DEPARTMENT OF THE INTERIOR
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Reconnaissance geology of the Zarghat quadrangle, sheet 26/40 B, Kingdom of Saudi Arabia

by

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

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

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ABSTRACT

The Zarghat quadrangle is located in the northern Precambrian shield of Saudi Arabia between lat 26°30' and 27°00' N. and long 41°00' and 41°30' E. The area is underlain by three Precambrian volcanosedimentary units and a range of Precambrian dioritoid and granitoid plutonic intrusive rocks. Paleozoic(?) sandstone crops out in small areas in the northwestern part of the quadrangle, and a lobe of Quaternary(?) basalt from Harrat Ithnain penetrates the southwest corner of the quadrangle.

The Banana greenstone, the oldest unit in the quadrangle, is composed of basic to intermediate volcanic and subvolcanic rocks and minor interbedded marble that have been metamorphosed to greenschist-facies assemblages. The volcanic rocks range from basalt to andesite and dacite, and the subvolcanic rocks are diabase and diorite.

Two less-metamorphosed Precambrian units, the Hadn formation and the Zarghat formation, unconformably overlie the Banana greenstone. The Hadn formation is composed of predominantly rhyolitic to dacitic volcanic rock and minor amounts of continental sedimentary rock; it is exposed only in the east half of the quadrangle. The Zarghat formation is also rhyolitic to dacitic volcanic rock but contains much more sedimentary rock that appears to have been deposited in a shallow-marine environment. The relation between these two formations is not clear at this time.

Two groups of intrusive rocks are recognized on the basis of their ages relative to the Hadn and Zarghat formations. An older group is composed of hornblende quartz diorite, granodiorite, tonalite, and lesser amounts of granite. These rocks intrude the Banana greenstone but predate the Hadn and Zarghat formations. Post-Hadn/Zarghat intrusive rocks are voluminous undivided granite, several varieties of alkali-feldspar granite, monzogranite, granophyre, hypabyssal rhyolite, aplite, diabase, and gabbro.

The structural grain within the quadrangle appears to trend north-south. The Precambrian volcanosedimentary rocks and older plutonic rocks define three major north-trending lithologic belts. The Zarghat formation makes up the

westernmost belt, and the Hadn formation comprises the easternmost belt. The central belt consists of Banana greenstone and older plutonic rocks. The north-south structural grain is crosscut by large plutons that postdate the Hadn and Zarghat formations. The dominant faults in the area belong to a northeast-trending system of shears; less common fault orientations are northwesterly, northerly, and east-westerly.

Outcrops of magnesite in the southwest corner of the quadrangle constitute the only known economic potential in the area.

INTRODUCTION

Geographic setting

The Zarghat quadrangle, sheet 26/40 B, occupies an area of approximately 2760 km^2 between lat 26°30' and 27°00' N. and long 40°30' and 41°00' E. (fig. 1). There are no paved roads, and the only access is by aircraft or desert tracks that connect with the Al Medina-Ha'il highway about 50 km east of the quadrangle.

Altitudes in the quadrangle range from about 900 to 1200 m; the topography is variable. Extensive peneplains and pediments are developed in the southern and central parts of the area. More rugged terrain is found in the vicinity of Jibal Hom, Jibal Sha'bah, Jibal Uahli, Jibal Amrah, and Jibal al Furs, where steep hills have as much as 300 m relief. Most of the quadrangle drains to the southeast via tributaries of Wadi Ar Rema; the northern third of the quadrangle is drained to the northwest by a system of smaller wadis. Most of these features are shown on the geographic map.

The largest permanent settlement, the village of Zarghat, is located in the southwest corner of the quadrangle and is estimated to have a population of 200-300.

Previous investigations

The Zarghat quadrangle is included within the 1:500,000-scale Northeastern Hijaz quadrangle (Brown and others, 1963). Parts of the area have been studied by the Bureau de Recherches Geologiques et Minieres (BRGM) and by Bowden (1982). The investigations by BRGM (Brosset, 1976, 1978; Brette and others, 1981) focused on magnesite deposits and water resources in the southwest corner of the quadrangle. Bowden (1982) mapped the south half of the quadrangle at a scale of 1:100,000 as part of a more extensive regional economic assessment.

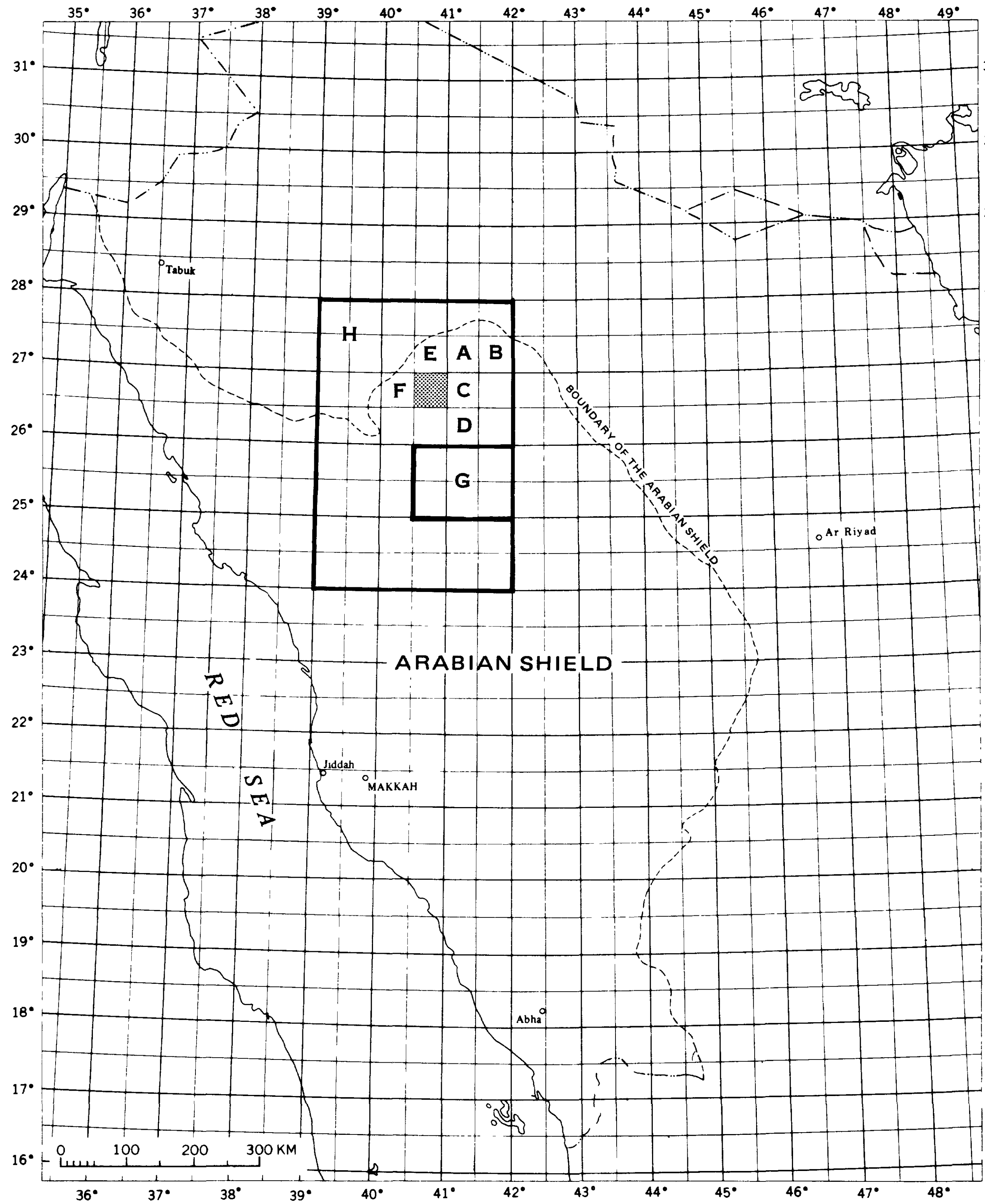

Figure 1.--Index map of western Saudi Arabia showing location of the Zarghat quadrangle (shaded) and other quadrangles referred to in this report: A, Al Qasr (Stoeser, 1984); B, Qufar (Kellogg, 1983); C, Ghazzalah (Quick, 1983); D, As Sulaymi (Quick, 1984); E, Jibal Matalli (Ekren, 1984); F, As Shamila (Fairer, 1984); G, Nuqrah (Delfour, 1977); H, Northeastern Hijaz (Brown and others, 1963).

Most of the adjacent quadrangles have been recently mapped by the U.S. Geological Survey at a scale of 1:100,000. Sheet 26/40 A to the west has been mapped by Fairer (unpub. data, 1984). Sheets 27/40 C and D to the north have been mapped by Ekren (1984). The Al Qasr quadrangle (27/41 C) to the northeast and the Ghazzalah quadrangle (26/41 A) to the east have been mapped by Stoeser (unpub. data, 1984) and Quick (1983), respectively.

Present investigation

The work on which this report is based was performed in accordance with a work agreement between the Ministry of Petroleum and Mineral Resources, Kingdom of Saudi Arabia, and the U.S. Geological Survey (USGS) for systematic mapping of 1:100,000-scale quadrangles in western Saudi Arabia. The Zarghat quadrangle was mapped by helicopter and surface vehicle during 25 days of fieldwork from November 1982 to May 1983. The investigation represents a direct extension of mapping by the author in the adjacent Ghazzalah quadrangle to the east, and some of the formation names introduced during the course of that investigation are used in this report.

Rocks are classified according to guidelines of the International Union of Geological Sciences (Streckeisen, 1976, 1979) and Fisher (1961). Units in which the rock composition varies were named for the most abundant lithology. Fine-grained silicic volcanic rocks were provisionally named on the basis of phenocryst populations. Rocks containing phenocrysts of quartz and potassium feldspar are termed rhyolite, those with phenocrysts of potassium feldspar are termed rhyodacite, and those with phenocrysts of plagioclase±quartz are termed dacite.

Acknowledgments

I thank G. M. Fairer and E. B. Ekren for ideas and insights on the geology of the Zarghat and adjacent quadrangles. A. El Bazli performed the stained-slab point-count analyses, and B. Green assisted in the computerized preparation of ternary diagrams.

GEOLOGIC OVERVIEW

The Zarghat quadrangle is located in the north-central Precambrian shield of Saudi Arabia and is centered 50-100 km west of the crest of the Ha'il arch, a north-trending regional upwarp of late Proterozoic rocks (Greenwood, 1973).

Within the study area, most of the bedrock consists of late Proterozoic granitic intrusive rock, low-grade metasedimentary rock, and metavolcanic rock that ranges in composition from basalt to rhyolite. Metavolcanic and sedimentary rocks that were mapped by Brown and others (1963) as Shammar rhyolite and Haliban formation were remapped during the present project as three locally defined formations. Small exposures of flat-lying quartz-rich sedimentary rocks in the northwestern part of the quadrangle unconformably overlie one of the younger plutonic rocks in the quadrangle and are therefore inferred to be Paleozoic in age. A lobe of Quaternary flood basalt from Harrat Ithnain extends into the southwest corner of the quadrangle.

