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Reconnaissance geology of the Al'Awshaziyah quadrangle, sheet 26/41 B, Kingdom of Saudi Arabia

by

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RECONNAISSANCE GEOLOGY OF THE AL 'AWSHAZIYAH QUADRANGLE, SHEET 26/41 B, KINGDOM OF SAUDI ARABIA

by

Gerhard W. Leo

ABSTRACT

The Al 'Awshaziyah quadrangle (26/41 B) is located between lat 26°30' and 27°00' N. and long 41°30' and 42°00' E. in the northeastern part of the Arabian Shield. The quadrangle contains surficial Quaternary deposits and locally exposed underlying upper Proterozoic intrusive, volcanic, and volcaniclastic rocks.

The oldest rocks, gabbro and pyroxenite, are tentatively correlated with the Ha'il mafic-ultramafic complex to the north of the quadrangle. Two younger volcanic sequences, structurally more or less distinct but compositionally transitional, have been identified. The Aqab formation (about 640-610 Ma old) consists of slightly metamorphosed, moderately to strongly folded flows and tuffs of basalt, dacite, and minor rhyolite. An interlayered subaerial conglomerate and a lack of deep-marine sediments distinguish the Aqab from the older and distinctly oceanic Nuf formation. The Aqab formation is overlain by felsic ash-flow tuffs and related fragmental rocks of the Al 'Awshaziyah formation whose major source is a large caldera in the western part of the quadrangle.

Plutonic rocks include granites that predate and postdate both the Aqab and Al 'Awshaziyah formations. The youngest granites, dated at about 580 Ma, are the Salma and Ar Rumman batholiths and are more alkaline and more silicic than the older granites. The Ar Rumman granite is peralkaline. Even the youngest intrusive rocks have been cut by faults that are probably related to the northwest-trending Najd fault system.

No metallic mineralization has been recognized in the quadrangle. A small quarry near the western boundary of the quadrangle produces crushed rock.

INTRODUCTION

Geographic setting

The Al 'Awshaziyah quadrangle is located near the northeastern limit of the Arabian Shield between lats 26°30' and 27°00' N. and longs 41°30' and 42°00' E. (fig. 1). The

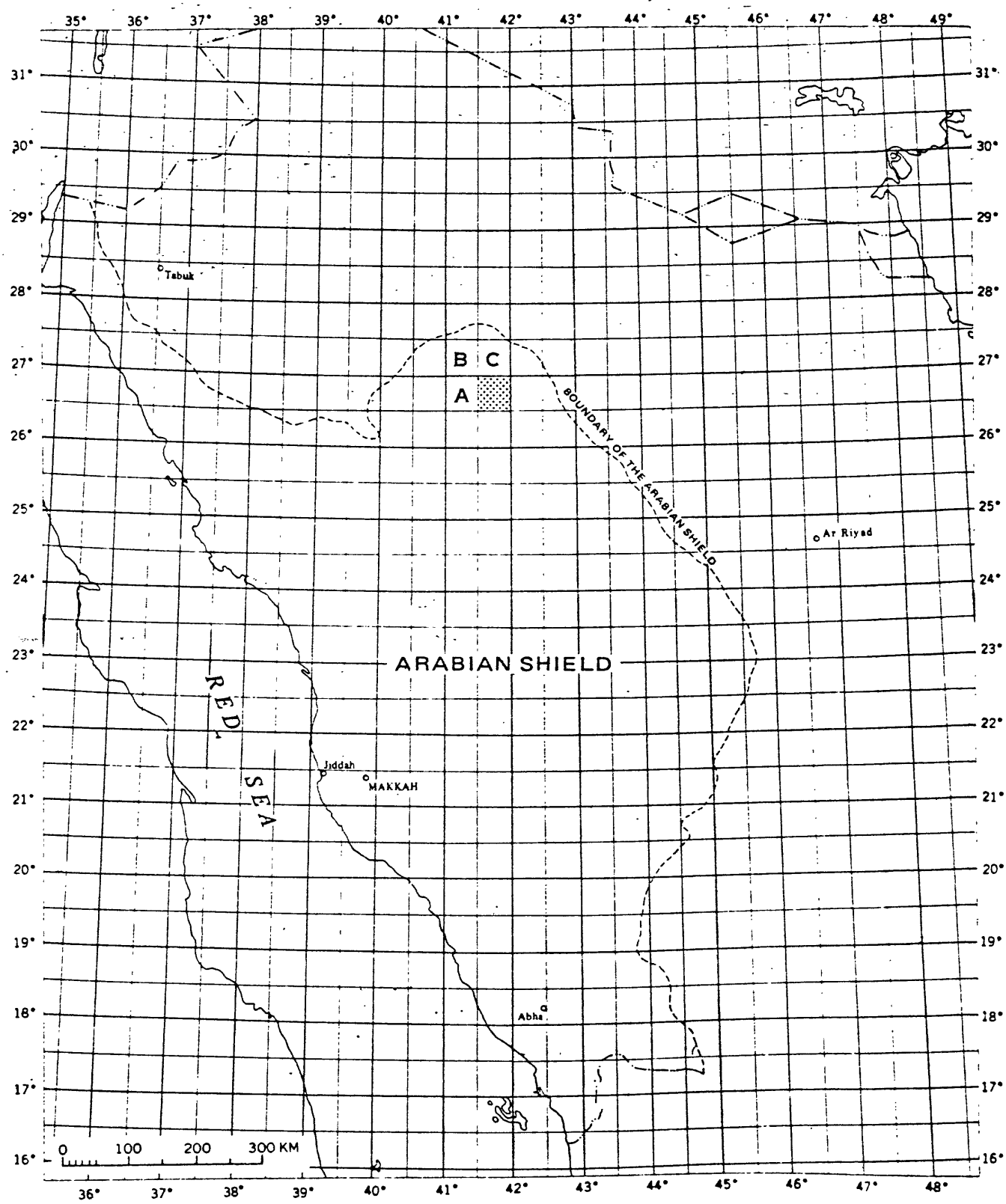

Figure 1.--Index map of western Saudi Arabia showing the locations of the Al 'Awshaziyah quadrangle, 26/41 B (shaded), and other quadrangles cited in this report: A, Ghazzalah, 26/41 A (Quick, 1983); B, Al Qasr, 27/41 C (D. B. Stoeser, unpub. data); C, Qufar, 27/41 D (Kellogg, 1983).

quadrangle is named after a centrally located village, which was designated Al 'Awshaziyah on the geographic map of the northeastern Hijaz quadrangle (Brown and Jackson, 1959); the current name of the same village is Al-Ruwdah. The latter name will be used henceforth to designate the village. The name Al 'Awshaziyah is retained as the quadrangle name and to designate a nearby large caldera-like feature (Al 'Awshaziyah eruptive center) as well as the associated felsic volcanic rocks.

A paved road connects Ha'il and Al-Ruwdah, and well-established dirt roads connect Al-Ruwdah and the large villages of Al 'Uqaylat and Mustajiddah. There are numerous other roads and tracks in the quadrangle; the principal ones are shown on a geographic map (Leo, 1984). There are also several smaller villages and semi-permanent to permanent encampments in the area. Farming, livestock raising, and trading are the principal occupations.

The quadrangle has an area of 2769 km^2. Altitudes at wadi level range from about 1000 m in the south to about 1100 m in the north. Rugged, dissected mountainous terrain, notably Jibal Dharaf and Jibal ar Rumman in the west and northwest parts of the quadrangle rise to an approximate maximum elevation of 1350 m.

Previous work

Early geologic mapping of the region that includes the Al 'Awshaziyah quadrangle was done at scale 1:500,000 by Brown and others (1963). Recent mapping at a scale of 1:100,000 includes the Qufar quadrangle (sheet 27/41 D; Kellogg, 1983), the Al Ghazzalah quadrangle (sheet 26/41 A; Quick, 1983), and the Al Qasr quadrangle (sheet 27/41 C; D. B. Stoeser, unpub. data). A reconnaissance study of mafic and ultramafic plutonic rocks of the Ha'il area, with observations on layered volcanic and volcaniclastic rocks (Chevremont, 1982) includes parts of the Al 'Awshaziyah quadrangle.

Present investigation

Field work in the Al 'Awshaziyah quadrangle occupied about 4 weeks in January and February of 1982 and an additional 2 weeks in February and March of 1983. Access was by helicopter during the initial period and by ground vehicle for followup in 1983.

