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Reconnaissance geology of the As Sulaymi Quadrangle, sheet 26/41C, Kingdom of Saudi Arabia

by

James E. Quick[1]

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(Plate in pocket)

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ABSTRACT

The As Sulaymi quadrangle, located in the Arabian Shield between lat 26°00' and 26°30' N. and long 41°00' and 41°30' E., is underlain by three volcano-sedimentary units and a wide range of dioritoid and granitoid plutonic intusive rocks.

The oldest unit, the Hulayfah group is composed of basaltic to intermediate volcanic and subvolcanic rocks, and interbedded sedimentary and silicic volcanic rocks. The metamorphic grade of this unit ranges from greenschist to amphibolite. Tight folds are apparent where marker beds are visible, and locally the rocks are foliated. Uranium- lead isotopic-age data from the adjacent Ghazzalah quadrangle require that the Hulayfah group is at least 738 Ma.

The Hulayfah group is unconformably overlain by the Hadn formation that is composed of silicic volcanic rocks and minor arkosic sandstone and conglomerate. The Hadn formation may include several varied volcanic sequences that were deposited at approximately the same time, but which were formed in different basins in association with separate eruptive centers. The effects of metamorphism and deformation are less pronounced in these rocks than in the Hulayfah group. Rubidium-strontium isotopic data from the Ghazzalah and Al Awshaziyah quadrangles suggest that the Hadn formation was deposited between 651 and 600±7 Ma.

Conglomerate, sandstone, and limestone of the Jibalah group were deposited in a narrow, northwest-trending graben that cuts across the southwestern corner of the quadrangle. Whole-rock potassium-argon ages from the adjacent Nuqrah quadrangle suggest that these rocks may be as young as 502-493 Ma.

Intrusive rocks are separable according to their ages relative to the three volcanic sequences. Small intrusions of quartz diorite and diorite appear to be approximately coeval with the Hulayfah group. Large granodiorite and monzogranite plutons were intruded into the Hulayfah group but appear to predate the Hadn formation. The Hadn formation, in turn, is crosscut by plutons of quartz syenite, quartz monzonite, alkali-feldspar granite, and alkali granite. Most of the extensive felsic dikes and small granophyric and rhyolitic intrusions appear to have been emplaced about this time. A final intrusive pulse formed gabbro and diorite bodies that may be related to Jibalah-age volcanism.

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Northwest-trending, predominantly left-lateral set of shears, offset a large alkali-granite pluton that is one of the youngest intrusions in the quadrangle. A shift to extensional faulting produced a graben along these faults in the southwestern corner of the quadrangle; this shift in tectonic style is recorded by the deposition of the Jibalah group.

The Hulayfah group has the greatest potential for resources in the quadrangle, and is host of two ancient gold workings.

INTRODUCTION

Geographic setting

The As Sulaymi quadrangle, sheet 26/41 C, occupies an area of approximately 2,750 km^2 between lat 26° 00' and 26°30' N. and long 41°00' and 41°30' E. (fig. 1). The quadrangle may be reached by a major highway that connects Ha'il and Al Madinah, and most points in the map area are accessible by new subsidiary paved roads, graded service roads, and desert tracks.

Extensive peneplains and pediments are developed in the southwestern part of the As Sulaymi quadrangle, where as rugged hills occur in the eastern and central parts of the quadrangle. Drainage is primarily to the south and east via tributaries of Wadi ar Rumah.

The largest permanent settlements are located near the center of the quadrangle on the flanks of high ranges of hills named Jibal Farafinak and Dil Qunay. As Sulaymi, for which the quadrangle is named, is the largest village.

Previous investigations

The As Sulaymi quadrangle is included within the 1:500,000-scale Northeastern Hijaz quadrangle (Brown and others, 1963). Adjacent 1:100,000-scale quadrangles to the east, north, and west have been mapped by the U. S. Geological Survey and the resulting maps and reports are published or on file at the U.S. Geological Survey office in Jiddah, Saudi Arabia (fig. 1). The As Sulaymi quadrangle is bordered to the south by the Nuqrah quadrangle, sheet 25E (Delfour, 1977).