The Precambrian metasedimentary and metavolcanic rocks are subdivided into three formations. The oldest rocks are an association of basaltic and intermediate-composition volcanic and volcaniclastic rocks that are metamorphosed to greenschist facies. These rocks are mapped as the Banana greenstone on the basis of a correlation with similar rocks in the Ghazzalah quadrangle (Quick, 1983). This unit may also be correlative with the Nuf formation to the northeast (Kellogg, 1983) and the Afna formation of the Hulayfah group to the southeast (Delfour, 1977). A sequence of younger rhyolitic to dacitic volcanic rocks and minor arkosic sedimentary rocks that crops out in the east half of the quadrangle is mapped as the Hadn formation because it is almost contiguous with exposures in the Ghazzalah quadrangle (Quick, 1983) and the Al Qasr quadrangle (Stoeser, unpub. data, 1984) Most of the Hadn formation appears to have been deposited in a subaerial environment. A second sequence of sedimentary and silicic volcanic rocks that crops out in the western part of the quadrangle is mapped as the Zarghat formation, named for exposures near the village of Zarghat. This formation, although similar to the Hadn, contains substantially more sedimentary rock and appears to have been deposited, at least locally, in a marine environment.

The plutonic rocks in the quadrangle are divisible into two principal groups based on their ages. One group, consisting of hornblende quartz diorite, granodiorite, tonalite, and lesser amounts of granitic rocks, intrudes the Banana greenstone but predates the Hadn and Zarghat formations. The Hadn and Zarghat formations are intruded by a younger group of granitic plutons that, for the most part, range in composition from alkali-feldspar granite to monzogranite. Smaller intrusions of granophyre, aplite, hypabyssal rhyolite, and diabase also appear to postdate the Hadn and Zarghat formations.

Distribution of units is shown on the geologic map.

PRECAMBRIAN VOLCANIC AND SEDIMENTARY ROCKS

Banana greenstone

Metamorphosed basaltic to andesitic volcanic and subvolcanic rocks are mapped as Banana greenstone (bg) in the central part and near the east margin of the quadrangle.This formation contains minor amounts of marble, graywacke, and dacitic to rhyolitic rocks. These rocks are similar in lithology, outcrop appearance, and apparent age to rocks in the type locality of the Banana greenstone, about 25 km to the east (Quick, 1983). Also, outcrops mapped as Banana greenstone in the adjacent Ghazzalah quadrangle to the east are contiguous with those described under that name here.

The volcanic and subvolcanic rocks form dark-gray hills and pediments. The regolith typically has a blue-green cast, reflecting the presence of abundant chlorite and epidote. The terrain is dotted with small patches of white detritus from underlying quartz veins. The topography is gentle, and, although hills may reach 100 m in relief, cliffs are not present. Boulders are subrounded and generally less than 0.5 m in size; they weather medium gray to ruddy brown.

The volcanic rocks are mostly flows, flow breccias, and agglomerates of andesite and andesitic basalt. These rocks are locally porphyritic, containing phenocrysts of white plagioclase (0.5-1 mm) set in a fine-grained (0.3 mm) diabasic to pilotaxitic matrix. Vesicles are locally abundant. In the flow breccias and agglomerates, the clasts are typically dark- to medium-gray aphanitic volcanic rocks that are as large as 0.3 m in diameter. A minor amount of dacitic to rhyolitic rock is also present; however, it is uncertain if these rocks constitute flows and tuffs that were contemporary with the basalt and andesite or if they are dikes that may be significantly younger.

In the Zarghat quadrangle, the Banana greenstone includes subvolcanic basic to intermediate intrusive rocks. Locally, dikes of olivine gabbro as much as 2 m wide cut the basalt and andesite. Diabasic texture, present at many localities, suggests that the rocks are intrusive rather than extrusive in origin. Generally, however, individual diabase dikes and sills are not discernible in outcrop.

Sedimentary rocks are locally abundant. In the central part of the quadrangle, fine- to coarse-grained graywacke is interbedded with basalt and andesite flows. Bedding is massive and individual beds are poorly defined in most places, although the finer grained sandstone beds are locally laminated.

Metamorphism has caused partial replacement of the primary mineral assemblages in the Banana greenstone. Primary hornblende and pyroxene are pseudomorphed by mats of chlorite and acicular actinolite. Plagioclase is partly saussuritized and locally replaced by epidote. However, the extent of recrystallization is generally less than in the adjacent Ghazzalah quadrangle (Quick, 1983).

Age and thickness

The Banana greenstone is interpreted to be the oldest rock in the quadrangle. As will be discussed below, the greenstone is clearly overlain by the relatively young Zarghat formation and is clearly intruded by relatively young plutons. However, exposures too poor to determine the age of the greenstone relative to any of the older units in the quadrangle, and the age assignment is therefore based on geologic mapping in the nearby Ghazzalah quadrangle (Quick, 1983), Qufar quadrangle (Kellogg, 1983), and Al Qasr quadrangle (Stoeser, unpub. data, 1984) where petrographically similar basalt, andesite, and diabase are the oldest rocks.

The stratigraphic thickness of the unit is unknown because of limited outcrop and the absence of basal exposures.

Hadn formation

Outcrops of predominantly silicic volcanic rocks are mapped as the Hadn formation (hu) in the east half of the quadrangle. The Hadn formation was named by D. B. Stoeser (written commun., 1982) and Chevremont (1982) for exposures of rhyolitic to rhyodacitic volcanic rocks and interbedded sedimentary rocks that underlie Jabal Hadn in the southern part of the Al Qasr quadrangle. Within the Zarghat quadrangle, the Hadn formation is composed predominantly of rhyodacitic to rhyolitic tuff and lesser amounts of massive rhyodacitic, dacitic, and andesitic flow rock. Sedimentary rock is scarce. Virtually continuous exposures of Hadn are traceable southwestward from Jabal Hadn into the Zarghat quadrangle, where they underlie a chain of small, rugged mountain ranges that extend from Jibal Sha'bah in the north to Jibal al Furs in the south. The rocks are more resistant to erosion than the Banana greenstone and form steep-sided hills, precipitous cliffs, and steep talus slopes with large angular blocks. Exposures typically weather rusty red brown to black, and the regolith ranges in color from red brown to tan to olive green.

Crystal-lithic tuffs are the most abundant volcanic rocks. Lithic fragments and phenocrysts ($\leq$ 5 mm) are contained within an aphanitic matrix that ranges in color from gray to pink to purple to red. Lithic fragments range in size to about 1 m, but most are smaller than 20 cm. Most fragments are volcanic rocks similar to the host rock, suggesting that considerable reworking and cannibalism occurred during the formation of the Hadn. Locally the Hadn includes fragments of fine-grained alkali-feldspar granite, quartz monzogranite, and quartz diorite. In most places, phenocrysts are salmon-colored alkali feldspar$\pm$quartz, suggesting that the bulk composition is rhyolitic to rhyodacitic. Locally, white plagioclase is the dominant phenocryst, suggesting that some parts of the Hadn may be dacitic. Fiamme are present in 20-30 percent of the rocks, and flow lamination is present in 10-20 percent.

The lithologic diversity of the Hadn increases from north to south within the Zarghat quadrangle. Jibal Sha'bah is underlain by massive lapilli-poor tuff and ignimbrite. Further to the south, along the west flank of Jibal Amrah, rhyolitic volcanic rocks overlie a well-bedded 15-m-thick section of fine-grained ($\leq$0.5 mm) purple to brown volcanic wacke. The volcanic rocks are locally well bedded and lapilli rich. At Jibal al Furs, the section contains poorly sorted volcanogenic wacke and conglomerate, dark-gray-green andesitic agglomerate, and thick layers of blue-gray tuff.

The internal structure of the Hadn is difficult to determine because layering, if discernible, is generally indistinct, thick (> 10 m), and irregular in orientation. Flow lamellae are frequently contorted on a scale of meters and are therefore unreliable for measuring dip and strike. In most places, the only reliable indicators of attitude appear to be fiamme and interbedded layers of sandstone.

Age and thickness

The age of the Hadn formation relative to the Banana greenstone cannot be determined within the map area because there are no contact relationships exposed. In the Ghazzalah quadrangle, the Hadn formation has been shown to overlie unconformably both the Banana greenstone and bodies of hornblende quartz diorite and granodiorite that intrude the Banana greenstone (Quick, 1983). Within the Zarghat quadrangle the volcanic wacke underlying Jibal Amrah contains abundant fragments of plagioclase that could have been derived from the subvolcanic rocks of the Banana greenstone or from post-Banana hornblende quartz diorite or granodiorite (see section entitled "Intrusive rocks").

The thickness of the Hadn formation is estimated to be 1 to 3 km. Chevremont (1982) and Quick (1983) estimated similar stratigraphic thicknesses of at least 1-2 km in the Ghazzalah quadrangle and 3 to 5 km in the Al Awshaziyah quadrangle. However, it is cautioned that the lower and upper boundaries of the Hadn formation are poorly exposed within the Zarghat quadrangle and could be tectonic rather than depositional in nature. Furthermore, the internal structure of the Hadn formation is not well documented enough to rule out significant tectonic repetition of section.

Zarghat formation

Interbedded volcanic and sedimentary rocks that crop out in the western third of the quadrangle are mapped as the Zarghat formation. The rocks are exposed in a northerly trending belt that extends from the vicinity of Zarghat to the north boundary of the quadrangle. The rocks that constitute the Zarghat formation are fundamentally the same as those that constitute the Hadn formation. However, the Zarghat formation is distinguished from the Hadn by greater abundance of sedimentary rocks and by the presence of a massive basal conglomerate. Because of its lithologic diversity, the Zarghat formation is subdivided into undivided volcanic and sedimentary rocks (zu), basal conglomerate (zc), basalt (zb), marble member (zm), and magnesite member (mag).

Basal conglomerate

The basal conglomerate (zc) of the Zarghat formation crops out along the east edge of the Zarghat formation. The thickness of the conglomerate is estimated to be as much as 400-500 m locally, and the unit is traceable, without major break, for 20 km in the southern part of the quadrangle and 15-20 km in the northern part of the quadrangle. The continuity and thickness of this unit are in striking contrast to the discontinuous conglomerate lenses in the Hadn formation, and suggest that the surface on which it was deposited was a major regional unconformity.

The conglomerate is a poorly sorted mixture of well-rounded pebble- to boulder-size lithic clasts and more angular sand-size fragments. Measured sizes range from 1 mm to 4 m in diameter. The matrix is variable in composition;

locally, it is composed of friable arkosic sandstone and, in other places, it is tuffaceous. The matrix is poorly indurated and, as a result, is not exposed in most places. Instead, the outcrop surfaces are littered with unconsolidated cobble- to boulder-size fragments.

The most abundant clasts in the conglomerate are composed of red- and dark-gray-weathering volcanic rock. Lithologic varieties are vitrophyre, aphanite, basalt, agglomerate, and volcanogenic sandstone. The vitrophyric rocks are the most abundant and typically contain phenocrysts of euhedral quartz, blocky potassium feldspar, and laths of plagioclase in a red to dark-gray aphanitic matrix. Although the clasts resemble lithologies in the Hadn formation, it must be emphasized that quartz in the Hadn volcanic rocks is generally anhedral. Therefore, the provenance of some of these clasts remains uncertain.

