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GEOLOGY OF THE AL JUNAYNAH QUADRANGLE,

SHEET 20/42 D,

KINGDOM OF SAUDI ARABIA

by

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ABSTRACT

The Al Junaynah quadrangle (sheet 20/42 D) is a 30-minute quadrangle mapped at 1:100,000 scale in the southern Najd province of Saudi Arabia. The quadrangle is located between lat 20°00' and 20°30' N. and long 42°30' and 43°00' E. The large ephemeral stream of Wadi Bishah crosses the quadrangle from southwest to northeast. Its extensive deposits record a cyclical, arid-pluvial climate during the Pleistocene and Holocene. Otherwise, the quadrangle is underlain entirely by late Proterozoic volcanic and plutonic rocks.

The quadrangle lies at the western edge of a younger crustal block of Halaban-age rocks and just east of an older crustal block of Jiddah-age rocks. The axis of a volcanic-magmatic arc of Halaban age lies to the east of the quadrangle and the region of the Al Junaynah quadrangle was a back-arc basin during Halaban volcanism.

The quadrangle is underlain in large part by calc-alkalic volcanic and volcaniclastic rocks of the Halaban group. Andesitic and dacitic rocks are dominant, and basaltic and rhyodacitic rocks are subordinate. The older, dominantly andesitic rocks are dated at about 785 m.y., but Halaban volcanism and volcaniclastic deposition probably extended to at least 720 m.y. ago.

Early subvolcanic, calc-alkalic plutons of hornblende diorite and gabbro, and late plutons of tonalite, trondhjemite, and granodiorite accompanied and were comagmatic with volcanism. Together, the volcanic and plutonic rocks constitute a primitive crust of Halaban age. This crust was substantially thickened at intermediate crustal depths during tonalitic and granodioritic plutonism about 725 m.y. ago. Intensive folding and faulting on northern trends was associated with the progressive development of the crust.

Orogeny culminated and granite plutonism began about 625 m.y. ago during the rise of the large Jabal al Qarah gneiss dome (asymmetrical antiform, 40 km wide), most of which lies to the east in the Jabal al Qarah quadrangle. All orogenic

structures trend northward. The earliest granitic rock, the leucocratic granodiorite-monzogranite batholith of Wadi Musayrah (15 km wide), was emplaced syntectonically late during the rise of the gneiss dome. The batholith was partly encased by a mobile, granodioritic migmatite (10 km wide) that grades into orthogneiss of the gneiss dome in the adjacent Jabal al Qarah quadrangle.

Between 625 m.y. and 600 m.y., posttectonic granite plutons of monzogranite, syenogranite, alkali-feldspar granite, and peralkalic granite were intruded at shallow crustal depths as erosion removed much of the upper part of the young Halaban crust. Two large ring-structured granite plutons are the deep roots of completely eroded caldera-type volcanoes. Explosive volcanism aided in bringing diabasic magma into these roots, and late intrusion of fractionated gabbro indicates that two magmas, one granitic and one gabbroic, coexisted at the base of the crust during posttectonic granite plutonism.

Basal conglomerate, arkosic sandstone, and siltstone of the Murdama group were deposited on the eroded posttectonic granite plutons. Murdama rocks are preserved only in downfaulted parts of large north-trending faults that are part of the north-south regional structure.

Development of the Halaban crust terminated with the Najd faulting event during latest Proterozoic or earliest Cambrian time. Although large faults of this event are not present in the Al Junaynah quadrangle, small fractures and many diabasic dikes of northwestern trend are present. Several small quartz veins bearing sparse base metals and rare gold resulted from hydrothermal activity during Najd time. They do not have economic potential at the present time.

INTRODUCTION

The Al Junaynah quadrangle (sheet 20/42 D) is in the Southern Najd quadrangle in the southwestern part of Saudi Arabia (fig. 1). The quadrangle lies between lat 20°00 and 20°30' N. and long 42°30' and 43°00' E. and encompasses approximately 2,895 km^2. Qalat Bishah, the largest village in the southern Najd, is located near the southern boundary of the quadrangle. Principal, well traveled, unimproved, dirt roads connect Bishah with At Taif to the northwest, with Ar Riyad to the northeast, and with Khamis Mushayt to the south. Numerous desert tracks crisscross the quadrangle and make vehicular access relatively easy, with the exception of the crossing of Wadi Bishah. Wadi Bishah cannot be crossed during a few days each spring when floodwater is high; most of the year the wadi bed is dry and sandy and can be crossed only with caution, in most places by motor vehicles. Maximum

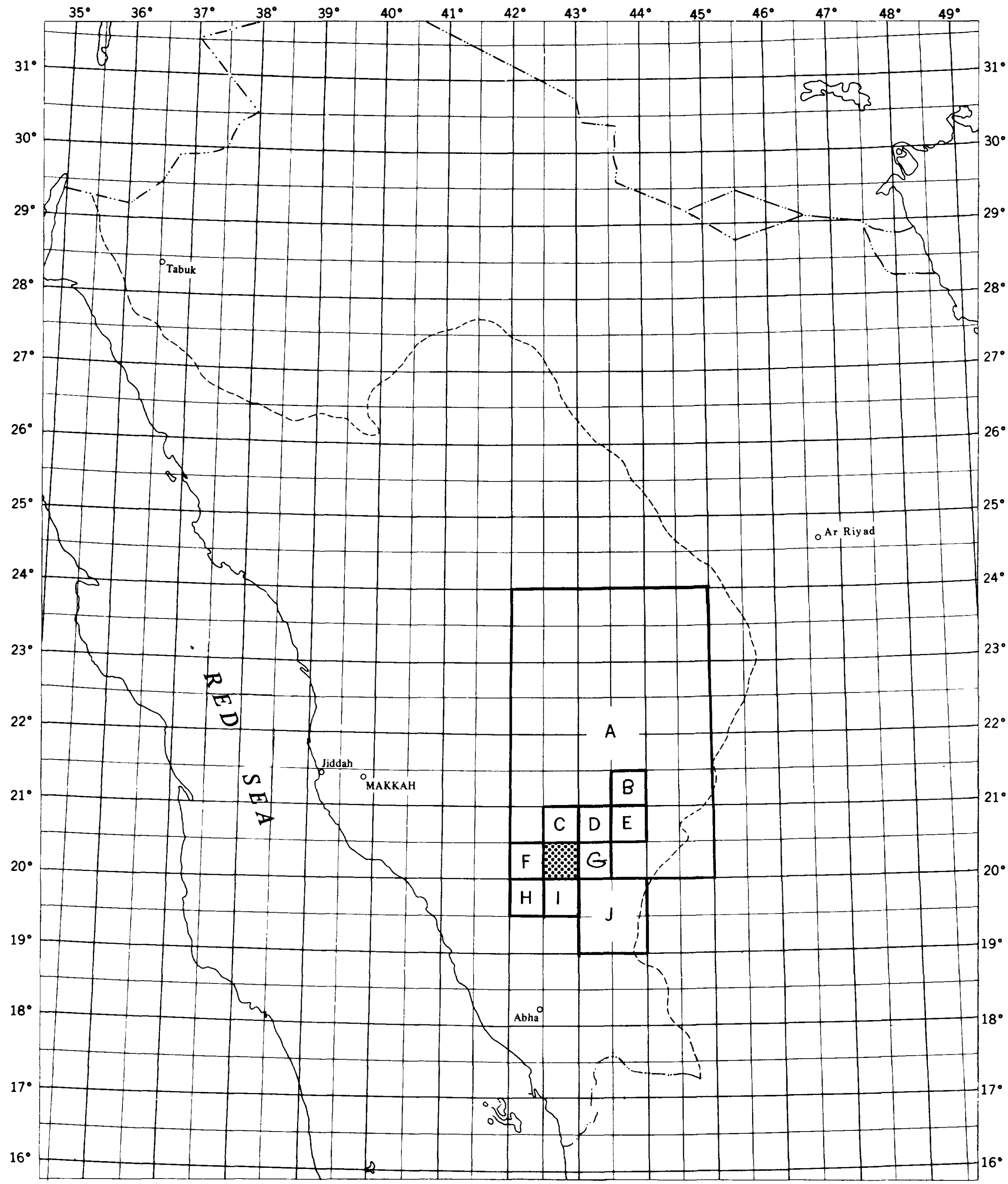

Figure 1.–Index map showing the location of the Al Junaynah quadrangle (shaded) and other quadrangles cited in this report: A, Southern Najd quadrangle (Jackson and others, 1963); B, Bi'r Juqjuq (Hadley, 1976); C, Wadi al Miyah (Schmidt, unpub. data); D, Jabal Ishmas (Gonzales, 1975); E, Jabal Yafikh (Schmidt, unpub. data); F, Thaniyat (Baghanem, written commun., 1976); G, Jabal al Qarah (Schmidt, unpub. data); H, Wadi Tarj (Anderson, 1977); I, Wadi Harjab (Cornwall, 1973); and J, Tathlith (Overstreet, 1978).

Lat. 20°-24°N Long 45°-42°E

average temperatures at about 1430 hours are about 22°C for January and over 40°C for July and August. Average temperatures at sunrise are about 8°C in January and 23°C in July and August.

About two-thirds of the quadrangle is an open, low-relief plain consisting of gently sloping pediments and dominated by the broad alluvial plain of Wadi Bishah. Above this plain, many hills and several small dissected mountain masses rise 50 to 100 m above their base pediments. The largest mountain mass, which includes Jabal as Sadah and Jabal as Sawad along the western border of the quadrangle, continues to rise in altitude to the west of the quadrangle, and the small mountain mass along the Junaynah fault zone in the southeast area continues to rise to the south. Most of the other hills and large inselbergs are underlain by granite, such as Jabal Khashmadheeb, Jabal ath Thamalah, and Jabal al Jafar, or by gabbro such as Jabal as Sidan. The broad alluvial deposits of Wadi Bishah cover approximately 20 percent of the quadrangle area, and sand dunes cover less than one percent.

Wadi Bishah has an altitude of 1,060 m at the northeastern corner of the quadrangle. The base-level plain rises to 1,160 m in the northwestern corner, and to 1,225 m in the southeastern corner; these altitudes were measured by helicopter altimeter in adjacent quadrangles. The altitude at Qalat Bishah is 1,161 m (Schyfsma, 1978).

Wadi Bishah drains the entire quadrangle. Wadi Tabalah, in the southwestern corner is the only large tributary to join Wadi Bishah in the quadrangle. Wadi Bishah has its headwater area in the high Asir Province to the south and intermittently carries floodwater into the Al Junaynah quadrangle during the winter or spring of most years. Annual ground-water recharge in the wadi alluvium can be relied upon only as far downstream as Junaynah. Seven kilometers downstream from Junaynah, Wadi Bishah contains low rapids in granitic bedrock, and downstream the annual recharge is erratic. During some years, floodwater does not reach this lower part of Wadi Bishah.

Several small villages, each with an adjoining date-palm grove, lie along the banks of Wadi Bishah as far north as Al Junaynah in the center of the quadrangle. In these villages, perennial ground water is available from shallow wells (birs) in the alluvium of the wadi. Downstream from Al Junaynah, where perennial ground water is not available, no villages exist; however, numerous wells dug in the wadi alluvium supply some water for parts of some years after seasonal floods. Two wells within the quadrangle are not along Wadi Bishah. The larger one, Bir Emgabliyah, is in the granite of Jabal al Jafar and may contain perennial water, whereas a smaller well in granitic gneiss, near Jabal Umm al Hashiyah, probably does not contain perennial water. Many sheep, goats, and camels are grazed in the quadrangle because water is available in the southern part of Wadi Bishah throughout the year. A few herds are those of the nomadic bedouin; however, many small herds belong to the sedentary populations of Bishah, Ranyah, and the smaller villages along Wadi Bishah.

Jackson, Bogue, Brown, and Gierhart (1963) first mapped the geology of the Al Junaynah quadrangle as part of the Southern Najd quadrangle at a scale of 1:500,000 (fig. 1). Total-intensity aeromagnetic maps at scales 1:100,000 and 1:500,000 (Andreasen and Petty, 1973) aided the geologic mapping and compilation of those rock units that have contrasting magnetic character. During 1964 and 1965, J. W. Whitlow (1971) made a brief geochemical survey of the Al Junaynah quadrangle based on samples of wadi alluvium; he located a small, ancient mine containing lead in the west-central part of the quadrangle.

During a mineral resource and geochemical survey, Overstreet (1978) mapped in reconnaissance the adjacent Tathlith one-degree quadrangle to the southeast. Other quadrangles mapped at scale 1:100,000 adjacent to the Al Junaynah quadrangle are shown on figure 1.

Field work for this report was done during parts of October and November 1971 and parts of January, February, March, and April 1972 and included 26 days of helicopter support and 26 days of vehicular (Landrover) traverse. 1,200 stations were occupied. Standard 9- by 9-inch aerial photographs at about 1:60,000 scale were used for mapping. A photomosaic at scale 1:100,000, prepared from this photography, is the base for the geologic map (plate 1). Photointerpretation was of limited use because most outcrops are coated by a black desert patina and much of the low-relief area is covered by a thin layer of eluvium and eolian sand. Approximately 775 polished slabs and thin sections were studied; all slabs were stained to facilitate identification of potassium feldspar.

Between 27 and 29 April 1972, Robert J. Fleck, and the author collected 11 samples of granitoid rock and 22 samples of metavolcanic-metasedimentary rock from the Al Junaynah quadrangle for geochronological study. On 26 February 1974, two additional samples of granitic rock were collected from the batholith near the eastern edge of the quadrangle.

This report was prepared in accordance with a work agreement between the U.S. Geological Survey and the Saudi Arabian Ministy of Petroleum and Mineral Resources. Excellent logistic and personnel support was provided by the Directorate General of Mineral Resources (D.G.M.R.). Ahmed H. al

Bazli assisted in part of the fieldwork and Wais I. Assumali cut and stained many rock specimens in the field. Ghanim Jeri Alharbi thoroughly prospected the quadrangle for mineral deposits and located occurrences of gold, chromium-nickel, and fluorite. Ralph J. Roberts visited and helped to evaluate two of the quartz-vein prospects in the quadrangle. Special thanks are due to Ahmed Hasan Nabhan, camp boss, and to Mohammed ibn Salayma Gharbi, camp guard. In the office Abdul Kader M. Afifi and Ahmed H. al Bazli made many modal analyses of the granitic rocks.

PRECAMBRIAN SEDIMENTARY AND VOLCANIC ROCKS

Volcanic and volcaniclastic rocks assigned to the Halaban group and conglomerate and sandstone assigned to the Murdama group are exposed in the Al Junaynah quadrangle. The Halaban group rocks are predominantly andesitic and dacitic and include subordinate basaltic and rhyodacitic rocks. Areas of exposure are small and scattered throughout the quadrangle and, as a result, the stratigraphic succession is not fully known and thicknesses have not been determined. The rocks have been intensely isoclinally folded, faulted, and metamorphosed to the greenschist facies. About half of the rocks have been metamorphosed to higher grades. Lithologies of the rocks were determined by field observation and by the study of 65 polished and stained slabs and thin sections.

The volcanic and volcaniclastic rocks are assigned to the Halaban group (Schmidt and others, 1973) on the basis of their lithology, which is similar to rocks assigned to the Halaban group in the adjacent Jabal al Qarah quadrangle. (Schmidt, unpub. data). Strong support for a Halaban group assignment comes from rubidium-strontium (Rb-Sr) studies within the quadrangle and in quadrangles to the north and east (Fleck and others, 1979). The Halaban rocks are subdivided on the basis of their predominant lithologies (plate 1). The suggested progression from more mafic to more silicic rocks with decreasing age coincides with that of other areas such as the Bi'r Juqjuq quadrangle (Hadley, 1976) where the volcanic succession is tentatively known.

Rocks assigned to the Jiddah group have been mapped to the southwest in the adjacent Wadi Tarj quadrangle (Anderson, 1977). It is possible that some of the volcanic and volcaniclastic rocks of the western part of the Al Junaynah quadrangle would be more appropriately assigned to the Jiddah group. However, a preference is given here to the Halaban group; Jiddah rocks are considered to occur slightly farther west of the quadrangle.

Halaban group

Basaltic and volcaniclastic rocks

The basaltic and volcaniclastic rocks underlie one small area, 7 km long by 1.5 km wide, in the southwestern part of the Al Junaynah quadrangle. They underlie a sinuous ridge consisting of resistant porphyritic flows of basaltic and andesitic composition. The rocks are dark green, very fine grained, and commonly contain 15 to 30 percent tabular phenocrysts of plagioclase, as long as 2 mm. These rocks are likely part of the adjacent map unit of andesitic and volcaniclastic rocks, but are shown separately because they illustrate the overall layered nature of the rocks in this area.

Andesitic and volcaniclastic rocks

The andesitic and volcaniclastic rocks are exposed in areas throughout the quadrangle. They are more massive and resistant than the rocks of adjacent map units, and therefore underlie areas of higher relief. The type area for the andesitic and volcaniclastic rocks is a few kilometers east of Jabal Yellah where they are assumed to be stratigraphically below dacitic and volcaniclastic rocks to the east. Three samples of andesite tuff from the type area (locality 1, pl. 2) have an indicated age of 785$\pm$ 2 m.y. by a Rb-Sr, whole-rock isochron (initial Sr ratio, 0.7025; Fleck and others, 1979). This suggests an early Halaban age.

The rocks consist of abundant andesitic crystal, lithic pyroclastic tuffs, subordinate basaltic and andesitic flows, and minor dacitic pyroclastic rocks. Volcaniclastic conglomerate, sandstone, and agglomerates are subordinate. The volcanic rocks are dark green, very fine grained, and commonly contain lithic fragments and phenocrysts.

Dacitic and volcaniclastic rocks

The dacitic and volcaniclastic rocks are exposed chiefly in the southeastern and northeastern parts of the quadrangle; two small areas were also mapped in the northwestern corner and between Jabal al Jafar and Jabal ath Thamalah. The rocks are less resistant than rocks of the other volcanic map units and underlie a low hilly terrain. The type area is along the southern border of the quadrangle, southeast of Jabal Yellah.

The rocks are predominantly dacitic to rhyodactic tuffs, commonly crystal and lithic tuffs. Dacitic to rhyodacitic flows, agglomerates, breccias, and welded tuffs are less common. Porphyritic andesitic flows, tuffs, and pyroclastic tuffs are subordinate, and argillite, conglomerate, and sandstone are sparse. Subordinate marble is characteristic; thick beds and lenses show intensive shear flowage. Most rocks are tan to brown but many are light gray to medium greenish gray. The rocks are fine grained to aphanitic, some are devitrified, and a few show lithophysal textures. Most of the rocks are chlorite-sericite-quartz schists as a result of intensive shearing and metamorphism to the greenschist facies. Contact metamorphism at some localities produced a dark-brown, siliceous, biotite hornfels and conspicuous calc-silicate rocks (tactites).

The dacitic and volcaniclastic rocks are probably part of the upper Halaban group and possibly correlate with part of the Arfan formation of the Juqjuq quadrangle (Hadley, 1976).

Volcaniclastic and andesitic rocks

The volcaniclastic and andesitic rocks are a distinctive, very well-bedded, predominantly clastic unit mapped in two small areas along the western border of the quadrangle. The type area is northwest of Jabal as Sawad.

The rocks are andesitic tuffs and reworked detrital tuffs containing subordinate dacitic to rhyodacitic crystal and lithic tuffs. Flows of andesite and basalt are sparse. One 8-m-thick, rhyodacitic, crystal-lithic tuff is welded and has a devitrified base that indicates the section is right side up at this locality. The abundant, well-bedded, commonly laminar bedded, detrital rocks are very fine to fine grained; graded bedding is common and indicates that the clastic part of the section is also right side up. One andesitic breccia contains a matrix of 40 percent marble, but calcareous beds are not common. The rocks are mostly light to medium gray; a few are tan to dark brown. In places the rocks are metamorphosed to hornfels of the amphibolite facies in contrast to the prevalent greenschist facies. The volcaniclastic and andesitic rocks have relatively well-preserved textures and structures and seem to be the youngest Halaban rocks in the quadrangle.

Nondivided Halaban rocks

The nondivided Halaban rocks consist of volcanic and volcaniclastic rocks that have been contact metamorphosed to amphibolite facies or higher grade. Most of these rocks are exposed in the western two-thirds of the quadrangle, where they constitute roof pendants, screens, and inclusions in the subvolcanic plutons of Halaban age primarily in the granodiorite-and-tonalite map unit. The rocks of the nondivided map unit grade across approximately located contacts such as south of Jabal al Jafar, into less metamorphosed volcanic and volcaniclastic rocks of the Halaban group--the nondivided rocks are obviously part of the Halaban group.

The type area is just west of Jabal al Jafar. Well-preserved sedimentary features and micro-scale fold structures are seen in thin-bedded, siliceous, biotite-garnet hornfels and amphibole-pyroxene hornfels. The rocks weather black and their internal textures and structures are seen only by slight differential weathering. Much of the rock just west of Jabal al Jafar is siliceous and the rock here probably correlates with the dacitic and volcaniclastic rocks in the adjoining area to the east. Rocks mapped as nondivided Halaban in the southwestern part of the quadrangle are chiefly amphibolites that probably correlate with the adjacent basaltic-and-volcaniclastic rocks and andesitic-and-volcaniclastic rocks. The large screen of nondivided Halaban rocks, 1 to 4 km wide by 15 km long, east of Jabal Biyon, consists of volcanic and volcaniclastic rocks of amphibolite facies that were initially tightly folded and intruded by subvolcanic hornblende diorite and were later intruded and isolated by the granodiorite-and-tonalite rocks.

Murdama group

Rocks assigned to the Murdama group consist of a basal, polymictic conglomerate and overlying thick-bedded sandstones and thin-bedded siltstones. They are restricted to a narrow belt, 34 km long by as wide as 3 km, in the large fault zone passing through Junaynah and east of Jabal Yellah. The clastic rocks dip about 45 degrees to the east in large, fault-bounded blocks. Along the block margins, however, the rocks are intensely sheared and have vertical attitudes. The type section is 6 km south of Jabal al Amoudah, where about 300 m of conglomerate is overlain by about 800 m of well-bedded, purple sandstone and siltstone. The section is internally faulted and the top boundary is a fault. The Murdama rocks lie disconformably upon the alkali-feldspar granite at Jabal Yellah. The granite is tentatively dated at about 600 m.y. and the Murdama rocks are younger.