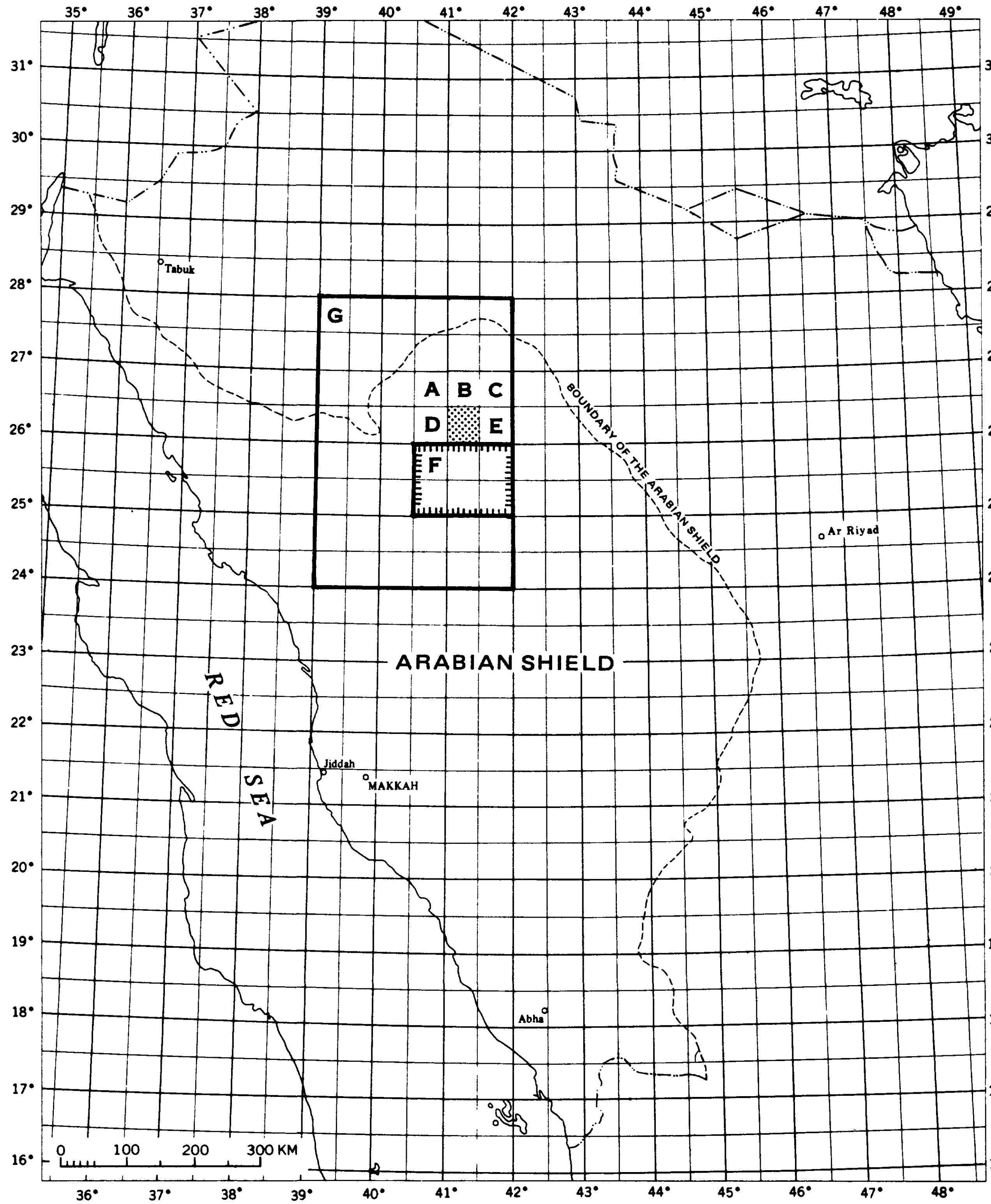

Figure 1.—Index map of western Saudi Arabia showing the location of the As Sulaymi quadrangle (patterned) and the other quadrangles referred to in this report: A, Zarghat (Quick, 1984); B, Ghazzalah (Quick, 1983); C, Al Awshaziyah (Leo, 1984); D, Ar Rawdh (O'Neill and Ferris, 1985, unpub data) E, Al Ba'ayith (Williams and Simonds, 1985): F, Nuqrah (Delfour, 1977); G, Northeastern Hijaz (Brown and others, 1963).

Present investigation

This study is based on three weeks of field investigations by helicopter during November, 1983.

Rocks are classified according to guidelines of the International Union of Geological Sciences (Streckeisen, 1976, 1979) and Fisher (1961). Units were named for the most abundant lithology in cases where the rock composition is variable. Fine-grained, silicic volcanic rocks were provisionally named on the basis of phenocryst populations as follows: Rocks containing phenocrysts of only 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.

The present report discusses most of the rocks in terms of local, informal formation- or member-rank units defined within or near the Wadi Ash Shu'bah quadrangle, sheet 26E (Quick and Doebrich, in press). Locally defined units are discussed relative to stratigraphic nomenclature used in nearby quadrangles as appropriate. This strategy was adopted because: (1) there are presently no formally defined formation- or group-rank units in the Proterozoic of the northern Arabian Shield; and (2) many formation or group names that have been applied previously within and near the As Sulaymi quadrangle were based on sweeping regional correlations that are virtually unsupported by stratigraphic evidence or isotopic age data.