Plutonic rocks are less abundant, amounting to only 10-20 percent of the clast population (fig. 2). Clasts of fine- to medium-grained alkali-feldspar granite, syenogranite, peralkaline granite, granodiorite, tonalite, and diorite (not point counted) are present in minor amounts throughout the conglomerate. Locally, the alkali-feldspar granite forms boulders as much as 3 m in diameter and is the dominant clast type. The size of these clasts suggests that much of the conglomerate was deposited in close proximity to its source terrane. As discussed below (see section entitled "Intrusive rocks"), mineralogically similar bodies of granitic and dioritic plutonic rocks crop out east of Jibal Hom near the conglomerate.

Basalt

Basalt (zb) is locally interbedded with and, in some places, overlies the basal conglomerate of the Zarghat formation. The largest exposures of basalt are along the east flank of Jibal Hom, where flows reach an aggregate thickness of about 100 m. In contrast to the Banana greenstone, the basalt member of the Zarghat formation is resistant to erosion and weathers dark gray to black without the green hues associated with abundant chlorite and epidote. Individual flows are discernible in many places and range from 1-3 m to tens of meters in thickness. Some flows have well-developed columnar jointing, and elongate quartz-filled vesicles as much as 2 cm long are locally abundant.

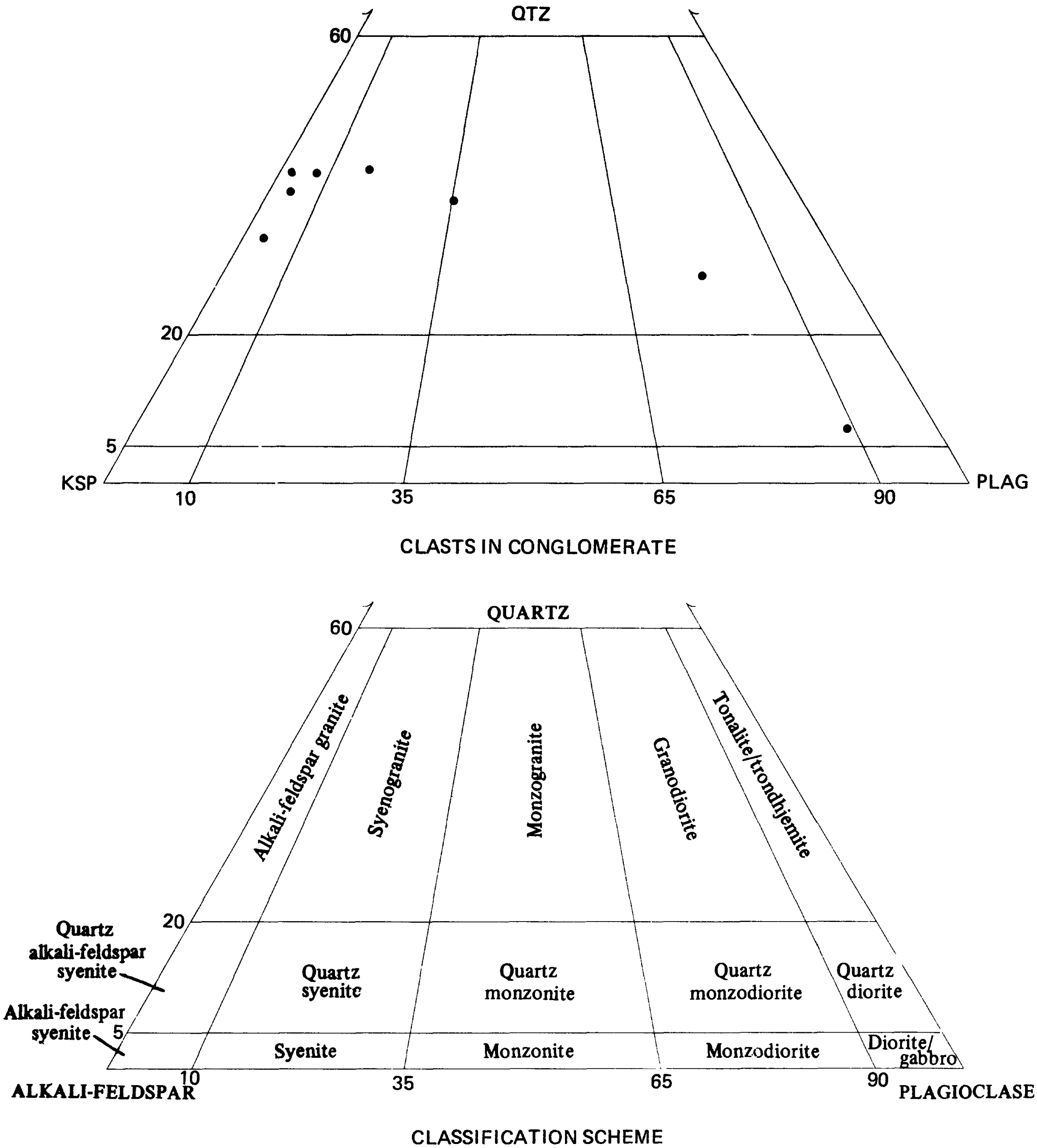

Figure 2.--Ternary diagram showing the relative modal abundances of quartz (QTZ), potassium feldspar (KSP), and plagioclase (PLAG) in clasts of plutonic rock in the Zarghat conglomerate. Fields in figures 2 and 4 through 10 are drawn according to Streckeisen (1976).

Undivided volcanic and sedimentary rocks

Interbedded volcanic and sedimentary rocks are collectively mapped as undivided volcanic and sedimentary rocks (zu). This unit constitutes the bulk of the Zarghat formation. The proportion of volcanic and sedimentary rock is variable. North of Jibal Hom, volcanic rocks predominate, amounting to more than 90 percent of the formation. South of Jibal Hom, sedimentary rocks make up 20-30 percent of the formation (fig. 3).

The volcanic rocks display some significant changes from north to south. Massive rhyodacitic to dacitic tuff, lapilli tuff, and agglomerate that resemble the volcanic rocks of the Hadn formation are abundant north of Jibal Hom. These rocks weather various shades of red brown, buff, and lavender and are resistant to erosion, forming steep-sided hills with precipitous cliffs and large angular boulders. Although flow lamination is locally developed and fiamme are present in some tuffs, they appear to be less abundant than in the Hadn formation. Most of the rocks are rhyodacite to dacite composed of white or salmon-colored feldspar phenocrysts and an aphanitic red-brown to gray matrix. Lapilli are composed of volcanic rock similar to the host rock. In the southeastern part of the quadrangle, the volcanic rocks are dominated by silicic agglomerate, lapilli tuff, and rhyolite and dacite flows. Bedding ranges from 1 m to tens of meters in thickness and is generally much more obvious than in the north. The terrain is less rugged than in the north and in most places is characterized by low, rolling hills. Fiamme are rare, and many of the rocks appear to grade from lapilli-rich tuff into volcanic wacke. Columnar-jointed rhyolite flows, composed of pink feldspar and quartz phenocrysts and pink aphanitic matrix, form prominent red-brown hogbacks south of Jibal Hom. North of Zarghat, dacite flows, composed of white feldspar phenocrysts in a gray matrix, form another set of prominent hogbacks.

The volcanic rocks are interbedded with beds and discontinuous lenses of fine- to coarse-grained volcanogenic wacke, arenite, conglomerate, and breccia. Most of the rocks weather red brown to medium or dark gray. In the northwestern part of the quadrangle, the occurrences of these rocks are similar to those in the Hadn formation in that they do not exceed 10 m in thickness and are discontinuous along strike. In sharp contrast, well-bedded wacke and conglomerate crop out with a total stratigraphic thickness of 400-500 m about 10 km southwest of Jibal Hom. Layers range in thickness from 5 cm to 1 m; individual layers are extremely uniform and continuous for hundreds of meters.

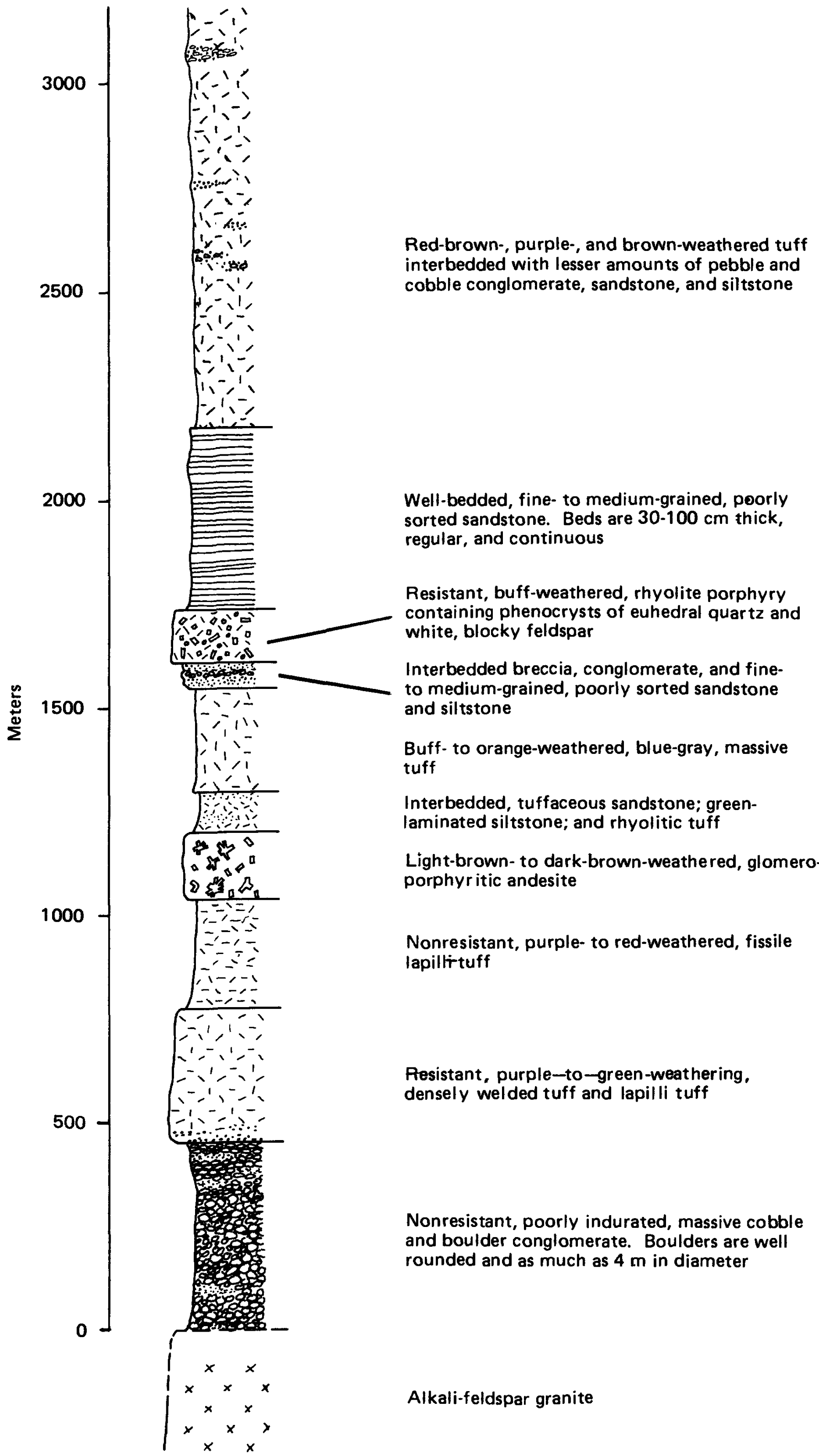

Figure 3.--Simplified columnar section through the Zarghat formation. The section was measured along an east-west traverse that ran approximately 1 km south of the southernmost exposure of graphic granite.