The basal polymictic conglomerate along the western side of the Murdama outcrop belt lies disconformably on the granodiorite-and-tonalite map unit and on the alkali-feldspar granite. The basal surface of the conglomerate is generally flat, and a paleotalus deposit, a few meters to many meters thick, was deposited on a deeply weathered, granitic paleosurface. The talus consists of locally derived, angular granitic blocks, ranging from a few centimeters to 30 cm in diameter. In many places, small paleochannels, for example 1 m deep by 100 m wide, were cut into the underlying granitic rock. At the type locality, the conglomerate filled a broad valley more than 300 m deep. The depth of the paleovalley and thickness of the conglomerate fill decrease to the south; for example, 2 km to the south, several thin conglomerate beds grade downward into talus on the granite bedrock surface. At the type locality, the conglomerate consists of large, well-rounded clasts of red granite in thick, massive beds that exfoliate and weather into rounded, bulbous surfaces that mimic outcrops of the massive granite bedrock. Thin, discontinuous beds of sandstone define bedding. In many beds, the average size of cobbles is 20 cm, and some beds contain many boulders about 1 m across.

The sandstone and siltstone member grades upward from thick, well-bedded, interbedded gritstone and sandstone to thin, well-bedded, fine-grained sandstone and siltstone. Beds of coarser grained rocks are commonly 30 to 60 cm thick, whereas beds of the finest grained rocks are laminated and commonly range from 1 to 20 mm thick. Some beds show graded bedding. The rocks are commonly reddish gray and are arkosic in that much of the detritus was derived from granitic rocks. Some detritus was derived from the Halaban volcanic rocks and where such detritus is abundant, the clastic rocks are green. The rock is mostly immature to submature, and clasts are mostly subangular. A few of the finer grained beds are calcareous.

Near faults, the clastic rocks are highly sheared and altered to fine- and coarse-grained sericite-quartz schists. In the conglomerate beds, the pebbles and cobbles may be tectonically stretched to as much as 4 times their original diameters.

PRECAMBRIAN INTRUSIVE ROCKS

The plutonic and dike rocks of the Al Junaynah quadrangle range in composition from gabbro to alkali-feldspar granite. In age, these intrusive rocks range from those synchronous with volcanism of Halaban age to those slightly older than the Murdama group. In addition, abundant mafic and some felsic dikes are younger and correspond to the age of the Najd faulting, that is, latest Precambrian. The intrusive rocks underlie about 65 percent of the quadrangle. The plutonic rocks in this report are classified according to recommendations of the International Union of Geological Sciences (IUGS), Subcommission on the Systematics of Igneous Rocks (Streckeisen, 1973, 1976; fig. 2), with exception one map unit is named "peralkalic granite" for an alkali-mafic, alkali-feldspar granite of the IUGS classification.

The lithologic and petrographic data for most of the plutonic rocks in the Al Junaynah quadrangle are summarized in table 1. About 700 polished slabs and thin sections of the plutonic rocks were studied. All the polished slabs were stained to facilitate the identification of potassium feldspar. About 150 modal analyses of quartz, potassium feldspar, plagioclase, and mafic minerals (200 to 500 counts per specimen) were made of representative specimens of the plutonic rock units. The number of modal analyses for each rock unit was considered adequate to define and classify each unit. The modal analyses are plotted on ternary diagrams (fig. 3-17) showing contents of quartz, alkali-feldspar, and plagioclase recalculated to the sum of 100 percent. For some units, additional modes were estimated to aid in defining the units.

The plutonic units are divided into pretectonic, syntectonic, and posttectonic suites according to the most significant orogenesis during which the Jabal al Qarah gneiss dome rose and the granodiorite-monzogranite of Wadi Musayrah was emplaced (see structure chapter).

Pretectonic plutonic rocks

The pretectonic rocks include the map units metagabbro, hornblende diorite, tonalite, trondhjemite, granodiorite-and-tonalite, and granodiorite (table 1). All but the tonalite and granodiorite units are subvolcanic rocks as defined for similar rocks in the Jabal al Qarah quadrangle (Schmidt, unpub. data). All the units represent primary crust that formed penecontemporaneously with the volcanic rocks of Halaban age. All the rocks have been sheared and recrystallized during greenschist facies metamorphism; those in the western half of the quadrangle have been more highly metamorphosed than those of the eastern half. In spite of intensive metamorphism, relict magmatic textures are preserved in many rocks.

Metagabbro and serpentinite

The metagabbro unit consists of gabbro, leucogabbro, and subordinate ultramafic rock and serpentinite. At two localities, serpentinite is mapped separately. Most of the rocks are small bodies intruded into the volcanic and volcaniclastic rocks or are large inclusions isolated in younger plutonic rocks. The metagabbro was probably synchronous with the hornblende diorite. The type area for the metagabbro is the body 5 to 7 km northeast of Qalat Bishah. The metagabbro is dark gray to black, medium grained, and consists of calcic plagioclase, clinopyroxene, and olivine. These minerals are altered to hornblende, oxybiotite, and serpentine. The rock is massive and generally poorly exposed. Relict compositional layering is found in some bodies, but is largely obscured by subsequent deformation, fragmentation, and metamorphism. Most of the rock is well foliated and metamorphosed to greenschist facies.

Table 1.--*Lithologic and petrographic data for the*
[NI, indicates insufficient data;

Estimated age (million years)	Letter symbol rock name (plate 1) (type locality)	Principal lithology	Texture and structure	Essential Mineralogy[1]
600	gbs Gabbro of Jabal as Sidan (Jabal as Sidan)	Leucogabbro troctolite, dunite anorthosite	Dark-gray, medium-grained, alliotriomorphic granular locally ophitic; concentric, compositional layering; layers dip steeply inward to subhorizontally layered core; many rocks flow foliated	Plagioclase olivine orthopyroxene clinopyroxene hornblende oxybiotite
600	gph Granophyre (Jabal as Sidan)	Monzogranite(?) to alkali-feldspar granite	Dark red brown, very fine- to medium-grained, some porphyritic, heterogenous texture, mostly xenomorphic inequigranular; micrographic, commonly spherulitic; little alteration	K-feldspar plagioclase quartz hornblende biotite ±acmite +riebeckite
600	gpa Peralkalic granite (Jabal Khashmadheeb	Alkali-mafic, alkali-feldspar granite	Light-gray to light-red, fine- to coarse-grained, some porphyritic, seriate, allotriomorphic granular; myrmekitic; some flow foliation	Perthite quartz albite ±hornblende ±acmite ±riebeckite ±aenigmatite ±biotite
600	gra Alkali-feldspar granite (Jabal Khashmadheeb)	Alkali-feldspar granite	Red, medium- to coarse-grained, commonly porphyritic, coarse-rounded grains of K-feldspar and quartz, subhypidiomorphic inequigranular; myrmekitic; some flow foliation	Perthite quartz albite hornblende ±biotite ±(aegirene-augite)
600	db Diabase (East of Jabal Khashmadheeb)	Diabase	Dark, fine- to medium-grained, diabasic texture moderately to intensely altered	Plagioclase clinopyroxene hornblende biotite ±oxybiotite ±quartz
		and hybrid rocks from quartz monzogranite to syenogranite	Medium dark-red or gray to light-red, heterogeneous texture, mixed fine- and medium-grained and commonly porphyritic, seriate, allotriomorphic inequigranular, granoblastic. Color and mafic composition closely related to proximity to diabase.	K-feldspar quartz plagioclase hornblende ±biotite ±aegirine-augite?
600	gra Alkali-feldspar granite (Jabal Yellah)	Alkali-feldspar granite	Red, coarse-grained, homogeneous, massive, allotriomorphic inequigranular	Perthite quartz albite biotite ±(hornblende) (pyroxene?)
o25-600	grm Monzogranite (northwest corner, south of Wadi Dhahab)	Monzogranite	Light-gray to pink, medium-grained allotriomorphic to hypidiomorphic inequigranular, some porphyritic, myrmekite common	Plagioclase K-feldspar quartz biotite ±hornblende
625	gmm Granodiorite-monzogranite of Wadi Musayrah (Jabal al Qarah quadrangle)	Monzogranite and granodiorite	Light-gray, medium-grained, subhypidio-inequigranular, seriate, granoblastic; myrmekite common; moderately foliated; mineral and gneissic layering	Plagioclase K-feldspar quartz biotite ±hornblende

principal plutonic rocks of the Al Junaynah quadrangle
(), mineral or rock subordinate]

Accessory Mineralogy[3]	Secondary Mineralogy	Feldspar characteristics	Color index[2] average (range)	Remarks	Relation to tectonism
Magnetite ±pyrite	±Serpentinite ±(chlorite) ±(carbonate)	Labradorite, commonly tabular and flow oriented.	30 (8-95)	Layering formed by multiple injection; thick dunite layers in and adjacent to core.	Postkinematic
Magnetite apatite ±zircon ±fluorite	±(chlorite) ±(saussurite) ±(epidote) ±(clinozoisite) ±(sericite) ±(carbonate)	K-feldspar in coarse-grained rock is partly perthitic of patchy type, some fine-textured microcline; plagioclase is sodic.	3 (1-5)	A hypabyssal intrusion, in part cut by dikes of same composition; granophyre probably intruded related volcanics in places.	Postkinematic; volcanic in parts?
Magnetite apatite ±zircon ±fluorite ±epidote	Little altered	K-feldspar, mostly perthite, patchy and veined types, some microcline, commonly as large phenocrysts; albite mostly interstitial, some rims on K-feldspar.	6 (4-8)	Rock emplaced late into nearby crystallized alkali-feldspar granite, some as ring dikes; conformable to ring structure of alkali-feldspar granite.	Postkinematic
Magnetite apatite zircon fluorite ±allanite	Little altered	K-feldspar is perthitic, veined type common, some patchy type common as large rounded crystals, commonly zoned; albite mostly interstitial.	4 (3-6)	Jabal Khashmadheeb an oblong semi-ring-structured body. Granitic and gabbroic magma coexisted at depth and alkali-feldspar granite and diabase intruded penecontemporaneously.	Postkinematic
Magnetite apatite ±pyrite ±(allanite) ±(zircon)	±(chlorite) saussurite ±(epidote) ±(carbonate)	Plagioclase fresh relative to older rocks; composition commonly andesine or more albitic; some rocks highly biotitic; sparse K-feldspar locally replaces some plagioclase during deuteric alteration.	40 (20-55)	Diabase is product of fractionated gabbro at depth.	Postkinematic
Magnetite apatite zircon ±allanite ±epidote	±Oxybiotite ±(chlorite) ±saussurite ±sericite	K-feldspar, perthitic, patchy type common, some veined type; sparse microcline; some myrmekite; plagioclase mostly anhedral, not well twinned, some patchy zoning.	12 (5-20)	Coexisting diabase and granite magma results in hybridized rock of variable and heterogeneous composition and textures.	Postkinematic
Magnetite fluorite zircon ±(allanite) ±(muscovite)	Saussurite (iron oxide) ±(chlorite) ±(sericite) ±(epidote) ±(calcite)	K-feldspar is perthite of coarsely veined and patchy type, large coarse albite content common perthite is saussuritized; albite content entirely in perthite; albite is slightly saussuritized.	2 (1-4)	Granite of the Jabal Yellah pluton is the most homogenous and massive--and has the least developed primary structures--of the posttectonic granite bodies.	Postkinematic
Magnetite NI	Chlorite sericite NI	Some euhedral, zoned plagioclase where preserved; K-feldspar anhedral, replaces plagioclase, some porphyroblastic microcline common, some perthite.	6 (4-9)	Plutons mostly as small bodies.	Postkinematic
±Magnetite ±apatite ±sphene ±allanite ±zircon	±Chlorite NI	Some euhedral, zoned plagioclase preserved, mostly deformed, cataclastic, some augen; some replacement by K-feldspar during post magmatic deuteric alteration. K-feldspar interstitial, porphyroblastic, poikilitic, and commonly irregularly distributed in detail; some is microcline, some perthite.	8 (2-15)	Forceful, viscous, deep intrusion with abundant late protoclasis and K-feldspar recrystallization; post magmatic autometamorphism.	Late-kinematic

Table 1.--*Lithologic and petrographic data for the*

Estimated age (million years)	Letter symbol rock name (plate 1) (type locality)	Principal lithology	Texture and structure	Essential mineralogy[1]
725 and 625	gnh Migmatite of Jabal Umm al Hashiyah (Jabal Umm al Hashiyah)	Granodiorite and monzogranite	Medium and light-gray, mixed fine- and medium-grained, seriate, inequigranular, granoblastic, locally porphyroblastic; myrmekitic; highly foliated, mineral and gneissic layering	Plagioclase quartz K-feldspar biotite
725	gd Granodiorite (North of Jabal Umm al Hashiyah)	Granodiorite	Gray, medium-grained, hypidiomorphic granular where preserved, seriate; moderately foliated	Plagioclase quartz K-feldspar hornblende biotite
725?	gdt Granodiorite and tonalite (area between Jabals Biyon and Yellah)	Granodiorite and tonalite	Medium to light-gray, medium-grained, relict hypidiomorphic granular; commonly seriate granoblastic; variably nonfoliated to intensely foliated	Plagioclase quartz K-feldspar biotite ±hornblende
740	to Tonalite (North of Wadi Tabalah on west border)	Tonalite	Medium-gray, medium-grained, relict hypidiomorphic granular; mostly intensely sheared and irregularly potassium metasomatized in and adjacent and abundant faults; intruded by late, potassic granite dikes	Plagioclase quartz hornblende biotite
740?	tj Trondhjemite (Southeast of Jabal as Sadah)	Trondhjemite and tonalite; secondary granodiorite	Medium-gray, medium-grained, hypidiomorphic granular seriate, locally porphyritic and graphic textured; commonly mortar textured and foliated by subsequent cataclasis and shear with associated local potassium metasomatism	Plagioclase quartz hornblende biotite
>740? <785	hd Hornblende diorite (North of Jabal as Sawad)	Diorite subordinate quartz diorite and metagabbro	Dark- to light-gray, medium-grained, massive, hypidiomorphic granular seriate, commonly moderate to strong superposed shear foliation	Plagioclase hornblende ±biotite ±clinopyroxene ±quartz
>740? <785	mgb Metagabbro (Northeast of Bishah)	Gabbro and leucogabbro; subordinate ultramafic and serpentinite	Dark-gray to black, medium-grained, allotriomorphic granular; commonly massive; common superposed tectonic foliation	Clinopyroxene plagioclase ±olivine ±hornblende ±biotite

1 Mineralogy listed in order of decreasing abundance from modal count; K-feldspar is potassium feldspar-nonspecific; ±, mineral present in some rocks.
2 Average percent mafic minerals by modal count; range in parentheses.
3 Magnetite as black magnetic opaque mineral, some may be ilmenite.

Accessory Mineralogy[3]	Secondary Mineralogy	Feldspar characteristics	Color index[2] average (range)	Remarks	Relation to tectonism
Magnetite ±apatite ±hornblende ±sphene ±allanite ±zircon	±Chlorite ±muscovite ±sericite NI	Plagioclase is cataclastic, K-feldspar heterogeneous in size and distribution, anhedral, some is poikiloblastic and porphyroblastic, some microcline.	8 (3-18)	Irregular, broad, zone of migmatite between orthogneiss of the Al Qarah dome and granodiorite-monzogranite of Wadi Musayrah batholith; plastic cataclastic flow associated with gneiss doming and batholithic intrusion.	Synkinematic
Magnetite allanite epidote sphene apatite	(chlorite) NI	Abundant euhedral and zoned plagioclase; K-feldspar interstitial but irregularly distributed.	16 (11-24)	Intermediate depth batholithic intrusion of uniform composition; moderately deformed and metamorphosed.	Prekinematic
Magnetite aplite ±sphene ±zircon	Chlorite saussirite NI	Plagioclase (andesine) euhedral and zoned where preserved; mostly altered some primary K-feldspar in most rocks, much irregular reworking and redistribution of K-feldspar plus local late K-metasomatism.	10 (1-20)	Compound intrusion of primary, subvolcanic plutons; rocks are complicated by polyphase tectonism, metamorphism, and local redistribution of K-feldspar.	Prekinematic
Magnetite apatite ±allanite ±sphene	Biotite chlorite ±epidote ±zoisite saussirite albite	Plagioclase (andesine) euhedral and zoned where preserved mostly saussuritized; common irregular K-feldspar replacement of plagioclase and loss of mafic minerals in late shear faults.	14 (12-17)	Border phase of large batholith; may be comagmatic with trondhjemite unit. Highly modified by late fault deformation.	Prekinematic
Magnetite apatite ±sphene ±allanite ±zircon	Biotite hornblende chlorite actinolite epidote ±zoisite ±sericite ±calcite ±K-feldspar	Plagioclase (andesine) euhedral and zoned where preserved, mostly saussuritized, common irregular K-feldspar replacement of plagioclase and cataclastic mortar.	10 (5-23)	A primitive, low potassium intrusive rock that has been thoroughly deformed and metamorphosed several times.	Prekinematic
Magnetite apatite ±sphene ±pyrite	Biotite chlorite actinolite epidote magnetite albite sericite ±calcite ±K-feldspar	Calcic plagioclase, euhedral and zoned where preserved, mostly highly altered; local K-feldspar replacement of plagioclase, mostly in sheared rocks.	40 (20-70)	Entirely metamorphosed and partly tectonized; in western half of quadrangle, mostly dark colored and of biotite and amphibole facies,, in northeast, chlorite facies.	Prekinematic
Magnetite apatite ±chromite ±pyrite	Amphibole biotite chlorite albite(?) ±serpentine	Calcic plagioclases mostly altered to more sodic types.	50 (30-70)	Variable and fine-grained textures suggests subvolcanic intrusion; common as large remnants in younger intrusive rocks. Mostly well tectonized and moderately metamorphosed to greenschist facies.	Prekinematic

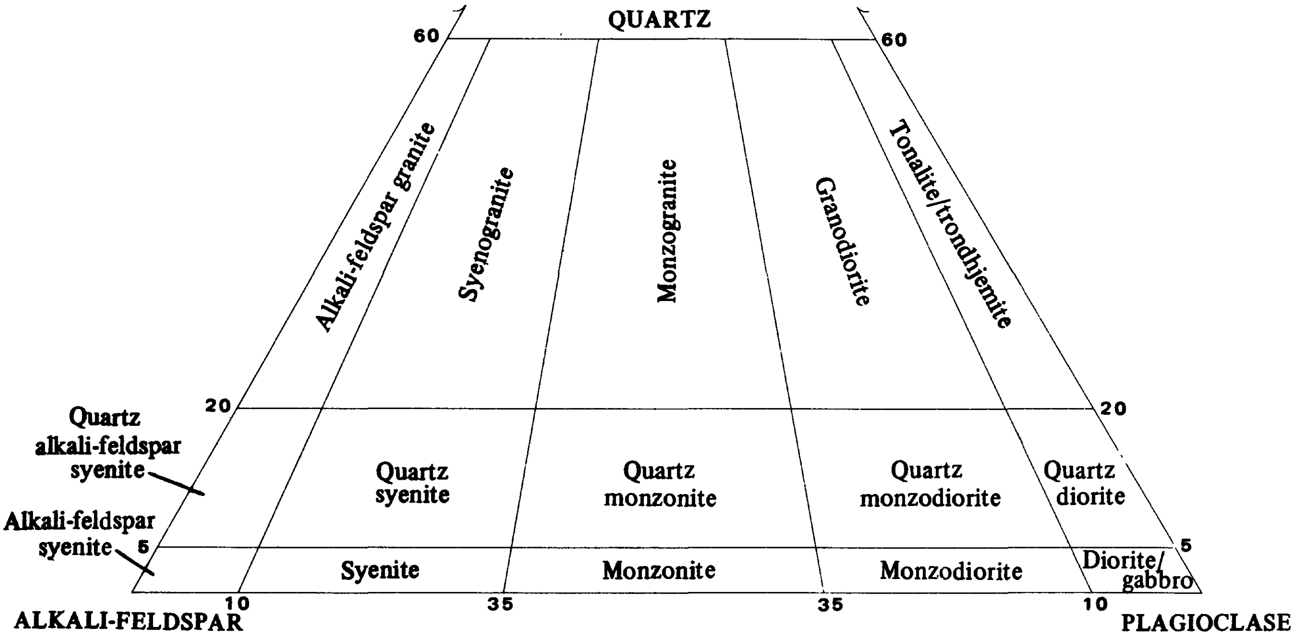

Figure 2.–Plutonic rock classification used for rocks of the Al Junaynah quadrangle; classification recommended by the International Union of Geological Sciences (IUGS), Subcommission on the Systematics of Igneous Rocks (Streckeisen, 1973; 1976).

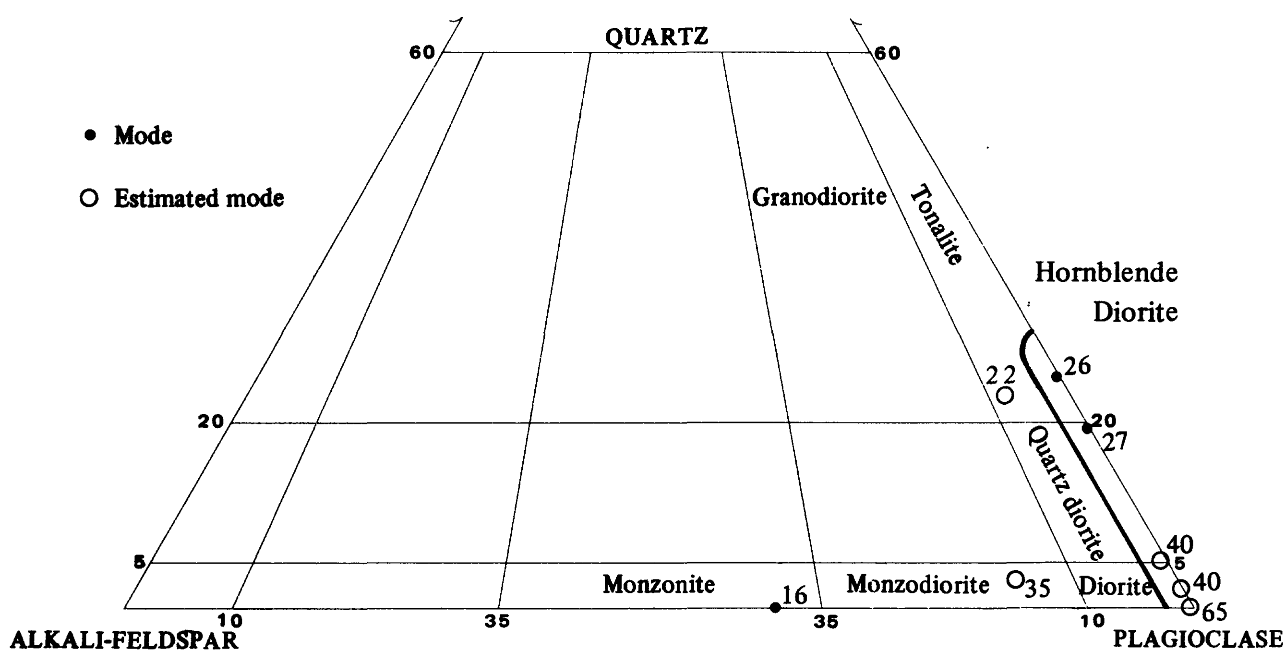

Figure 3.–Modal composition of hornblende diorite from the Al Junaynah quadrangle. A few rocks are potassium feldspathized. Line encloses type rocks. Numbers are mafic mineral content in percent.