Acknowledgments

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GEOLOGIC OVERVIEW

The As Sulaymi quadrangle is located in the north central part of the Precambrian shield of Saudi Arabia, and is centered close to the crest of the Ha'il arch, a north-trending regional upwarp of late Precambrian rocks (Greenwood, 1973). The bedrock is late Proterozoic to early Paleozoic in age and is composed of a wide compositional range of plutonic intrusive rocks and three distinct sequences of volcanic rock and(or) sedimentary rock that are metamorphosed to varying degrees. (see pl. 1).

The volcanic and sedimentary rocks were previously mapped by Brown and others (1963) as Shammar rhyolite and Halaban formations. During subsequent work in the Nuqrah quadrangle, Delfour (1977) elevated the Shammar to group status and subdivided it into the Kuara and Malha formations. Delfour also substituted the Hulayfah group for rocks previously classified as Halaban by Brown and others (1963), and utilized an additional unit, the Jibalah group. Most of the previously mentioned unit names have been applied to rocks over wide regions of the Arabian Shield without adequate stratigraphic control or isotopic age data. More recently, geologic thought has emphasized interpretation of the Arabian Shield in terms of one or more oceanic-volcanic arc environments followed by development of an intracratonic volcanic arc on the foundation of the older arc(s) (Schmidt and others, 1979; Al-Shanti and Gass, 1983; Stacey and others, 1984; Stoeser and Camp, in press). Analogy to well-documented volcanic arc systems (e.g. Hamilton, 1979) suggests that the Proterozoic history of the Arabian Shield was complex and that similar sequences of volcanic and sedimentary rocks may have been produced at radically different times in different parts of the shield. Primarily for this reason, the preexisting regional stratigraphic nomenclature has mostly been avoided in favor of locally defined units. The Hulayfah group is subdivided into basaltic and intermediate-composition volcanic and volcanoclastic rocks of the Banana greenstone and into undivided sedimentary and silicic volcanic rocks. These rocks are metamorphosed to greenschist and, locally, to amphibolite facies. The Hadn formation, which was defined 50-70 km north of the As Sulaymi quadrangle (Chevremont, 1982; Stoeser, written commun., 1982), is composed of mostly massive ash-flow tuff and minor continental sedimentary rocks. Small exposures of the Cambrian-age Jibalah group (Delfour, 1977) are composed of boulder conglomerate, sandstone, and limestone deposited in a northwest-trending graben that parallels Wadi al Qahad.

The plutonic rocks in the quadrangle are divisible into three principal groups based on their ages relative to the Hulayfah group and Hadn formation. One group, composed of quartz diorite and diorite, intrudes but is thought to be coeval with the Hulayfah group. A younger group, consisting of granodiorite and monzogranite, intrudes the Hulayfah group, predates the Hadn formation, and may be roughly equivalent to the "syntectonic granites" of Schmidt and others (1979). The third group intrudes the Hadn formation and is composed of granitic plutons that, for the most part, range in composition from monzogranite to alkali-feldspar granite. Smaller intrusions of granophyre, aplite, hypabyssal rhyolite, diabase and gabbro also appear to postdate the Hadn formation. The post-Hadn plutons are collectively equivalent to the "post-tectonic granites" of Schmidt and others (1979).

PRECAMBRIAN VOLCANIC AND SEDIMENTARY ROCKS

Hulayfah group

The Hulayfah group is named for greenstone and interbedded silicic volcanic rocks and sedimentary rocks that crop out in the Nuqrah quadrangle to the south. This unit extends to the southwestern and south central parts of the quadrangle. Hulayfah group, as used in this report, includes undivided silic volcanic rocks and the Banana greenstone of Quick (1983), and is continuous with rocks also mapped in the adjacent Ar Rawhd quadrangle by O'Neill and Ferris(1995 unpubl data)as informal subdivisions of the Hulayfah group. Possibly equivalent rocks are mapped as the Afna and Nuqrah formations of the Hulayfah group in the Nuqrah quadrangle (Delfour, 1977), as the Nuf formation in the Qufar and Rak quadrangles (Kellogg, 1983, 1984), and as the Aqab formation in the Awshaziyah quadrangle (Leo, 1984).

Rocks assigned to the Hulayfah group consist of metamorphosed basalt, andesite, diabase, and fine-grained diorite, which are collectively mapped as greenstone. These rocks are mapped as gneissic greenstone where metamorphism has been sufficiently intense to produce a gneissic or schistose fabric. Interbedded with the greenstone are lenses of metamorphosed silicic volcanic and sedimentary rocks.

Greenstone

Metamorphosed basaltic to andesitic volcanic and subvolcanic rocks are mapped as greenstone (bg) of the Hulayfah group. This unit contains minor amounts of marble, graywacke, and dacitic to rhyolitic extrusive rocks. The volcanic and subvolcanic rocks form dark-gray hills and pediments. The regolith is typically blue green, 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 some hills are as much as 100 m high, cliffs are not present. Boulders are generally less than 0.5 m in diameter, subrounded, and weather to a medium-gray to ruddy-brown color.