Igneous rock descriptions in this report follow the International Union of Geological Sciences (IUGS) guidelines (Streckeisen, 1976; IUGS, 1973). Some of the designations of volcanic rocks are tentative when insufficiently characterized by petrography. About 300 thin sections were examined. Modal data mentioned in the text are based on visual estimates only.

Plagioclase compositions are based on flat-stage optical determinations of appropriate extinction angles in polysynthetically twinned grains by using the curves of Troger (1972, p. 129). Chemical analyses have been requested for about 20 representative samples, mostly of volcanic rocks.

Rock descriptions include measurements of radioactivity using a Geometrics GR-101A portable, total-count scintillometer. This instrument measures the intensity of all gamma rays above 0.05 MeV energy. Results are reported in counts per second (cps), which reflects the total abundance of potassium (K), uranium (U), thorium (Th), and the radioactive daughter products of U and Th. The instrument is not calibrated for quantitative determination of abundances of these elements, and the results are reported for qualitative comparison only. As a field tool, however, the scintillometer is extremely useful for discriminating among compositionally diverse rocks, especially among the volcanics.

This report was prepared in accordance with a work agreement between the Saudi Arabian Ministry of Petroleum and Mineral Resources and the U.S. Geological Survey (USGS).

GEOLOGIC SETTING

The Al 'Awshaziyah quadrangle is situated in the northern part of the Arabian Shield, a region characterized by large and abundant late-orogenic to post-orogenic plutons with extensive inliers of layered volcanic rocks and associated sediments. Brown and others (1963) recognized three layered sequences in the region that are from oldest to youngest: (1) the dominantly andesitic Halaban formation, (2) the overlying, shallow-marine Murdama formation, and (3) the post-orogenic Shammar rhyolite, comprising felsic flows, ash-flow tuffs, and associated sediments. Two generations of granite plutons were identified, the older forming a basement for the Halaban, the younger intruding the Halaban but pre-dating the Shammar.

The current mapping has confirmed the general lithology of Brown and others (1963), in that there is a variety of volcanic and intrusive (mostly granitic) rocks. However, because of important differences in interpretation of stratigraphic sequence, structure, and distribution of major units, the terms Halaban, Shammar, and Murdama will not be used here. Instead, a local terminology is adopted, part of which is already in use in adjacent areas and part of which is new.

Two compositionally overlapping but temporally distinct volcanic sequences have been identified in the Al 'Awshaziyah quadrangle. The younger sequence consists of slightly to

moderately deformed flows, ash-fall tuffs, and associated volcaniclastic rocks ranging in composition from rhyolite to dacite. This sequence, here named Al 'Awshaziyah formation, is correlated with the Hadn formation described in regions to the north and northeast (Chevremont, 1982; Kellogg, 1983; Quick, 1983; D. B. Stoeser, unpub. data).

The Al 'Awshaziyah formation unconformably overlies the relatively older, more deformed, and generally more altered Aqab formation. The Aqab volcanic sequence consists of rocks ranging from rhyolite through basalt, hence it compositionally overlaps the Hadn formation. The Aqab is probably younger than the more-metamorphosed and oceanic Nuf formation of Chevremont (1982) and Kellogg (1983) and the Banana greenstone of Quick (1983). However, several mafic to ultramafic intrusive bodies in the quadrangle may be equivalent to the Ha'il mafic-ultramafic complex, which has been spatially and temporally correlated with the Nuf formation (Chevremont, 1982).

VOLCANIC AND VOLCANICLASTIC ROCKS

Aqab formation

The Aqab formation as here defined is a rather thick sequence of volcanic to volcaniclastic rocks ranging in composition from dacite to basalt. Within the upper third of the formation is extensive conglomerate which, except for ubiquitous channeling, is conformable with individual volcanic layers (Chevremont, 1982). Chevremont regarded the conglomerate as post-dating the Hadn formation and resting unconformably on the volcanics; he named it Jabal al 'Aqab formation. In the present study, the term "Aqab formation" refers to the entire volcanic and volcaniclastic sequence; Chevremont's younger, post-Hadn conglomerate could not be confirmed.

The Aqab formation is exposed extensively in the eastern part of the quadrangle and only locally in the northwest. The formation typically underlies low rounded hills of a gray-green to black color. The most continuous exposures are in a broad belt trending northeast from Jabal al 'Aqab in a somewhat arcuate pattern. This belt is henceforth referred to, in the context of the Aqab formation as the "northeast-trending belt" or "Aqab belt." The section within this belt mostly dips northwest and generally faces in the same direction although sporadic southeast-facing layers indicate at least localized tight folding. Along ridges north of Al-Ruwdah and east of Beit Aw'wah, divergent attitudes in the Al 'Awshaziyah and Aqab rocks suggest angular unconformities. An angular unconformity is exposed near the southern edge of Jabal Dharaf, approximately 10 km northeast of Mustajiddah (pl. 1; fig. 2C). Because of the range of compositions within

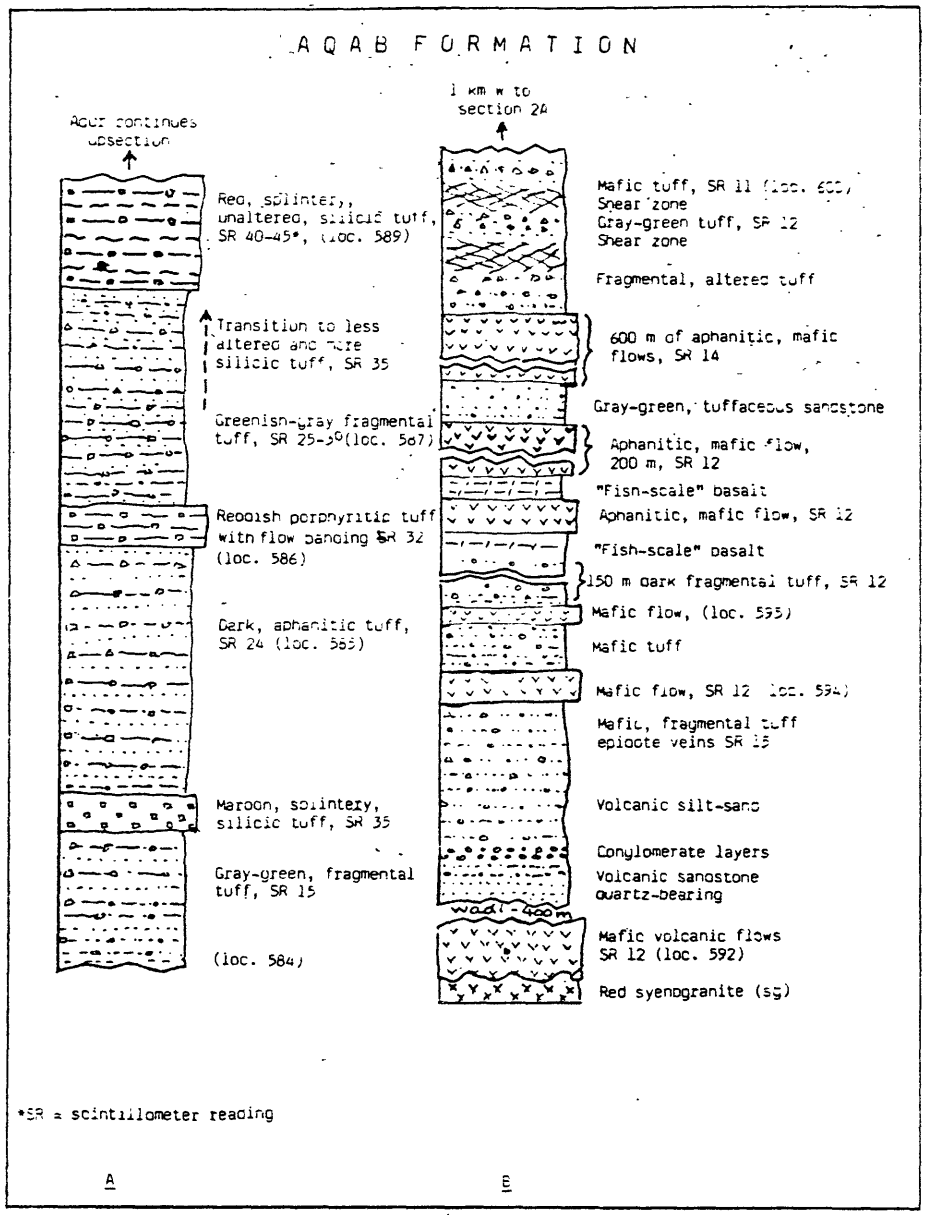

Figure 2.--Representative columnar sections of the Aqab and Al 'Awshaziyah formations. A, Central part of the Aqab formation, dominantly the dacite-rhyolite member (aqdr) near Jabal al 'Aqab, in northeast-trending belt. B, Lower part of the Aqab formation, dominantly the basalt-andesite member (aqba) structurally and stratigraphically(?) underlying section 2A. C, Welded-tuff member (awt) of the Al 'Awshaziyah formation near the southern margin of the eruptive center (see fig. 3) overlying Aqab formation(?) with angular discordance. D, Lower part of the welded-tuff member (awt) of the Al 'Awshaziyah formation in northeast part of the eruptive center. Traverse is approximately 900 m along a northeast-trending spur. E, Distal part of the Al 'Awshaziyah formation (welded-tuff and sediments member, awts) on the east side of Jabal Dharaf. Section locations are plotted on plate 1; sample localities are plotted on a separate map, which has been data filed (Leo, 1984).