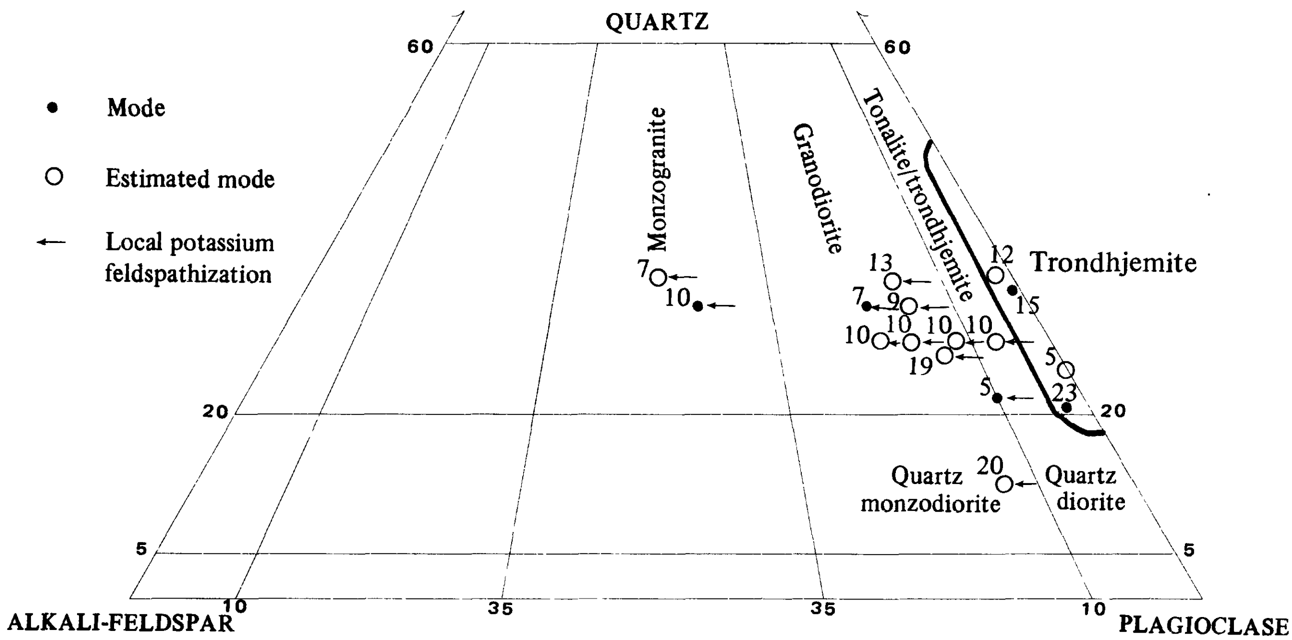

Figure 4.–Modal composition of trondhjemite from the Al Junaynah quadrangle. Many rocks are locally potassium feldspathized. Line encloses typical initial rock. Numbers are mafic mineral content in percent.

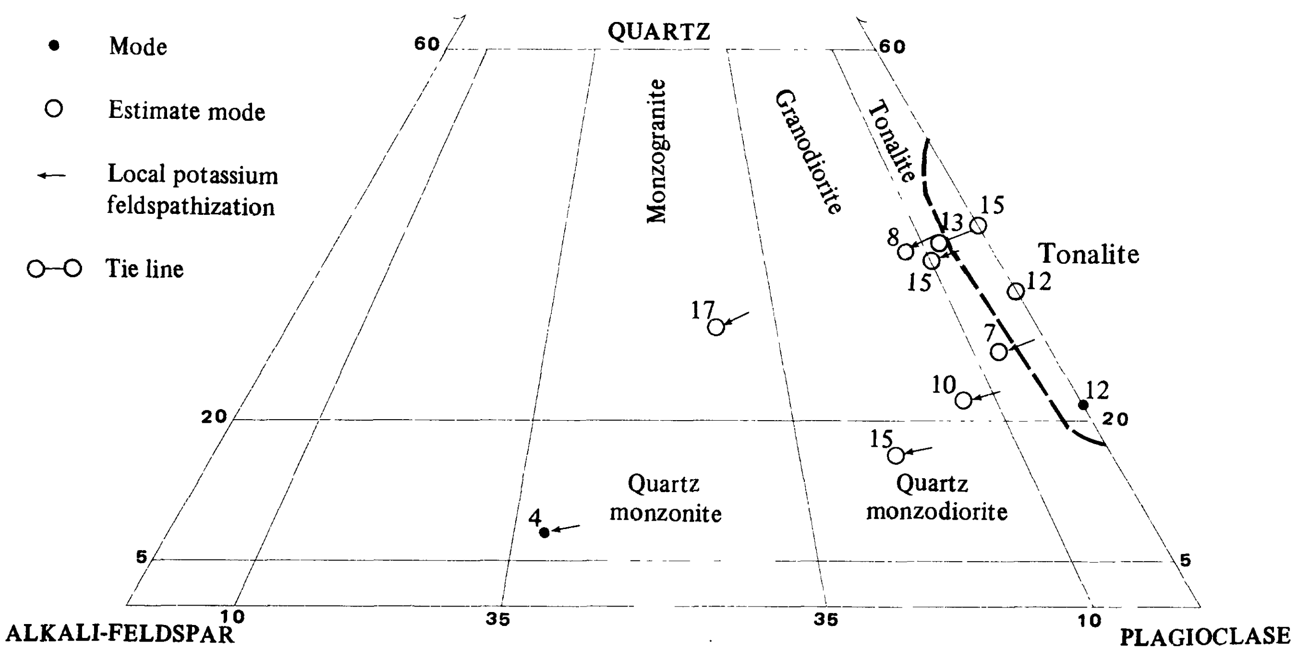

Figure 5.–Modal composition of tonalite from the Al Junaynah quadrangle. Many rocks are locally potassium feldspathized. The tie line is between sheared, potassium feldspathized rock and adjacent nonaltered rock. Dashed line encloses type trondhjemite composition from figure 4; initial tonalite was probably similar. Numbers are mafic mineral content in percent.

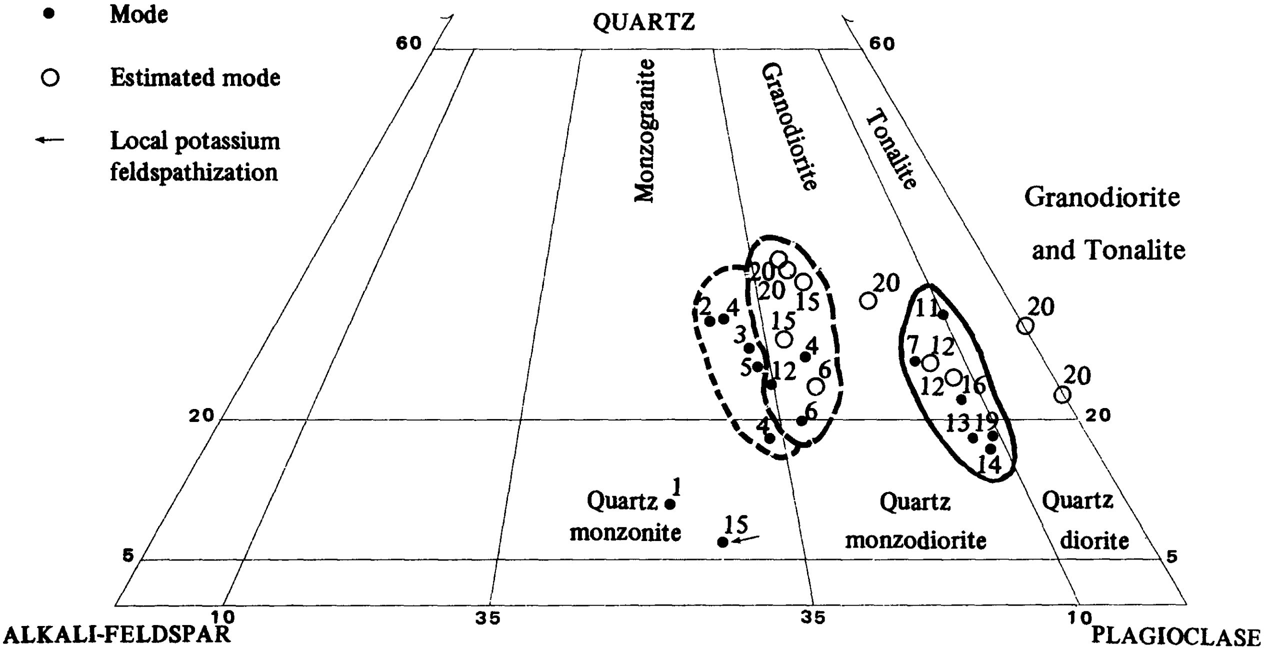

Figure 6.–Modal composition of granodiorite-and-tonalite map unit from the Al Junaynah quadrangle. Map unit probably includes several independent plutonic rocks not separated during field mapping. Local potassium feldspathization is probably more widespread than indicated. Solid line encloses a possible primary plutonic rock. Long-dashed line encloses a possibly independent granodioritic rock. Short-dashed line encloses an independent fine-grained monzogranite possibly as young as the granodiorite-monzogranite rock unit of Wadi Musayrah (fig. 9). Numbers are mafic mineral content in percent.

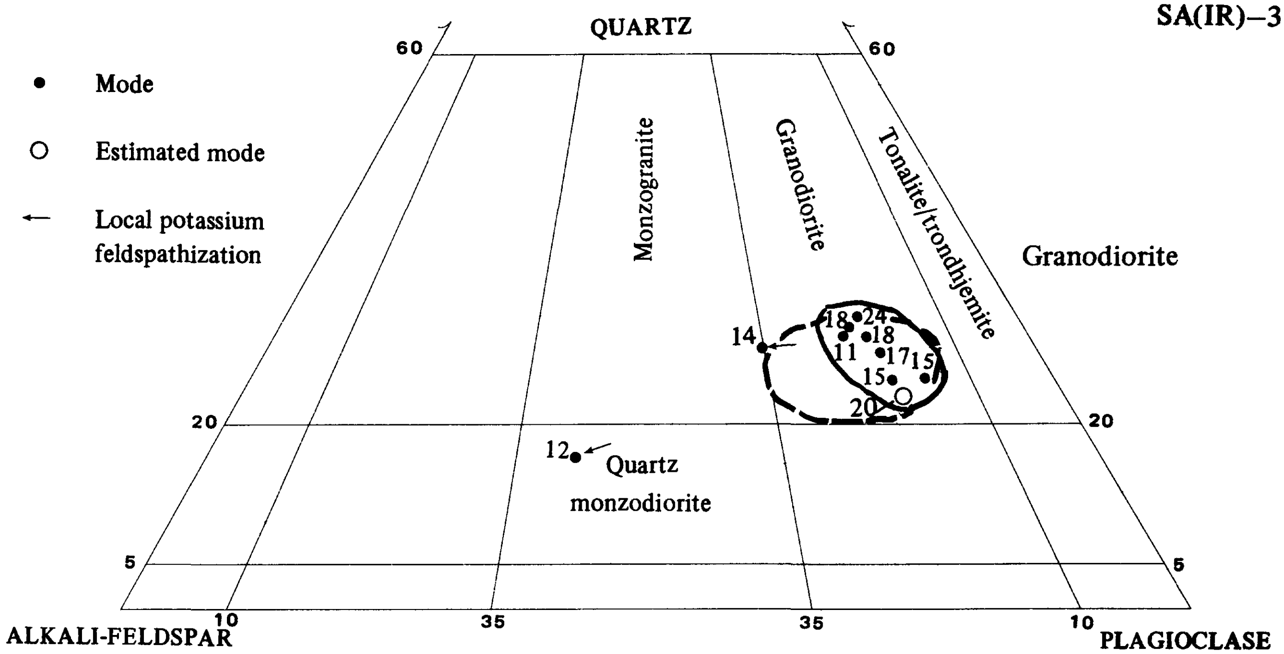

Figure 7.–Modal composition of granodiorite from the Al Junaynah quadrangle. A few rocks are locally potassium feldspathized. Solid line encloses characteristic composition. Dashed line shows characteristic composition of the granodioritic orthogneiss of the Jabal al Qarah quadrangle (Schmidt, unpub. data) with which the granodiorite is correlated. Numbers are mafic mineral content in percent.

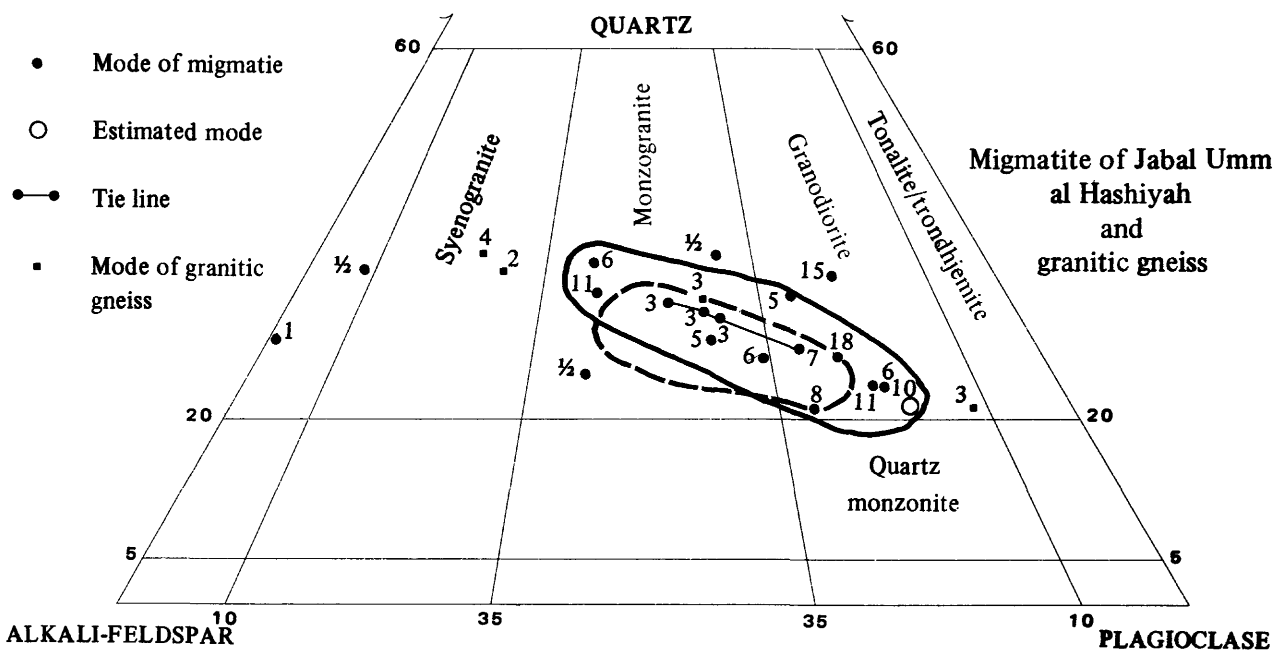

Figure 8.–Modal composition of migmatite of Jabal Umm al Hashiyah and granitic gneiss from the Al Junaynah quadrangle. Tie line connects modes from adjacent gneissic layers. Solid line encloses characteristic composition of the migmatite of Jabal Umm al Hashiyah in the Al Junaynah quadrangle; dashed line encloses characteristic composition of the migmatite of Jabal Umm al Hashiyah in the Jabal al Qarah quadrangle (Schmidt, unpub. data). Numbers are mafic mineral content in percent.

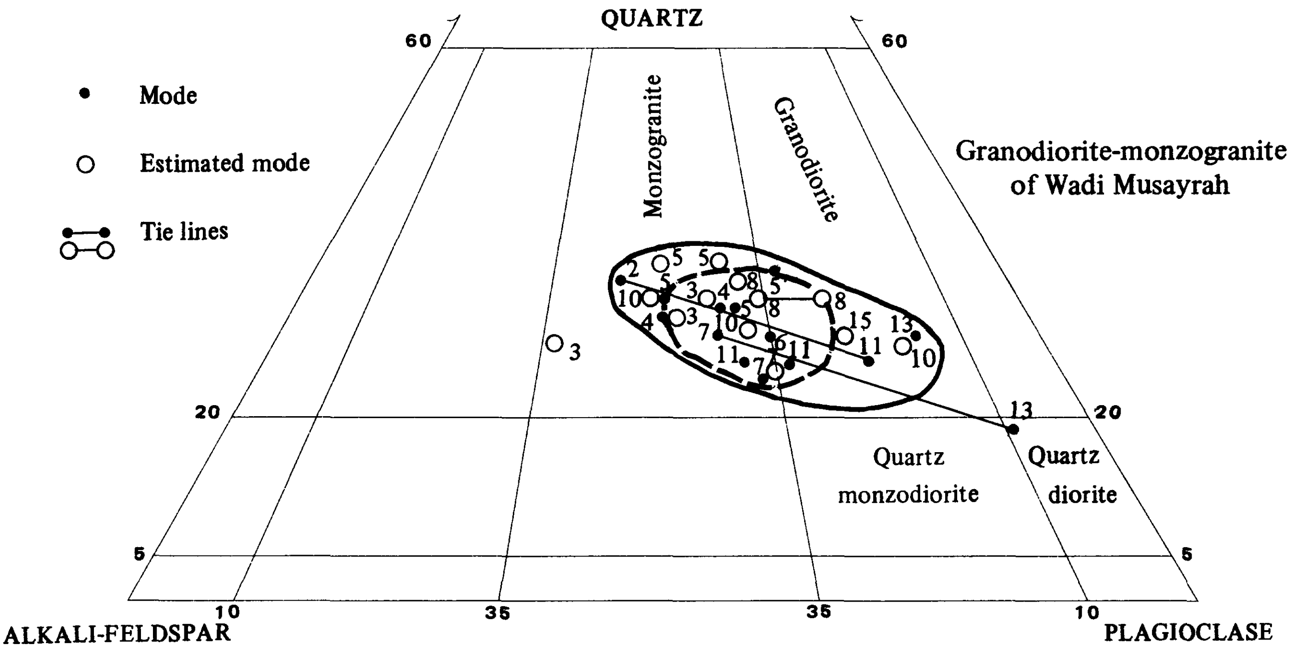

Figure 9.–Modal composition of granodiorite-monzogranite of Wadi Musayrah. Tie lines connect modes from adjacent gneissic layers. Solid line encloses characteristic composition of the granodiorite-monzogranite of Wadi Musayrah in the Al Junaynah quadrangle; dashed line encloses its characteristic composition in the Jabal al Qarah quadrangle (Schmidt, unpub. data). Numbers are mafic mineral content in percent.

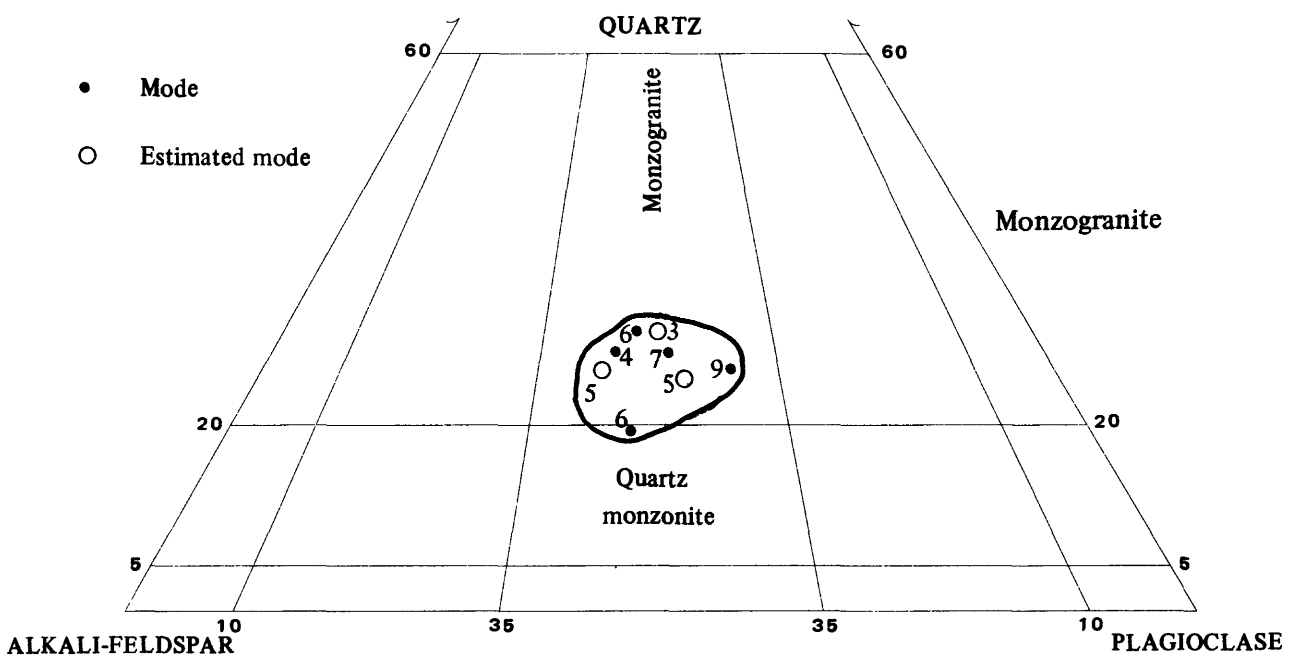

Figure 10.–Modal composition of monzogranite from the Al Junaynah quadrangle. Solid line encloses characteristic composition. Numbers are mafic mineral content in percent.