The greenstone consists of flows and flow breccia. The more mafic rocks are commonly vesicular, and, immediately north of Al Birkah, have locally developed pillow structures. In hand specimen, the rocks are aphanitic to plagioclase- and(or) pyroxene-phyric. Rare interbeds of volcanic wacke contain clasts of flow-banded volcanic rock, plagioclase-phyric volcanic rock, felsite, mafic aphanite, and diorite. Bedding is undiscernable except where thin beds of marble or wacke crop out.

The volcanic rocks are locally intruded by dikes and sills of diabase and microdiorite too small or too intimately intercalated with flows to map as separate units. The intrusive rocks are mineralogically similar to and display the same degree of metamorphism and deformation as the volcanic rocks and, therefore, are postulated to have formed as shallow intrusions that may have been comagmatic.

The rocks have recrystallized at lower to middle greenschist facies in most places. Primary hornblende and pyroxene are partly to completely replaced by chlorite and actinolite. Plagioclase is partially saussuritized and locally replaced by epidote.

Gneissic greenstone

Gneissic greenstone (bgg) is mapped where epidote amphibolite grade assemblages are developed and the rocks have a foliated or gneissic fabric. This unit crops out near the southern border of the As Sulaymi quadrangle where it forms an aureole around a granodiorite pluton and also underlies a broad peneplain east of Jibal Awbariyat.

Sedimentary rocks and silicic volcanic rocks

Sedimentary rocks and silicic volcanic rocks (svs) that are interbedded with the greenstone locally constitute mappable horizons. These rocks consist fine- to coarse-grained volcanic sandstone, massive silicic volcanic lava flows and ash-flow tuffs, and interbedded basalt and andesite flows. The silicic volcanic rocks range in composition from dacite to rhyolite. These sedimentary rocks and silicic volcanic rocks are on strike with similar rocks to the southwest in the Ar Rawdh quadrangle (O'Neill and Ferris, 1985, unpubl. data), and to the northeast in the Ghazzalah quadrangle where they were previously assigned to the Hadn formation (Quick, 1983).

The silicic volcanic rocks are clearly recrystallized although the affects of metamorphism are more subtle than in the associated greenstone. The matrices of these rocks consist of a felty-textured mosaic of quartz and feldspar. Epidote and chlorite are locally abundant.

Age and thickness

The Hulayfah group is interpreted to be the oldest unit of volcanic or sedimentary rocks in the quadrangle. Its stratigraphic thickness is unknown because its internal structure and stratigraphy are poorly documented and because of the absence of a basal contact. In the Ghazzalah quadrangle, granodiorite that intrudes the Banana greenstone (Quick, 1983) is dated at 738 Ma by uranium-lead isotopic measurements of zircon separates (Hedge, written commun., 1984).

Hadn formation

Silicic volcanic rocks and minor interbedded arkosic sandstone and conglomerate that crop out along the eastern boundary of the quadrangle are mapped as the Hadn formation (hu). 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. Chevremont (1982) traced the Hadn formation from its type locality into the Al Awshaziyah quadrangle where he described stratigraphic sections at Jibal Rumman as Sumr. The rocks mapped as Hadn formation in the As Sulaymi quadrangle extend northward without major break into the Al Awshaziyah quadrangle where, at Jibal Rumman as Sumr, they are separated from the Hadn section by an unexposed gap of only about 7 km. The Hadn formation, as used in this report, comprises some of the rocks previously mapped as Shammar rhyolite (Brown and others, 1963) and may be equivalent to parts of the Malha formation of the Shammar group as mapped in the Nuqrah quadrangle (Delfour, 1977).

The Hadn formation is composed predominantly of rhyolitic to rhyodacitic ash-flow tuff, lesser amounts of massive rhyolitic and rhyodacitic lava flows, and minor amounts of arkosic sandstone and conglomerate. Dacitic, andesitic, and basaltic lava flows are scarce. The rocks are more resistant to erosion than the Hulayfah group and form steep-sided hills, precipitous cliffs, and steep talus slopes. Exposures typically weather rusty red brown, and the regolith ranges in color from red brown to tan to olive green.

The volcanic rocks are composed mostly of crystal-rich, ash-flow tuff. The phenocryst are plagioclase, potassium feldspar, and quartz, which are present in various proportions. Blue alkali-amphibole is present locally. The phenocryst populations suggest that the rocks span a range in composition from rhyolite to dacite, and the presence of blue amphibole suggests that some rocks may be peralkaline in composition. Major-element chemistry for rocks from the Hadn type locality indicate that most of those volcanic rocks are rhyolite (D.B. Stoeser, written commun., 1984).