All of the sedimentary rocks are poorly sorted and immature. The clast suite is dominated by a volcanic component; most of the clasts are fine-grained to aphanitic volcanic rocks that are texturally and mineralogically similar to the volcanic rocks in the Zarghat and Hadn formations. Fragments of quartz, potassium feldspar, plagioclase, and opaque minerals are less abundant. Individual beds may be composed of less than 5 up to 50 percent matrix that consists of clastic material, clay, and devitrified glass that is finer grained than 0.1 mm. There is a considerable range in matrix/clast ratio and abundance of devitrified glass shards, and the sedimentary rocks actually appear to grade from volcanic arenite to volcanic wacke to fragment-rich tuff that may have been reworked or deposited initially in water.

Marble member

Well-bedded marble and limy sandstone crop out in the southwest part of the quadrangle and are mapped as the marble member (zm) of the Zarghat formation. Buff to blue-gray marble and sandy marble contain laminated chert blocks as much as 0.5 m in size that may be silicified algal mats. These rocks are interbedded with laminated calcareous siltstone and sandstone. Graded bedding, mudcracks, and ripple marks are preserved in the clastic rocks. These features and the possible algal structures suggest shallow-water deposition.

Magnesite member

Magnesite (mag) crops out in the southwest corner of the quadrangle in close association with the marble member. Although these exposures are small, they are mapped as a separate member because of their economic importance as a potential source of magnesium (Kahr, 1962). The rocks crop out with low relief but are easily discerned because they weather bright white.

PRECAMBRIAN INTRUSIVE ROCKS

Hornblende quartz diorite

Hornblende quartz diorite (hqd) crops out in the south-central part of the Zarghat quadrangle and in smaller, isolated outcrops near the southeast and northwest corners of the quadrangle. The rocks weather to low hills covered with gray-green regolith and small, subangular, dark-gray boulders. Bodies of identical hornblende quartz diorite crop out in close association with the Banana greenstone in the Ghazzalah quadrangle to the east (Quick, 1983).

In the Zarghat quadrangle, the rock is an intersertal intergrowth of mostly plagioclase and green hornblende. Quartz is present in variable amounts, and the rock actually grades from diorite to quartz diorite. Alteration has resulted in saussuritization of plagioclase and chloritization of amphibole.

The hornblende quartz diorite is not in contact with any of the volcanosedimentary units in the Zarghat quadrangle. Indirect evidence on its age is as follows. Within the Zarghat quadrangle, clasts of dioritic rocks are contained within the basal conglomerate of the Zarghat formation. In the Ghazzalah quadrangle (Quick, 1983), hornblende quartz diorite is intruded by granodiorite that is in turn overlain unconformably by the Hadn formation; the same hornblende quartz diorite is interpreted to intrude the Banana formation. These observations suggest that the hornblende quartz diorite postdates the Banana greenstone and predates the Hadn and Zarghat formations. Hornblende quartz diorite was found to be the oldest plutonic rock in the Ghazzalah quadrangle (Quick, 1983). The evidence in the Zarghat quadrangle is consistent with this age assignment, and, as discussed below, the hornblende quartz diorite appears to be older than all other plutonic rocks.

Granodiorite and tonalite

Medium- to coarse-grained hornblende granodiorite and tonalite (gd) crop out in the central part of the quadrangle, north of Jibal Amrah, and in the northern part of the quadrangle, west of Jibal Sha'bah. The rocks form low gray to dark-gray hills with gray-green regolith and are identical in outcrop appearance to granodiorite and tonalite that crop out in the Ghazzalah quadrangle, where the two lithologies are mapped as separate units. The two lithologies are combined as a single unit in the Zarghat quadrangle because they are mineralogically similar and because exposures of tonalite are scarce and subordinate to granodiorite in area.

Figure 4 illustrates the relative abundance of quartz, potassium feldspar, and plagioclase in these rocks. The granodiorite is composed of euhedral to subhedral green amphibole, subhedral plagioclase, and variable amounts of interstitial quartz and potassium feldspar and magnetite; apatite and zircon are present as accessory minerals. Locally, a protoclastic texture is overprinted on the primary igneous texture. The tonalite is almost a bimodal intergrowth of quartz and plagioclase; green amphibole and magnetite are present in minor amounts. The tonalite grades into the granodiorite with increasing color index and potassium feldspar content.

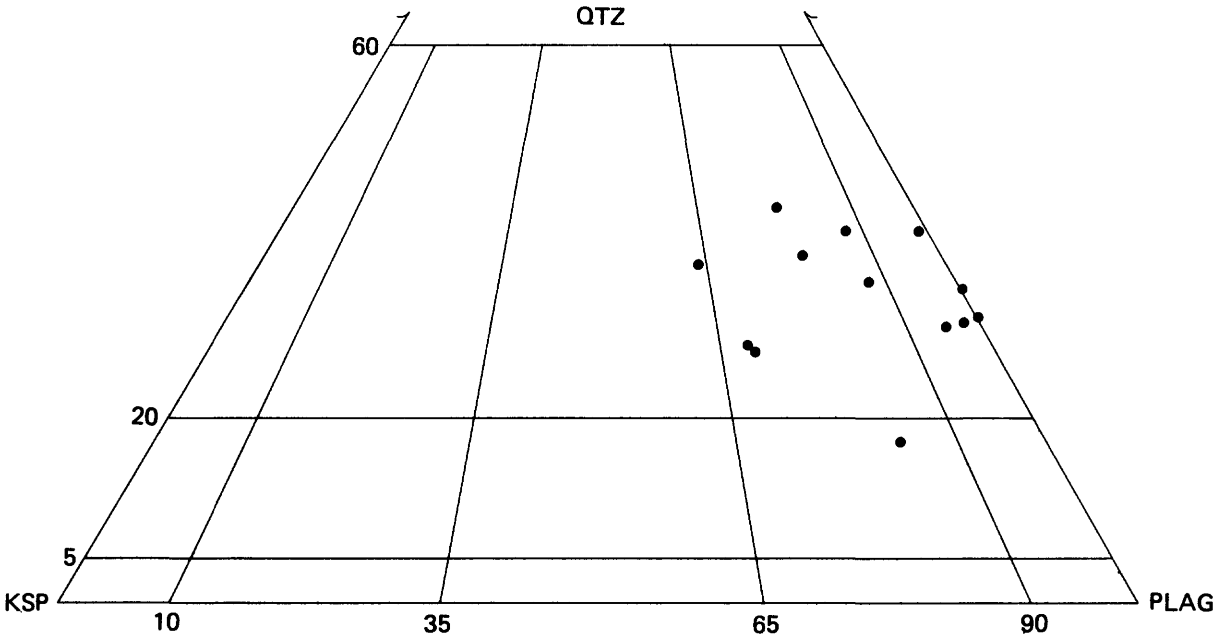

Figure 4.--Ternary diagram showing the relative modal abundances of quartz (QTZ), potassium feldspar (KSP), and plagioclase (PLAG) in granodiorite and tonalite. Fields are drawn and labeled as in figure 2.

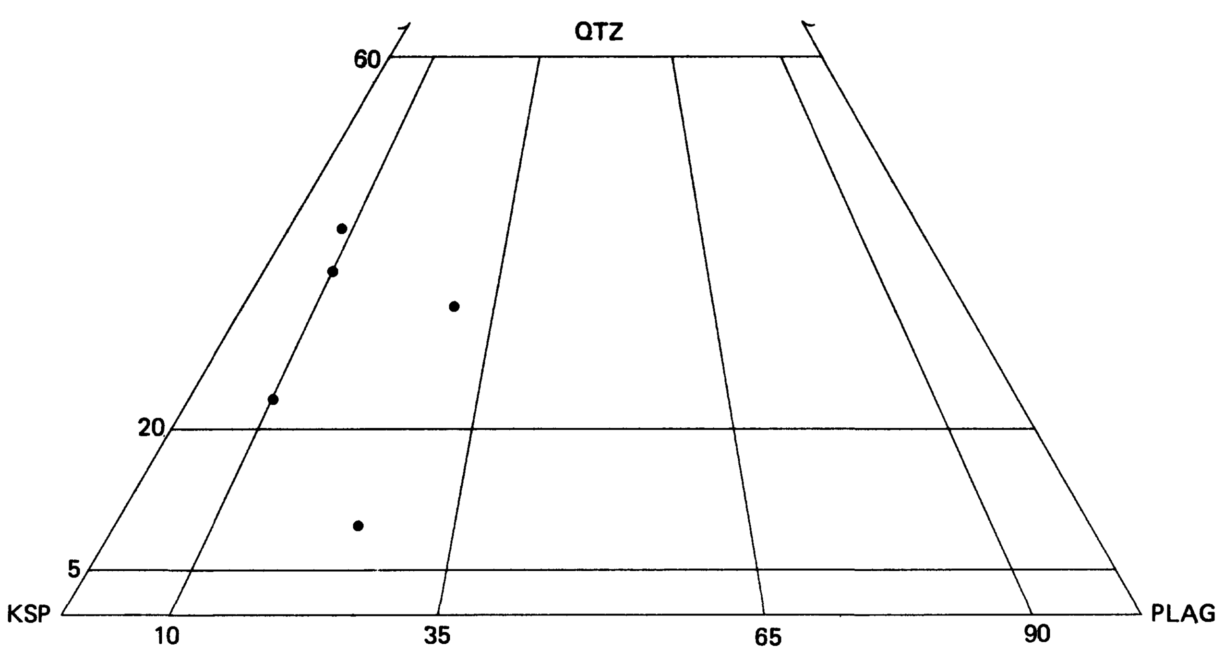

Figure 5.--Ternary diagram showing the relative modal abundances of quartz (QTZ), potassium feldspar (KSP), and plagioclase (PLAG) in pre-Zarghat granite. Fields are drawn and labeled as in figure 2.

The granodiorite and tonalite appear to postdate the Banana greenstone and hornblende quartz diorite but predate the Hadn and Zarghat formations. Diabase xenoliths do occur within the granodiorite and tonalite near Jibal Amrah, and it is likely that these were derived from the Banana greenstone. Similar bodies of tonalite and granodiorite in the Ghazzalah quadrangle contain xenoliths of Banana greenstone and are, therefore, clearly post-Banana (Quick, 1983). The granodiorite and tonalite are interpreted to postdate the hornblende quartz diorite because they are more chemically evolved. The basal conglomerate of the Zarghat formation contains cobbles and boulders that are identical in hand specimen to the granodiorite and tonalite, a condition which strongly suggests that the Zarghat formation is younger, although mutual contacts between these rocks are not exposed. The Hadn formation appears to unconformably overlie granodiorite at the north end of Jibal Amrah. Exposures are poor and the contact is irregular, but a discontinuous sandstone layer that contains clasts of granodiorite is exposed locally at the contact and suggests that the Hadn was deposited on the granodiorite.