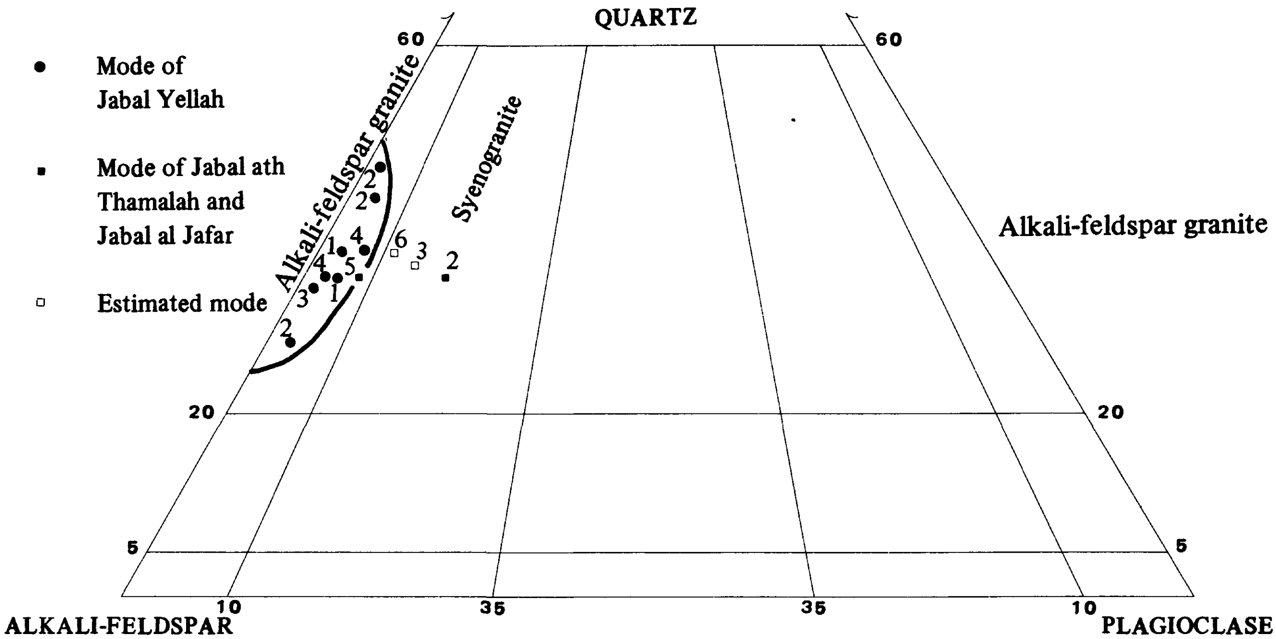

Figure 11.–Modal composition of alkali-feldspar granite from type area of Jabal Yellah (dots) and from other parts of same batholithic zone (squares). Most "modal plagioclase" is probably albite. Solid line encloses characteristic composition. Numbers are mafic mineral content in percent.

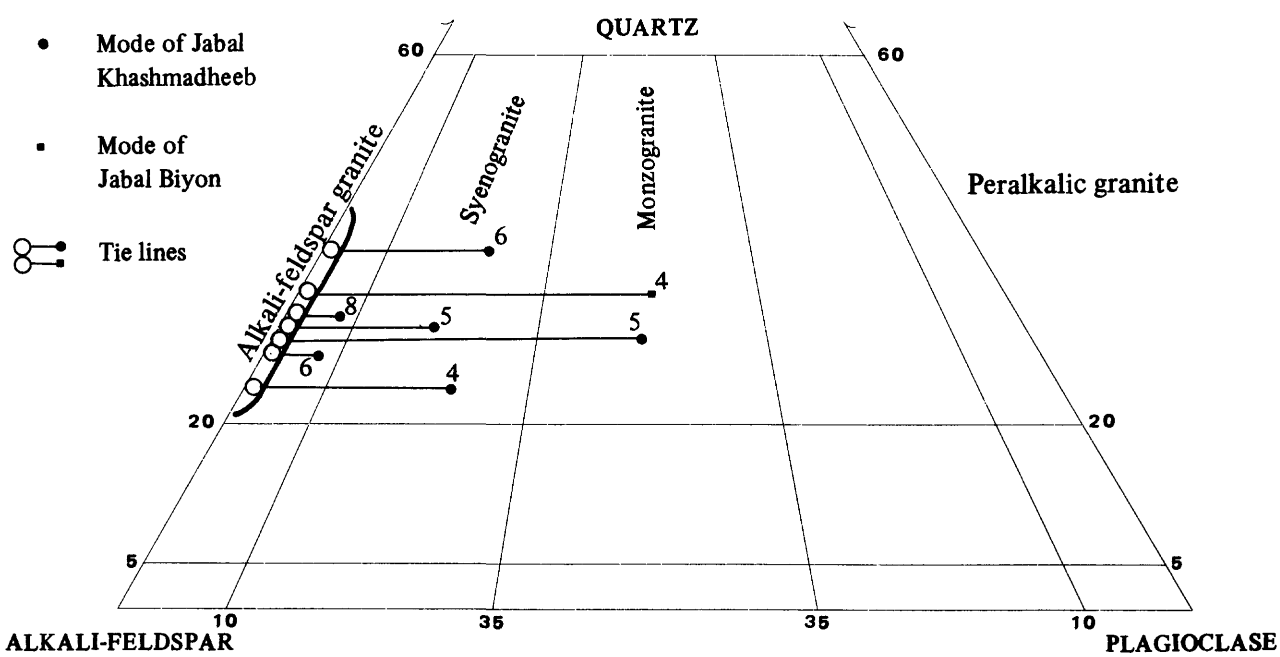

Figure 12.–Modal composition of peralkalic granite (alkali-mafic, alkali-feldspar granite), Al Junaynah quadrangle. Most "modal plagioclase" is albite. Tie lines show content of granular albite that is independent of perthite. Solid line encloses proposed composition. Numbers are mafic mineral content in percent.

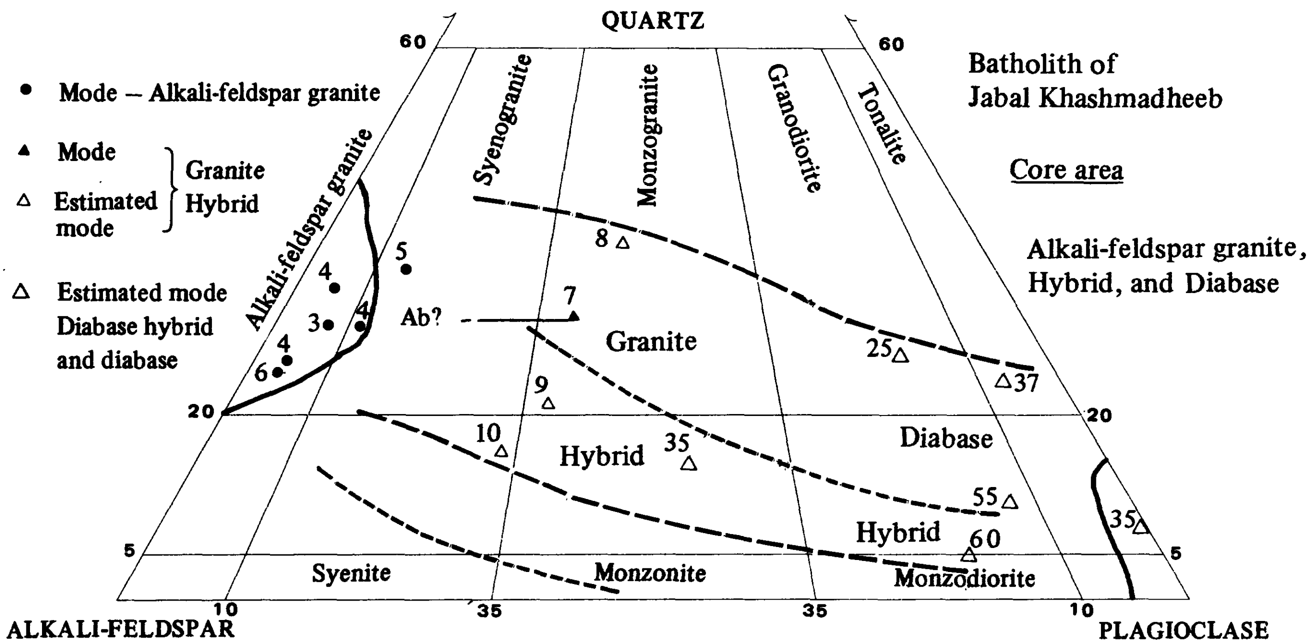

Figure 13.–Modal composition of alkali-feldspar granite, granite hybrid, diabase hybrid, and diabase from the core area of the batholith of Jabal Khashmadheeb. Solid lines enclose characteristic composition of alkali-feldspar granite of Jabal Khashmadheeb (on left) and diabase (on right). Long-dashed lines bound broad compositional zone for diabase hybrid and granite hybrid; the average quartz content in this zone is relatively high. Short-dashed lines bound compositional zone for hybrid rocks of less-than-average quartz content from the outer part of the batholith of Jabal Khashmadheeb; see figure 14. Line labeled "Ab?" for one sample suggests that some "modal plagioclase" may be albite in this sample and possibly in other samples. Numbers are mafic mineral content in percent.

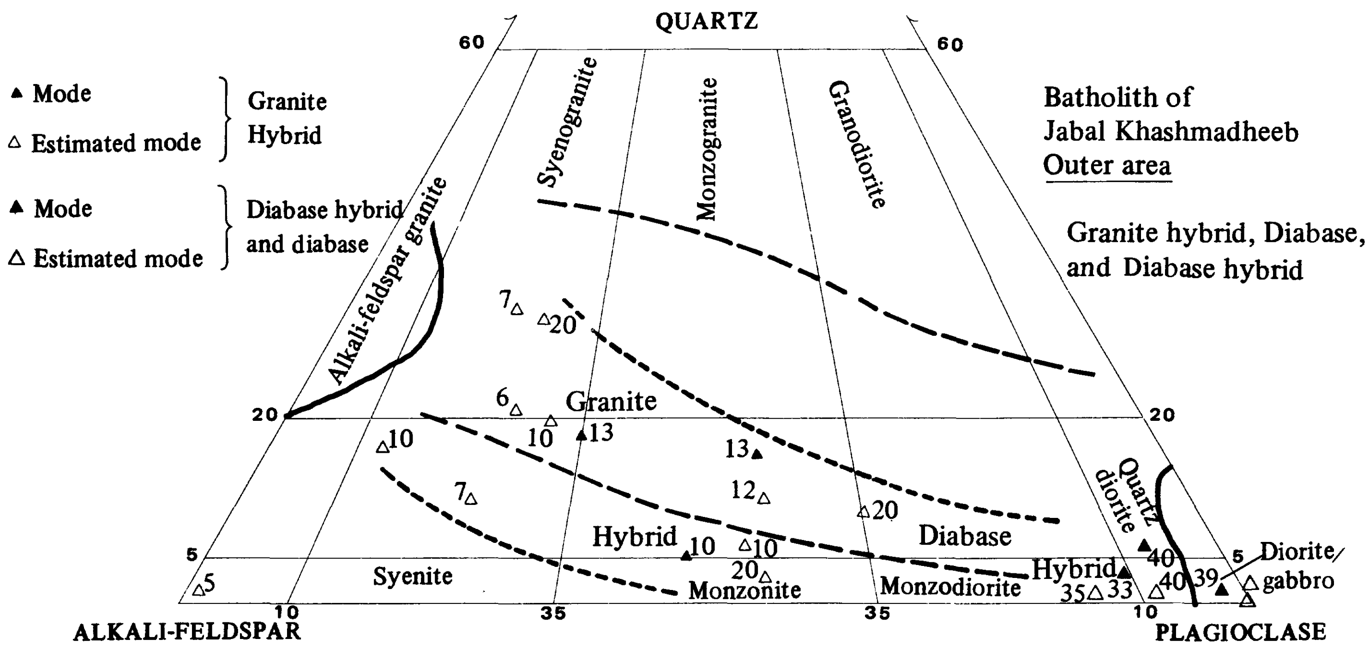

Figure 14.–Modal composition of granite hybrid, diabase hybrid, and diabase from outer part of the batholith of Jabal Khashmadheeb. Solid lines enclose characteristic composition of alkali-feldspar granite of Jabal Khashmadheeb (on left) and diabase (on right). Long-dashed lines bound broad compositional zone for diabase hybrid and granite hybrid; the average quartz content in this zone is relatively high. Short-dashed lines bound broad compositional zone for diabase hybrid and granite hybrid; the average quartz content in this zone is lower than that in the zone of hybrid rocks from the core area. Numbers are mafic mineral content in percent.

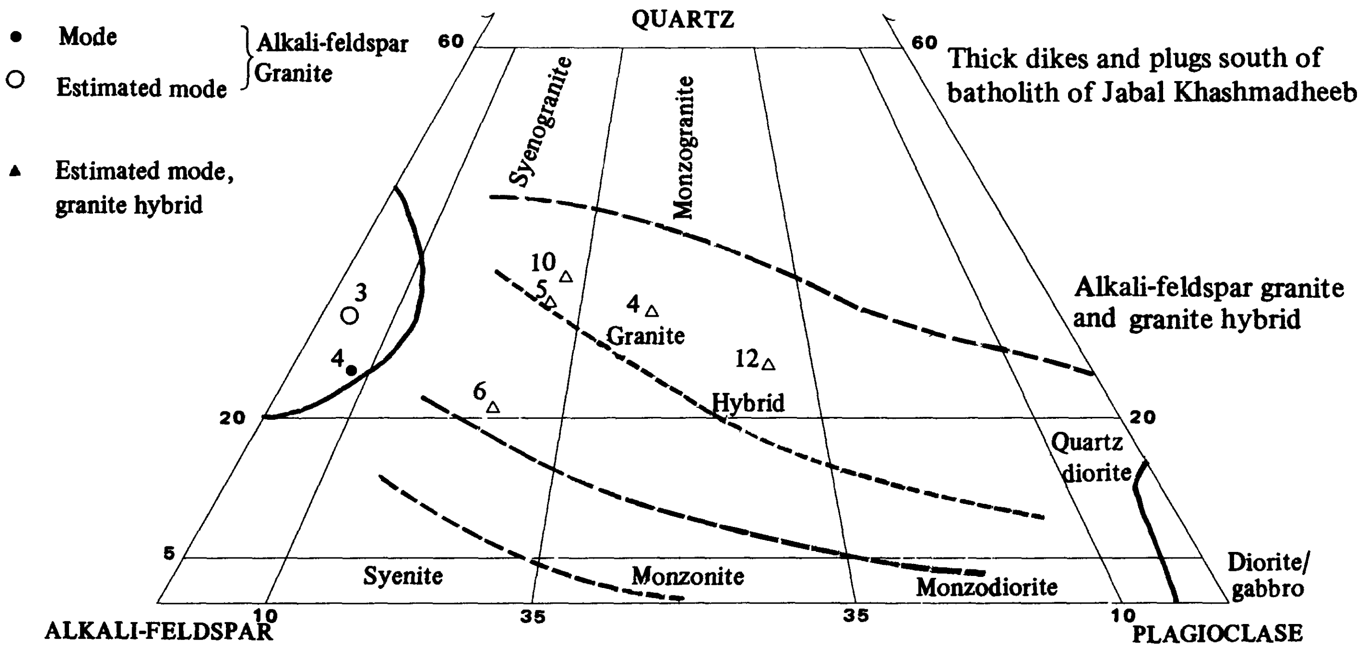

Figure 15.–Modal composition of alkali-feldspar granite and granite hybrid in thick dikes and small plugs from the area south of the batholith of Jabal Khashmadheeb. Solid lines enclose characteristic composition of alkali-feldspar granite of Jabal Khashmadheeb (on left) and diabase (on right). Long-dashed lines bound broad compositional zone for diabase hybrid and granite hybrid; the average quartz content in this zone is relatively high. Short-dashed lines bound compositional zone for hybrid rocks of less-than-average quartz content from the outer part of the batholith. Numbers are mafic mineral content in percent.

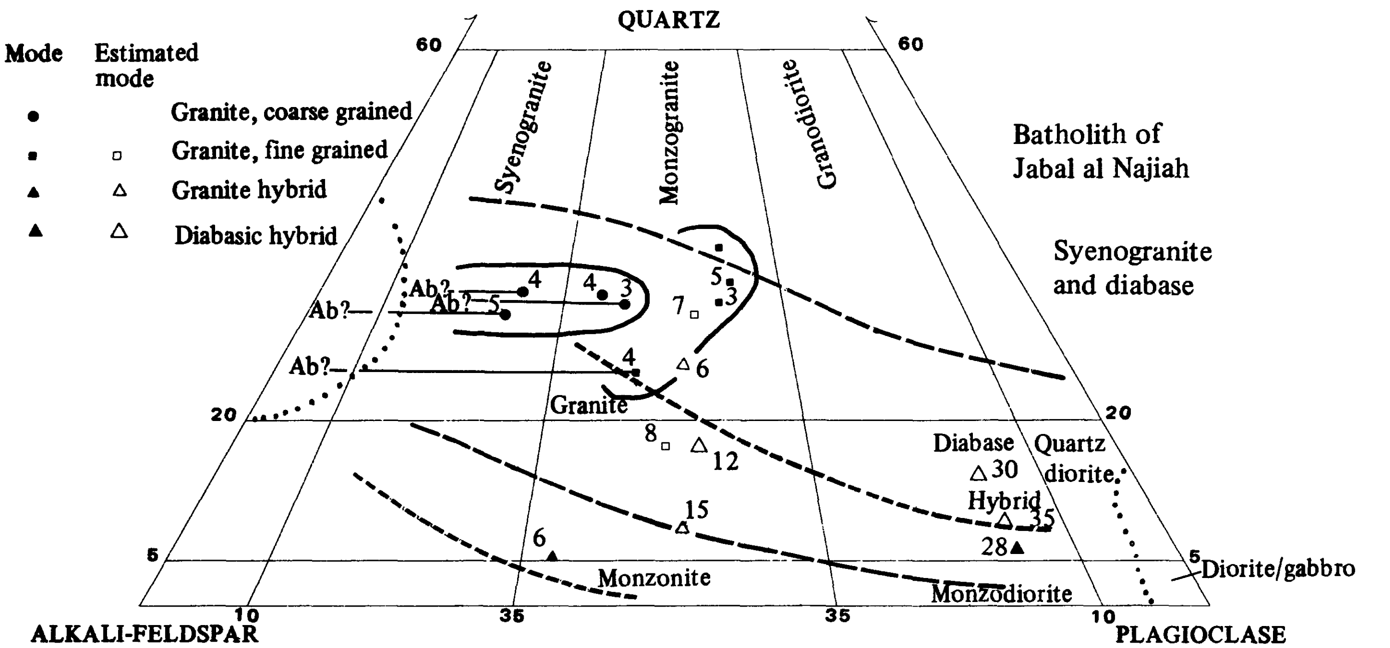

Figure 16.–Modal composition of granite, granite hybrid, and diabase hybrid from the ring-structured batholith of Jabal al Najiah. Solid lines outline coarse-grained granite (dots; syenogranite) and fine-grained granite (squares; monzogranite) of the batholith. Lines labeled "Ab?" suggest that some "modal plagioclase" may be albite and that the coarse-grained granite may be an alkali-feldspar granite. Dotted line on left shows field of characteristic composition of alkali-feldspar granite of the Jabal Khashmadheeb batholith; dotted line on right shows field of diabase composition from the Jabal Khashmadheeb batholith (figs. 13 and 14). Long-dashed lines bound broad compositional zone for diabase hybrid and granite hybrid; the average quartz content in this zone is relatively high. Short-dashed lines bound compositional zone for hybrid rocks of less-than-average quartz content from the outer part of the batholith of Jabal Khashmadheeb. Numbers are mafic mineral content in percent.

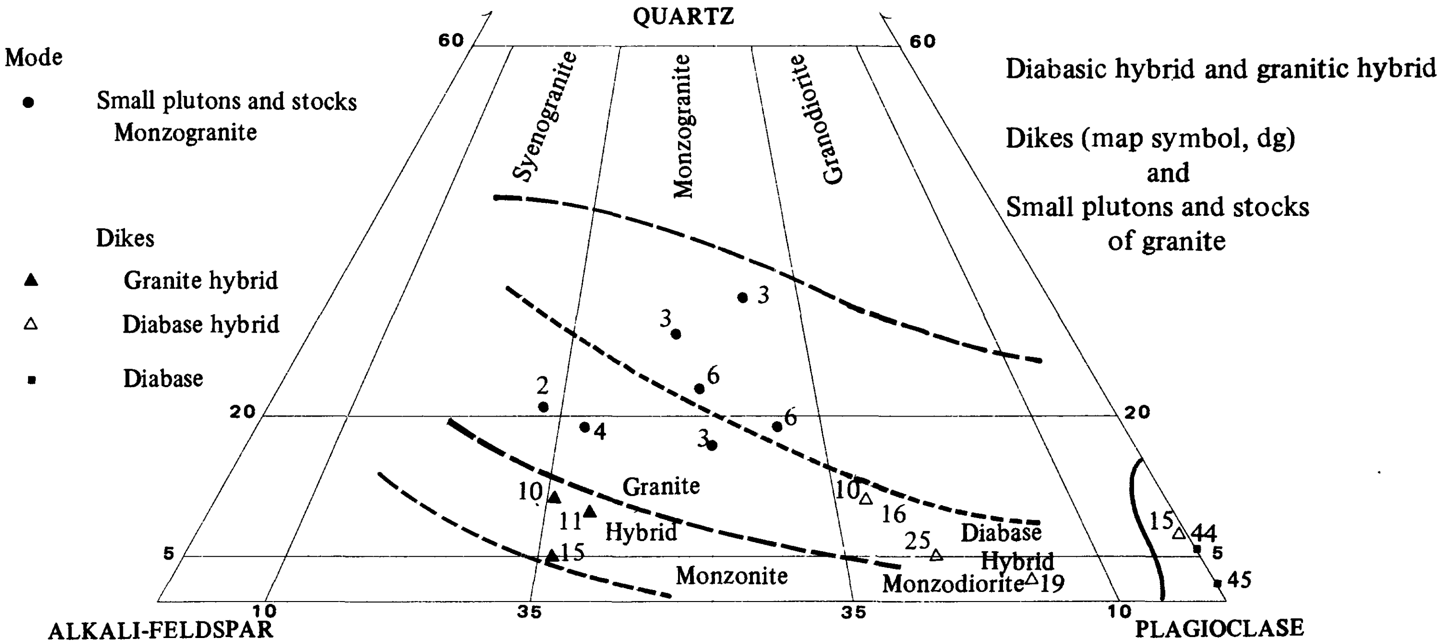

Figure 17.–Modal composition of diabase hybrid and granite hybrid dikes and small plutons and stocks of granite between Jabal Yellah and the batholith of Jabal al Najiah. Solid line encloses composition of diabase from the Jabal Khashmadheeb batholith (figs. 13 and 14). Long-dashed lines bound broad compositional zone for diabase hybrid and granite hybrid; the average quartz content in this zone is relatively high. Short-dashed lines bound compositional zone for hybrid rocks of less-than-average quartz content from the outer part of the batholith of Jabal Khashmadheeb. Numbers are mafic mineral content in percent.