Lithic fragments and phenocrysts are typically set in an extremely fine grained (0.01-0.1 mm) mosaic of quartz, alkali-feldspar, chlorite, and opaque minerals, with or without biotite, amphibole, and pyroxene. Fiamme structures and flow bands have devitrified to a somewhat coarser grain size (0.05-0.1 mm) and commonly contain spherulitic aggregates of quartz and feldspar. The matrix in some rocks contains acicular microlites (0.05-0.15 mm) of albite, which define a pilotaxitic-like fabric that wraps around phenocrysts. Microphenocrysts of sanidine are abundant in other rocks.

Arkosic sandstone and conglomerate beds are present locally near the base of the Hadn section. The abundance of these sedimentary rocks relative to the volcanic rocks is low in the southern part of the As Sulaymi quadrangle but increases northward into the Al Ba'ayith and Al Awshaziyah quadrangles.

The Hadn volcanic rocks have been only incipiently recrystallized. Some amphibole and pyroxene grains are partially replaced by chlorite. Potassium-feldspar phenocrysts and, to a lesser extent, plagioclase phenocrysts are partially altered to a cryptocrystalline intergrowth of hematite, albite, and clay(?) minerals. Vugs are commonly filled by chlorite, epidote, and stilbite. Primary igneous textures are widely preserved, including fiamme, fine (0.2 mm) flow banding, lithophysae, and spherulites. Original shapes of glass shards appear to be preserved locally, and there are possible relics of perlitic fractures. The extent to which primary igneous features are preserved is in striking contrast to the metamorphism in the Hulayfah group.

Age and thickness

The thickness of the Hadn formation is estimated to be at least 2 km at Jabal Aba al Ghubtan where the base of a west-dipping homoclinal section is exposed. This is a minimum thickness because the top of the section is truncated by granite pluton. Chevremont (1982) measured a similar thickness of 3-5 km at Jibal Rumman as Sumr in the al Awshaziyah quadrangle. Extrapolation of these thickness is not advised because it is likely that the Hadn formation is composed of several, broadly coeval volcanic piles that developed near separated eruptive centers. These sequences may intertongue locally and, in other places, may have been deposited is isolated basins. The presence of interbedded continental sedimentary rock suggest that many of the basins were subaerial (Quick and Doebrich, in press). If this model is correct, extreme lateral variations in stratigraphic thickness are predicted.

The Hadn formation overlies the Hulayfah group and the contact is broadly conformable and poorly exposed in the As Sulaymi quadrangle. The contact is, however, interpreted to be an unconformity because a conglomerate that contains clasts of Banana greenstone and of granodiorite that intrudes the Banana greenstone is exposed at the base of the Hadn in the Al Ba'ayith quadrangle. This interpretation is consistent with the demonstrated age relationships in the Al Awshaziyah, Ghazzalah, and Zarghat quadrangles (Leo, 1984; Quick, 1983, 1984). Furthermore, the Hadn formation is known to be younger than 651 Ma, based on uranium-lead dates on zircons from a granodiorite body that is unconformably overlain by the Hadn in the northeastern corner of the Al Awshaziyah quadrangle (Hedge, 1983, written commun.). A minimum age for the Hadn is provided by a rubidium-strontium age date of 600$\pm$7 Ma on a peralkaline granite that intrudes the Hadn formation at Jabal Ba'gham in the Ghazzalah quadrangle (Stuckless and others, 1984b).

PRECAMBRIAN AND PALEOZOIC INTRUSIVE ROCKS

Quartz diorite and diorite

Small intrusions of quartz diorite and diorite (hd) crop out at several localities in the quadrangle. The largest body is at Dil Ahbad. Smaller intrusions are located in the northeast corner of the quadrangle, and in the southwest corner of the quadrangle near Wadi al Qahad. From a distance, the rock appears similar to the greenstone, forming outcrops of low-lying hills covered with gray-green regolith and small, rounded to subangular, dark-gray boulders.

The rock shows a complete gradation between diorite and quartz diorite. Textures range from hypidiomorphic-granular to intersertal. Color indices range from 15 to 30, and brown, magmatic hornblende is the dominant ferromagnesian mineral although minor amounts of biotite are present locally. Plagioclase ranges in composition from An_{30} to An_{50}. Alteration has resulted in saussuritization of plagioclase and chloritization of amphibole and biotite. Calcite and epidote veins are locally abundant.

As discussed previously, the quartz diorite and diorite are interpreted to be coeval and possibly comagmatic with the mafic- and intermediate-composition flows of the Banana greenstone, based on a strong spatial association and similar mineralogy.

Granodiorite

Medium- to coarse-grained granodiorite (gd) underlies extensive peneplains in the As Sulaymi quadrangle. Large plutons are located west and northeast of Dil Ahbad, and south and southeast of Jabal Dibi. The rocks weather gray and are covered by a coarse grus.