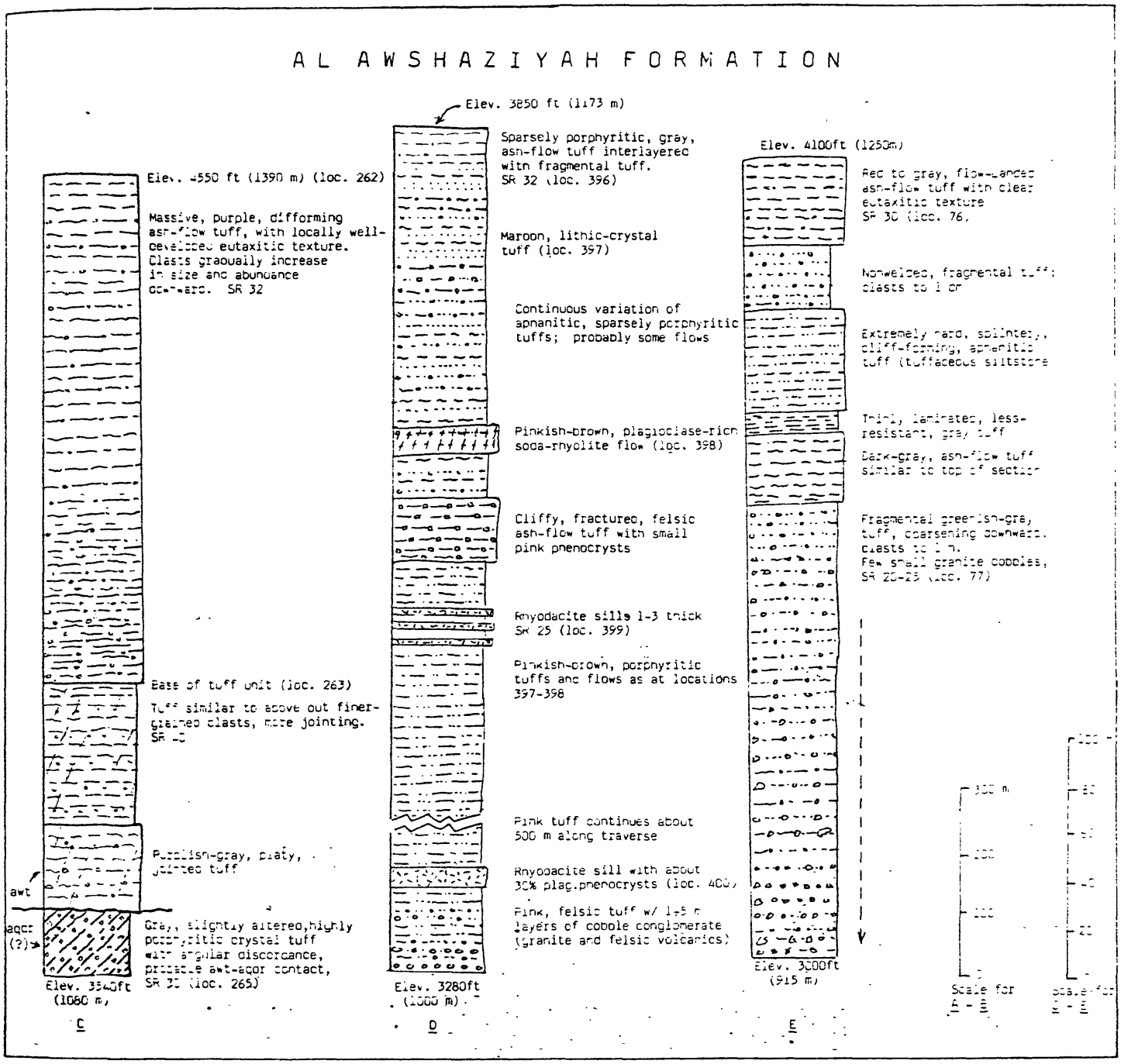

Figure 2.--Continued

both the Aqab and Al 'Awshaziyah formations, definite identification of isolated outcrops of intermediate composition was not always possible.

The compositionally transitional character of the Aqab formation is well displayed in the principal outcrop areas northeast of Jabal al 'Aqab. Traverses across the section (localities 592-600, 584-589 and 659-662, Leo, 1984; fig. 2A, B) reveal a 3-4 km wide belt on the southeast underlain mostly by andesite or basalt locally interlayered with dacitic tuff. To the northeast, a distinct break in slope marks the transition to more erosionally resistant felsic rocks, typically green-gray, fragmental tuff or purplish, aphanitic, crystal tuff with small feldspar phenocrysts. Reddish rhyolitic tuff is locally interlayered, but green-gray dacitic fragmental tuff continues to dominate. A high ridge (loc. 589) is capped by red siliceous crystal tuffs essentially indistinguishable from Al 'Awshaziyah tuff (fig. 2A). Toward the northwest, the section continues upward in dark-purple dacitic tuff, andesite, basalt, and interlayered conglomerate consisting mainly of volcanic clasts with a small proportion of granite. All these rocks dip steeply, are locally overturned, and clearly underlie the Al 'Awshaziyah volcanics. Therefore, despite lithologic similarities between the most siliceous parts of the Aqab formation and the overlying Al 'Awshaziyah formation the two units are distinct on both structural and stratigraphic grounds.

Basalt-andesite member

Rocks of basaltic to andesitic composition (aqba) are well exposed near the base of the Aqab formation but, as described above, can occur almost anywhere within it. Isolated andesite exposures in the southeastern part of the quadrangle probably belong to this member. Field identification of these rocks is based on their dark-gray to black color, aphanitic to fine-grained, locally amygdaloidal, typically non-porphyritic texture, and scintillometer counts typical for mafic volcanic rocks. A common variant is a dark greenish lava with abundant grayish-white plagioclase phenocrysts as much as 1 cm long that mimic fish scales. Such rocks are henceforth referred to as "fish-scale" basalt (or andesite), or as possessing "fish-scale" texture. In thin section, these rocks show a well-preserved primary texture comprising felted plagioclase laths in a largely amorphous dark matrix. Plagioclase phenocrysts (An_{25-40}) are faintly cloudy to moderately saussuritized; extensive breakdown of plagioclase is uncommon. Mafic constituents are represented by patches of chlorite, epidote, $\pm$amphibole (actinolite?). Amygdules are filled by crystalline epidote and (or) quartz. Disseminated

magnetite constitutes 3-5 percent. This assemblage corresponds to lower greenschist facies characterized by retrograde breakdown of minerals but lacking any pervasive prograde recrystallization and reconstitution of primary textures to produce a metamorphic fabric. More extensive metamorphic recrystallization has been found only near granite contacts, such as that 1 km northwest of Jabal U'waygat, where a primary andesite texture is still recognizable but the amorphous groundmass has recrystallized to red-brown biotite and green hornblende. Even here, primary zoned plagioclase (An_{25-31}) has remained intact.

Because of the irregular distribution of the mafic, basalt-andesite member and its resemblance in the field to rocks of intermediate composition, the major outcrop areas of the basalt-andesite member have been designated on plate 1 by a screen pattern that implies indefinite intraformational contacts.