Hornblende diorite

The hornblende diorite is a dark- to medium-gray, medium-grained, plagioclase and hornblende rock with or without biotite and subordinate quartz (table 1). Locally, as the subordinate quartz content increases and the mafic content decreases, the rock grades to quartz diorite and tonalite (fig. 3). As the mafic content increases, particularly pyroxene and more calcic plagioclase, the rock becomes gabbro. The different rock types were not mapped separately because of extensive alteration and poor exposure. Hypidiomorphic granular texture, formed largely by subhedral zoned plagioclase, is preserved in many places. The diorite was emplaced at a shallow crustal level directly into the volcanic and volcaniclastic rocks.

The diorite has been moderately to strongly altered during deformation and metamorphism. In the western two-thirds of the quadrangle, the diorite weathers dark gray and contains abundant hornblende and biotite; the diorite was metamorphosed to amphibolite facies prior to superposed greenschist facies metamorphism. In contrast, in the northeastern part of the quadrangle, the hornblende diorite weathers light gray and the primary mafic minerals are largely metamorphosed to actinolite and chlorite.

Trondhjemite

The trondhjemite in the western half of the Al Junaynah quadrangle is a shallow, subvolcanic intrusive rock. The rock is medium gray, medium grained, and has a relict hypidiomorphic granular texture (table 1; fig. 4). Locally the rock is porphyritic and contains euhedral quartz phenocrysts or has a graphic texture, both characteristic of hypabyssal intrusion. In places the rock grades into tonalite. The type area is the large body, 5 to 10 km southeast of Jabal as Sadah, in the central western part of the quadrangle. The trondhjemite characteristically weathers to low relief and underlies broad valleys in this hilly terrain.

The trondhjemite intruded volcanic and volcaniclastic rocks, metagabbro, and hornblende diorite in the Al Junaynah quadrangle, and is similar to the subvolcanic tonalite of the Jabal al Qarah quadrangle (Schmidt, unpub. data). The trondhjemite has been repeatedly deformed, metamorphosed, and intruded by widespread dikes and small plugs of late granite. Potassium feldspar, related to granite intrusion, irregularly replaced plagioclase and mortar in cataclastic trondhjemite and the resulting rock is locally of granodiorite composition.

Tonalite

The tonalite, north and south of Wadi Tabalah in the southwestern corner of the quadrangle, is part of a large batholith that is exposed for 30 km to the west in the Thaniyat quadrangle (Baghanem, written commun., 1976). Anderson (1977) mapped the southern part of the batholith, along the northern edge of the Wadi Tarj quadrangle, as trondhjemite. The tonalite (table 1; fig. 5) is similar to the trondhjemite described above but is slightly more mafic and is coarser grained even at its contact. Whereas the trondhjemite is hypabyssal and subvolcanic, the tonalite is clearly batholithic.

The contact between tonalite and volcanic-and-volcaniclastic rocks is well exposed. A short distance from the contact, the tonalite weathers to a flat rock pediment that extends many kilometers to the west of the Junaynah quadrangle. The tonalite is intensely sheared and altered along many large and small faults in the Al Junaynah quadrangle. Some of the faults contain thick dikes of late microgranite and wide zones of reddened wall rock. In thin sections, this reddened wall rock is irregularly replaced by potassium feldspar and its mafic content is reduced; this alteration is related to emplacement of the microgranite dikes.

Granodiorite and tonalite

The granodiorite-and-tonalite map unit (table 1) is complex in both lithology and structure and may include some younger intrusive rocks. The rock is exposed in several widely separated areas of the Al Junaynah quadrangle. The type area is between Jabal Biyon and Jabal Yellah. The rock weathers to low relief and to pediment surfaces, and internal contacts and gradations are obscure. Three distinctive rock types are apparent in hand specimens and by modal analysis. The granodiorite-and-tonalite in the central and southern part of the quadrangle is most likely a multiple intrusive body in which the most potassic phase was independently intruded at a much later time. The granodiorite-and-tonalite, mapped 15 km east of the northwestern corner of the quadrangle, is poorly exposed and extends into the Wadi al Miyah quadrangle (Schmidt, unpub. data).

The tonalitic rocks are medium to dark gray, medium grained, and contain enough potassium feldspar to be classified as granodiorite (fig. 6). A few do not contain potassium feldspar and may be a mafic phase of the slightly older trondhjemite unit. The relatively constant low content of potassium feldspar suggests that the tonalitic rocks represent a distinct low-potassium intrusion.

The granodioritic rocks are medium to light gray, medium grained, and plot across the granodiorite-monzogranite border on the ternary diagram (fig. 6). They are subdivided by mafic mineral content into medium-gray rocks containing 12 to 20 percent hornblende and biotite and light-gray rocks containing 2 to 6 percent biotite. Separate intrusive phases are indicated by sharp contacts seen in several hand specimens, but such contacts were not mapped.

The variable but mostly medium grain size and relict hypidiomorphic granular texture, formed mostly of subhedral zoned plagioclase, suggest shallow subvolcanic intrusion for the granodiorite-and-tonalite rocks. The rocks intrude the metagabbro, hornblende diorite, and volcanic and volcaniclastic rocks. Many of the granodiorite-and-tonalite rocks have a moderately developed tectonic foliation and display moderate to strong cataclasis and recrystallization. During cataclasis and shearing, the initial potassium feldspar was partly redistributed and is now irregularly disposed through the rock.

Granodiorite

The granodiorite has a uniform composition and texture and is the remnant of a large batholith. The type area is the flat terrain 5 to 8 km north of Jabal Umm al Hashiyah in the southeastern part of the quadrangle. The granodiorite is a gray, medium-grained, hornblende-biotite rock (table 1; fig. 7). Moderate tectonic foliation and greenschist facies metamorphism tend to obscure an initial hypidiomorphic granular texture. Potassium feldspar is largely interstitial. In thin section the potassium feldspar has been recrystallized and locally redistributed adjacent to some late granitic dikes.

The granodiorite intruded dacitic and volcaniclastic rocks of the Halaban group and formed a conspicuous contact metamorphic zone of hornfels about 1 km wide. The granodiorite has been intruded by the granodiorite-monzogranite of Wadi Musayrah and the gabbro of Jabal as Sidan. The contact between the granodiorite and the migmatite of Jabal Umm al Hashiyah is gradational over one to several kilometers.

The granodiorite correlates with the granodioritic orthogneiss of the Jabal al Qarah quadrangle (Schmidt, unpub. data). The moderately foliated structure of the granodiorite, which is at the margin of the Jabal al Qarah gneiss dome, is not comparable to the strongly developed foliation of the granodioritic orthogneiss, which is within the gneiss dome; the granodiorite in the Al Junaynah quadrangle was but slightly affected by tectonic transport, during gneiss doming. Also, the exposed part of the granodiorite in the Al Junaynah quadrangle represents a shallower level of crustal intrusion than the intermediate crustal depth represented by the granodioritic orthogneiss of the Jabal al Qarah quadrangle.

Syntectonic plutonic rocks

The syntectonic rocks include the map units: migmatite of Jabal Umm al Hashiyah, granitic gneiss, and granodiorite-monzogranite of Wadi Musayrah. The migmatite and granodiorite-monzogranite both extend eastward into the Jabal al Qarah quadrangle. Both map units are part of the Jabal al Qarah gneiss dome that underlies the western two-thirds of the Jabal al Qarah quadrangle (Schmidt, unpub. data). The granodiorite-monzogranite of Wadi Musayrah is a large batholith intruded late during gneiss doming. The migmatite of Jabal Umm al Hashiyah forms a broad zone between the batholith and the orthogneisses of the gneiss dome.

Migmatite of Jabal Umm al Hashiyah

The migmatite of Jabal Umm al Hashiyah is named for Jabal Umm al Hashiyah in the southeastern corner of the Al Junaynah quadrangle. The rock is defined in the Jabal al Qarah quadrangle where the type area is about 10 km east of the Jabal Umm al Hashiyah (Schmidt, unpub. data). The migmatite is a mixture of tonalitic and granodioritic orthogneisses and of the granodiorite-monzogranite of the batholith of Wadi Musayrah. The migmatite moved as a migma during emplacement of the Jabal al Qarah gneiss dome and formed a wide plastic zone on the magmatic core of the Wadi Musayrah batholith. Because of the asymmetry of the gneiss dome, the Wadi Musayrah batholith in the Al Junaynah quadrangle was directly intruded into rocks not involved in the gneiss dome; the migmatite appears on the west side of the gneiss dome only where the batholith is absent as in the southeastern part of the Al Junaynah quadrangle.

The migmatite of Jabal Umm al Hashiyah is described in table 1 and its compositional variations are shown on figure 8. On figure 8, several leucocratic gneisses (mafic contents of 0.5 to 1 percent) probably represent segregations of uncommonly leucocratic and potassic migma within the migmatite. After its emplacement the migmatite of Jabal Umm al Hashiyah was moderately deformed and partly metamorphosed to greenschist facies.

Granitic gneiss

The granitic gneiss is a migmatitic gneiss of granodioritic to syenogranitic composition (fig. 8) that is similar to the migmatite of Jabal Umm al Hashiyah. The gneiss is mapped as a separate unit because it occurs in two small areas far outside the Jabal al Qarah gneiss dome, one in the south-central part and the other in the northwestern part of the quadrangle. In both areas the granitic gneiss is associated with, or emplaced into, the granodiorite-and-tonalite unit. The rocks from both areas are fine- or medium-grained, layered, granoblastic gneisses. Four modal analyses of the granitic gneiss from the south-central area are shown on figure 8. One mode falls close to the average composition of the migmatite of Jabal Umm al Hashiyah, two are considerably more potassic, and one is considerably less potassic. The more potassic rocks may have been locally potassium metasomatized by posttectonic granites.

The granitic gneisses are the result of cataclasis and migmatization that is younger than the emplacement of the granodiorite-and-tonalite unit and older than the intrusion of the posttectonic granites. Hence, they may be the same age as the migmatite of Jabal Umm al Hashiyah. They represent the ductile rise of older crustal rocks from deeper levels on a small scale and they probably rose in response to causes similar to those that produced the large-scale movement of the Jabal al Qarah gneiss dome. It is likely that a large gneiss dome underlies the central area between the exposures of granitic gneiss.

Granodiorite-monzogranite of Wadi Musayrah

The granodiorite-monzogranite of Wadi Musayrah in the Al Junaynah quadrangle constitutes the western half of the Wadi Musayrah batholith. The batholith forms the core of the large asymmetric gneiss dome of Jabal al Qarah. The type rock is defined and described in the report for the Jabal al Qarah quadrangle (Schmidt, unpub. data). In the Al Junaynah quadrangle the granodiorite-monzogranite rock represents a phase of the Wadi Musayrah batholith that is shallower than the eastern part of the batholith in the Jabal al Qarah quadrangle. In the Al Junaynah quadrangle the granodiorite-monzogranite intruded passively its metavolcanic and metavolcaniclastic wallrock and was contact metamorphosed to hornfels.

The granodiorite-monzogranite is light gray and medium grained (table 1). The rock has a mineral foliation and in places has a gneissic, compositional layering on both a megascopic and microscopic scale; it has a variable composition as shown on figure 9.

In the Al Junaynah quadrangle cataclasis accompanied at least the final stage of intrusion of the granodiorite-monzogranite. Most potassium feldspar crystallized late; some is interstitial, but most replaces cataclastic plagioclase and is commonly poikilitic or porphyroblastic. The batholithic rock is characterized by late autometamorphism that followed early magmatic crystallization. The rock was later partly deformed and metamorphosed to the greenschist facies.

Posttectonic granite, diabase, and gabbro

Posttectonic intrusive rocks in the Al Junaynah quadrangle are mostly monzogranitic, syenogranitic, and alkali-feldspar granites that are widely called red granite in the field. They were intruded during a relatively short interval of about 25 m.y. following the emplacement of the Wadi Musayrah batholith. The monzogranite is somewhat older than the alkali-feldspar granite. Diabase is closely associated in time and space with posttectonic granite in two large ring-structure plutons; the one at Jabal Khashmadheeb is taken as the type and the other is at Jabal al Najiah. A layered gabbroic body at Jabal as Sidan was probably emplaced slightly later than the alkali-feldspar granite.

The posttectonic granites constitute about 20 percent of the area of the quadrangle. Textures and structures indicate that they were emplaced at shallower crustal levels than the granodiorite-monzogranite of the Wadi Musayrah batholith. This implies considerable erosion between these events. Most of the granite plutons and the layered gabbro pluton are elongated in a northern direction and intruded crust that was regionally stressed. The granite pluton of Jabal al Najiah, in contrast, is a circular structure and suggests that regional stress was not continuous during the interval of granite emplacement. The penecontemporaneous intrusion of diabase and some granite implies a coexistence of gabbroic and granitic magmas deep in the crust.

Monzogranite

The monzogranite underlies only a small part of the Al Junaynah quadrangle. It is mapped as numerous stocks, presumably representing the uppermost parts of larger plutons. In the northwestern corner, it forms the marginal part of a larger pluton that extends into the quadrangles to the west and north. In the northeast corner, it forms the southern part of a large pluton mapped as hornblende-biotite monzogranite in the Wadi al Miyah quadrangle (Schmidt, unpub. data). The monzogranite probably correlates with the monzogranite of Jabal Shoke in the Jabal al Qarah quadrangle to the east (Schmidt, unpub. data). The monzogranite is intermediate in composition and time of emplacement between the granodiorite-monzogranite of Wadi Musayrah and the alkali-feldspar granite.

The type area for the monzogranite is the crescent-shaped inselberg, 8.5 km south of the northwestern corner of the Al Junaynah quadrangle. The rock is a medium-grained, leucocratic monzogranite (table 1; fig. 10). Elsewhere in the Al Junaynah quadrangle, many small bodies mapped as monzogranite contain rock that has variable textures and compositions. Such variations are expected in small bodies containing variable marginal phases. The numerous small plugs, sills, and dikes of irregular shape, 7 to 10 km south of the type area, represent the passive roof zone of a large, underlying monzogranite pluton.

Alkali-feldspar granite

The alkali-feldspar granite constitutes an almost continuous north-trending batholithic zone across the central part of the Al Junaynah quadrangle. Numerous outlying plutons of alkali-feldspar granite crop out west of the batholithic zone. The type pluton, at Jabal Yellah, is composed of red, coarse-grained, homogeneous and massive, alkali-feldspar granite (table 1; fig. 11). The rocks of Jabal ath Thamalah and Jabal al Jafar are similar. The modal compositions of some of these rocks plot as syenogranite (fig. 11); however, the "modal plagioclase" is probably granular albite and hence these rocks are probably alkali-feldspar granite. Biotite occurs in small amounts and magnetite, fluorite, and zircon are accessory minerals. Biotite is commonly altered to iron oxides. The intense red coloration of the rock is caused by submicroscopic hematite in interstices and in feldspar and by iron oxides derived from altered biotite. Presumably, the rock has been hydrothermally altered after, and independently of, its emplacement.

Peralkalic granite

The type area for the peralkalic granite is the southwestern part of Jabal Khashmadheeb. In addition, two small stocks at Jabal Biyon are mapped as peralkalic granite. At Jabal Khashmadheeb the peralkalic granite is a phase of the alkali-feldspar granite batholith of Khashmadheeb. The contact between the peralkalic granite and the alkali-feldspar granite at Jabal Khashmadheeb was drawn during map compilation after the peralkalic granite was identified in thin sections, therefore, the location of the contact on plate 1 is uncertain. Peralkalic granite is used in this report as a convenient map-unit name and refers to alkali-feldspar granite (Streckeisen, 1976) containing sodium-rich mafic minerals (alkali-mafic, alkali-feldspar granite).

In the type area the rock is a light-gray to pink, fine- to coarse-grained, and locally porphyritic alkali-feldspar granite (table 1, fig. 12). The rock contains coarse-grained perthite of coarsely veined type and varying amounts of granular albite that is independent of perthite. Tie lines between the actual modal plots and the plots in the alkali-feldspar field (made on the assumption that all white feldspar in the mode is albite) are proportional to the content of granular albite that is independent of perthite. As seen in figure 12, this independent, granular albite is highly variable in different specimens. The sodium-rich mafic minerals are riebeckite, arfvedsonite (?), and acmite. Aenigmatite, in crystals 1 to 2 mm long, has been tentatively identified in one specimen from a locality 0.8 km N. 11 km W. from the south peak of Jabal Khashmadheeb. Chemical analyses of similar rocks from Jabal Taweel in the Wadi al Miyah quadrangle suggest that these rocks are peralkalic (Schmidt, unpub. data).

The peralkalic granite mapped 1 km south of Jabal Biyon is an albite granite according to one specimen examined. It occurs in a small stock, less than 1 km in diameter, that intruded the granodiorite-and-tonalite map unit. The rock is a medium-grained, quartz-perthite granite porphyry containing about 30 percent granular albite that is independent of perthite (fig. 12). The granular albite occurs as small, oriented laths in a flow-foliated, felted groundmass. Apatite, muscovite, and fluorite are accessory minerals. Apatite crystals as large as 2 mm across by 5 mm long are common.

A similar rock is suggested to underlie Jabal Biyon, although outcrops of the rock were not examined. Jabal Biyon is partly surrounded by large quartz veins and perthite-quartz pegmatite pods; the pegmatite locally contains abundant purple fluorite and accessory brannerite (see chapter on ECONOMIC DEPOSITS).

Semiring-structured batholith of Jabal Khashmadheeb

Jabal Khashmadheeb is a compound, alkali-feldspar granite batholith about 20 km long by about 10 km wide. The core area, underlying the large inselberg of Jabal Khashmadheeb, consists of two semiring structures containing peralkalic granite, alkali-feldspar granite, and diabase. The partial rings are well expressed by the topography because of differential weathering of alternating zones of fine- and coarse-grained granite or alternating zones of granite and diabase. The eastern half of the batholith is chiefly diabase that is poorly exposed; it contains wide dikes of alkali-feldspar granite and gabbro that conform to the overall ring structure. The diabase was comagmatic with the granite, but because it congealed at a higher temperature than the granite, it locally shows thin, chilled margins against granite. In most places the contact zone consists of hybridized diabase and granite. Some small black inclusions of amphibole hornfels in the batholith are probably inclusions of the intruded volcanic wallrock; only two are mapped on plate 1.

The two semiring structures are coincident with a gamma-ray radiation anomaly. The radiation data are part of an aeromagnetic survey of the Precambrian Shield flown and compiled at 1:100,00 scale during 1966 and 1967 by a consortium of Lockwood Survey Corporation, Limited; Aero Service Corporation; Hunting Geology and Geophysics, Limited; and the Arabian Geophysical and Surveying Company. The batholith is not well outlined by the total-intensity aeromagnetic data, although the predominantly granitic part is shown by a generally low magnetic intensity and the predominantly diabasic part by a higher intensity. On the 1:500,000-scale compilation of these magnetic data (Andreasen and Petty, 1973), the batholith produces as a large negative anomaly.

Peralkalic granite.--The peralkalic granite at Jabal Khashmadheeb was described in the preceding chapter. On plate 1, the peralkalic granite is shown as forming the core of the two semiring structures. The contacts enclose the locations of the five samples studied in thin section (table 1; fig. 12), but the shapes of the peralkalic granite bodies are diagrammatic and were drawn to conform approximately to the radiation anomaly. Detailed mapping is needed to delineate the peralkalic granite.

Alkali-feldspar granite.--The semiring structures of Jabal Khashmadheeb are formed of curvilinear intrusions and dikes, 100 m to several hundred meters thick. Adjacent semirings vary from medium- to coarse-grained alkali-feldspar granite; some rock is porphyritic. The coarse-grained rock, similar to the alkali-feldspar granites from Jabals Yellah, ath Thamalah, and al Jafar, is red, hypidiomorphic inequigranular, and contains abundant perthite, chiefly of the veined type, and variable amounts of granular albite that is independent of perthite (table 1; fig. 13). In figure 13 several of the modes plot as syenogranite but most of the "modal plagioclase" is granular albite and the rock is an alkali-feldspar granite. Hornblende, partly altered to biotite, is the prevalent mafic mineral. Traces of pyroxene, possibly aegirine-augite(?), have been found in several specimens. Magnetite, apatite, zircon, and fluorite are the accessory minerals and some rocks contain allanite. Most of the northern one-third of the batholith consists of coarse-grained alkali-feldspar granite devoid of a curvilinear layered structure.

Diabase and hybrid rocks.--Diabase appears to make up most of the poorly exposed eastern half of the batholith of Jabal Khashmadheeb. Within the core area underlying Jabal Khashmadheeb, diabase is subordinate and occurs as curvilinear, lenticular dikes. These thick dikes of diabase accentuate the semiring structure. The diabase is fine to medium grained and has a diabasic texture (table 1). The rock is characterized by abundant biotite. Much of the diabase was altered by magmatic fluids from the alkali-feldspar granite; the highly variable contents of potassium feldspar, biotite, and quartz increase as the mafic content decreases. Clinopyroxene is abundant in the least altered diabase, but most pyroxene is partly to entirely altered to hornblende and biotite and much of the diabase contains only hornblende and biotite.

Some diabase grades into diabase hybrid and granite hybrid. The hybrids are believed to result from the contamination of diabasic and granitic magmas through an exchange of mutual magmatic fluids. Because both hybrids were mobile enough to form dikes, the alteration is thought of as a mutual magma-fluid reaction restricted to areas where the two magmas were in direct contact with each other. The two magmas did not physically mix as bulk liquids, except locally where pseudoagglomerates consist of abundant, rounded clots of diabase in a granitic matrix; presumably these clots were hot and plastic globs of viscous diabasic magma when incorporated in the granite magma.

The hybrid rocks are described in table 1 and their modes are shown on figures 13 and 14. The diabasic hybrid is medium gray, medium grained, and more leucocratic than diabase; the rock contains some potassium feldspar and quartz, and most of the mafic content is biotite. The granitic hybrid is medium reddish gray and has heterogeneous textures; the rock is fine to medium grained and commonly porphyritic. The phenocrysts are perthite, albite, and quartz; most were formed before their parent magma was contaminated by diabasic fluids. Figure 13 shows modal analyses for diabase, diabase hybrid, and granite hybrid from the dominantly granitic core area underlying Jabal Khashmadheeb. The modes of the hybrid rocks on the ternary diagram form a wide band that extends from diabase to alkali-feldspar granite. These hybrid rocks tend to have slightly higher quartz contents that the hybrid rocks from the area east of Jabal Khashmadheeb (fig. 14) where the batholith is dominantly diabase. Apparently, hybrids containing more than average amounts of quartz formed where granitic magma predominated over diabasic magma, and hybrids containing less than average amounts of quartz formed where diabasic magma predominated over granite magma.