The granodiorite is composed of euhedral to subhedral, green amphibole, subhedral plagioclase and variable amounts of interstitial quartz, potassium feldspar and magnetite; apatite and zircon are present as accessory minerals, and biotite is present locally. Individual plagioclase grains show strong concentric zonation. Locally, the rocks have a protoclastic texture overprinted on the primary igneous texture.

The granodiorite is clearly younger than the Banana greenstone because it contains rafts of Banana greenstone of Jabal Dibi. The granodiorite is also interpreted to be younger than the quartz diorite and diorite unit on the basis of its more evolved composition and relationships in adjacent quadrangles. In the Ghazzalah quadrangle (Quick, 1983), quartz diorite is intruded by tonalite that is probably cogenetic with the granodiorite. The granodiorite is interpreted to be older than the Hadn formation, although there are no definitive relationships in the As Sulaymi quadrangle, because the Hadn formation unconformably overlies granodiorite and related tonalite in the Ghazzalah, Zarghat, and Al Awshaziyah quadrangles (Quick, 1983, 1984; Leo, 1984).

Monzogranite

Monzogranite (mg) forms large plutons in the northern and central parts of the As Sulaymi quadrangle. Smaller exposures of monzogranite are located along the eastern boundary of the quadrangle. The rocks form low-lying, cavernous-weathering outcrops that are relatively free of boulders and that are covered with a distinctive white grus. The rock is composed mostly of quartz, plagioclase, and microcline, that form a medium- to coarse-grained hypidiomorphic-granular intergrowth. Rapikivi texture is developed locally. Biotite typically forms interstitial clusters (less than 1.5 mm) of tiny grains associated with opaque minerals, albite, quartz, and zircon. Green hornblende is present in about 10 to 20 percent of the rocks and is most common in the isolated intrusions. Biotite in many rocks is extensively replaced by chlorite, and microcline is altered to dusty, red, disseminated hematite and clay minerals. Deformation is variable; the fabric of the rocks ranges from essentially undeformed to foliated, with increasing replacement of the primary texture with a protoclastic texture. Deformation is particularly pronounced in the southeastern part of the Wadi Ash Shu'bah area.

Clasts of monzogranite were noted in the Hadn formation in the Al Ba'ayith quadrangle at Jibal al Jabiriyah and Jibal Umm as Saham by the author. Similar monzogranite clasts are common constituents of conglomerate beds in the Al Awshaziyah and Ghazzalah quadrangles (Leo 1984; Quick 1983). Monzogranite intrudes the Hulayfah group where the two units are in contact. Monzogranite appears to grade into biotite-hornblende granodiorite south of Jabal Dibi, and west of Dil Ahbad. It is suggested, therefore, that many of the bodies of monzogranite and granodiorite may be slightly different facies of a single suite of pre-Hadn, post-Hulayfah felsic plutonic rocks.

Quartz syenite and quartz monzonite

Small plutons of weakly to strongly porphyritic quartz syenite and quartz monzonite (sm) crop out in the eastern part of the quadrangle. The rocks are composed of a fine-grained hypidiomorphic inequigranular to locally granophyric granite. They are distinguished from the monzogranite unit in the field by smaller grain size, greater abundance of alkali-feldspar, and lower abundance of quartz. Two feldspars are evident in hand specimen; white-weathering plagioclase typically forms small phenocrysts in a finer-grained, alkali-feldspar-rich matrix. Modal abundances of quartz, plagioclase, and alkali-feldspar are extremely variable; the rocks range in composition from syenite and monzonite to syenogranite and monzogranite.

At Jabal Mushaqqaq and Jibal Abu Mughayr, the quartz zyenite and quartz monzonite crosscut bedding in the Hadn and contain xenoliths derived from the Hadn. A post-Hadn age is significant because it distinguishes these rocks from the coarser-grained pre-Hadn monzogranites.

Biotite alkali-feldspar granite

Two small plutons of biotite alkali-feldspar granite (afg) crop out about 10 km northeast of As Sulaymi. The rock is composed of a medium- to coarse-grained, hypidiomorphic-inequigranular intergrowth of perthitic alkali-feldspar and quartz. Color indices rarely exceed 1. Biotite, opaque minerals, sphene, and zircon are concentrated in small (less than 1 mm in diameter) interstitial clots.

At Jibal abu Mughayr, biotite alkali-feldspar granite intrudes the monzogranite, the granodiorite, and quartz diorite and diorite units, and crosscuts the Hadn formation. The age of the alkali-feldspar granite is not known relative to the quartz syenite and quartz monzonite.

Alkali granite

Alkali granite (ga) forms a large, elongate pluton in the central part of the quadrangle near the village of As Sulaymi. The rock is distinguished from the surrounding granites by its characteristic rugged topography that comprises medium-gray, steep-sided mountains and deep valleys, littered with large, angular boulders.

