of the eastern part of the Arabian Shield involved an early period of island arc formation (950-700 Ma) which was terminated by an episode of continental collision, in which the arc terrane in the west collided with one or more continental plates to the east (700-630 Ma). By this proposal, the Banana formation belongs to the pre-collision island arc assemblages and at least some of the early granitoids, particularly the foliated granitoids, are synorogenic plutonic rocks that formed during the peak period of collision. The later granitic rocks and the Najd wrench fault system to the south (Delfour, 1981) are viewed as intracratonic in origin but related to compression generated by continued collision, similar to the intracratonic tectonism occurring behind the present Himilayan collisional suture zone. After collisional activity waned, the Shield subsided and the epicontinental Cambrian-Ordovician Saq Formation sandstone was deposited over the northern part of the Arabian neocraton.

ECONOMIC GEOLOGY

The earliest mineral reconnaissance of the Ha'il region was by Hummel and others (1970) during 1964 to 1966. They found no significant mineral occurrences in the al Qasr quadrangle. They did note the occurrence of barren pegmatite and silicified fault breccia veins in the core of the Jabal Aja intrusive complex, and a barren silicified fault breccia in the Hadn formation west of al Jufayfah (their locality numbers 2599, 2600, and 2601 respectively).

A later mineral reconnaissance of the Ha'il region by Chevremont (1982) included the al Qasr quadrangle, where he concentrated on the Hadn volcanic rocks. Chevremont concluded ".....that the Jabal Hadn formation has no metallogenic potential. No mineral occurrences have been discovered within it, and the continental and essentially aerial nature of the silicic volcanism is an unfavorable factor for the existence of any economic mineralization." The authors feel this conclusion is perhaps a little harsh in that, as noted by Ekren (in press), the Hadn volcanics are very similar to those of western United States which are associated with calderas, and which are known to host molybdenium, copper, silver, and gold mineralization.

The 1966-1967 aerial scintillation counter survey of the Arabian Shield revealed a number of radiometric anomalies (2x to 3x background) within the Jabal Aja intrusive complex. Follow-up work by the authors and others failed to detect any mineralization associated with these anomalies (Meissner and Petty, written commun., 1970), and it is assumed that these anomalies are mainly due to mass effect coupled with non-altitude corrected data related to the irregular topography of the Jabal Aja intrusive complex. Some sparse niobium-thorium enriched veins occur along the eastern flank of the Jabal Aja intrusive complex in the Ha'il quadrangle (Meissner and Petty, written communication, 1970; Matzko and Naqvi, 1978). The occurrence of these veins and the Nisiyah alkali apogranite in the Ha'il quadrangle (Kellogg and Stoeser, 1985) and the small alkali apogranite (aga) in the al Qasr quadrangle suggest that Nb, Th, REE mineralization of the type found at Jabal Sayid and in the Midyan and central Hijaz regions (Drysdall and others, 1984) may also occur in the al Qasr quadrangle. Since no geochemistry is available on the al Qasr alkali apogranite futher work on this intrusion is recommended.

The occurrence of a possible zinnwaldite-bearing peraluminous granite, the muscovite-biotite alkali-feldspar granite (afm), is noteworthy. Similar granites elsewhere in the northeastern part of the Shield are associated with tin and tungsten mineralization (Cole and others, 1981; du Bray, in press), including the Akash tin greisen in the Ha'il quadrangle (Kellogg and Stoeser, 1985). Follow-up work on this intrusion is recommended.

No ancient mines are known within the quadrangle and the only reported Mineral Occurrence Documentation System (MODS) entries for the al Qasr quadrangle are for two occurrences of fluorite, one of which also had associated minor wolframite. The flourite-wolframite vein (MODS 02237) occurs within the Marma granite of the Jabal Aja intrusive complex and the other fluorite-bearing veins occurs within the pink core granophyre of the Jabal Aja intrusive complex (MODS 02244). The authors report an additional occurrence of vein fluorite within the Jabal Aja intrusive complex (MODS entry in process). This occurrence consists of fluorite-bearing quartz veins within an area of 6 by 20 meters and with pure zones of white, green and purple fluorite up to 15 cm thick. These veins are localized along a fault that cuts the Aja porphyritic rhyolite (ajr). Reported MODS occurrences are summarized in the table below.

MODS No.	Lat.N.	Long.E.	Commodity	Occurrence
02237	27°14'20"	41°16'10"	W, fluorite	Vein
02244	27°26'11"	41°28'07"	Fluorite	Vein
*	27°22'01"	41°22'25"	Fluorite	Vein

* MODS entry being processed.

The overall economic potential appears minimal, but mineral exploration within the quadrangle so far has been superficial. The probable existence of one or more caldera structures related to the Hadn formation volcanic rocks, the presence of an alkali apogranite intrusion, and a possible zinnwaldite-bearing peraluminous granite, indicates potential for granitophile elements Sn, W, Th, Ta, Nb, REE, Mo, and Au throughout much of the quadrangle

DATA STORAGE

Only one MODS entry resulted from this study (see above). All other data from this investigation are stored in Data-File USGS-DF-04-13.

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