Pre-Zarghat granite

Pre-Zarghat granite (ga) crops out between Jibal Hom and Wadi Asmarah. Isolated granite outcrops on the west side of Wadi Asmarah have been included in this unit on the basis of their proximity to known pre-Zarghat granite outcrops. The granite crops out as pink- to red-weathering knobs that stand out above a pediment surface.

The rock is composed of fine- to medium-grained two-feldspar biotite granite. Perthite is the dominant feldspar. In the areas known to be pre-Zarghat in age, the ratio of potassium feldspar to plagioclase is about 10:1, and the rock is properly termed an alkali-feldspar granite (fig. 5). Elsewhere, plagioclase appears to be more abundant. The texture is hypidiomorphic-granular; graphic intergrowths of potassium feldspar and quartz occur locally. Biotite is extensively chloritized, and potassium feldspar is turbid, reflecting the presence of disseminated oxides and sericite.

A pre-Zarghat age for the granite is clearly established on the east flank of Jibal Hom, where the basal conglomerate and basalt members of the Zarghat formation unconformably overlie the granite. The conglomerate contains boulders of potassium-feldspar-rich granite, and the contact truncates quartz veins that are traceable in the underlying granite for tens of meters. The surface of the unconformity appears to have substantial relief, with vesicular basalt and arkosic sandstone deposited in the ancient valleys and, in turn, overlain by conglomerate that was deposited directly on the granite on higher ground. The age of the granite relative to the other units in the quadrangle is not known with certainty due to poor exposures. It is presumed to be younger than the hornblende quartz diorite, the granodiorite, and the tonalite because of its more evolved composition.

Monzogranite

Monzogranite (mg) crops out in the southeast corner of the Zarghat quadrangle. The outcrops are part of a much larger monzogranite pluton that underlies the southwest corner of the Ghazzalah quadrangle (Quick, 1983). The rocks weather white to light gray and crop out with low relief.

The monzogranite is composed of small (1 cm) phenocrysts of perthite and quartz in a fine-grained matrix of quartz, potassium feldspar, plagioclase, biotite, and equant opaque minerals. Apatite and sphene are accessory minerals. Biotite is incipiently altered to chlorite, but the other minerals are essentially pristine.

Exposures of the monzogranite are limited within the Zarghat quadrangle, and its age is not demonstrated by its contact relations there. However, in the Ghazzalah quadrangle to the east (Quick, 1983), contiguous outcrops of monzogranite intrude the Banana greenstone, contain rafts of hornblende quartz diorite, and are interpreted to be post-Hadn in age.

Undivided granite

Undivided granitic rocks (gu) underlie large areas in the northwestern, north-central, and south-central parts of the quadrangle. The granite forms subdued, pink- to white-weathering outcrops with broad, slightly convex faces. The undivided granitic rocks are continuous with a unit of magnetite syenogranite that is mapped in the Ghazzalah quadrangle to the east. Within the Zarghat quadrangle, however, the granite appears to span a much wider range of compositions (fig. 6) that extend from alkali-feldspar granite to monzogranite and include quartz alkali-feldspar syenite and quartz monzogranite.

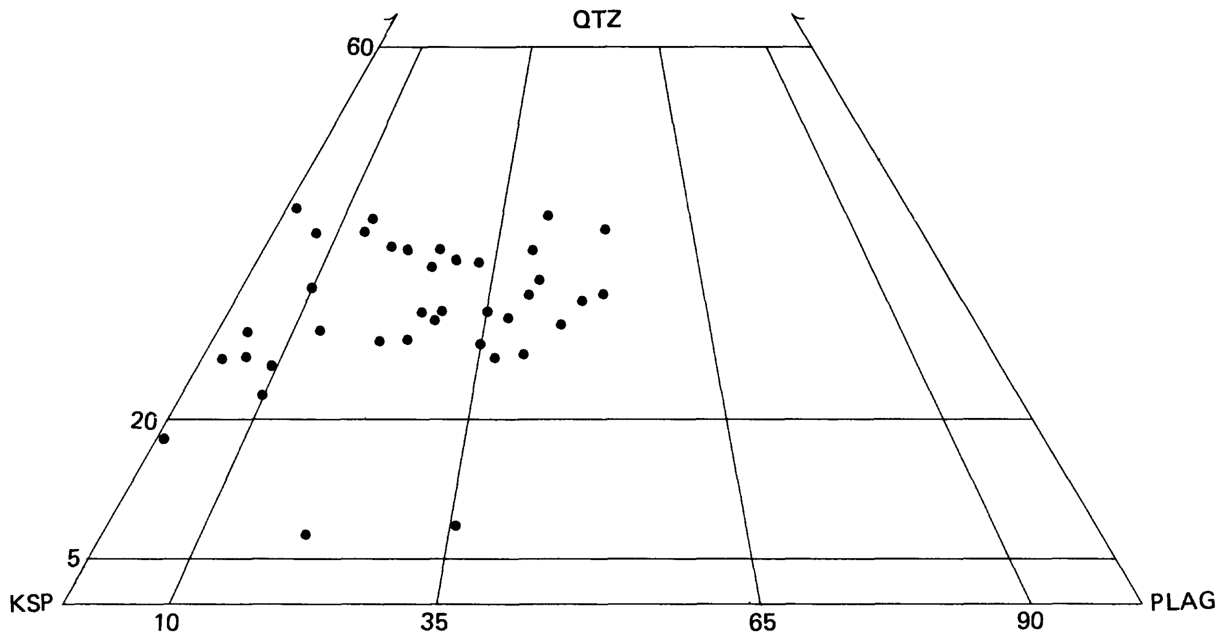

Figure 6.--Ternary diagram showing the relative modal abundances of quartz (QTZ), potassium feldspar (KSP), and plagioclase (PLAG) in undivided granite. Fields are drawn and labeled as in figure 2.

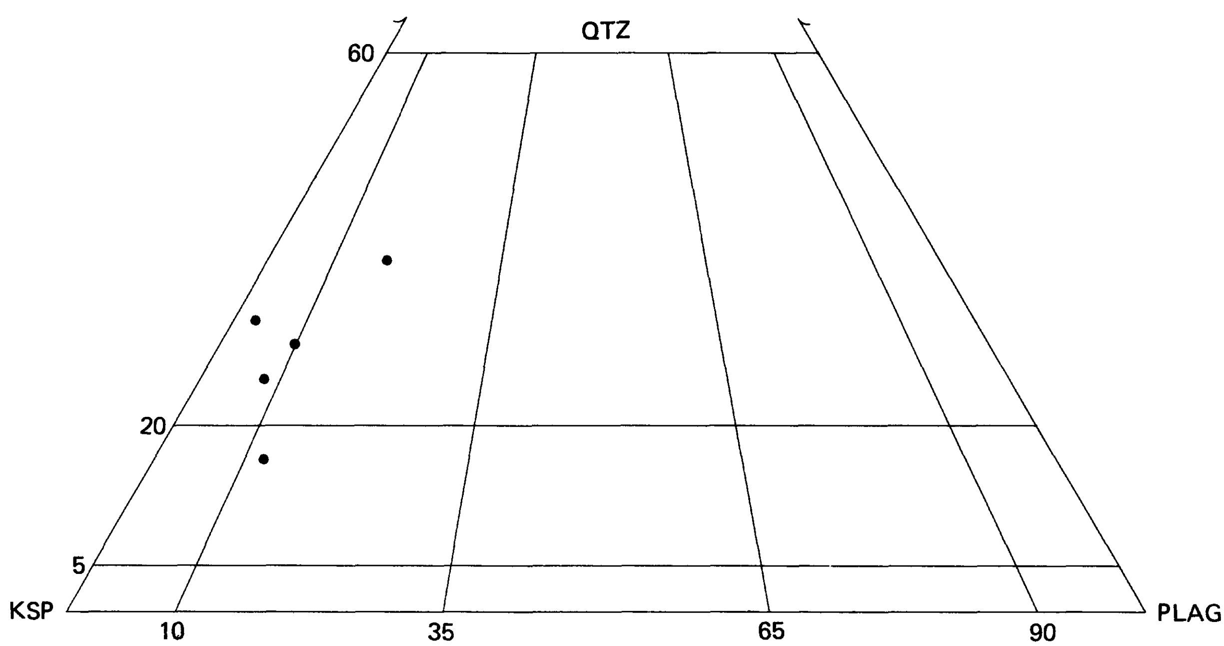

Figure 7.--Ternary diagram showing the relative modal abundances of quartz (QTZ), potassium feldspar (KSP), and plagioclase (PLAG) in biotite alkali-feldspar granite. Fields are drawn and labeled as in figure 2.

Pervasive pink to red staining of the feldspars makes discrimination of the different lithologies in outcrop difficult, but most of the rocks appear to be alkali-feldspar granite or syenogranite. In most places, the rocks are composed of a medium- to coarse-grained hypidiomorphic-granular intergrowth of quartz and turbid perthite. Plagioclase, if present, is subordinate to alkali feldspar in abundance. Biotite and(or) magnetite compose less than 1 percent to 7 percent of the rock. Accessory minerals are apatite and zircon. The effects of alteration are variable. Potassium feldspars are generally turbid and weather red, reflecting the presence of disseminated oxides and sericite. Biotite is commonly replaced by chlorite. In some rocks, calcite veining is abundant and plagioclase is pervasively sericitized.

Poor exposures make subdivision of this unit difficult, and it is uncertain whether the rocks constitute large plutons of variable composition or complex aggregates of smaller plutons. For example, outcrop patterns in the northern part of the quadrangle suggest the presence of at least two plutons that share a southerly trending contact to the south of Jibal Sha'bah. However, that area is poorly exposed, and the hypothetical plutons are too similar in appearance to infer existence of a contact.

The undivided granitic rocks intrude and contain roof pendants of granodiorite immediately west of Jibal Sha'bah. An age assignment with respect to the Hadn and Zarghat formations is more difficult to determine. Rocks mapped as undivided granite intrude the Zarghat formation along the north border of the quadrangle and intrude the Hadn formation at Jibal Sha'bah. However, clasts of alkali-feldspar granite and syenogranite similar to rocks in the undivided granite unit are present in the conglomerate of both the Zarghat and Hadn formations. Furthermore, exposures of Zarghat and Hadn unconformably overlie similar granitic rocks on the west side of Jibal Hom and in the Ghazzalah quadrangle (Quick, 1983). Therefore, the undivided granite may actually include several ages of granitic rocks that are mineralogically indistinguishable.

Biotite alkali-feldspar granite

Plutons of biotite alkali-feldspar granite (afg) are exposed in the central and northwestern parts of the quadrangle. These plutons are clearly visible on Landsat imagery as high-albedo plains. In the field, the plutons are characterized by white, grus-covered pediments and isolated white to light-gray whalebacks.