The rock is composed of a hypidiomorphic- to xenomorphic-granular intergrowth of quartz, microcline microperthite, amphibole, opaque minerals, and trace amounts of zircon and apatite. The amphibole is identified as kataphorite, based on its dark-green to brown pleochroism, small optic angle, and negative interference figure. Disseminated hematite and clay minerals have partially replaced microcline, giving it a cloudy, red appearance.

Crosscutting relationships indicate that the alkali granite intrudes the adjacent granodiorite, Hulayfah group, and the quartz diorite and diorite unit. Similar alkali granite plutons in the Ghazzalah quadrangle at Jabal Ba'gham and Jibal Rumman al Humr have been dated by whole-rock rubidium-strontium method at 600 ± 7 and 581 ± 4 Ma, respectively (Stuckless and others, 1984a, unpub. data, 1984b). The alkali granite may be younger than the quartz syenite and quartz monzonite because of its evolved composition. However, all these units may be coeval and even cogenetic.

Granophyric intrusions

Granophyric intrusions are subdivided into two-feldspar granophyre (gph1), alkali-feldspar granophyre (gph2), and bodies that have uncertain mineralogy (gph). All of these rocks weather brick red, and form small, isolated, irregular intrusions. The outcrops are resistant to erosion and form prominent hills and ridges.

All of the granophyre intrusions are rich in potassium feldspar. The alkali-feldspar granophyre contains phenocrysts of quartz and alkali feldspar set in a very fine grained graphic- to hypidiomorphic-granular-textured matrix of quartz, feldspar, magnetite, and(or) biotite. The two-feldspar granophyre contains phenocrysts of white plagioclase in a similar matrix. Grain size is variable, and in some bodies becomes coarse enough that the rock grades into a fine-grained hypidiomorphic-inequigranular granite.

The bodies mapped as granophyre are not thought to represent a single set of genetically or temporally related intrusions. Locally, granophyric intrusions grade into adjacent coarser-grained granite bodies, which suggests that in many places the granophyre represents the hypabyssal phase of a nearby pluton. The similarities in grain size and texture of the different granophyre intrusions probably reflect emplacement into similar, shallow-level environments rather than a consanguineous relationship.

Dikes, undivided

Dikes are abundant throughout the quadrangle. The dikes weather red to black and are generally less than 2 m wide. They are readily discernable where they cut granite, granodiorite, or dioritic rocks because they are more resistant and weather to darker hues. In contrast, the dikes are similar in resistance and color to the volcanic rocks in the Hadn formation from which they are difficult to distinguish.

The dominant dike trend is about 20 degrees east of north, with a subdominant trend developed in a general northwesterly direction.

Most of the dikes are felsic in composition and are formed mainly of quartz and feldspar. Salmon-colored potassium feldspar is the most common phenocryst; quartz and plagioclase phenocrysts are less common.

The felsic dikes are most abundant in the country rocks immediately adjacent to the alkali granite pluton and near the granophyre at Jabal Dibi. This association suggests that the alkali granite and granophyre intrusions are the sources of most of the felsic dikes in the quadrangle.

Intrusive rhyolite

Small outcrops of red aphanitic rock 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. However, they are completely devoid of compositional layering, eutaxitic structures, and clasts, unlike volcanic rocks in the area. 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 the felsic dikes suggests that they are genetically related. Locally, intrusive rhyolite grades into granophyre with decreasing grain size, which suggests that these rock types may be cogenetic.

Gabbro

Gabbro (gb) crops out at Dil Ahbad and Jibal Awbariyat. Outcrops are typically covered by dark-ruddy-brown to black subangular boulders and greenish-gray regolith.

The primary mineralogy 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 and olivine are the predominant ferrmagnesian minerals. The gabbro appears to be unaltered in most places.

The age of the gabbro is poorly understood. Both plutons intrude the Hulayfah group and quartz diorite and diorite, but contact relations with younger units are not exposed. The gabbro bodies are essentially devoid of felsic dikes, which suggests a young age assignment. This apparent young age and basaltic composition suggest that the gabbro may be related to the Jibalah-age (Cambrian ?) basaltic volcanism (Delfour, 1977).

Diabase

A single body of diabase (di) intrudes alkali feldspar granite in the northeast part of the quadrangle. The diabase forms dark-gray-weathering outcrops. The diabase is intruded along a northwest-trending "Najd" fault (see Structure section). The basaltic composition of the diabase and its young age relative to the alkali feldspar granite suggest that it may be related to Jibalah-age basaltic volcanism and may be the hypabyssal equivalent of the gabbro intrusions.

PALEOZOIC SEDIMENTARY ROCKS

Jibalah group

Conglomerate, marble, and limy sandstone that crop out along Wadi Al Qahad are mapped as sedimentary rocks of the Jibalah group (js) (Delfour, 1977). Delfour (1977), and O'Neill and Ferris (1985, unpub. data) demonstrated that these rocks were deposited in a narrow graben formed by northwest-trending Najd faults. In the As Sulaymi quadrangle, boulders of monzogranite, as large as 4 m in diameter and mineralogically similar to a nearby pluton, occur in the conglomerate, suggesting that the conglomerate was deposited immediately adjacent to its source.