Granitic dikes.--Thick dikes, lenticular pods, and plugs of granite probably represent a roof segment of the Khashmadheeb batholith to the south of Jabal Khashmadheeb. Modal analyses of these dike rocks are plotted on figure 15. Only two are hypabyssal phases of the alkali-feldspar granite; most are granite hybrid containing more than average amounts of quartz and are comparable to the hybrid rocks from the core area of Jabal Khashmadheeb (fig. 13). The predominantly granitic hybrid rock in this roof segment suggests that the hybrid magma was more mobile than the parent magma of alkali-feldspar granite.

Ring-structured batholith of Jabal al Najiah

The ring-structured batholith of Jabal al Najiah is about 16 km in diameter. The batholith is similar to the semiring-structured batholith of Khashmadheeb, but is more circular in shape, is more syenogranitic in composition and contains more abundant inclusions of volcanic hornfels. The gross ring structure is not symmetrical and is well depicted by the low-relief topography of the area. Exposures in the numerous small inselbergs in the southern half of the batholith show that the ring structure consists of alternating thick dikes of finer and coarser grained, leucocratic granite and of curvilinear, lenticular masses of black diabase. Alined angular inclusions of black hornfels conform vaguely to the internal circular structure. The inclusions are silicic and contain biotite or amphibole; they are volcanic and volcaniclastic rocks that were metamorphosed to hornfels. They are similar to the nondivided rocks of the Halaban group to the north and southwest of the batholith.

The ring-structure probably represents the deeply eroded root zone of a caldera. The ring dikes of granite have textures that suggest rapidly fluctuating physical conditions during emplacement, such as might be expected within the magma chamber beneath an explosively erupting volcano. Two coexisting magmas, one granitic and one gabbroic, were involved in the origin of the batholith of Jabal al Najiah.

The circular shape and concentric ring structure of the Najiah batholith show well as alternating magnetic highs and lows in the total-intensity aeromagnetic data compiled at 1:100,000 scale for the Junaynah quadrangle. The circular outline shows less well on the 1:500,000-scale aeromagnetic map (Andreasen and Petty, 1973). No gamma-ray radiation anomaly was recorded by the airborne survey over the batholith of Jabal al Najiah, suggesting that the granite is less potassic than the granite of Jabal Khashmadheeb.

Syenogranite of Jabal al Najiah.--The granitic rock of the batholith of Jabal al Najiah occurs in curvilinear dikes, ranging from 10 m to several hundreds of meters thick. Modes of these rocks plot as syenogranite and monzogranite on figure 16. From a limited thin section study, some of the "modal plagioclase" is granular albite independent of albite in the abundant perthite and the rock is probably at least syenogranite and some may be alkali-feldspar granite.

Diabase and hybrid rocks.--Curvilinear lenses of diabase were intruded discontinuously along some ring fractures in the southern half of the Najiah batholith. Many of these lenses were disrupted and partly rotated by the intrusion of later granite. Most samples of the diabase contain more biotite than those from the batholith of Jabal Khashmadheeb.

Diabase hybrid and granite hybrid are subordinate rocks in the batholith of Jabal al Najiah. The hybrid rocks are similar to those described for the batholith of Jabal Khashmadheeb and several modes plotted on the ternary diagram (fig. 16) are in the same zone of more than average amounts of quartz that is characteristic of the predominantly granitic part of the Khashmadheeb batholith.

Diabasic hybrid and granitic hybrid dikes

Three swarms of dikes constitute the diabasic hybrid and granitic hybrid dikes (pl. 1). They occur about 5 km southeast and 3 km south of Najiah village and 5 to 8 km east of Ruqayqah village. The dikes consist of granite, diabase, and hybrids of granite and diabase. The rocks are equivalent in composition and age to the hybrid rocks of the batholiths of Jabal Khashmadheeb and Jabal al Najiah. The same process of mutual magma-fluid interaction discussed above is involved in their genesis.

The dike swarms consist of multiple dikes, one meter to several tens of meters thick, and small stocks trending east or southeast; in places the dikes widen to small stocks. Modal analyses of the diabasic and hybrid parts of the dikes are shown on figure 17. Several specimens exhibit rapakivi textures in which large rounded to subhedral phenocrysts of potassium feldspar are mantled by a rim of sodium plagioclase.

The abundant small plutons and stocks mapped as alkali-feldspar granite, syenogranite, and monzogranite west of the central batholithic zone of alkali-feldspar granite (between Jabal Yellah and Jabal al Jafar, plate 1) consist partly of granite hybrid similar to those plotted in figure 17 for the dike swarms. Modes of rocks from several small stocks, mapped as monzogranite on plate 1, are also plotted on figure 17. The granitic plutons and stocks are probably related in age as well as source. In conclusion, the posttectonic granites, diabase, and hybrid rocks are parts of a single magmatic episode of granite and gabbro.

Granophyre

The granophyre unit is part of a large hypabyssal intrusion extending from Jabal as Sadah near the northwestern corner of the quadrangle into the Thaniyat quadrangle to the west. The rock is dark reddish brown; its texture is heterogeneous and variable from outcrop to outcrop (table 1). Grain size ranges from very fine to medium grained. The finer grained rocks commonly contain a few discrete phenocrysts. The rock is characterized by a granophyric texture that ranges from micrographic to spherulitic. Intergrowths of very fine grained quartz and alkalic feldspar result from either eutectic crystallization or solid-solution unmixing. Modal estimates indicate compositions that range from monzogranite to alkali-feldspar granite and include quartz monzonite and quartz syenite types; all rocks are leucocratic. The quartz content is variable, and the amount of albite was not determined. The tentative identification of acmite and riebeckite in several specimens suggests that the rock may be an alkali-feldspar granite.

The fine-grained granophyre is similar to the granophyre map unit in the Wadi al Miyah quadrangle (Schmidt, unpub. data) just north of the northwestern corner of the Al Junaynah quadrangle. The granophyric body in the Al Junaynah quadrangle coincides with the eastern part of a large elliptical aeromagnetic anomaly, 27 km long in an easterly direction by 17 km wide (Andreasen and Petty, 1973). The anomaly has a strong polarization that is normally oriented. The elliptical anomaly is the southeastern part of a large concentric anomaly, about 60 km across, that may be the expression of a large gabbro-granite complex at depth.

The granophyre probably forms the roof zone of a large alkali-feldspar granite pluton. The granophyre is cut by many rhyolite dikes; some rhyolite may actually be deformed flow rock in the eastern part of the area mapped as granophyre, and the granophyre may have intruded its own volcanic pile. The variety of similar fine-grained rocks makes subdivision of the granophyre difficult, but the granophyric rocks are clearly related to widespread alkali-feldspar granite plutonism.

Fine-grained granitic gneiss

Fine-grained granitic gneiss crops out in a small area in the northwestern corner of the quadrangle. The rock is red, leucrocratic, and has a syenogranitic composition. Gneissic foliation is caused by crystalloblastic growth of quartz and feldspar and by alinement of sparse dark minerals. An initially nearly crystallized magma was probably cataclastized and recrystallized late during its emplacement. The rock is exposed in the adjoining quadrangles to the north and northwest where it is directly associated with granophyre. The rock is more fully described in the report on the Wadi al Miyah quadrangle (Schmidt, unpub. data).

Gabbro of Jabal as Sidan

The gabbro of Jabal as Sidan is, except for certain dikes, the youngest and least altered rock in the quadrangle. It is named for Jabal as Sidan where it constitutes a north-northeast trending, concentrically layered gabbroic pluton, 13 km long by 6 km wide. The pluton consists of two coalescent, oblong, compound intrusions, each consisting of thick layers that dip steeply inward toward a subhorizontal core. Both bodies were formed by multiple injections of gabbroic magma.

The gabbro is a dark-gray, medium-grained olivine leucogabbro (table 1). Most of the rock sampled contains more than 50 percent plagioclase, abundant orthopyroxene and clinopyroxene, and 10 percent olivine; some gabbro contains 40 percent olivine. Late magmatic crystallization resulted in an assemblage of orthopyroxene, clinopyroxene, brown hornblende, red-brown biotite (oxybiotite), and magnetite, with or without relict olivine. Subsequently some serpentine formed. Three layers of dunite, each about 30 m thick, lie at and near the gently inward dipping core (plate 1). The dunite is largely altered to serpentinite. The outer layers of the pluton are more leucocratic and contain less olivine than the inner layers. Near the outer contact, olivine has been replaced by pyroxene and some pyroxene by oxybiotite. The contact has a chilled zone, commonly a few meters wide, that consists of fine-grained leucogabbro. Thin dikes and small pods of fine-grained leucogabbro intruded the wall rock over a width of several tens of meters. Coarse-grained to pegmatitic, ophitic anorthosite occurs along parts of the contact.

A long tongue of leucogabbro, 1.5 km wide, extends about 10 km northwest of the northern end of the Jabal as Sidan pluton. About 5 km farther northwest, a well layered gabbroic body, 2.5 km wide by 3 km long, intruded the southeastern contact zone of the batholith of Jabal Khashmadheeb. The layered rock is an olivine leucogabbro, similar to the average composition of the Jabal as Sidan pluton. Its curvilinear layers conform to the layering in the batholith of Jabal Khashmadheeb, and the layers project into the wall rock and terminate in sawtooth fashion. This layered body could have formed only by multiple injection. Two kilometers farther northwest, thick dikes of the slightly finer grained leucogabbro intrude the eastern diabasic part of the batholith of Jabal Khashmadheeb. They also conform to the semiring structure of the batholith.

All these gabbroic bodies are mapped as gabbro of Jabal as Sidan. Even inside the batholith of Jabal Khashmadheeb, they are not contaminated by granitic components as is some of the diabase of the batholith. The gabbro is distinctly more fractionated than the fine-grained diabase of the batholith of Jabal Khashmadheeb. It was intruded shortly after the batholithic rocks consolidated, because the gabbro near and within the batholith mimics the internal structure of the batholith. The Jabal as Sidan pluton has a northeastern orientation similar to the batholith of Jabal Khashmadheeb and may have been emplaced under the same regional stress field. The gabbro of Jabal as Sidan is likely a late fraction of the same deep-seated gabbro magma that was the parent to the diabase.

Dikes

Abundant mafic and felsic dikes, mostly granitic or diabasic, intrude all the rocks of the Al Junaynah quadrangle (plate 1). These dikes are too numerous and complex to be shown on plate 1.

Most spectacular are the curvilinear dikes of granite that are part of the ring-structured pluton of Jabal al Najiah. The youngest are diabase dikes of northwest trend that are especially abundant in the Wadi Musayrah batholith. Most dikes mapped are younger than the granodiorite-monzogranite of Wadi Musayrah. The Precambrian crust rose during the emplacement of the Wadi Musayrah batholith and all subsequent intrusion was at a relatively shallow crustal level, such that brittle fracture and dike emplacement were mechanically feasible. Dikes older than the batholith of Wadi Musayrah undoubtedly intruded the volcanic rocks and subvolcanic plutonic rocks but have been fragmented, deformed, and metamorphosed and consequently are difficult to recognize. About 60 thin sections and stained slabs of various dike rocks were examined.

Felsic dikes (map symbol, f) consist of gray alaskite and microgranodiorite that may be as old or older than the Wadi Musayrah batholith. They seem unrelated to the Wadi Musayrah batholith, however, because few are exposed in the contact zone of the batholith. Presumably at the level presently exposed, the batholith was forcefully emplaced below the level of brittle fracture (Schmidt, unpub. data).

Pink to red microgranite dikes (map symbol, g) containing abundant potassium feldspar are the most abundant dikes throughout the quadrangle. They include subordinate red aplite and pegmatite dikes. Most are associated with the posttectonic granites. Abundant microgranite dikes of syenogranite west of Jabal Yellah and Jabal al Amoudah are related to the alkali-feldspar granite batholith of these jabals and are associated in part with the granitic hybrid dikes of the area. Red microgranite dikes are abundant throughout the western one-third of the quadrangle, suggesting that posttectonic granite plutons are more extensive at a depth below the present level of exposure. The abundant red microgranite ring dikes in the syenogranite batholith of Jabal al Najiah conform to the ring structure and were emplaced concurrently with the batholith.

Syenitic dikes and plugs (map symbol, s or ss) are reddish-brown to bluish-gray trachytic and syenitic rocks containing less than 10 percent quartz. Most are very fine grained; many have spherulitic textures. Some rocks contain sodic amphiboles, sodic pyroxene, and fluorite. The dikes are most probably related to peralkalic granite plutonism. The syenitic plug, 1.5 km across, and associated dikes along the northern border of the map east of Jabal al Jafar correlate directly with abundant dikes and small plugs in the Wadi al Miyah quadrangle (Schmidt, unpub. data).

Basalt dikes (map symbol, b) are mapped adjacent to the tongue of gabbro extending northwestward from Jabal as Sidan. They are correlated with the gabbro of Jabal as Sidan because of their proximity to the gabbro and their lack of diabasic texture. The basalt dikes, mapped inside the eastern part of the Jabal Khashmadheeb batholith, are probably correlative with nearby lenticular masses of the gabbro of Jabal as Sidan. These basalt dikes conform to the semiring structure of the batholith.

Many diabasic dikes (map symbol, n) are mapped as being younger than the Murdama group rocks because they trend northwest parallel to the post-Murdama Najd faults and intrude Murdama rocks at one locality. The relationship between time of intrusion of these dikes and the Najd faulting is best documented in the Jabal al Qarah quadrangle (Schmidt, unpub. data). Two diabasic dikes, each about 3 m thick, intrude the Murdama conglomerate about 6 km south of Jabal al Amoudah. One of these diabasic dikes is directly associated with a lenticular dike, as wide as 16 m, of dark red-brown quartz trachyte (map symbol, r). It is evident at the outcrop that subordinate, comagmatic, alkali-rich magma was associated with--and immiscible in--the diabasic magma.

The quartz trachyte contains many radial, orbicular structured spherulites, as much as 1 cm across, consisting of potassium feldspar in a groundmass of albite and sparse quartz. Brown and green microlites after pyroxene and amphibole have been deuterically altered to iron oxide and chlorite; fluorite is sparse. To the west in rocks beneath the Murdama conglomerate, this dike merges with a northwest-trending swarm of quartz trachytic to rhyolitic dikes.

Abundant rhyolitic dikes (map symbol, r) and diabasic dikes (map symbol, d) are shown as older than Murdama, but criteria for dating these dikes as pre-Murdama or post-Murdama are few.

Small quartz-breccia zones and quartz veins are widely distributed along small shear zones in which the sheared wall rock is propylitically altered. In places these shear zones are devoid of quartz-veins and conspicuous wall-rock alteration and they are then mapped as "shear-fracture zones" or, where altered as "alteration zones." Most of this deformation, alteration, and quartz deposition is probably associated with Najd faulting.

QUATERNARY SURFICIAL DEPOSITS

The surficial deposits of the Al Junaynah quadrangle resulted from a cyclical, arid-pluvial climate during the Quaternary period. Deposits of Quaternary age include: recent alluvium in wadis and on pediments; older alluvium on wadi and pediment terraces; loessic silt deposits in wadi terraces; and eolian sand in presently active dunes and in older, stabilized dunes. The Quaternary history is best displayed in the abundant terrace deposits of Wadi Bishah (fig. 18) and its principal tributary from the west, Wadi Tabalah.

Wadi Bishah flows in a semi-sinous broad valley for a distance of 75 km from the southwestern corner to the northeastern corner of the quadrangle. Its headwaters are on the east slope of the Red Sea Escarpment at altitudes of more than 2,200 m, 225 km south of Qalat Bishah. This high Asir region receives considerable rainfall (Escarpment, estimated 1,000 mm annual rainfall; Khamis Mushayt, altitude 2,057 m, annual rainfall 271 mm; Qalat Bishah, altitude 1,161 m, annual rainfall 110 mm; Schyfsma, 1978), but little surface water reaches the Al Junaynah area. Surface water flows in Wadi Bishah at Qalat Bishah only a few weeks a year.

The regional Quaternary stratigraphy was understood in greater detail after a study of a gold placer in the Jabal al Qarah quadrangle, where the stratigraphy was well exposed in

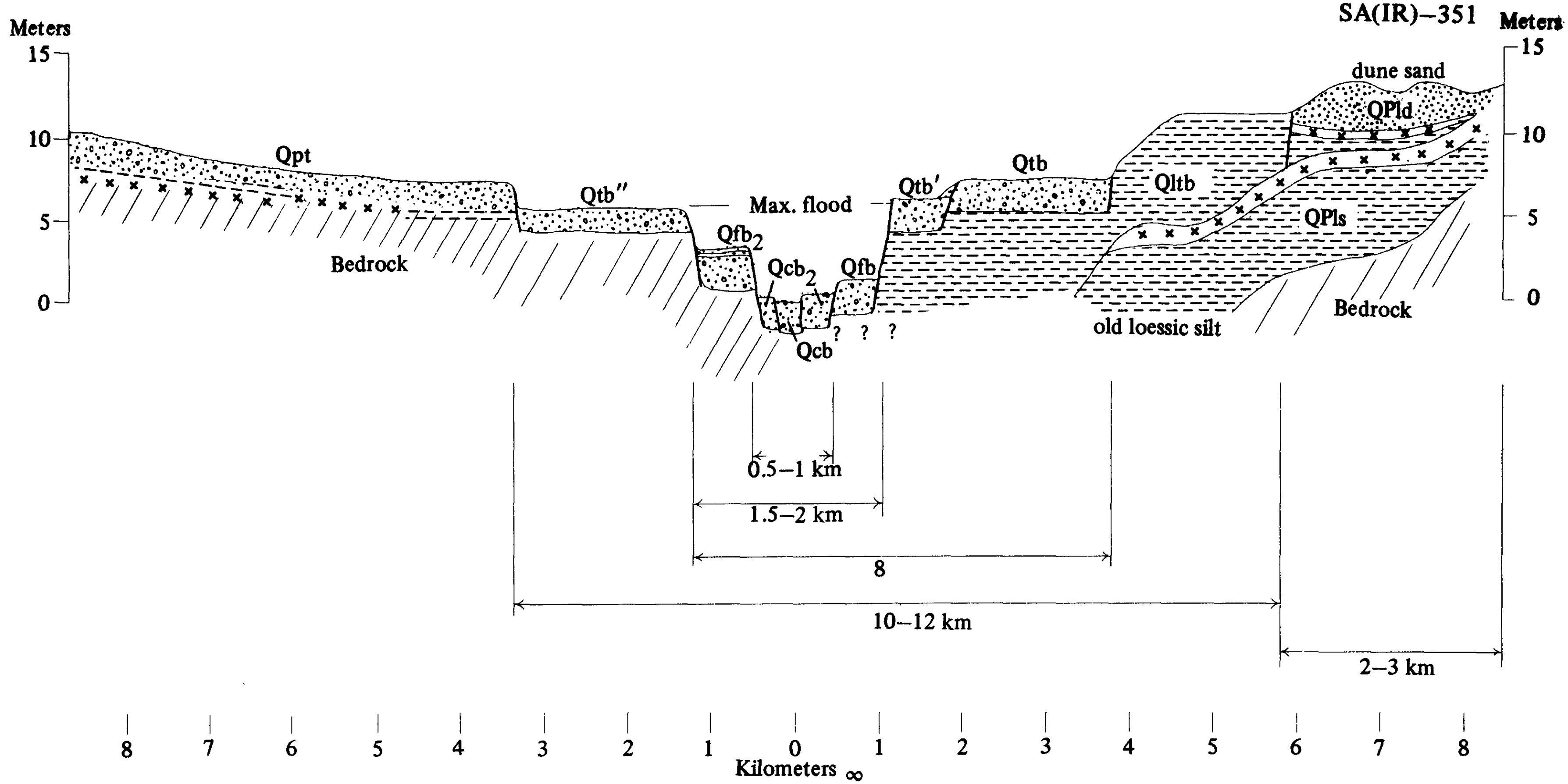

Figure 18.–Schematic cross section of Wadi Bishah in the southern half of the Al Junaynah quadrangle showing: present-day alluvial channel (Qcb), recently abandoned channel terraces (Qcb_2); low flood-plain terrace (Qfb), high flood-plain terrace (Qfb_2); sand and gravel in terraces capped by lag gravel (Qtb, Qtb', Qtb") that were cut after the last deposition of silt; loessic silt terrace (Qltb) representing aggradation of loessic silt by Wadi Bishah during the Holocene Altithermal; and stabilized, eroded dunes of Pleistocene age (QPld) overlying loessic silt deposits of Pleistocene age (QPls)–the Pleistocene silt is capped by duricrust (symbol, xxxx) of Pleistocene age. Pediment terraces (Qpt) of sidestreams are capped by lag gravel; the pediments mostly postdate the Holocene loessic silt, and are cut on Pleistocene and older pediment deposits as well as bedrock. The Pleistocene and older pediment deposits and bedrock beneath the alluvium of the pediment terrace (Qpt) contains a thick zone (about 3 m) of carbonate-cemented gravel and bedrock (symbol, ////).

trenches dug for that study (Schmidt and others, unpub. data). I have also studied the Quaternary stratigraphy of the Wadi Bishah deposits in their continuation north of the Al Junaynah quadrangle into the Wadi al Miyah quadrangle (Schmidt, unpub. data).

Wadi Alluvium

Sand and gravel deposits in wadis are best classified in the master stream, Wadi Bishah. The present-day active channel of Wadi Bishah is 0.5 to 1 km wide, except in parts of the northern half of the quadrangle where the wadi is confined between resistant bedrock walls and the channel is, in places, less than 100 m wide. Throughout the length of the wadi, low terraces of sand and gravel, about 0.5 m high, represent recently abandoned channel floor. They suggest that the wadi is actively entrenching at the present time.

The flood plain of the wadi is 1.5 to 2 km wide and about half of this width consists of flood-plain terraces, 1 m to several meters high. The terraces consist of sand and gravel covered by flood silt and a moderate amount of vegetation. The flood-plain terraces are covered by water during floods. Only the larger floods inundate the higher flood-plain terraces. A high flood level of 5.5 m, perhaps a debris flood front, is recorded along Wadi Bishah in the Wadi Miyah quadrangle to the north (Schmidt, unpub. data). Again, these terraces imply a steady down cutting by the stream during recent time.

Higher terraces, up to about 7 m above the present channel, constitute an ancestral valley floor about 8 km wide. The terraces are covered with lag gravel that has a well-developed desert patina and consist of sand and gravel of Wadi Bishah. These high terraces are mostly devoid of vegetation. The highest terrace level at about 7 m probably represents a re-established sand and gravel channel level for Wadi Bishah after the loessic silt aggradation of Holocene age.

A similar Holocene history is less well developed, but consistently similar in the other wadis of the Al Junaynah quadrangle and indicates a regional control by changing climate. Small side wadis commonly have many terraces, 1 to 2 m high, containing locally derived sand and gravel.