Dacite-rhyolite member

The dacite-rhyolite member (aqdr) is much more abundant and widely distributed than the basalt-andesite member. The most common rock types are purple to brown dacitic ash-flow tuff, which commonly shows eutaxitic texture and has small white to pink phenocrysts, and greenish-gray, poorly sorted lithic tuff, which contains angular clasts generally less than 1 cm across. These rock types are closely associated in the field, and both give scintillometer counts typical of intermediate volcanics. They underlie most of Jibal al Wutaydat, an east-southeast-trending belt of low hills in the east-central part of the quadrangle, the northwest part of the northeast-trending Aqab belt, and parts of most of the remaining exposures of the Aqab formation. Rhyolitic welded tuffs are much less common than dacitic rocks occupying parts of Jabal al 'Aqab and the high ridges to the northeast. The designation "aqdr" is used where dacite and rhyolite are estimated to constitute more than 80 percent of the section.

The dacitic tuffs have silicic, devitrified matrices that are slightly to moderately altered. Crystal tuffs contain subidiomorphic, cloudy to saussuritized plagioclase phenocrysts (An_{10-25}), subordinate quartz, and volcanic rock fragments. Flow rocks with "fish-scale" texture have more mafic bulk compositions, with green hornblende (pseudomorphous after primary pyroxene?) as phenocrysts and as a groundmass constituent; these rocks may contain chlorite and epidote and also contain primary quartz. The degree of alteration varies markedly, depending partly on bulk composition (more mafic rocks are generally more altered) and partly on the proximity to shear zones.

Conglomerate member

Conglomerate (aqc) is distributed sporadically within the Aqab formation, ranging from single layers 1-3 m thick, near the bottom of the section (fig. 2B), to a megalens nearly 3 km in outcrop width along the north side of Jabal al 'Aqab. The conglomerate typically consists of relatively well-sorted and well-rounded cobbles 5-10 cm in diameter in a tough, highly lithified sandy matrix (arkose to graywacke). In some places the clasts are of boulder or pebble size, and it is not uncommon to find well-developed graded-bedding ranging in clast size from boulders or large cobbles to sand-size material. Individual conglomerate beds are commonly interlayered with volcanic tuff and tuffaceous sandstone, either in essentially conformable layers or in channels eroded into the tuff. Except in one channel, attitudes on conglomerate beds are everywhere parallel to those of adjacent tuff; in the steeply tilted section of the northeast-trending Aqab belt, the Jabal al 'Aqab belt, conglomerate layers are the best indicators of bedding and facing directions. These conglomerates were described by Chevremont (1982) as a younger deposit unconformably overlying the Al 'Awshaziyah formation, which in the area of Jabal al 'Aqab is mapped for this report as the dacite-rhyolite member of the Aqab formation. An angular unconformity between conglomerate and adjacent volcanic rocks of the Aqab formation has nowhere been observed by the writer, and Chevremont's (1982) interpretation of a younger conglomerate is, therefore, strongly brought into question.

The clasts of the Aqab conglomerate are composed predominantly of felsic to intermediate volcanic rocks generally similar to the upper Aqab formation, plus a variety of granitic rocks. Locally, as along the western edge of the northern large conglomerate exposure, the relative proportion of cobble and boulders of pre-Aqab monzogranite (mgl) increases toward the contact with the monzogranite. In many exposures of the Aqab conglomerate, there is little correlation between granite clasts and the nearest apparent sources of the granite.

Aqab formation, undivided

The designation (aqu) is used (1) where mafic and felsic volcanics are known to be interlayered, as in the Jabal al 'Aqab area or (2) where available information is insufficient to define the lithology more specifically, as in some of the exposures in the southern part of the quadrangle.

Thickness and age

The maximum measured thickness of the Aqab formation in the northeast-trending belt is between 5000 and 6000 m, although this section is known to be repeated at least locally

by folding, so the true stratigraphic thickness may be considerably less than this. The presence of granite cobbles in conglomerate in different parts of the formation and the abundance of these cobbles near the eastern contact with the oldest monzogranite (mgl) indicate that this granite forms a basement for the Aqab. This relationship also indicates that at least the upper part of the Aqab formation is younger than the Nuf formation, for which no base is known (Kellogg, 1983; Quick, 1983; D. B. Stoeser, unpub. data, 1982).

Al 'Awshaziyah formation

The Al 'Awshaziyah formation consists of thick, layered ash-flow tuff, associated flows and fragmental rocks varying from unsorted volcanic breccia to well-sorted tuffaceous sandstone and siltstone. The compositional range, as far as has been determined, is rhyolite to dacite. The Al 'Awshaziyah formation thus overlaps compositionally with the dacitic member of the Aqab formation, but is distinguished from the latter by being less altered and generally less deformed. Two members of the Al 'Awshaziyah formation are here defined: (1) a sequence of massive welded tuffs with subordinate flows and fragmental rocks, and (2) a lithologically similar sequence consisting of thinner tuff sheets and proportionately greater amounts of volcaniclastic sediments, essentially the distal parts of the eruptive sequence (fig. 2C-E). The two members must be regarded as coeval and thus are more properly facies than members. The distinction between them as map units is necessarily somewhat subjective.

Al 'Awshaziyah eruptive center

The feature here designated Al 'Awshaziyah eruptive center is a subcircular highland approximately 25 km in north-south extent, and centered about 8 km west of Al-Ruwdah village (see pl. 1). The area is underlain by rugged, craggy ridges rising 300-350 m from the surrounding plains and shedding a detritus of angular blocks up to several meters across. The lithology is dominated by ash-flow sheets as much as 200 m thick. Abrupt variations in attitudes near the center of the structure may be related partly to foundering following magma withdrawal, and partly to later block faulting affecting the entire region. Out from the center of the structure, strikes are tangential, and dips are low to moderate and radially inward. The subcircular shape and the massive ash-flow tuffs indicate that the structure is a caldera, or at least an eruptive center for the Al 'Awshaziyah volcanics. Because characteristic features of many calderas, such as an inner rim and resurgent domes, were not identified, the somewhat less specific term eruptive center is here used.

Without more specific knowledge of the existence and location of a caldera rim, the diameter of an underlying magma chamber only can be guessed, although it is unlikely to reach beyond the confines of the highlands area. Centripetal attitudes are also found in outliers of Al 'Awshaziyah rocks such as in the ridges near the southwest corner of the quadrangle and some exposures of rocks mapped as Hadn formation in the Ghazzalah quadrangle to the west (Quick, 1983).

Welded-tuff member

Welded tuff (awt) underlies the high rugged ridges of Jibal Dharaf. Surface coloration is dark brown to black, due mainly to desert varnish. On fresh surfaces these rocks are pink, violet, greenish or dark gray, and have conchoidal fracture. Surface weathering brings out flow and compaction (eutaxitic) structures which are locally very well developed, both on a megascopic and microscopic scale. Individual ash-flow tuff units are as much as 200 m thick. They are interlayered with lavas (distinguished mainly on textural grounds) and with volcaniclastic sediments, varying from microbreccias with angular fragments to 5 cm to well-sorted volcanic sandstones. Nonwelded volcaniclastic rocks are estimated to constitute from 25 to 50 percent of the section. Composition change downward from rhyolitic to dacitic compositions. Near the base of the section are thin (less than 3 m), conformable conglomerate horizons (fig. 2D). Scintillometer readings are typical for rocks of granitic or rhyolitic composition.

Under the microscope the welded tuffs show a devitrified groundmass and 5 to 25 percent phenocrysts including elongated, well-twinned plagioclase prisms, quartz, and sanidine (the latter in a minority of samples). Accessory constituents include magnetite±biotite. Alteration in most samples ranges from very slight to moderate. Fragmental rocks are generally more altered than welded tuffs and flows, and rocks of more mafic composition are more altered than the siliceous rocks. The overall extent of alteration of these rocks is less than that of the Aqab formation.

Welded-tuff and sediments member

The lithology of the welded-tuff and sediments member (awts) is similar to that of the welded tuff member except in relative proportions of rock types, nonwelded volcaniclastic rocks constitute from 50 to 75 percent of the total section, and the ash-fall tuffs are on the average finer-grained than tuffs of the welded-tuff member. A representative exposure of this member is on Jabal Dharaf in the southeastern part of the quadrangle (pl. 1; fig. 2E), where welded-tuff layers 20-40 m thick alternate with well-sorted, fine-grained ash-fall tuff and grade downward into progressively coarser fragmental rocks.