In most places, the rock is medium- to coarse-grained (0.25-0.5 cm) alkali-feldspar granite (fig. 7) that is composed mostly of a hypidiomorphic intergrowth of perthitic alkali feldspar and quartz. The color index rarely exceeds 1, and most rocks appear to be one-feldspar hypersolvus granite. Locally, perthitic exsolution is sufficiently coarse grained (0.5 mm) that exsolved albite was point counted as a separate phase, partly accounting for the presence of plagioclase in figure 7. In some samples, however, pink perthite grains contain blocky cores of white plagioclase, and the rock is truly a two-feldspar granite. Biotite, opaque minerals, sphene and zircon are concentrated in small (1 mm) interstitial clots. Within 10-20 m of the margins of the plutons, the rock is finer grained (1 mm) and locally shows graphic texture, but it is mineralogically identical to the coarser grained interior.

The biotite alkali-feldspar granite is clearly younger than the Hadn formation and is interpreted to be younger than the undivided two-feldspar granite. Dikes of fine-grained biotite alkali-feldspar granite are traceable from the plutons into adjacent rocks of the Hadn formation, the Banana greenstone, and the granodiorite. The contact relations between the biotite alkali-feldspar granite and the undivided granite are more obscure. In most places, these two plutonic rocks are separated by septa of volcanic rocks or diorite and granodiorite. The biotite alkali-feldspar granite is presumed to be younger because it appears to be chemically more evolved and because it forms isolated plutons of circular plan in contrast to the widespread, basementlike outcrop of the undivided granite.

Graphic granite

A large pluton of graphic granite (gg) underlies about 300 km^2 near the west margin of the quadrangle. The core of the pluton weathers light gray to white, and the topography is characterized by extensive, flat, grus-covered plains and isolated east-northeast-trending whalebacks with well-rounded faces. In contrast, the rim of the pluton weathers to red-brown hues and forms hills with rugged relief and blocky faces. The northern 25 km^2 of the pluton weathers medium gray and forms high hills with steep walls and cliffs; the appearance is similar to that of the Ba'gham peralkaline granite in the Ghazzalah quadrangle (Quick, 1983).

The rocks range in composition from alkali-feldspar granite to syenogranite (fig. 8) and are, in most places, characterized by a graphic-textured groundmass. In the core of the pluton, phenocrysts (0.5-4 mm) of turbid, red-brown

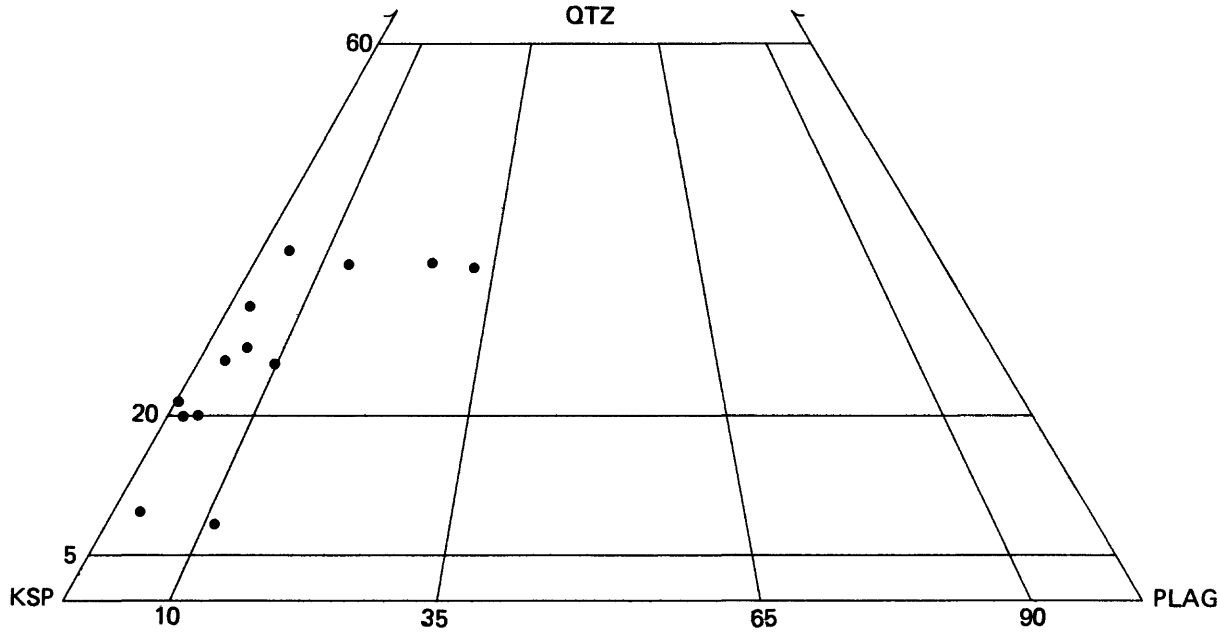

Figure 8.--Ternary diagram showing the relative modal abundances of quartz (QTZ), potassium feldspar (KSP), and plagioclase (PLAG) in graphic granite. Fields are drawn and labeled as in figure 2.

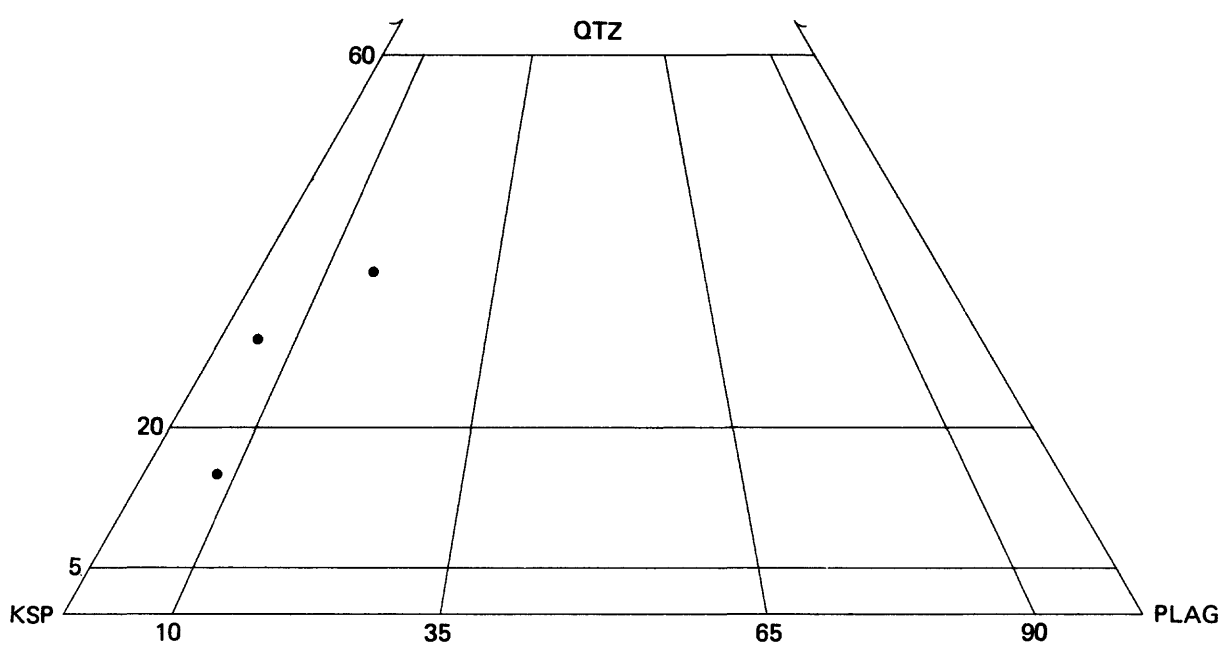

Figure 9.--Ternary diagram showing the relative modal abundances of quartz (QTZ), potassium feldspar (KSP), and plagioclase (PLAG) in amphibole alkali-feldspar granite. Fields are drawn and labeled as in figure 2.

perthite and rounded quartz are contained within a graphic intergrowth of red-brown alkali feldspar and quartz. The presence of plagioclase as small irregular grains associated with perthite suggests that it is an exsolution feature rather than a primary igneous mineral; the primary mineralogy appears to have been "hypersolvus". Interstitial biotite and opaque minerals are present in minor amounts, and zircon and sphene are accessory phases. Slight chloritization of biotite and the turbid red-brown color of the feldspar are the only significant alterations. The red-brown weathering rim of the pluton is petrographically similar to the core granite except that it is finer grained (1 mm) and contains minor amounts of lath-shaped plagioclase. The presence of plagioclase suggests that the rim crystallized under subsolvus conditions. The northern, medium-gray-weathering part of the pluton also contains minor amounts of lath-forming plagioclase. In this area, however, the primary mafic silicate appears to have been an acicular amphibole that is now completely pseudomorphed by oxides.

The graphic granite is clearly younger than the Zarghat formation. Dikes of the granite intrude the adjacent Zarghat formation along the eastern and southern contacts of the pluton.

Amphibole alkali-feldspar granite

Amphibole-bearing alkali-feldspar granite (afga) crops out north of Jibal Sha'bah in the northeast corner of the quadrangle. These rocks compose a well-defined pluton that extends into the Al Qasr (Stoeser, unpub. data, 1984)and Jibal Matalli (Ekren, 1984) quadrangles to the north. In the Zarghat quadrangle, the core of the granite weathers to pinkish hues and forms bold, steep-sided whalebacks. The margins of the pluton form red-colored hills of low relief. The pluton is cut by an easterly trending set of silicic dikes, but they are less abundant than in the undivided granite.

The rock is composed mostly of medium- to coarse-grained quartz and perthite. Minor amounts of sodic plagioclase occur as partial rims on perthite and as small interstitial grains; in some rocks, plagioclase is sufficiently abundant that the rock is a syenogranite (fig. 9). There is some variation in the ferromagnesian minerals. In the southern part of the pluton, dark pleochroic blue arfvedsonite and green aegirine are intergrown with opaque minerals in interstices between quartz and feldspar. Arfvedsonite is partly replaced by opaque minerals along fractures and grain boundaries. North of the Zarghat quadrangle, the rocks near the margin of the pluton contain amphibole that is zoned from kataphorite to arfvedsonite, and the rocks from the core of the pluton contain common green magmatic hornblende (Ekren, 1984). Stoeser (unpub. data, 1984) reports electron-microprobe data that substantiate the presence of kataphorite and arfvedsonite, and reports elpidite and allanite as accessory minerals. Whole-rock analyses reported by Ekren (1984) and Stoeser (unpub. data, 1984) demonstrate that the pluton has a peraluminous core and a peralkaline rim.

The pluton intrudes volcanic rocks of the Hadn formation on the northwest flank of Jibal Sha'bah and surrounds roof pendants of Hadn volcanic rocks near its east margin. The intrusive nature of the contact is clearly demonstrated by dikes of granite that cut the volcanic rocks. The age of the pluton relative to the other rocks in the quadrangle is not well constrained. The amphibole granite is presumed to postdate the undivided granitic rocks because it is more chemically evolved. The rocks are mineralogically similar to parts of the graphic granite to the southwest, and a similar age is therefore tentatively proposed.

Felsic dikes

Felsic dikes are abundant throughout the quadrangle. The dikes weather red to black and are generally less than 2 m wide. The dikes are readily discernible where they cut granite, granodiorite, or dioritic rocks because they are more resistant and weather to darker colors. In contrast, the dikes are similar in resistance and color to the volcanic rocks in the Hadn and Zarghat formations, where they are difficult to distinguish.