Pediments are widespread throughout the quadrangle but are shown on plate 1 only where the underlying bedrock has not been mapped. A large part of the pediment surface consists of pediment terraces covered with lag gravel that has a well-developed black patina. These surfaces are black in contrast to the gray alluvium of the active part of the pediment which is dissected 0.5 to 2 m below the older surface.

In a few places the Holocene loessic silt is seen beneath the older alluvial veneer and indicates that most of these pediments formed since the Holocene pluvial of Arabia (6,000-9,000 years ago; McClure, 1976).

Large sand surfaces east of Jabal al Amoudah and west of Jabal ath Thamalah are mapped as pediment flood sand. These are active pediments composed of sand that are entirely inundated by a sheet of flowing water during large rainstorms. Most of the sand is washed eolian sand that accumulates in small quantities between storms. The sheetflow of water causes large ripples of graded sand to form on the pediment surface. These sheetwash ripples of sand are about 1 m high by several kilometers long and have wavelengths of 100 to 300 m.

Loessic silt deposits and duricrust

Loessic silt is conspicuously exposed in the banks of Wadi Bishah and forms at least two deposits of Holocene and of Pleistocene age, respectively. The deposits consist of water-worked silt that was derived from desert loess that accumulated during the pluvial periods of the Quaternary (Schmidt and others, unpub. data). Along Wadis Bishah and Tabalah the youngest silt deposit forms a high terrace, which on Wadi Bishah is about 11 m above the channel level. In the more open, flat terrain of Wadi Bishah in the southern part of the quadrangle, the terrace is 10 to 12 km wide. The deposit represents an aggregational fill of silt in the wadi, and may extend below the present channel level.

The loessic silt is buff, very fine grained, and has a vague to distinct, thick bedding. It stands with vertical faces where dissected. One sample collected by C.L. Hummel (USGS, written commun., 1964) from an area in Wadi Bishah, 16 km south-southwest of Qalat Bishah, consists of unconsolidated detritus of which 45 percent is coarser than 44 microns (+325 mesh) and 55 percent is finer. The silt contains a well-mixed assortment of feldspar, quartz, calcite, chlorite, weathered mica, amphibole, gypsum, montmorillonite (less than 10 percent), and kaolinite (trace); the relative amounts of these minerals are about the same in the two size fractions (P.S. Blackman, USGS, written commun., 19 March, 1965).

The age of the upper part of the loessic silt deposit is about 6,000 years B.P. as dated by Carbon-14 method on charcoal from several fire hearths of ancient man (Meyer Rubin, written commun., 1974, 1975) from sites in the Jabal al Qarah quadrangle (Schmidt and others, unpub. data) and in the Wadi al Miyah quadrangle (Schmidt, unpub. data). This date indicates that the loessic silt accumulated during the Holocene pluvial (McClure, 1976).

The loessic silt is characteristic of desert loess that was initially eroded from the Precambrian rocks of the Arabian Shield. Much of the silt in the deposit, however, has been recycled throughout the Quaternary within the large closed drainage system. The closed basin terminates in the Rub al Khali where terminal lakes and playas existed during pluvial periods (McClure, 1976). The gypsum content of the silt suggests that much of the loess blows out of the Rub al Khali (G. O. Bachman, oral commun., 1978) and accumulates on the Precambrian shield during the pluvial periods.

During the pluvial periods, rainfall and stream flow were probably gentler and more distributed through the year than at present, even though the total rainfall and total stream flow was not likely much greater than present. Under these conditions, the stream regime was drastically changed from that of the present day--the streams transported only silt on a course that meandered extensively across a densely vegetated silt plain. Of course, the valley gradient, which is approximately the same as the present-day stream gradient, did not change; a meandering stream, greatly restricted by vegetation during the pluvial periods, accounts for the great change in stream regime. This situation can be compared to the present-day Sudd on the Nile River in southern Sudan (Whiteman, 1971, p. 112).

A duricrust of silt cemented by gypsum and calcite forms locally on the Holocene silt. The crust is soft and porous and as thick as 30 cm. Its youthfulness is indicated by its undulating conformity to even, steep erosional slopes on the silt. This duricrust forms only where gypsum is presently leaching out of the loessic silt deposit. The gypsum is a part of the eolian loess (G. O. Bachman, U.S. Geological Survey, oral commun., 1978). In most of the loessic silt, gypsum was leached out long ago and no gypsiferous crust forms today.

On the older, poorly exposed loessic silt, a calcium carbonate duricrust has formed. This calcrete was seen in one place where the younger silt has been stripped away. The carbonate crust is 0.5 to 2 m thick and is massive and tough in comparison to the Holocene gypsum crust. The thickness of the massive duricrust suggests a Pleistocene age.

Calcic duricrust, as small erosional remnants, is also found on a few outcrops of diverse bedrock in the Al Junaynah quadrangle. It is likewise indicative of fluctuating climate during the Pleistocene and its sparseness and erratic distribution suggest that the climate was generally too arid for caliche development during the Quaternary. Trenching in the Jabal al Qarah quadrangle indicates that as much as 3 m of caliche underlies the old pediment surfaces and suggests that the climatic cycles extended back into the Pliocene.

Dune sand

Active dune sand is sparse in the quadrangle in spite of the broad alluvial plain of Wadi Bishah where eolian sand might be expected to accumulate. The sparseness suggests overall gentler circulatory winds here as compared to areas to the north and east of the quadrangle where abundant sand dunes are present. Perhaps the low topography in the quadrangle in combination with the more rugged topography to the west is effective in moderating wind conditions. Perhaps, also, the Wadi Bishah alluvium in the Al Junaynah quadrangle remains moist longer, supports slightly more vegetation, and thus stabilizes the alluvial sands of the wadi plain more effectively than it does farther north. And finally, perhaps the prevailing southeasterly winds do not bring sands directly from the Rub al Khali as they do to the quadrangles to the east. A thin cover of eolian sand is abundant in many areas of bedrock throughout the quadrangle but is not sufficiently thick to yield abundant dunes. This sand is washed by infrequent and seasonal storm rains that wash the eolian sand from nearby slopes and redeposits the sand on the pediments and in the wadis.

Pleistocene dune sand in stabilized dunes is mapped in two large areas along Wadi Bishah. These dunes are identified by their sinuous, erosional surface form, by their high level above the Holocene loessic silt terrace of Wadi Bishah, and by their obvious eolian sand composition. They are not dissected and only the landform has been mapped.

Saline alluvium

Saline alluvium containing a white surface efflorescence is mapped in two small areas, one northwest of Jabal ath Thamalah and the other northwest of Jabal Yellah. In both areas, small tributary streams have been slightly ponded at their confluence with their small master streams, which are locally aggrading because they carry abundant eolian sand washed from their watersheds. Evaporation of both ponded surface water and subsurface water produces the saline efflorescence.

STRUCTURE AND METAMORPHISM

Two large fault zones, herein named the Junaynah and Rawshan fault zones, divide the Al Junayunah quadrangle into three nearly equal structural blocks. Attitudes of the faults and of rock structure within the blocks are northerly and about vertical. Movement on the faults reflects deformation during at least three orogenic episodes (Schmidt and others, 1973). During the Yafikh orogeny, volcanic and volcaniclastic rocks of the Halaban group and asssociated subvolcanic plutonic rocks were deformed; during the Bishah orogeny, sedimentary rocks of the Murdama group and the posttectonic granites were deformed; and finally during the Najd faulting event (Najd orogeny), all the rocks were further deformed on a conjugate set of northwest- and northeast-trending fractures. The Al Junaynah quadrangle lies in a transition zone between Jiddah-age rocks to the west and southwest (Anderson, 1977) and Halaban-age rocks to the east (Schmidt, unpub. data); as noted previously, no rocks of Jiddah age were recognized in the Al Junaynah quadrangle.

The older rocks of the eastern structural block, east of the Junaynah fault zone, are continuous with volcanic and plutonic rocks of Halaban age in the Jabal al Qarah quadrangle to the east and have the same geologic history as those rocks (Schmidt, unpub. data). In summary, the Halaban volcanic and volcaniclastic rocks of the eastern block were isoclinally folded, intensely faulted, and metamorphosed to the greenschist facies during the Yafikh orogeny. A conspicuous contact metamorphic zone of amphibolite hornfels was formed adjacent to granodiorite of late Halaban age.

The Bishah orogeny culminated much later during the rise of the Jabal al Qarah gneiss dome in the Jabal al Qarah quadrangle and in the southeastern part of the Al Junaynah quadrangle. The rise of the gneiss dome was accompanied by emplacement of the granodiorite-monzogranite batholith of Wadi Musayrah. Emplacement of the dome was asymmetric in that mobile migma and batholithic magma rose only on the west side of the dome, and both were intruded directly into Halaban rocks. Intensive deformation of regional extent during gneiss doming caused renewed movement along the Junaynah and Rawshan fault zones and renewed deformation in the rocks of Halaban age between these faults.

Rocks in the central and western structural blocks and in the Rawshan fault zone were also deformed during the Yafikh and Bishah orogenies. However, the presence of a gneiss dome or domes is only suggested by small outcrops of granitic gneiss in the central block. The overall metamorphic grade of the volcanic and volcaniclastic rocks is higher in these blocks than in the eastern block, and biotite and amphibole are the stable metamorphic minerals; this higher grade metamorphism also suggests that orthogneiss may underlie the central block and probably the western block.

The red granites are posttectonic relative to the Jabal al Qarah gneiss dome and the Musayrah batholith, and were intruded at a shallower crustal level than was the batholith. Brittle fracture is particularly well demonstrated by the ring-structured plutons of Jabal al Najiah and Jabal Khashmadheeb. Emplacement of the alkali-feldspar granite parallel to and along the entire length of the Junaynah fault zone means that the fault was somehow involved during emplacement of the granite. Continued movement along north-trending structures after plutonism is indicated by deformation of the posttectonic granites in both the Junaynah and Rawshan fault zones. The preservation of Murdama clastic rocks in downfaulted blocks, and the strong shearing of these rocks in the Junaynah fault zone, clearly indicate faulting of post-Murdama age.

The youngest deformation was the Najd faulting, characterized by left-lateral transcurrent faulting on northwest trends and reactivation of some north-trending faults. The Najd faults are not identified easily in the Al Junaynah quadrangle, but the northwest-trending faults in the south-central part of the quadrangle are probably of Najd age and the Junaynah fault zone was probably reactivated during Najd time. Furthermore, the northeast-trending faults in the western part of the quadrangle may be early conjugate fractures of the Najd event.

GEOCHRONOLOGY

Four significant geological events in the Al Junaynah quadrangle have been dated by rubidium-strontium (Rb-Sr) and potassium-argon (K-Ar) methods (Fleck and others, 1976; Fleck and others, 1979). These events are: 1) early Halaban volcanism about 785 m.y. ago; 2) late Halaban plutonism about 725 m.y. ago; 3) the rise of the Jabal al Qarah gneiss dome and associated emplacement of the granodiorite-monzogranite batholith of Wadi Musayrah about 625 m.y. ago; and 4) intrusion of the posttectonic granites about 600 m.y. ago. The geochronological data are summarized in table 2. These dates and the sequence of events in the development of the Halaban-age crust agree well with other dates in the adjacent Jabal al Qarah quadrangle to the east (Schmidt, unpub. data).

Table 2.--*Rubidium-strontium (Rb-Sr) and potassium argon (K-Ar) dates, determined by R.J. Fleck*[2] *on rocks from the Al Junaynah quadrangle*

[Leaders -- indicate not available; W.R., whole rock; Bi, biotite; Hb, hornblende; Pl, plagioclase]

Number on plate 1	Station No. Schmidt[1]	Sample No. Fleck[2]	Text No. Fleck[3]	Method	Rock type	Map unit (Map symbol as on plate 1)	Number of points on isochron	date m.y.	Initial $^{87}Sr/^{86}Sr$
1	J115-1	724-28-J	16	Rb-Sr/W.R.	dacitic tuff	dacitic and	--	--	--
1	J115-J	724-28-K	16	Rb-Sr/W.R.	dacitic tuff	volcaniclastic	3	785±2	0.70254±0.00001
1	J115-K	724-28-L	16	Rb-Sr/W.R.	dacitic tuff	rocks (hdc)	--	--	--
2	J114-Q	724-28N	17	Rb-Sr/W.R.	granodiorite	granodiorite	2 of a 4-point	723±11	0.70254±0.00005
3	J 99-R	724-28P	18	Rb-Sr/W.R.	granodiorite	(gd)	isochron[4]	--	--
2	J114-Q	724-28N	--	K-Ar/Bi	granodiorite	--	--	593.3±8.1	--
2	J114-Q	724-28N	--	K-Ar/Hb	granodiorite	--	--	596.6±7.4	--
4	83613-A	742-26A	48	Rb-Sr/W.R.	granodiorite	granodiorite-	2 of a 7-point	623±8	0.7033±0.0001
4	83613-B	742-26B	48	Rb-Sr/W.R.	and	monzogranite	isochron[5]	--	--
					monzogranite	of Wadi			
						Musayrah (gmm)			
5	J116-A	724-29A	--	K-Ar/Bi	syenogranite	--	--	602.1±7.6	--
5	J116-A	724-29A	--	Ar-Ar	syenogranite	syenogranite	--	598.	--
				spectra/Hb		of Jabal al			
6	J116-E	724-29B	--	K-Ar/Bi	syenogranite	Najiah (grsn)	--	596.3±7.4	--
6	J116-E	724-29B	--	K-Ar/Pl	syenogranite		--	535.6±14.1	--

1 Field number used during mapping Al Junaynah quadrangle
2 Fleck and others, 1976; Fleck and others, 1980.
3 Fleck and others, 1980 .
4 2 other isochron points are from rocks of the Wadi Harjab quadrangle (Fleck and others, 1979)
5 5 other isochron points are from rocks of the Jabal al Qarah quadrangle (Fleck and others, 1979)

Halaban volcanism probably extended from about 785 m.y. to about 720 m.y. according to an interpretation (Schmidt, unpub. data) of Rb-Sr isochron dates from the southern Najd region (Fleck and others, 1979). However, individual isochron dates of the volcanic rocks have considerable uncertainty. For instance, rocks from the Arfan formation of the Bi'r Juqjuq quadrangle, which overlie rocks of the main phase of the andesitic volcanism and are similar to the dacitic and volcaniclastic map unit of the Al Junaynah quadrangle, give a 2-point isochron of about 775 m.y. and a 3-point isochron of about 761 m.y. If geologic relations are the same in the Al Junaynah quadrangle, then the 785 m.y. date for the dacitic and volcaniclastic map unit (table 2; locality 1, pl. 2) may be several tens of millions of years too old.

Two samples from the granodiorite of the southeastern part of the Al Junaynah quadrangle, combined with two samples of tonalitic gneiss from the granodiorite orthogneiss unit from the Wadi Harjab quadrangle (Cornwall, 1973), give a good quality 4-point isochron and a date of 723±11 m.y. (table 2; localities 2 and 3, pl. 2). These rocks were emplaced during the thickening of the Halaban-age crust at intermediate crustal depth after subvolcanic plutonism. The fact that samples of both rocks lie on this 4-point isochron, even though the granodiorite was only weakly affected by the rise of the Jabal al Qarah gneiss dome whereas the granodiorite orthogneiss was intensely affected, suggests that the gneiss doming, 100 m.y. after the intrusion of these rocks, did not affect their whole rock Rb-Sr date. In contrast, K-Ar dates on biotite and hornblende from one sample of the granodiorite from the Al Junaynah quadrangle (table 2) have been reset to about 600 m.y., which is the time of widespread posttectonic granite plutonism.

The Wadi Musayrah batholith is well dated at about 623 m.y. by a 7-point isochron of very good quality. Two points of this isochron were determined from adjacent samples, one granodiorite and the other monzogranite, from a single outcrop of layered gneissic granite in the Al Junaynah quadrangle (table 2; locality 4, pl. 2). The other points were determined on samples from the Jabal al Qarah quadrangle (Schmidt, unpub. data). In as much as field and petrographic relations indicate that the Wadi Musayrah batholith was emplaced during the rise of the Jabal al Qarah gneiss dome, this same date is applicable to the time of gneiss doming.

Posttectonic granite plutonism in the Al Junaynah quadrangle is dated at about 600 m.y. by K-Ar analyses of biotite and hornblende from the syenogranite of Jabal al Najiah (table 2; localities 5 and 6, pl. 2). The three dates on biotite and hornblende in table 2 average 599 m.y.; they have only a small spread on either side of the average, have good analytical precision, and are considered reliable, in spite of the fact that they are minimum dates. In the Al Junaynah quadrangle and surrounding area, the posttectonic granites are on the basis of field relations younger than the granodiorite-monzogranite of Wadi Musayrah, which is dated at about 625 m.y., and were probably intruded during the interval between 625 m.y. and about 600 m.y. Fleck and others 1979) suggest that granitic plutonism in the southern Arabian Shield (granodiorite to granite) took place from about 650 m.y. to 610 m.y. ago.

ECONOMIC DEPOSITS

Metallic deposits located in the Al Junaynah quadrangle do not have economic potential at present. Three small systems of quartz veins locally contain sparse base-metal sulfides and rare gold. All three were worked by ancient miners on a small scale. They are probably indirectly related to the Najd faulting event. Fluorite pegmatite veins containing brannerite occur at Jabal Biyon. The posttectonic alkali-feldspar granite paralleling the entire length of the Junaynah fault contains traces of tin, beryllium, and molybdenum.

The largest ancient mine is about 15 km south of Jabal as Sadah and west of the southern end of the Najiah ring-granite pluton (locality A, pl. 2). The mine site was discovered by J. W. Whitlow during 1964-1965, includes the stone ruins of a village of about 30 dwellings, a few hammer stones, stone anvils, and circular grindstones, and a small amount of slag. The country rock is trondhjemite containing inclusions of hornblende diorite; a contact with the hornblende diorite is nearby. A shallow east-trending mine pit is about 40 m long by 8 m wide and has a surrounding dump containing not more than 1,000 m^3 of debris. No quartz veins are exposed but the dump contains some highly fractured quartz (less than 20 percent) as well as highly altered trondhjemitic wall rock. A few specimens of quartz from the dump contain sparse galena, chalcocite, malachite, azurite, and cerussite. Three analyses of selected, high-grade samples from the dump are given in table 3 (map letter A). Lead, zinc, and silver are significant metals in the samples. The ancient mine site is characteristic of ancient gold mines of the region.

About 4 km east of the ancient mine at locality A, a small quartz-breccia pod about 6 m wide by 30 m long contains copper-stained, pyrite-bearing quartz (locality B, pl. 2). The quartz-breccia is part of a highly sheared vertical fracture that trends N.30°E., is 6 to 12 m wide, and is along a poorly exposed contact between metavolcanic rock and a small tongue of the nearby trondhjemite pluton.

A small ancient mine, 3 km west-northwest of Jabal Wadon (locality C, pl. 2), was mined for gold. The site was discovered by Ghanim Jeri Alharbi. It extends discontinuously about 300 m along an east-northeast-trending fracture system that contains white quartz veins and crosses the contact between a small stock of monzogranite and metavolcanic hornfels. The western and eastern ends of the quartz-vein system were worked by ancient miners. The western end, in metavolcanic rock, consists of many shallow pits, 3 to 4 m wide by 60 m long on a N.70°E. trend; the eastern end, in monzogranite, consists of a trench, 1 to 3 m wide by 2 to 3 m deep, and extends about 50 m along a N.40°E. trend. Many small dumps contain a total of several thousand cubic meters of waste rock consisting of altered wall rock and white, mostly barren quartz. Selected specimens of quartz from the dump contain particles of free gold, as much as 1 mm across, and associated sparse pyrite, gruenlingite, and copper stain. Gruenlingite (Bi_4TeS_3(?)) was identified by X-ray diffraction by Mohammed Naqvi (U.S. Geological Survey, Jiddah Laboratory). Analyses of two carefully selected samples from the dump are given in table 3 (map letter C).

Small galena-bearing quartz veins about 4 km northwest of Jabal Biyon (locality D, pl. 2) have been worked for galena either by ancient miners or possibly more recently by local people for cosmetic use. A prospect trench about 60 m long by 1 m wide by about 1 or 2 m deep trends from N. 50°E. to N. 23°E. Quartz veins in the trench are near the contact of a large inclusion of metavolcanic rock in granodiorite-and-tonalite. The N.50°E. trend is parallel to a red, fine-grained dike of mafic syenite, whereas the N.20°E. trend is parallel to a diabasic dike. The wall rocks are intensely hydrothermally altered. The white quartz contains sparse, anhedral galena crystals, as much as 1 cm across, as well as sparse pyrite, sphalerite, and a trace of copper stain. The paragenetic sequence is coarse white quartz, pyrite, sphalerite, and galena followed by euhedral, clear quartz crystals in vugs in late fractures cutting the early white quartz. An analysis of a selected dump sample contains minor silver, a trace of gold, and 500 ppm arsenic in addition to lead and zinc (table 3, map letter D).

The three ancient mines (localities A, C, and D) have all the characteristics of the sparsely mineralized quartz veins that are associated with the Najd faulting event of latest Precambrian age; they occur throughout the southern Najd province (Schmidt and others, unpub. data). Each has different wall rocks, yet their wall-rock alteration is the same and characteristic of the Najd vein deposits. Each is associated with northeast- to east-trending fractures that in the western part of the quadrangle are early and conjugate to the northwest-trending Najd faults. The analyses (table 3) indicate locally anomalous arsenic, bismuth, and antimony; bismuth and antimony have been noted previously in some Najd quartz veins (Schmidt and others, unpub. data) and all three elements are probably indicative of relatively high-temperature vein systems that have been deeply eroded since Najd time. There is no indication that the mineralization is related to posttectonic granite plutonism.

Small pegmatite veins containing brannerite and purple fluorite crop out on the northwestern side of Jabal Biyon (locality E, pl. 2). The site was found by Ghanim Jeri Alharbi. Jabal Biyon is presumably a plug of peralkalic granite, about 0.5 km across. It is surrounded by a discontinuous ring of quartz veins and quartz-potassium feldspar pegmatites whose abundant white quartz makes conspicuous white slopes on the underlying dioritic host rock. Only the quartz pegmatite lenses in the northwestern part of the ring have been found to be radioactive. V. J. Flanigan (U.S. Geological Survey, written commun.) reports radioactivity at the outcrops of 10 times background (Flanigan, written commun., 1974), and some large specimens tested in the laboratory count as high as 50 times background. The poorly exposed veins trend N.30°E to N.60°E., dip steeply to the northwest, and are about 0.5 m wide by 10 m long. The deposit warrants further examination.