Conglomerate

Conglomerate layers (cgl) are thicker and more abundant in the welded tuff and sediment member than in the welded tuff member, although they are not as voluminous as the conglomerate of the Aqab formation. The most extensive conglomerate in the Al 'Awshaziyah formation is on the flanks of a plateau in the northeast part of the quadrangle, approximately 12 km northeast of Beit Dhaba (pl. 1). The conglomerate here attains a maximum thickness of about 30 m and crops out more or less continuously over a lateral distance of 4 km. This conglomerate is generally similar to that of the Aqab formation, consisting of well-rounded cobbles and subordinate boulders (diameter greater than 25 cm). The clasts are dominantly felsic volcanics with less than 5 percent granite where observed. This conglomerate section is conformable with adjacent layering and is bounded above and below by tuffaceous sandstone; although, it is not far above the base of the Al 'Awshaziyah formation, this conglomerate is not a basal conglomerate but rather is an intraformational feature. Less-extensive and thinner conglomerate crops out on the south side of east-trending ridges near the southwestern corner of the quadrangle, as well as 1-2 km north of Mustajiddah, where there is a high proportion of pink granite clasts. Because of its sporadic distribution and relatively small volume, the conglomerate is not given member status but is designated simply by cgl.

Thickness and age

The thickness of the Al 'Awshaziyah formation within the eruptive center is difficult to estimate, because neither the top nor the bottom of the formation was observed, but is likely to be several km. The thickness of the welded tuff and sediment member is necessarily very much less than the maximum for the formation; the Jabal Dharaf section measures approximately 335 m (fig. 2E). The age of the Al 'Awshaziyah has not been determined within the quadrangle, but a poorly defined preliminary Rb/Sr whole-rock isochron age of 613 Ma was obtained by R. Fleck (Pers. commun., 1983) for the Hadn formation in the Al Qasr quadrangle, which is regarded as equivalent to the Al 'Awshaziyah formation.

Comparison between the Aqab formation, the Nuf formation, and equivalent rocks

The Aqab formation as here defined, particularly the basalt-andesite member, is lithologically somewhat similar to the Nuf formation in the Qufar quadrangle (Chevremont, 1982; Kellogg, 1983 and pers. commun.) and to the equivalent Banana greenstone in the Ghazzalah quadrangle to the west (Quick, 1983). (Henceforth these two units will occasionally be

referred to collectively as Nuf-Banana). However, there are also some significant differences between the Aqab and the Nuf-Banana that preclude a simple correlation (table 1). The differences in metamorphic grade, deformational style, depositional environment, and the fact that at least the upper part of the Aqab rests on granite, which elsewhere intrudes older mafic and ultramafic rocks (probably part of the Ha'il mafic-ultramafic complex, coeval with the Nuf formation; Chevremont, 1982), all suggest that the Aqab is distinct from, and probably younger than, the Nuf-Banana. Other exposures of mafic rocks that are not demonstrably older than the Aqab formation may also be part of the Ha'il mafic-ultramafic complex (see section on gabbro and diabase, this report).

Given the reconnaissance nature of the mapping and the structural and stratigraphic complexities, the possibility that some of the Aqab rocks may in fact be equivalent to the Nuf-Banana cannot be categorically excluded. The question might be resolved by more detailed mapping, by additional petrographic and chemical data, and by radiometric dating of the relevant units.

INTRUSIVE ROCKS

Gabbro-pyroxenite complex

Two bodies of layered gabbro and pyroxenite (gp) are exposed in the quadrangle. The larger body is subrectangular, about 2.5 km by 3.5 km in extent, located near the western boundary of the quadrangle, north of the Ar Rumman batholith (pag). The smaller body, measuring approximately 1 by 1.5 km, is located near the northern border of the quadrangle somewhat west of center. The gabbro and pyroxenite crop out as low, greenish-black hills shedding relatively small blocks of detritus. Layering is readily visible on a scale from several millimeters up to several meters. The rocks are black on fresh surfaces and show conspicuous stubby clinopyroxene megacrysts (2-3 mm).

The microscope reveals a felted groundmass consisting of 0 to 50 percent plagioclase (An_{37-65}) and amphibole (actinolite?); phenocrysts are pyroxene (diopside?) partly or completely replaced by amphibole, and rare, partly serpentinized olivine. Hence, the rocks range from gabbro to pyroxenite. These ultramafic bodies are small layered intrusions, possibly, but by no means necessarily, part of an ophiolite assemblage (see Coleman, 1977, p. 6-7). The northern body is intruded by monzogranite (mgl) that predates the Al 'Awshaziyah formation and locally forms a basement for the Aqab formation. Hence, the gabbro and pyroxenite are older than the Aqab and may be related to the Ha'il mafic-ultramafic complex, which is coeval with the Nuf formation (Chevremont, 1982).

Table 1.-- Comparison between the Aqab formation and the Nuf and Banana formations

Formation, location, and reference (fig. 1)	Aqab formation, Al 'Awshaziyah quadrangle (this report)	Nuf formation, Qufar and Jabal Salma quadrangles (Chevremont, 1982; Kellogg, 1983)	Banana greenstone, Ghazzalah quadrangle (Quick, 1983)
Lithology	Upper part: dacitic and subordinate rhyolitic tuffs, flows, and associated sediments; locally abundant conglomerate. Lower part: basalt and andesite, associated volcanic sandstone and sparse conglomerate. No pillow structures noted.	Dominantly andesite and basalt, locally showing pillow structure; subordinate intermediate volcanics and associated volcaniclastic rocks; interlayered marble and local quartzite.	Dominantly andesite and basalt, locally showing pillow structure, and associated volcaniclastic rocks; subordinate intermediate volcanics; thin beds and lenses of marble.
Metamorphic grade	Low greenschist facies; breakdown of primary minerals but retention of primary textures; no lineation or foliation; metamorphic fabrics found only near intrusive contacts.	Dominantly amphibolite facies with mafic volcanics represented by hornblende + plagioclase ± sphene, with well-developed foliation and (or) lineation. In some areas rocks are at low to middle greenschist facies, showing only retrograde metamorphism; such rocks resemble lower Aqab formation.	Mostly middle to upper greenschist facies resulting in recrystallization to mosaic textures and ubiquitous development of albite + actinolite + chlorite ± biotite. Lineation and foliation common; preservation of primary textures relatively rare.
Depositional environment	Upper part of formation definitely terrestrial; lower part probably terrestrial.	Marine.	Marine.
Contact relationships with younger felsic volcanics (Al 'Awshaziyah formation in Al'Awshaziyah quadrangle, Hadn formation elsewhere)	Lithologic sequence from Al 'Awshaziyah formation through Aqab formation is compositionally continuous. An angular unconformity between the two units has been tentatively identified at one locality. At least upper part of Aqab formation rests on granite that elsewhere intrudes mafic to ultramafic rocks assumed to be of Nuf age. Granite regarded as post-Hadn intrudes the lower Aqab formation in the eastern part of the quadrangle.	Contact between Nuf and Hadn formations assumed to be unconformable, but not identified.	Banana greenstone not in contact with Hadn formation. Unconformity assumed.

Quartz diorite

Gray to grayish-pink quartz diorite (qd) consisting of strongly zoned plagioclase (An_{10-40}) and quartz with 5-25 percent hornblende and biotite±diopsidic clinopyroxene crops out in a belt 12 km long and about 2 km wide near the northwest corner of the quadrangle and in smaller exposures near the northeast corner. Locally there are variations to trondhjemite with less than 5 percent mafic minerals, to hornblende granodiorite with less than 5 percent mafic minerals, and to hornblende granodiorite with as much as 15 percent K-feldspar. Scintillometer readings range from 20 to 35 cps. The quartz diorite underlies low, rolling hills; the northwestern belt is cut by pink, aphanitic felsic dikes with a west-northwest trend.

The age of the quartz diorite has not been established in the Al 'Awshaziyah quadrangle as no contacts were found. However, similar quartz diorite in the Qufar quadrangle is intruded by pre-Hadn monzogranite (equivalent to biotite-hornblende monzogranite, below; K.S. Kellogg, pers. commun., 1983). Thus, the quartz diorite is regarded to be of pre-Al 'Awshaziyah age (equivalent to pre-Hadn age as used by Quick, 1983, and Kellogg, 1983).

Biotite-hornblende monzogranite

Pink to gray, medium-grained biotite-hornblende monzogranite (mgl) underlies the northernmost part of the quadrangle and continues far north into the Qufar quadrangle ('Ishsh monzogranite of Kellogg, 1983). Generally similar monzogranite also underlies much of the terrain north of Jibal al Wutaydat east of the northeast-trending belt of Aqab formation, and it occurs as clasts near the base of Jabal Dharaf at its southeastern corner. The monzogranite terrain has a characteristic topography of low rolling subparallel ridges that reflect the orientation of diabase or rhyolite dikes cutting the granite.