The felsic dikes are very fine grained and composed mainly of quartz and potassium feldspar. Salmon-colored potassium feldspar is the most common phenocryst, and quartz and plagioclase phenocrysts are less common. Porphyritic dikes containing phenocrysts of euhedral to subhedral quartz and white plagioclase intrude the Banana greenstone between Jibal Hom and Jibal Amrah. These dikes may be the source of the quartz-plagioclase porphyry boulders in the Zarghat formation.

Most of the dikes are organized into sets within which there is a limited range of preferred orientations. These swarms are not continuous on the scale of the quadrangle, and the preferred orientation of dikes varies greatly from area to area. This fact and the observation that the younger plutonic rocks are cut by fewer felsic dikes than the older plutonic rocks suggest that the dikes were emplaced episodically over a long span of time.

Intrusive rhyolite

Outcrops of red aphanitic rock in the southeastern and south-central parts of the quadrangle are mapped as intrusive rhyolite (ry). The rocks are structureless, weather dark red to black, and superficially resemble rhyolitic volcanic rocks because of their fine grain size. Unlike volcanic rocks in the area, however, they are completely devoid of layering, eutaxitic structures, and lapilli. The rocks are composed of small (1-3 mm) phenocrysts of biotite and pink alkali feldspar in a felsic groundmass of minute grain size. The similarity in mineralogy between this rock and many of the felsic dikes suggests that they may be consanguineous.

Granophyre

Brick-red fine-grained granophyre (gph) forms small, isolated intrusions. The granophyre is resistant to erosion and tends to form prominent hills and ridges.

All of the rocks mapped as granophyre are very fine grained and rich in potassium feldspar (fig. 10). Most of the bodies are porphyritic, containing phenocrysts of quartz and alkali feldspar set in a very fine grained graphic to hypidiomorphic-granular matrix of quartz feldspar and magnetite and(or) biotite. Feldspars are uniformly turbid and rust colored.

Contact relations generally indicate that the intrusions of granophyre are younger than the adjacent rocks. Granophyre bodies are essentially devoid of dikes, which suggests that they may all be relatively young. The Zarghat formation is intruded by plugs of granophyre west of Jibal Hom and north of Jibal Uahli. The Hadn formation is intruded by granophyre on the northwest flank of Jibal al Furs. Several small intrusions of granophyre invade the graphic granite near the west margin of the quadrangle. The bodies mapped as granophyre are not, however, thought to represent a single set of genetically or temporally related intrusions. Granophyre along the east margin of the quadrangle grades into the adjacent biotite alkali-feldspar granite, suggesting that the two rock types are genetically related. Similarly, small exposures of granophyre west and north of Jibal Hom may be related to the associated graphic granite. The similarities in grain size and texture of the different granophyre intrusions probably reflect intrusion into similar shallow-level environments rather than a consanguineous relationship. Intrusive rhyolite grades into the adjacent

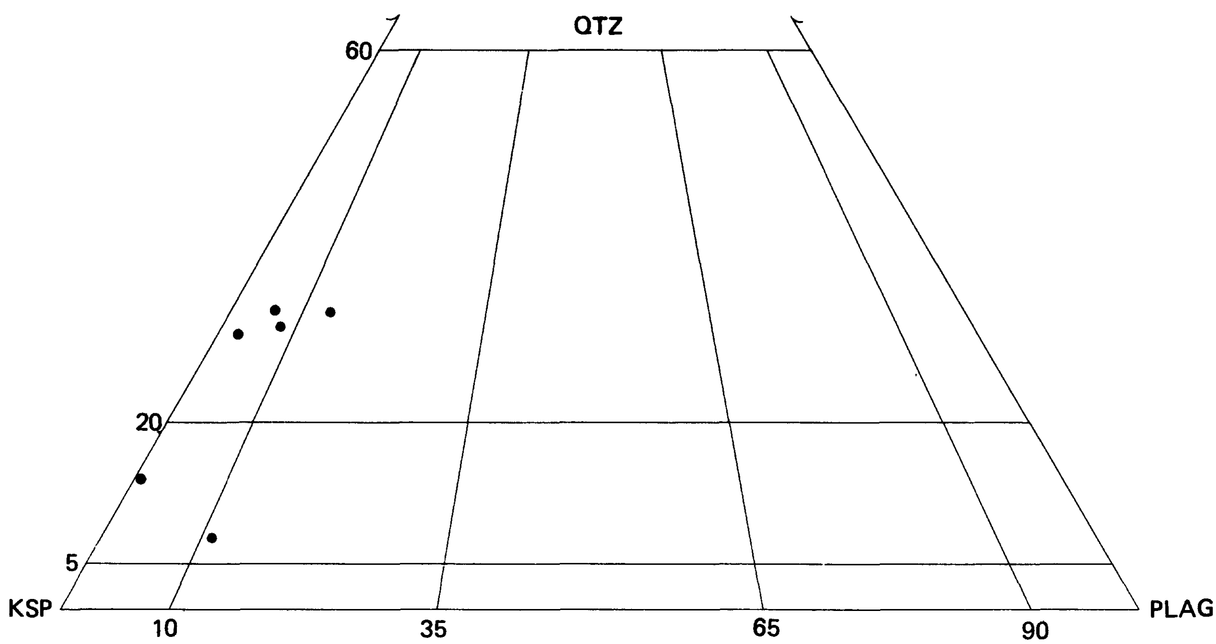

Figure 10.--Ternary diagram showing the relative modal abundances of quartz (QTZ), potassium feldspar (KSP), and plagioclase (PLAG) in granophyre. Fields are drawn and labeled as in figure 2.

granophyre in the southeast corner of the quadrangle with increasing grain size. These two rocks, therefore, are inferred to be cogenetic and contemporaneous where in contact.

Diabase

Diabase (di) intrudes the Zarghat formation in two small areas on the east side of Jibal Uahli. The diabase forms dark-gray-weathering outcrops with virtually no relief. The timing of diabase emplacement is not well constrained in the quadrangle. One diabase-Zarghat contact is crosscut by a body of granophyre, indicating that, at least locally, the diabase is older than the granophyre. In the Ghazzalah quadrangle to the east (Quick, 1983), diabase intrusions are located along a system of northeast-trending faults and intrude even the youngest plutonic rocks. However, in the Qufar and Al Awshaziyah quadrangles, diabase dikes are unconformably overlain by the Hadn formation (Kellogg, 1983; Leo, 1984). Therefore, although two bodies of diabase are clearly young, diabase may have emplaced episodically over a long period of time in the vicinity of the Zarghat quadrangle.

Gabbro

Gabbro (gb) crops out as isolated, alluvium-surrounded plugs near Jibal al Furs in the southeastern part of the quadrangle and forms dikes that cut the undivided granite and graphic granite to the north and west of Jibal Hom. Outcrops are typically covered by dark-ruddy-brown to black subangular boulders and greenish-gray regolith. Part of the gabbro that crops out east of Jibal al Furs weathers white.

The primary mineral assemblage of the gabbro is a hypidiomorphic-granular to subophitic intergrowth of plagioclase, augite, and(or) green hornblende and magnetite. The grain size is variable, ranging from fine to coarse grained in a single body. The ferromagnesian minerals are interstitial to larger, subhedral plagioclase grains. Augite is the predominant mafic silicate in the gabbro dikes in the western part of the quadrangle, whereas hornblende is the only mafic silicate in the gabbro body east of Jibal al Furs. Alteration of the gabbro has incompletely saussuritized plagioclase and replaced hornblende and augite with intergrowths of chlorite±actinolite. Calcite veins and laumontite are locally abundant in the gabbro body east of Jibal al Furs and account for the local white coloration of those rocks.

The gabbro dikes in the western part of the quadrangle intrude both the undivided granite and the graphic granite and therefore are relatively young. Felsic dikes do not cut the gabbro, which is consistent with a young age for the gabbro. The apparent young age and basic composition suggest that the gabbro may be consanguineous with the diabase intrusions. The gabbro outcrops in the southeastern part of the quadrangle are interpreted to be the same age, although no contact relations with intrusive or volcanosedimentary rocks are exposed.

Aplite

Aplite (ap) crops out in the southern part of the quadrangle about 5 km west of Wadi Asmarah. The rock is aphanitic, light purple to lavender on a fresh surface, and weathers buff to light orange brown. Flow layering is developed within a few meters of the contact with the adjacent Zarghat formation, but for the most part the rock is structureless. The aplite is resistant and underlies more rugged terrain than the adjacent Zarghat formation; steep hills as much as 100 m high have distinctive convex faces that are similar to the morphology of the granophyric intrusions.

The aplite is composed of an extremely fine grained (0.1-0.2 mm) intergrowth of turbid alkali feldspar, quartz, and equant magnetite. The texture is typically xenomorphic-granular, but there are some euhedral potassium feldspar crystals.

Aplite intrudes the Zarghat formation. The northwestern contact of the aplite is clearly exposed and is seen to truncate layering in the Zarghat formation. The age of the aplite relative to the other intrusive rocks is uncertain. The aplite is essentially devoid of dikes, which suggests that it is a relatively young intrusion.

Hornblende-plagioclase porphyry

Dikes of hornblende-plagioclase porphyry (hpp) intrude the undivided granite south of Jibal Sha'bah. The rock is resistant and weathers dark red to black. Phenocrysts (0.5-2 mm) of euhedral brown amphibole and white plagioclase are contained in a very fine grained (0.05 mm) matrix of graphic alkali feldspar and quartz. There are no contraints on the age of this unit except that it must postdate the undivided granite.

PALEOZOIC(?) SEDIMENTARY ROCKS

Siq Sandstone

Poorly sorted sandstone that crops out near the west margin of the quadrangle, west and northwest of Jibal Hom, is mapped as Siq Sandstone (O€s) (Brown and others, 1963). Beds range from 1 to 10 m in thickness and are essentially flat lying; the resulting outcrops form distinctive flat-topped mesas. The rocks are composed of red-, purple-, or white-weathering, poorly sorted, friable arkosic sandstone. Well-rounded pebbles are locally abundant near the base of the formation. Crossbedding, local unconformities, channel deposits, and graded bedding are ubiquitous, and these features suggest that the sediments may have been fluvial deposits.

The Siq Sandstone appears to be one of the youngest rocks in the quadrangle; it unconformably overlies a large pluton of graphic granite, which, as discussed above, intrudes the Zarghat formation. The unconformity is best exposed in a small cave in the northernmost occurrence of Siq Sandstone, where the basal 2 m of the Siq contains large angular boulders of graphic granite. Although most of the outcrops are erosional relicts that sit on top of granite hills, the largest single outcrop is situated within a low point between granite hills that are about 100 m higher than the base of the Siq. This outcrop suggests that the Siq Sandstone was deposited on an irregular surface and supports the interpretation that the rocks are fluvial deposits.

CENOZOIC SEDIMENTS AND VOLCANIC ROCKS

Quaternary basalt

A large tongue of basalt (Qb) extends from Harrat Ithnain (Fairer, unpub. data, 1984) into the southwest corner of the Zarghat quadrangle. The basalt is black and vesicular and forms a massive pahoehoe flow (Williams and McBirney, 1979) with an extremely rugged surface. Individual lobes of basalt are tens of meters wide and as much as 7 m thick and are broken by deep fractures. It is assumed to be a Quaternary feature because the surface of the flow has undergone virtually no modification by erosion. Extensive farming along the margin of the flow and between lobes within the flow suggests that the basalt is an excellent aquifer.