Analyses of samples from locality E are given in table 4 for three types of closely associated rocks. 1) A milky quartz vein (sample 83211) contains white fluorite and bladed ilmenite crystals, 2 cm by 1 cm by less than 1 mm; abundant liquid- and gas-filled bubbles occur in some quartz crystals. 2) A white quartz-potassium feldspar pegmatite (sample 83212) contains about 20 percent coarse, white fluorite crystals 1 to 5 cm across, about 20 percent knots of fine-grained muscovite, and dispersed, prismatic crystals of brannerite less than 1 cm long. Where the brannerite crystals adjoin fluorite, the fluorite is purple. 3) A medium-grained rock (sample 83213) contains about 25 percent purple fluorite, about 50 percent quartz, knots of fine-grained muscovite, about 25 percent potassium feldspar, and less than 1 percent long, slim, prismatic crystals of brannerite less than 1 cm long by 1 mm by 0.1 mm. The brannerite crystals are highly metamict and have a soft, pale-yellow, outer rind and a dark-brown, vitreous core. They are concentrated in the fine-grained muscovite knots and at contacts between quartz and fluorite. Brannerite, $(U,Ca,Ce)(Ti,Fe)_2O_6$, was identified by X-ray diffraction analyses by J. J. Matzko

Table 3.--*Analyses of small quartz veins containing sparse gold, copper, and lead*

[All samples were selected from dumps or as float of ancient mines or prospects and analyzed by atomic absorption and semiquantitative spectrographic methods. For spectrographic analyses, N designates content less than limit of detectability shown in parentheses at top of column. Leaders --indicate no analysis was made by atomic absorption; <, less than amount shown; >, greater than amount shown; A-A, atomic absorption; Semiquant., semiquantitative spectrographic analysis. Results in parts per million. Analyst: Ibrahim Jambi, USGS-DGMR Chemistry Lab., Jiddah.]

Map letter	Sample number	Type of analyses	Ag (0.5)	Au (10)	Ba (20)	Cr (10)	Cu (5)	La (20)	Mn (10)	Mo (5)	Ni (5)	Pb (10)	V (10)	Y (10)	Zn (200)	Other
A	27554	semiquant.[1]	100	--	--	--	150	--	--	2	--	7,000	--	--	1,000	--
A	64115	A-A	352	0.46	--	--	264	--	--	--	--	1,500	--	--	500	--
		semiquant.	300	N	100	300	70	N	10	N	N	N	N	N	300	--
A	59042	A-A	560	0.16	--	--	605	--	--	--	--	--	--	--	--	--
		semiquant.	500	N	50	300	500	N	20	N	7	5,000	10	N	200	--
A	59043[2]	A-A	180	0.47	--	--	27,000	--	--	--	--	--	--	--	--	--
		semiquant.	300	N	300	200	>20,000	N	70	N	10	3,000	100	N	5,000	3,000 Sb (100)
C	59074	A-A	20	330	--	--	6	--	--	--	--	--	--	--	--	400 Bi
		semiquant	10	300	N	500	5	N	30	15	20	N	20	N	N	500 Bi (10)
C	59075	A-A	<0.2	0.44	--	--	35	--	--	--	--	--	--	--	--	15 Bi
		semiquant.	0.5	N	N	300	5	N	15	5	10	N	10	N	N	10 Bi (10)
D	59049	A-A	3.4	0.43	--	--	37	--	--	--	--	4,460	--	--	6,600	--
		semiquant.	3	N	50	100	50	N	10	N	5	5,000	50	N	5,000	500 As (200)

1 Partial analysis, no data on elements other than shown.

2 Float sample associated with slag in ancient village; probably not from local ancient mine.

Table 4.--*Analyses of radioactive pegmatite containing brannerite and purple fluorite at Jabal Biyon*

[Leaders --, designates not analyzed; <, less than amount shown; >, greater than amount shown. Analyst, K. J. Curry, USGS-DGMR Chemistry Laboratory, Jiddah.]

					X-RAY FLUORESCENCE					ATOMIC ABSORPTION	
					Parts per million					Parts per million	
Map letter	Sample number	Field number	Sample source	Rock type	F	U	Th	Ce	Y	Au	Ag
E	83211	83195B	outcrop	Quartz vein	2,400	--	--	--	--	0.06	0.2
E	83212	83195E	outcrop	Pegmatite	6,600	100	190	<200	190	0.12	2.2
E	83213	83195F	outcrop	Pegmatite	8,900	140	190	<200	200	0.02	0.7

SEMIQUANTITATIVE SPECTROGRAPHIC

Sample number	Percent				Parts per million							
	Fe	Mg	Ca	Ti	Mn	Ba	Cr	Cu	Pb	Sr	V	Y
83211	3.0	0.3	0.2	>1.0	2,000	50	500	50	50	<200	<20	<20
83212	0.1	0.1	>20.0	0.3	50	50	150	5	50	5,000	100	250
83213	0.2	0.1	>20.0	0.1	150	200	150	5	150	>5,000	150	300

(U.S. Geological Survey, Jiddah). R. B. Finkelman (U.S. Geological Survey, Reston, oral commun., 1979) states that X-ray pattern, chemistry, and morphology are consistent with brannerite; the black, vitreous mineral gave two weak, diffuse lines interpreted as brannerite(?); and energy dispersive analyses of two grains indicate major uranium and titanium and traces of iron, aluminum and silicon; neodymium and tantalum were not detected.

A conspicuous outcrop of weathered red-brown serpentinite lies along a large fault that is part of the Junaynah fault zone in the northeastern part of the Al Junaynah quadrangle (locality F, pl. 2). Analyses (table 5) indicate contents of chromium and nickel that are typical of serpentine. The rock is intensely sheared along planes dipping gently to the east. The serpentinite contains small veinlets of a bright green, chromium-nickel mica (fuchsite?). The layer of weathered serpentinite, 3 to 10 m thick, is underlain by pale-green to dark-green, antigoritic serpentinite and talc containing disseminated grains and veinlets of magnetite and chromite(?). The serpentinite is cut by veins and dikes of magnesite(?), quartz, and albite(?). This occurrence of serpentinite, except for its small size, is similar to the abundant pods of serpentine and talc in the large Nabitah fault zone 50 km to the east (Gonzales, 1975; Schmidt, unpub. data).

Tin and beryllium anomalies are consistently associated with the alkali-feldspar granite on the west side of the Junaynah fault zone. During 1964-65, J. W. Whitlow (U.S. Geological Survey) collected and had analyzed about 62 samples of alluvium from small, headwater wadis throughout the Al Junayunah quadrangle (Whitlow, unpublished data). The size fraction, minus 30 to plus 80 mesh, was analyzed. Seven of 10 alluvium samples collected from near the alkali-feldspar granite of Jabal Yellah, Jabal al Amoudah, Jabal ath Thamalah, and Jabal al Jafar on the west side of the Junaynah fault zone contain 10 to 30 ppm tin and 2 to 3 ppm beryllium (localities G through M, pl. 2). Most contain copper and molybdenum, and one contains anomalous niobium (50 ppm) and yttrium (300 ppm). In the northern part of the Jabal ath Thamalah pluton and the eastern part of the ring-structured batholith of Jabal al Najiah, magnetite from panned concentrates of alluvium contains 150 to 300 ppm molybdenum. Whitlow recommended that these granitic plutons should be examined and sampled further for tin and molybdenum mineralization.

Table 5.--*Analyses of serpentinite in Junaynah fault zone*

[Symbols: <, less than amount shown; >, greater than amount shown (), limit of detectability shown in parentheses in parts per million. The following elements were not detected by semi-quantitative spectrographic analysis: Ag (0.5), As (200), Au (10), B (10), Be (1), Bi (10), Cd (20), La (20), Mo (5), Nb (20), Pb (10), Sb (100), Sn (10), W (50), Y (10), Zn (200), Zr (10). Analyst: Ibrahim Jambi, USGS-DGMR Chemistry Lab., Jiddah.]

Map letter	Sample number	Field number	Rock	Percent				Parts per million								
				Fe (0.5)	Mg (0.02)	Ca (0.05)	Ti (0.002)	Ba (20)	Co (5)	Cr (10)	Cu 1/	Mn (10)	Ni 1/ --	Sc (5)	Sr (100)	V (10)
F	59058	J104B	Red-brown talc rock	5	7	10	0.005	50	30	1,000	8	1,000	1,625	5	200	30
F	59059	J104B	Red-brown serpentinite	7	7	10	.007	30	50	1,500	10	500	1,855	5	200	30
F	59060	J104B	Weathered serpentinite	2	5	5	.003	50	20	700	9	500	1,520	<5	500	20
F	59061	J104G	Red-brown serpentinite	5	>10	1	.01	<20	30	2,000	9	300	1,310	10	<100	30
F	59062	J104F	Banded serpentinite	2	7	0.5	<.002	<20	20	700	12	70	1,905	<5	<100	10
F	59063	J104B	Asbestoid serpentinite	20	5	5	.002	30	70	500	13	1,000	1,000	<5	<100	10

1/ Analysis by atomic absorption method.

In addition, a wadi-alluvium sample from the monzogranite inselberg (locality P, pl. 2) north of Jabal as Sadah, also contains anomalous tin (10 ppm) and niobium (50 ppm) along with molybdenum and copper (Whitlow sample, 27478). A wadi-alluvium sample from the north side of Jabal Biyon (locality N, pl. 2) contained anomalous tin (10 ppm) and beryllium (7 ppm) along with molybdenum and copper (Whitlow sample, 27686). This latter locality is near the radioactive, fluorite pegmatites described above and warrants further examination and sampling.

PRECAMBRIAN GEOLOGIC HISTORY

The Al Junaynah quadrangle lies between an older crustal block of Jiddah age to the west (Anderson, 1977) and a younger crustal block of Halaban age to the east (Schmidt, unpub. data). The quadrangle may contain elements of both blocks, but this study suggests that the entire quadrangle, as exposed, is probably underlain by rocks of Halaban-age. By this interpretation, an abrupt break separating Jiddah rocks from Halaban rocks lies slightly west of the Al Junaynah quadrangle. No ancient basement rocks, that is, rocks older than Jiddah age, are known to occur in the quadrangle or in the adjoining quadrangles (Schmidt and others, 1979).

The geology of the eastern one-third of the quadrangle east of the Junaynah fault zone, is continuous with crustal rocks of Halaban-age that are well displayed in the Jabal al Qarah quadrangle (Schmidt, unpub. data). Isotopic dating by R.J. Fleck (Fleck and others, 1979) indicates that calc-alkalic volcanism of Halaban age was initiated about 785 m.y. ago and extended to perhaps about 720 m.y. ago. Volcanism, dominantly andesitic, was accompanied by comagmatic diorite and gabbro in a shallow subvolcanic environment to form a primitive crust of early Halaban age.

As the Halaban crust became thicker, volcanism, dominantly dacitic, was accompanied by comagmatic tonalite, trondhjemite, and granodiorite intruded at shallow crustal depth as well as at intermediate crustal depth. Granodiorite in this plutonic suite is dated about 725 m.y. Volcaniclastic sedimentation was abundant. The crust was significantly thickened, especially by large homogeneous batholiths of tonalite and granodiorite, during this crustal development of late Halaban age. The volcanic rocks were isoclinally folded. The volcanic and plutonic rocks were intensely faulted and metamorphosed to the greenschist facies. Structural trends were northward.

The development of the Halaban-age crust, consisting entirely of low-potassic, calc-alkalic rocks, is highly suggestive of primary crustal growth related to a volcanic-magmatic arc. The Halaban-age crust in the Al Junaynah area was constructed on oceanic crust adjacent to a volcanic island arc; the arc axis was located farther to the east. The island arc was underlain by a west-dipping subduction zone (Schmidt and others, 1979). Evidence suggesting primary crustal growth is indicated in particular by: 1) the low-potassium, calc-alkalic rock types (Greenwood and others, 1976); 2) the low initial strontium ratios of the volcanic and plutonic rocks in the quadrangle (table 2) as well as of those of Halaban age in the southern Najd region as a whole (Fleck and others, 1979); and 3) the apparent absence of an ancient basement rock in the region.

Rocks with ages between about 725 m.y. and 625 m.y. have not, as yet, been recognized or dated in the Al Junaynah area. The Halaban-age crust probably continued to thicken and evolve for some time after 725 m.y. ago, and a major orogeny began some time before 625 m.y. ago.

Granitic plutonism began about 625 m.y. ago when the granodiorite-monzogranite batholith of Wadi Musayrah was syntectonically emplaced during the rise of the Jabal al Qarah gneiss dome (Schmidt, unpub. data). The emplacement of the Wadi Musayrah batholith culminated the major orogenesis of the Halaban-age crust. Strong compressive forces were probably directed westward as indicated by 1) the asymmetry of the gneiss dome and the emplacement of the Musayrah batholith on its western side, and 2) the reactivation of most north-trending structures. Perhaps the compression resulted from a major continental collision with--and to the east of--the Halaban-age crustal block (Schmidt and others, 1979).

Granite plutonism continued in a posttectonic setting from 625 m.y. to about 600 m.y. ago. Large volumes of magma rose diapirically to shallow depths in the crust to form plutons of monzogranite, syenogranite, alkali-feldspar granite, and peralkalic granite. At least some plutons, such as the ring-structured plutons of Jabal Khashmadheeb and of Jabal al Nabitah, probably explosively erupted at the surface. Their presently exposed ring structures are probably the deep roots of former calderas. Dodge (1979) has suggested that the Uyaijah ring structure in Halaban crust in the central Najd region is a deeply eroded caldera intrusion of the Valles type. The violent eruptions aided in the rise of large volumes of diabase in both of the ring-structured plutons in the Junaynah quadrangle. Cobbing and Pitcher (1972) depict similar bimodal intrusion in deeply eroded calderas in the Coastal batholith of central Peru.

Two magmas coexisted at the base of the Halaban crust during posttectonic plutonism. A primary gabbro magma was probably derived from the mantle and chiefly contributed to the rise of the geothermal gradient and consequently to the production of the second magma of granitic composition. The granitic magma was probably produced largely from lower crustal rocks of Halaban-age. This is suggested by the moderately evolved initial strontium ratio, 0.7033, of the granodiorite-monzogranite of Wadi Musayrah (table 2). Dodge (1979) and Dodge and others (1979) suggest on the basis of chemical evolution that the posttectonic granites in the central Najd region were probably generated by partial melting of Halaban crustal rocks.

The two magmas did not mix, except that mutual magmatic fluid reaction on a limited scale resulted in small amounts of diabase-hybrid and granite-hybrid rocks associated with diabase in the Jabal al Najiah and Jabal Khashmadheeb plutons. Fractionated gabbroic magma rose late during the posttectonic plutonism. The gabbro of Jabal as Sidan was intruded by multiple injections of leucocratic gabbro and dunite to form a concentrically layered pluton.

Large-scale orogenic uplift during the gneiss doming was accompanied by erosion. Continued epeirogenic uplift and erosion is evident by the emplacement of the posttectonic granites at shallower crustal levels from 625 m.y. to about 600 m.y. ago. Deposition of molasse-type rocks of the Murdama group transgressed westward as erosion progressed. In the Al Junaynah quadrangle, basal conglomerate and overlying arkosic sandstone and siltstone of the Murdama group were deposited on the youngest posttectonic granite. Elsewhere, as in the northeastern part of the Arabian Shield, evidence of the westward transgression of the Murdama sediments is seen by the fact that many of the posttectonic granites intruded the Murdama rocks. In places the Shammar group of predominantly rhyolitic rocks was synchronous in time with the Murdama (Delfour, 1977). The extent and great volume of the Shammar rhyolitic rocks suggest that the Shammar rocks are the volcanic equivalents of the extensive posttectonic granites. In the southern Najd region, all or most volcanic deposits of Shammar-age were eroded prior to the late Murdama deposition; it is possible that the hypabyssal granophyre in the Al Junaynah quadrangle may be a subvolcanic rock of the Shammar type.

A renewed pulse of compression during the latest Precambrian and possibly earliest Cambrian resulted in the Najd faulting event. By this time, the thick Halaban crust responded, first, by the development of small, well-distributed, conjugate fracturing on northeast and northwest trends, and later, by the concentration of movement along large shear zones of northwest trend. The northwest-trending shears have left-lateral, transcurrent displacements. The final movement was concentrated along three wide fault zones with a total left-lateral displacement of 200 to 300 km. In the Al Junaynah quadrangle, movement on small faults of northwest and northeast trend merged with reactivated movement on old faults of northern trend. Many diabasic dikes of northwest trend are Najd age, and are characteristic of the region. Several small quartz veins containing sparse base-metal sulfides and rare gold are probably associated with hydrothermal solutions activated during the faulting and the emplacement of diabase dikes of Najd age.

REFERENCES CITED

Anderson, R. E., 1977, Geology of the Wadi Tarj quadrangle, sheet 19/42 A, Kingdom of Saudi Arabia: Saudi Arabian Directorate General of Mineral Resources Geologic Map GM-29, scale 1:100,000.

Andreasen, G. E., and Petty, A. J., 1973, Total intensity aeromagnetic map of the Southern Najd quadrangle and part of the Southern Tuwayq quadrangle, Kingdom of Saudi Arabia: Saudi Arabian Directorate General of Mineral Resources Geologic Map GM-13, 3 p., scale 1:500,000.

Cobbing, E. J., and Pitcher, W. S., 1972, The coastal batholith of central Peru: Journal of the Geological Society of London, v. 128, p. 421-460.

Cornwall, H. R., 1973, Geology of the Wadi Harjab quadrangle, Kingdom of Saudi Arabia: Saudi Arabian Directorate General of Mineral Resources Geologic Map GM-3, 5 p., scale 1:100,000.

Delfour, J., 1977, Geology of the Nuqrah quadrangle, 25 E, Kingdom of Saudi Arabia: Saudi Arabian Directorate General of Mineral Resources Geologic Map GM-28, scale 1:250,000.

Dodge, F. C. W., Fleck, R. J., Hadley, D. G., and Millard, H. T., Jr., 1979, Geochemistry and Sr^{87}/Sr^{86} ratios of Halaban rocks of the central Arabian Shield: King Abdulaziz University Institute of Applied Geology Symposium on the Evolution and mineralization of the Arabian-Nubian shield, Jiddah, February 1978, Bull. 3, v. 2, p. 153-163.

Dodge, F. C. W., 1979, The Uyaijah ring structure: Kingdom of Saudi Arabia: U.S. Geological Survey Professional Paper 774-E, p. E1-E17.

Fleck, R. J., Coleman, R. G., Cornwall, H. R., Greenwood, W. R., Hadley, D. G., Prinz, J. S., Ratte, W. C., and Schmidt, D. L., 1976, Geochronology of the Arabian Shield, western Saudi Arabia: K-Ar results: Geological Society of America Bull., v. 87, no. 1, p. 9-21.

Fleck, R. J., Greenwood, W. G., Hadley, D. G., Anderson, R. E., and Schmidt, D. L., 1979, Age and evolution of the southern part of the Arabian Shield; also, Rubidium-strontium geochronology and plate tectonic evolution of the southern part of the Arabian Shield: King Abdulaziz University Institute of Applied Geology Symposium on the Evolution and mineralization of the Arabian-Nubian shield, Jiddah, February 1978, Bull. 3, v. 3, p. 1-17.

Fleck, R. J., Greenwood, W. R., Hadley, D. G., Anderson, R. E., and Schmidt, D. L., 1980, Rubidium-strontium geochronology and plate-tectonic evolution of the southern part of the Arabian Shield: U.S. Geological Survey Professional Paper 1131, 38 p., 30 figs, 2 tables.

Gonzales, Louis, 1975, Geology of the Jabal Ishmas quadrangle, Kingdom of Saudi Arabia, with a section on Aeromagnetic studies, by V. J. Flanigan: U.S. Geological Survey open-file report 75-181, (IR)SA-186, 34 p.

Greenwood, W. R., Hadley, D. G., Anderson, R. E., Fleck, R. J., and Schmidt, D. L., 1976, Late Proterozoic cratonization in southwestern Saudi Arabia: Society of London, Phil. Trans., v. A280, p. 517-527.

Hadley, D. G., 1976, Geology of the Bi'r Juqjuq quadrangle, sheet 21/43 D, Kingdom of Saudi Arabia: Saudi Arabian Directorate General of Mineral Resources Geologic Map GM-26, 30 p., scale 1:100,000.

Jackson, R. O., Bogue, R. G., Brown, G. F., and Gierhart, R. D., 1963, Geologic map of the Southern Najd quadrangle, Kingdom of Saudi Arabia: U.S. Geological Survey Miscellaneous Geologic Investigation Map I-211 A, scale 1:500,000.

McClure, H. A., 1976, Radiocarbon chronology of late Quaternary lakes in the Arabian desert: Nature, v. 263, no. 5580, p. 755-756.

Overstreet, W. C., 1978, A geological and geochemical reconnaissance of the Tathlith one-degree quadrangle, sheet 19/43, Kingdom of Saudi Arabia: U.S. Geological Survey open-file report 78-1072 ((IR)SA-230), 139 p., 4 pl.

Schmidt, D. L., Hadley, D. G., Greenwood, W. R., Gonzales, Louis, Coleman, R. G., and Brown, G. F., 1973, Stratigraphy and tectonism of the southern part of the Precambrian shield of Saudi Arabia: Saudi Arabian Directorate General of Mineral Resources Bulletin 8, 13 p.

Schmidt, D. L., Hadley, D. G., Stoeser, D. B., 1979, Late Proterozoic crustal history of the Arabian shield southern Najd Province, Kingdom of Saudi Arabia: King Abdulaziz University Institute of Applied Geology Symposium on the Evolution and mineralization of the Arabian-Nubian shield, Jiddah, February 1978, Bull. 3, v. 2, p. 41-58.

Schyfsma, E., 1978, Regions of investigation: Cevesta region of the Tuwayq Mountains; General geology and stratigraphy in Quaternary period *in* Saudi Arabia; Sedimentological, hydrological, hydrochemical, geomorphological, and climalogical investigations in central and eastern Saudi Arabia, p. 31-44, Springer-Verlag, Vienna, Austria.

Streckeisen, A. L., 1973, Plutonic rocks, Classification and nomenclature recommended by the IUGS Subcommission on systematics of igneous rocks: Geotimes, v. 18, no. 10, p. 26-30.

______________, 1976, To each plutonic rock its proper name: Earth-Science Reviews, v. 12, no. 1, p. 1-33.

Whiteman, A. J., 1971, The geology of the Sudan Republic: Oxford University Press, 290 p.

Whitlow, J. W., 1971, Areas in the Southern Najd quadrangle, Saudi Arabia, recommended for mineral investigation: U.S. Geological Survey open-file report (IR)SA-79, 11 p.