The biotite-hornblende monzogranite consists of quartz, perthitic potassium feldspar, and plagioclase (An_{20-30}) in about equal proportions, and contains approximately 5 percent chloritized biotite±hornblende±disseminated epidote. Both potassium feldspar and plagioclase are typically somewhat altered; microfractures and shear zones in the granite are common.

The biotite-hornblende monzogranite is older than both the Al 'Awshaziyah and Aqab volcanics. A conspicuous butte near the northern border on the east side (Leo, 1984, locs. 18-20) is capped by Al 'Awshaziyah welded tuff lying unconformably on monzogranite and truncated dikes. Abundant rounded to angular blocks of similar granite occur in dacite

of the basal Al 'Awshaziyah formation at the southeast extremity of Jabal Dharaf, (Leo, 1984, locs. 688-689), although granite bedrock is not exposed. Elsewhere, biotite-hornblende monzogranite constitutes some of the clasts throughout the Aqab conglomerate. On the northwest side of the northeast-trending Aqab belt (Leo, 1984, locs. 324-325), cobbles of monzogranite increase markedly toward the granite contact. On the southeast side of the Aqab belt, the lower Aqab likewise appears to overlie hornblende-biotite monzogranite, although a basal granite conglomerate is lacking and the relationship is further obscured by the intrusion of the lower Aqab by a younger syenogranite.

The biotite-hornblende monzogranite is intruded by Jabal Salma syenogranite on the east and by the younger (post-Aqab) Jabal U'waygat monzogranite to the southeast; the contact between the two monzogranite units is rather approximate. Along the northern quadrangle boundary the older monzogranite intrudes gabbroic rocks interpreted as part of the Ha'il mafic-ultramafic complex (Kellogg, 1983). Thus, the biotite-hornblende monzogranite is older than at least the upper part of the Aqab formation and younger than the Ha'il complex. The biotite-hornblende monzogranite is correlated with the pre-Hadn monzogranite of Quick (1983) in the Ghazzalah quadrangle and the 'Ishsh monzogranite of Kellogg (1983) in the Qufar quadrangle.

Diabase dikes

Swarms of north-northeast-trending diabase dikes cut the older biotite-hornblende monzogranite (mgl). The dikes range from 1 to 3 m wide and consist of moderately altered diabase with well-preserved subophitic texture consisting of saussuritized plagioclase, epidote, and opaque minerals (approximately 7 percent). Similar northwest-trending dikes cut quartz diorite (qd) in the northwestern part of the quadrangle.

Gabbro and diabase

Plug-like bodies of gabbro (gb) crop out sporadically throughout the quadrangle. The largest of these underlies a group of dark hills approximately 8 km northeast of Al Qusayr village. The gabbro at this locality is medium grained with hypidiomorphic texture and most commonly consists of calcic plagioclase (An_{70-82}) and pyroxene (diopside?) partly replaced by pale amphibole (tremolite?). A more iron- and alkali-rich variant from another location contains plagioclase (An_{50}), partly serpentinized olivine, clinopyroxene, hornblende (kaersutite?), red biotite, and 1-2 percent interstitial apatite.

Hornblende-plagioclase gabbro that is texturally transitional to coarse diabase and fine- to medium-grained diabase forms several bodies underlying rugged hills or low, boulder-strewn mounds. Some bodies appear to be entirely fine- to medium-grained diabase (d); the units designated (gb) and (d) are differentiated on textural grounds only. Both the gabbro and the coarse diabase consist of highly zoned and calcic plagioclase (An_{32-75}) and hornblende that may be green or zoned green to reddish brown. Some of these rocks are unaltered (for example, north of Beit Dhaba) or are moderately to strongly altered (as in the south-central part of quadrangle).

The age of the gabbro and diabase relative to most other units is uncertain. The gabbro body northwest of Al Qusayr is cut by leucomonzogranite regarded as post-Aqab; the coarse diabase north of Beit Dhaba is spatially related to the broad central Aqab belt. On this basis, these rocks are provisionally correlated with lower Aqab (aqba), although the occurrences in the southern part of the quadrangle are not near other parts of the Aqab formation. The altered condition of the gabbro and diabase in the south suggests the possibility that these rocks may be remnants of Nuf-Banana or of the Ha'il mafic-ultramafic complex.

Diorite

A body of diorite (dr) measuring about 2 by 3 km is located within the northeast-trending belt of Aqab formation about 7 km south of the northern quadrangle boundary. The rock is dark gray, fine grained, and has a subophitic texture. It consists of about 65 percent plagioclase (An_{20-30}), 25 percent clinopyroxene (diopside?) largely replaced by actinolite and (or) hornblende, and 5 percent quartz. The diorite adjoins a plug of gabbro which is somewhat similar but contains relatively more amphibole and no quartz. The contact between the diorite and gabbro may be gradational.

Trondhjemite

~~Light~~-gray, medium-grained trondhjemite (tr) consisting mostly of plagioclase and quartz with subordinate mafic minerals makes up an isolated hill 3 km southwest of Beit Dhaba. The trondhjemite cuts surrounding Aqab formation and therefore probably has a similar age to the gabbro and diorite described above. The rock consists of about 70 percent idiomorphic, moderately altered plagioclase with 20 percent interstitial quartz with striking myrmekitic texture. The remainder of the rock is composed of chloritized hornblende and biotite(?) containing patchy magnetite.

Al Qusayr leucogranite

Pink to grayish-pink, generally fine-grained leucogranite (qlg) crops out near the southeastern corner of the Al 'Awshaziyah quadrangle and extends at least 7 km east of the quadrangle boundary. The granite mostly underlies flat to gently rolling terrain but also constitutes much of the anomalously steep and rugged peak of Jabal al Qusayr, as well as a small plug cutting the dacite-rhyolite member of the Aqab formation in the western part of the quadrangle (pl. 1). The major outcrop area of the leucogranite has a lobate outcrop pattern with maximum dimensions of 13 km from north to south and 7 km from east to west. The contacts are defined in large part by areas of sharp aeromagnetic anomalies (BRGM, 1967; D. Kleinkopf, pers. commun., 1983), probably related to the relatively high magnetite content of most of the granite. Some exposures such as those at Jabal al Qusayr, do not have related magnetic anomalies. Such rocks contain less magnetite but are petrographically similar in other respects.

The leucogranite is characterized by a fine-grained, allotriomorphic groundmass consisting of quartz, microcline, and plagioclase (An $_{10-15}$). Relative proportions of feldspars are commonly about 1:1 but significant variation in the feldspar ratio is evident in thin sections and is also suggested by the large range (30-65 cps) in scintillometer readings. Small (1 mm), tabular to embayed phenocrysts of quartz and altered feldspars constitute 10-50 percent of the rock. Accessory minerals are limited to less than 5 percent brown-green biotite, commonly chloritized, and 2-3 percent granular to patchy magnetite.

U'waygat monzogranite

The U'waygat monzogranite (mg2) is named after Jabal U'waygat, a prominent isolated peak characteristic of this widely distributed unit, that rises from the plain south of the Jabal al 'Aqab (pl. 1; Leo, 1984, loc. 121). It is a pink to beige, medium-grained hornblende-biotite monzogranite that constitutes the single largest granitic rock unit in the quadrangle, underlying most of the southeastern quadrant and probably much of the southwestern quadrant where it is covered by eolian sand. Additional exposures are found in the north-central part of the quadrangle. The monzogranite is marked by a virtual absence of aeromagnetic anomalies (BRGM, 1967).

The U'waygat monzogranite has mostly been eroded to flat plains except for scattered sharp peaks and ridges such as those along the southern margin of Jabal al 'Aqab. These

vuggy-weathered erosional remnants have altered rinds several tens of centimeters thick. Small (less than 20 cm) mafic inclusions are sparsely distributed.

The U'waygat monzogranite has hypidiomorphic texture and consists of quartz, perthitic potassium-feldspar, and prominently twinned plagioclase (commonly An_{18-12}, locally with calcic cores of An_{27-30}). Gray-green hornblende and red-brown biotite together constitute 3-10 percent of the rock, and, in some places, form clots in association with sphene and magnetite.