Undivided Quaternary deposits

Undivided Quaternary deposits (Qu) are composed of colluvium, talus, flood-plain and terrace deposits, and alluvium in channels too small to map. These deposits are extensive in the southern and eastern parts of the quadrangle.

Alluvium

Alluvium (Qal) consists of unconsolidated sand and silt that is actively being moved in large wadi channels. These sediments are generally lighter colored, better sorted, and more mature than the undifferentiated Quaternary deposits.

Playa-lake deposits

Playa-lake deposits (Qp) consist mostly of clay and fine silt and lesser amounts of evaporative salts deposited in small playa lakes.

METAMORPHISM

The Banana greenstone appears to have been more altered than either the Hadn or Zarghat formations. The presence of actinolite, chlorite, and epidote replacing primary mineral assemblages indicates that the Banana greenstone has recrystallized under greenschist-facies conditions. However, considering the extent to which primary minerals are preserved, it is not clear if recrystallization actually involved a regional, prograde metamorphic event. The effects of recrystallization in the Hadn and Zarghat formations appear to be restricted to devitrification of glass, turbid alteration of feldspar phenocrysts, and local development of calcite- and epidote-filled veins. The contrast in metamorphism between the Banana greenstone and younger formations is much less pronounced than in the adjacent Ghazzalah quadrangle, where the Banana greenstone has recrystallized under upper-greenschist- to amphibolite-facies conditions.

STRATIGRAPHIC CONSIDERATIONS

The relation between the Hadn and Zarghat formations is poorly understood at the present time. Bowden (1982) interpreted the Zarghat formation to be younger than the Hadn formation, whereas Ekren (1984) maps the extension of the Zarghat formation in the Jibal Matalli quadrangle as Hadn. Although definitive relations cannot be found in the Zarghat quadrangle, two points must be reconciled. First, both formations contain many of the same lithologies.

Second, the formations differ in terms of relative amounts of sedimentary and volcanic rocks and, therefore, appear to have been deposited in somewhat different environments. The thick ignimbritic section of the Hadn and the interlayered continental sedimentary rocks suggest that it was deposited predominantly in a subaerial environment. In contrast, the characteristics of the Zarghat formation suggest that it was deposited in an environment that was transitional between marine and subaerial. The basal boulder conglomerate must have been either a terrestrial or nearshore deposit, and the columnar jointing in some of the basalt and rhyolite flows in the lower third of the formation suggests that they were erupted on land. The rocks appear to take on a submarine character higher in the section. A thick section of well-bedded sandstone (fig. 3) may have formed as "marine" turbidite, and the marble member of the Zarghat formation may have been a shallow-water marine deposit. A large lake is a possible alternative environment for the deposition of these sediments. Many of the rocks in the undivided member have characteristics that are intermediate between sedimentary and volcanic rocks, suggesting that they were either volcanic rocks deposited in water or reworked volcanic deposits.

The thickness and continuity of the Zarghat basal conglomerate strongly suggests that the surface on which it was deposited was a major unconformity. The surface of the unconformity and the bedding within the overlying Zarghat formation dip uniformly to the west. Pre-Zarghat basement rocks are east of the unconformity and include the Banana greenstone, hornblende quartz diorite, and a granitic rock that ranges in composition from biotite alkali-feldspar to syenogranite. It is possible that the Hadn formation, which crops out further to the east, is part of this pre-Zarghat basement. Peralkaline granite intrudes the Hadn formation in the Ghazzalah quadrangle (Quick, 1983), whereas clasts of peralkaline granite occur in the basal conglomerate of the Zarghat formation. Furthermore, the "Hadn-like" volcanic clasts in the Zarghat conglomerate and the apparent differences in depositional environments for the two formations could be explained by deposition of the Zarghat formation on a post-Hadn erosional surface. If the Hadn formation is unconformably overlain by the Zarghat formation, then there are at least two major, relatively young sequences of volcanic rocks in the quadrangle that are separated by a major unconformity. However, the Hadn formation has also been demonstrated to lie unconformably on the Banana greenstone, hornblende quartz diorite, and granodiorite in the Ghazzalah quadrangle (Quick, 1983). It is, therefore, also possible that the Hadn and Zarghat formations are correlative and that the center of the

Zarghat quadrangle marks a major facies change from subaerial volcanic rocks and continental sediments in the east to submarine volcanic and sedimentary rocks in the west. The Hadn formation may have constituted an ancient topographic high formed by deposition of ignimbritic volcanic rocks in a predominantly subaerial environment. The Zarghat formation was deposited in a subsiding basin adjacent to this volcanic highland. Reworked Hadn volcanic rocks may have contributed to the basal conglomerate of the Zarghat, which was a nearshore facies, and supplied finer grained clastics for the sedimentary rocks higher in the Zarghat section. Many of the volcanic rocks in both formations may have been deposited by the same eruptions.

STRUCTURE

The most obvious structures in the Zarghat quadrangle are the numerous rounded to irregular bodies of granite. The Banana greenstone, the hornblende quartz diorite, the granodiorite, and the Hadn and Zarghat formations occur as septa between and as roof pendants within these plutons. These units may constitute only a relatively thin veneer over large volumes of granite at depth. The granitic plutons display little evidence of internal deformation and were probably emplaced relatively late in the structural evolution of the quadrangle. Postplutonic deformation appears to be limited to minor faulting and regional uplift and erosion prior to the deposition of the Siq Sandstone.

Two sets of faults are present. A northeast-trending set of faults appears to be an extension of the Saqf system of right-lateral faults described in the adjacent Ghazzalah quadrangle (Quick, 1983). The largest of these faults occupies an alluviated valley in the northern part of the Zarghat quadrangle and cuts the graphic granite, a small alkali-feldspar granite pluton, and the Zarghat formation. The offsets on the granite-Zarghat contacts and on the Zarghat basal conglomerate suggest a large right-lateral component of slip. The sense of slip on a second fault set that trends predominantly northwesterly is not known.

If the large granitic plutons and the effects of faulting are palinspastically removed, the area appears to be underlain by three major north-trending lithologic "belts". The Zarghat formation occupies the westernmost belt and the Hadn formation makes up the easternmost belt. Between these two, in the center of the quadrangle, is a central belt composed of older rocks that include the Banana greenstone, hornblende quartz diorite, granodiorite, tonalite, and pre-Zarghat granite. Outcrops of these rocks in the southeast corner of the quadrangle are outliers of yet another north-trending belt that is exposed in the Ghazzalah quadrangle, where reconnaissance mapping has demonstrated that they may be treated as a single, complex terrane of pre-Hadn rocks (Quick, 1983). Small outcrops of hornblende quartz diorite and Banana greenstone in the northwest corner of the quadrangle suggest that another belt of this terrane may be exposed to the west of the Zarghat quadrangle. In order to consider the possible relations between these belts and the gross structure of the quadrangle, it is necessary to outline the internal structure of each belt.

Although poorly exposed, the hornblende quartz diorite, granodiorite, tonalite, and granite are interpreted to form dikes, stocks, and small plutons that intrude the Banana greenstone; the primary shapes of these intrusions have been obfuscated by subsequent intrusions and Quaternary deposits. All of the above rocks appear to be relatively undeformed. In particular, the Banana greenstone and hornblende quartz diorite lack the well-developed foliation that is present locally in rocks of similar age in the Ghazzalah (Quick, 1983), Qufar (Kellogg, 1983), and As Sulaymi (Quick, unpub. data, 1984) quadrangles. Exposures of Banana greenstone are too small and available attitudes of bedding are too sparse to allow its internal structure to be accurately evaluated. Consequently, the extent of folding in these rocks is unknown.

The internal structure of the Hadn formation is better documented. In the vicinity of Jibal Sha'bah, the Hadn formation dips predominantly to the west. There is some variation in direction of dip, which suggests that the rocks may be folded. Outcrops at and to the northeast of Jibal Amrah, for the most part, have attitudes that suggest a large, bowl-shaped structure with beds dipping toward a central area located about 10-15 km northeast of Jibal Amrah. The rocks immediately underlying Jibal Amrah are more deformed. Two small, tight synclines in the Hadn formation are sandwiched between intrusions of granite. At Jibal al Furs, Hadn volcanic rocks are folded into an open, northeast-trending syncline defined by attitudes within the Zarghat formation and by the shape of the basal Zarghat contact. In the southwest corner of the quadrangle, the Zarghat formation dips more or less uniformly to the west except for one minor, north-trending syncline in the vicinity of the magnesite deposits. A larger, northeast-trending syncline is exposed immediately west of the quadrangle boundary in the Harrat Ithnain quadrangle (Fairer, unpub. data, 1984).

Although it is possible to speculate on the gross structure of the quadrangle, the data are insufficient to provide a clear choice between several possible hypotheses. One possibility is that the north-trending belts were produced by preplutonic regional folding along north-trending axes. According to this interpretation, the Banana greenstone and associated hornblende quartz diorite, granodiorite, tonalite, and old granitic rocks are exposed in the cores of large anticlines, whereas the younger Hadn and Zarghat formations are preserved in the centers of the intervening synclines. Another hypothesis is that the belts are produced by regional deformation along north-trending faults. Delfour (1977) has mapped major north-trending faults in the Nuqrah quadrangle about 50 km to the south, and these structures may extend to the north. However, it is emphasized that there is absolutely no field evidence for such structures in the Zarghat quadrangle; if they exist, they have been obliterated by subsequent granitic intrusions and Quaternary cover. The favored hypothesis is that the belts were produced by deformation during emplacement of the younger granitic rocks. The Banana greenstone and associated old plutonic rocks crop out around the margins of and as roof pendants within the larger granitic plutons. In contrast, the largest exposures of Hadn and Zarghat rocks are in areas that appear to fall between major plutons. These rocks are deformed into synclinal or bowl-shaped structures with a curious absence of large anticlines. This pattern could be interpreted to suggest that large granitic plutons carried large blocks of Banana greenstone and old plutonic rocks upward and deformed the Zarghat and Hadn formations so that bedding in those formations dips predominantly away from the intrusions. As a result, large areas of Zarghat and Hadn formations would appear to form synformal or bowl-shaped structures. The best evidence in support of this hypothesis is the synclinal deformation of the Hadn formation between granitic intrusions at Jibal Amrah. If this hypothesis is correct, then the "belts" reflect the pattern of plutonism in the Zarghat quadrangle rather than the orientation of a regional stress field.

ECONOMIC GEOLOGY

Magnesite (MODS 711) crops out in close association with the marble member of the Zarghat formation in the southwest corner of the quadrangle. Individual exposures range in diameter from a few meters to hundreds of meters across. The deposits were first reported by Kahr (1962) and have subsequently been studied in detail by BRGM to determine their economic potential (Brosset, 1976, 1978; Brette and others, 1981). No other deposits with economic potential are known to occur in the quadrangle.

DATA STORAGE

The magnesite deposit mentioned in this report is entered into the Mineral Occurrence Documentation System (MODS) data bank. No new entries were made as a result of this report. Inquiries regarding this data bank may be made through the Office of the Technical Advisor, Saudi Arabian Deputy Ministry for Mineral Resources, Jiddah.

Field and laboratory data used in this report are filed as USGS-DF-04-07.

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