Potassium-argon whole-rock isotopic ages (502 to 493 Ma) for andesite flows of the Jibalah group in the Nuqrah quadrangle are interpreted by Delfour (1977) to reflect either the original crystallization ages of the rocks or a subsequent complete Ar-loss event. Although these must be regarded as minimum ages, the Jibalah group appears to post-date all large granitic plutons in the Nuqrah quadrangle (Delfour, 1977) and Ash Shu'bah quadrangle (Quick and Doebrich, in press), and, therefore, a Cambrian age is tentatively assigned to these rocks.

CENOZOIC SEDIMENTARY ROCKS AND VOLCANIC ROCKS

Cenozoic basalt

Cenozoic basalt (QTb) forms one isolated plug near Wadi Al Qahad. The plug is tentatively assigned a Tertiary age because Kellogg (1983) reports a whole-rock potassium-argon age of 23.4 Ma for a similar volcanic remnant in the Qufar quadrangle to the north.

Terrace gravel deposits

Terrace gravel (Qtg) is mapped along the banks of Wadi Al Qahad. These deposits form low hills and ridges that parallel the wadi and that consist of unconsolidated angular fragments of silicic volcanic rock and granite in an unconsolidated matrix of silt and sand. In the Al Ba'ayith quadrangle, the author has observed similar deposits that locally contain primitive stone tools. A Pleistocene age is suggested for these deposits on that basis.

Quaternary deposits, undivided

Undivided Quaternary deposits (Qs) are composed of colluvium, talus, flood plain and terrace deposits, and alluvium in channels too small to map.

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 undivided 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 Hulayfah group appears to have undergone more metamorphism than any of the other rocks in the map area. In most places, the presence of actinolite, chlorite, and epidote replacing primary assemblages indicates that the Hulayfah group has recrystallized under greenschist facies conditions. In sharp contrast, the effects of recrystallization in the Hadn formation appears to be restricted to devitrification of glass, turbid alteration of feldspar phenocrysts, and local development of calcite- and epidote-filled veins. The contrasting grades of metamorphism are consistent with geochronologic data that indicate that the Hulayfah group is as much as 100 m.y. older than the Hadn formation.

STRUCTURE

Faults

All of the Precambrian rocks in the quadrangle are cut by a network of northwest-striking faults that belong to the Najd fault system (Schmidt and others, 1979). These faults appear to have had a complex history that involved components of both strike-slip and dip-slip movement. The most important of these structures consists of anastamosing faults that are best exposed in the adjacent Ar Rawdh quadrangle along the banks of Wadi Al Qahad (O'Neill and Ferris, 1985, unpub. data). A total left-lateral motion of 50 to 75 km is estimated elsewhere for this set of faults based on displacements in the Hadn formation and and Murdama group rocks (Quick and Doebrich, in press). This deformation must have continued until about 600 to 580 Ma because a set of northwest-trending faults clearly offsets the alkali granite pluton in the As Sulaymi quadrangle. A change from strike-slip to dip-slip motion associated with crustal rifting in the Cambrian is marked by the deposition of the Jibalah formation in a narrow graben along the Wadi Al Qahad faults.

Folds

The Hulayfah group is deformed into nearly vertical, isoclinal, north-northeast-striking, mesoscopic folds to the east in the Ar Rawd quadrangle (O'Neill and Ferris, 1985, unpub. data) Although less well documented, similar folds are apparent in the Hulayfah group in the As Sulaymi quadrangle where carbonate beds are exposed. In contrast, the Hadn formation crops out as an essentially undeformed, west-dipping section. The greater deformation of the Birkah formation relative to the Hadn formation is consistent with the great difference in the ages of the two units.

ECONOMIC GEOLOGY

Gold

During the course of this study, two ancient gold workings were identified in the Hulayfah group 2 km south of the village of Al Birkah and 2-3 km south of Jabal Dibi. The workings south of Jabal Dibi are the largest, consisting of pits, trenches and structures that are developed for approximately 1000 m along the strike of quartz veins in the Banana greenstone. The workings south of al Birkah consist of a single 6-m-deep, 8-m-long excavation along a steeply dipping rhyolite dike in the Hulayfah silicic volcanic rocks.

DATA STORAGE

Basic field and laboratory data contributing to this report are stored in the Jiddah office of the U.S.Geological Survey Mission as Data-File USGS-DF-04-41. Mineral resources in the Kingdom of Saudi Arabia are recorded as numbers in the Mineral Occurrence Documentation System (MODS). Two MODS entries were made for the two gold showings mentioned above, but no numbers have yet been assigned.

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