A small plug of Qusayr leucogranite intrudes the upper Aqab formation in a south-facing ridge 10 km east of Mustajiddah (pl. 1; Leo, 1984, loc. 566). U'waygat monzogranite intrudes leucogranite on Jabal al Qusayr (southeastern corner of the quadrangle) and on Jabal Safra 10 km to the northwest. Consequently U'waygat monzogranite is younger than Qusayr leucogranite. Dikes of both leucogranite and monzogranite cut gabbro northeast of Jabal Safra, in the southwest extension of Jibal al Wutaydat, and elsewhere. As the gabbros are almost certainly of Aqab age or older, both granites are post-Aqab. Neither granite is known to cut the Al 'Awshaziyah formation.

Syenogranite

Pink to brick-red, highly felsic syenogranite (sg) occurs as relatively small intrusions (up to 9 by 4 km) throughout the quadrangle. The syenogranite is closely jointed and fresh in outcrop, is relatively fine-grained, and may locally resemble the Al 'Awshaziyah volcanics, especially where the two are juxtaposed and have the usual veneer of desert varnish. The syenogranite underlies prominent hills and ridges, such as on Jabal al Hamrah in the northwestern part of the quadrangle.

The syenogranite consists dominantly of quartz and typically cloudy feldspar; albite (An_5) is locally present. Some samples are granophyric. Mafic constituents range from nearly nil, constituting only scattered patches of amorphous or opaque material, to about 5 percent partly chloritized biotite$\pm$green hornblende. The altered feldspar is reddish in reflected light, presumably due to disseminated hematite.

The syenogranite intrudes Al 'Awshaziyah rocks, notably on the northwest side of the eruptive center. The intrusive contacts are sharp where observed, but local exposures of very fine grained granite may represent a transitional phase. Available evidence suggests that the syenogranite may be a subvolcanic phase of the Al 'Awshaziyah rhyolite.

Felsic and subordinate mafic dikes

Pink to pinkish-gray or brick-red, aphanitic to slightly porphyritic dikes cut syenogranite (sg) and several older units, notably the U'waygat monzogranite (mg2). These dikes are particularly concentrated in north-northwest- to west-northwest-trending swarms in the southeast quadrant, but are present throughout the quadrangle. The dikes are typically 1-3 m wide; a particularly large rhyolite dike (ry) (300 m wide and greater than 2 km long) crops out in the east-central part of the quadrangle. Fault offsets of several meters are common. Compositionally the dikes are mostly felsic, consisting of a microcrystalline to intergranular groundmass of quartz and feldspar and phenocrysts of plagioclase±quartz± biotite±muscovite. Some dikes are mafic, containing strongly zoned plagioclase (An_{15-45}) and red-brown hornblende without quartz or K-feldspar, thus corresponding to andesite. A few diabase dikes have also been noted among the north-northwest-trending sets and are included herein, as are the brick-red rhyolitic dikes cutting syenogranite.

Salma syenogranite

The Salma syenogranite (sgs) crops out in the northeastern corner of the Al 'Awshaziyah quadrangle, where it constitutes the southwestern extension of a batholith that extends over 50 km to the north-northeast along Jabal Salma. The pink, medium-grained Salma granite forms steep and rugged, characteristically pink ridges that rise to heights of 200-300 m above the adjacent wadis. The Salma is bouldery-weathering and has a weathering rind as much as several tens of centimeters thick. The interior part of the granite consists of approximately equal proportions of quartz and perthitic microcline, 5-10 percent albite (An_{7-10}) and about 5 percent deep red-brown biotite. Samples near the margin show a gradational change to a greater relative proportion of plagioclase (1/3 of total feldspar) and also contain a few percent green hornblende. Thus, the marginal Salma syenogranite shows some resemblance to U'waygat monzogranite, but field relations clearly show it to be younger. The Salma syenogranite (sgs) intrudes syenogranite (sg) along a contact traceable for several km near the northeast corner of the quadrangle. A preliminary Rb/Sr whole-rock isochron age on the Jabal Salma syenogranite is 580±7 years (Aldrich and others, 1978).

Ar Rumman peralkaline granite

The Ar Rumman granite (pag) is exposed along the western boundary of the Al 'Awshaziyah quadrangle and is a nearly circular batholith, with a diameter of approximately 20 km, that extends westward into the Ghazzalah quadrangle. The terrain of the Rumman batholith is very rugged, generally

comparable to that of the Al 'Awshaziyah eruptive center, featuring gray-brown ridges that rise as much as 400 m above the wadi floors. Strongly developed box canyons reflect major directions of jointing and faulting, the most prominent of which trend about N. 65° E. A weathering rind is typical of this granite, making fresh samples difficult to obtain. The Ar Rumman batholith forms a magnetic low (BRGM, 1967).

The Ar Rumman granite is a medium-grained, brownish-gray rock. The composition is about 70 percent perthitic microcline, 25 percent quartz, and 5 percent mafics including strongly pleochroic (blue-green and brown) amphibole locally replacing aegirine, and a deep-red, strongly absorbing, unidentified mineral, possibly enigmatite. The amphibole, identified as kataphorite by Quick (1983) is more likely barkevikite on the basis of optical orientation (OAP=010 approximately normal to c). The texture is generally hypidiomorphic granular, but in some samples a granophyric matrix is developed. Apatite is an abundant accessory.

The Ar Rumman granite intrudes the Al 'Awshaziyah formation and distinct baking was locally noted. The resulting hornfels can be confused with fine-grained syenogranite which locally occurs as dikes. No contact relationships between the Ar Rumman and granites younger than the Al 'Awshaziyah formation were established. However, a Rb/Sr whole-rock isochron age of 581±4 Ma (C. E. Hedge, written commun., 1983) shows this granite to be among the youngest post-orogenic intrusions and of almost identical age as the Salma syenogranite.

QUATERNARY DEPOSITS

Eolian sand and silt

Eolian sand and silt (Qes) denote heterogeneously textured sand, silt, and local pebbles distributed in thin, flat-lying deposits on pediment surfaces; mapped where deep enough to conceal bedrock, mainly in the southwestern part of the quadrangle. The unit is sparsely vegetated and cut by active wadi channels. The thickness is unknown but is probably mostly less than 10 m. Dune deposits were not noted in the quadrangle.

Alluvium and colluvium

Alluvium and colluvium (Qal) denote dominantly water-transported, undifferentiated surficial material comprising clay, silt, sand, and pebbles deposited in active wadi channels. Alluvium and colluvium are not everywhere distinguishable from eolian sand and silt. The thickness is unknown but is probably less than 10 m.

Gravel

Gravel, cobble, and boulder deposits (Qg) consist of subangular to angular clasts typically coated with desert varnish that are generally less than 50 cm in diameter. Gravel deposits form broad, gently sloping dissected fans adjacent to upland areas. Gravel is a readily mappable unit because of its color contrast with alluvium and sand. The thickness is probably less than 30 m.

Saline deposits

Saline deposits or playas (Qs) consist of white to tan, salt-encrusted silt and sand in shallow closed depressions. The largest such deposit, near the northwest corner of the quadrangle, measures approximately 0.5 by 1.5 km. The thickness of such deposits is unknown but may amount to a few tens of meters.

STRUCTURE

The dominant structures in the Al 'Awshaziyah quadrangle are (1) folds that range from isoclinal to open, with amplitudes from about one meter to hundreds of meters; and (2) faults and shear zones of a brittle type, with offsets ranging from a few meters to several km. Gneiss, schist, or other pervasively or complexly deformed rocks appear to be absent. This is in distinct contrast to the region to the north (Kellogg, 1983), and forms part of the basis for interpreting the oldest exposed layered rocks in the Al 'Awshaziyah quadrangle, the lower Aqab formation, to be younger than the Nuf-Banana and the related Ha'il mafic-ultramafic complex.

Folding and tilting

The most deformed rocks in the quadrangle are those of the Aqab formation in the belt trending northeast from Jabal al 'Aqab. Open to isoclinal folding is especially evident near the northeast edge of the belt, where facing directions can be readily determined from graded bedding in conglomerate and associated graywacke. The degree of deformation diminishes both southeast across strike and to the northwest where the Aqab is overlain by the Al 'Awshaziyah formation.

The contact between the Aqab and Al 'Awshaziyah formations is an angular unconformity, which was confirmed in only one place but is mostly inferred from contrasting attitudes such as are found north of Al-Ruwdah and in the vicinity of Beit Dhaba and Beit Aw'wah. The angular discordance between the Aqab and Al 'Awshaziyah formations diminishes west and northwest of the northeast-trending Aqab belt. Where the

discordance is slight or lacking, upper Aqab formation cannot be distinguished with certainty from the lower, dacitic Al 'Awshaziyah formation.

The markedly intense deformation of the volcanics of the Aqab formation within the northeast-trending belt as compared to its deformation in most of the rest of the quadrangle, suggests northwest-southeast compression of the belt concurrently with deposition of Aqab volcanics in this area. The belt may represent the locus of a subsiding basin, which was progressively filled by Aqab volcanics in late Proterozoic time. Compression of the basin from the southeast possibly could have been facilitated by buttressing along the northwest margin by the pre-Aqab monzogranite (mgl). This monzogranite, as well as previously deposited rocks of the Aqab formation, had to be subaerially exposed during the deformational episode since both units furnished cobbles for the extensive conglomerates (aqc).

The rocks of the Al 'Awshaziyah formation are, on the whole, less deformed than those of the Aqab formation. The former are moderately tilted to nearly horizontal, with a marked pattern of radial dips toward the Al 'Awshaziyah eruptive center, and are everywhere upward facing. Some comparatively high-angle dips (30^{o}-70^{o}) with diverse directions are believed to be due to foundering and related block faulting of the caldera roof (caldera collapse) following eruptions of large volumes of ash-flow tuff.

Faulting

Two prominent directions of faulting are apparent in the quadrangle: (1) E. to N. 70^{o} E. and (2) N. 30^{o} W. to N. 45^{o} W. Measurable lateral offset occurs along some of these faults, and vertical displacement is inferred across others. Major shear zones are locally developed. Only major faults and (or) minor faults with clearly evident displacement are shown in plate 1. Numerous faults with small displacement, although evident (for example those offsetting dikes in the southeastern quadrant), have not been mapped.

The E. to No. 70^{o} E. fault set, which is very prominent in the Ghazzalah quadrangle to the west (Quick, 1983), enters the Al 'Awshaziyah quadrangle but dies out and (or) is truncated by northwest-trending faults. Satellite imagery at scale 1:250,000 indicates some continuation of the N. 70^{o} E. set in the southern part of the quadrangle. Several minor faults with W.-NW. to W.-SW. strikes have been mapped in the northern part of the quadrangle on the basis of discordant strikes and (or) apparent vertical offset in layered rocks.

Estimated left-lateral offsets of about 3 km are evident on two of the northwest-trending faults, which is the same sense of movement as shown by the Najd fault system well-developed to the south (Schmidt and others, 1978). Activity on the Najd fault system has been dated at about 590-540 Ma (Schmidt and others, 1978). This time interval agrees with observations in the Al 'Awshaziyah quadrangle, where all the crystalline rocks, including the two 580-Ma old plutons at Jibal ar Rumman and Jabal Salma, have been faulted.

METAMORPHISM

Metamorphism in the Al 'Awshaziyah quadrangle is generally low-grade, rarely exceeding greenschist facies, and is broadly related to the age and composition of the rocks. The Al 'Awshaziyah rhyolitic rocks are virtually unmetamorphosed, showing only devitrification of the felsic groundmass. Rocks of intermediate composition locally contain saussuritized plagioclase and chloritized biotite. The Aqab rocks are generally somewhat more altered, typically with a dirty groundmass and ubiquitous chlorite and biotite, and amphibole (actinolite?) in some samples. However some basalts from the Aqab formation, as well as some gabbros, are virtually unmetamorphosed. Except for contact-metamorphosed rocks, primary textures are preserved thoughout the Aqab formation and also in the layered gabbro and pyroxenite. The local and sporadic changes in the degree of alteration indicate that much of the alteration may be hydrothermal and related to shearing and intrusive activity rather than to any broad regional metamorphism. None of the rocks in the quadrangle exhibit the thorough recrystallization with pronounced directed fabrics developed in much of the Nuf formation to the north (Kellogg, 1983, and pers. commun.).

The only distinctive granoblastic textures were seen in volcanics adjacent to intrusive granite contacts where the rock has been hornfelsed. In such hornfels, biotite and poikiloblastic hornblende have developed extensively in mafic rocks and decussate quartz-feldspar mosaics in felsic ones. Even in these hornfelses, primary textures are still clearly recognizable.

GEOLOGIC HISTORY

The Al 'Awshaziyah quadrangle is located within a much larger region of late Proterozoic sialic volcanism and plutonism developed on and in the the older and generally more mafic "Halaban crust", hypothetically in response to continental collision around 625 Ma ago in the southeastern part of the present Arabian Shield (Schmidt and others, 1978). The Halaban Group, renamed Hulayfah Group (see Routhier and Delfour, 1975; cited in Fitch, 1980, p. 106), has been correlated in part with the Nuf formation and the

related Ha'il mafic-ultramafic complex (Chevremont, 1982), implying a correlation also with the petrologically similar Banana greenstone (Quick, 1983). The part of the Hulayfah section correlated with Nuf-Banana has an estimated age of 740 Ma (Quick, 1983, citing Delfour, 1977). Layered gabbro-pyroxenite in the northern part of the Al 'Awshaziyah quadrangle may be equivalent in age to the Ha'il mafic-ultramafic complex and is the oldest rock in the quadrangle.

Except for the aforementioned mafic-ultramafic rocks, the oldest dated unit in the Al 'Awshaziyah quadrangle is biotite-hornblende monzogranite and related quartz diorite with an estimated age of 640-620 Ma (C. E. Hedge, pers. commun., 1983) which at least locally formed a basement for the Aqab formation. By the onset of Aqab volcanism the depositional environment had changed to shallow-marine and (or) subaerial, possibly due to uplift related to a postulated collisional event at about 625 Ma ago (Schmidt and others, 1978). Eruption of basalt, andesite(?), dacite, and subordinate rhyolite probably began along the southeast margin of the northeast-trending Aqab belt, but Aqab volcanic rocks also were erupted west of this belt, possibly from fissure sources, while plugs of probably related gabbro, diorite, and diabase were emplaced. Near the end of the eruptive cycle a period of general uplift and erosion led to formation of abundant conglomerate that became incorporated in the Aqab formation. Deposition of conglomerate was followed by tilting and folding, the most intense deformation occurring along an axis near the contact between the Aqab and the biotite-hornblende monzogranite (mgl) and probably reflecting compression from the southeast. Several major monzogranite plutons were emplaced about this time. Erosion continued while eruption of dacitic tuffs and flows commenced from the Al 'Awshaziyah eruptive center, followed by rhyolitic eruptions. An age determination on volcanics of the Hadn formation to the northwest correlated with the Al 'Awshaziyah formation, yielded 613 Ma (Quick, 1983, citing pers. commun. from R. Fleck). Collapse within the eruptive center due to magma withdrawal produced discordant altitudes in adjacent blocks. A red, granophyric granite cutting Al 'Awshaziyah volcanics may represent a cogenetic, subvolcanic intrusion. Post-orogenic, calc-alkaline to peralkaline granite plutons of nearly the same age (about 580 Ma) are the youngest intrusions within the quadrangle; similar plutons of comparable age and composition are distributed throughout the Arabian Shield but are especially concentrated in its northern half (Stoeser and Elliott, 1979; Stuckless and others, 1982). Regional faults with relatively small offsets cut all the crystalline rocks of the quadrangle. A predominant north-northeast-trending set is probably related to the Najd fault zone, estimated to be active approximately 590-540 Ma ago (Schmidt and others, 1978).

ECONOMIC GEOLOGY

The Al 'Awshaziyah quadrangle appears to be nearly devoid of rocks that are visibly mineralized or otherwise give evidence of economic potential. Apparently barren quartz veins cut the Aqab formation in several places near the eastern border (Leo, 1984, locs. 538 and 539). Approximately 11 km north of Al-Ruwdah village (Leo, 1984, loc. 385) porphyritic dacite of the Al 'Awshaziyah formation is markedly altered to punky, brown, soft material suggestive of hydrothermal alteration. The altered area including an adjacent bleached zone appears to be strata-controlled and extends some 100 m parallel to strike, with a maximum thickness of about 10 m. No metallic mineralization was noted, and a spectrographically analyzed sample showed no significant metal values.

An active quarry at the northwest end of Mustajiddah village produces crushed rock from volcanics of the Al 'Awshaziyah formation. The rate or volume of production is not known.

DATA STORAGE

All field and laboratory data for this report, including sample location maps, are stored in data-file USGS-DF-04-03 (Leo, 1984) in the Jiddah office of the U.S. Geological Survey Saudi Arabian Mission.

No updated information was added to the Mineral Occurrence Documentation System (MODS) data bank, and no new files were established.

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