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KINGDOM OF SAUDI ARABIA

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PLATE 1b

EXTENDED EXPLANATION TO ACCOMPANY RECONNAISSANCE GEOLOGIC MAP OF THE HARRAT TUFFIL QUADRANGLE, SHEET 20/39 B, KINGDOM OF SAUDI ARABIA

ABSTRACT

The Harrat Tuffil quadrangle, sheet 20/39 B, is located between lat 20°30' and 21°00' N. and long 39°30' and 40°00' E. about 50 km southeast of Jiddah. A western belt of Proterozoic metapelites and related rocks, defined as the Sa'diyah formation, structurally underlies and locally is interlayered with Proterozoic metabasaltic rocks of oceanic chemical affinity to the east. The Sa'diyah formation and the metabasaltic rocks are tentatively correlated with the Sabya formation and Baish group. These rocks may represent a miogeosynclinal tectonic setting in the 800 to 850 Ma period of development of the southwestern Arabian Shield. The presence of aluminous metasediments suggests a continental source area, probably west of oceanic and (or) immature island-arc rocks of the Baish(?) igneous suite.

The Sa'diyah formation and metabasaltic rocks are intruded by a granite gneiss batholith, probably about 600 Ma old, and by small plutons of granodiorite and syenogranite. Peraluminous monzogranite occurs within the western part of the Sa'diyah formation belt and may provide an alternate source for the aluminous pelitic rocks.

Tentative correlation of an isolated exposure of Jurassic(?) dolomite with the Hanifa Formation significantly extends the areal range of possible Jurassic sedimentary rocks in the Tihamat province.

An intense dike swarm intrudes all of the pre-Miocene rocks in the quadrangle. This Damm dike complex is named for Wadi ad Damm. Dike chemistry shows both subalkaline and alkaline bimodal suites. The Sita formation is broadly coeval with the Damm dike complex and contains volcanic rocks with similar bimodal chemistry. The Sita formation conformably overlies and is locally interbedded with the Shumaysi formation, which is palynologically dated in the Makkah quadrangle as Eocene (~ 50 Ma). Potassium-argon dating indicates intrusion and volcanism over the period ~ 50 Ma to ~ 20 Ma ago. The Tertiary volcanic, hypabyssal, and plutonic rocks are all light rare-earth element enriched as would be expected in a rift-related tectonic setting. These rocks represent proto-Red Sea igneous activity and are correlated with the Jizan group. Shama rhyolite near Harrat Tuffil is unconformably overlain by a boulder conglomerate correlated with the Bathan formation.

Miocene alkali basalt forms a large paleovalley-fill lava flow at Harrat ad Damm and small flow remnants north of Jabal Sita. Erosional downcutting at Harrat ad Damm averaged ~10 m per Ma over the past 11 Ma. Pliocene alkali basalt unconformably overlies Bathan formation and Shama rhyolite at Harrat Tuffil.

The uplift of Quaternary reef limestone along the Red Sea coast indicates recent faulting as shown in the adjoining Shu'ayba and Al Ghalah quadrangles.

A perlite deposit at Jabal Shama may be suitable as light aggregate for concrete. Sparse barite veins were discovered in the lower Shumaysi formation. Relatively small deposits of Sa'diyah formation marble may be of interest for local use in building or cement. The Jurassic dolomite is locally quite pure and may have economic applications.

DESCRIPTION OF MAP UNITS

Plutonic rocks are classified according to the recommendations of the International Union of Geological Sciences (Streickeisen, 1973). Volcanic rocks are classified according to the method of Irvine and Baragar (1971). Varietal minerals and phenocrysts are listed in order of increasing abundance. The following abbreviations are used: K-Ar, potassium-argon; Rb-Sr, rubidium-strontium; REE, rare-earth element; LREE, light rare-earth element; XRD, X-ray diffraction. Potassium-argon dates are from Pallister (unpublished data) unless otherwise referenced.

SEDIMENTS AND SEDIMENTARY AND METASEDIMENTARY ROCKS

Qe EOLIAN SAND--Mainly mobile sheet sand and barrier dunes; includes minor alluvially reworked sand in small drainages

Qal Qao ALLUVIAL DEPOSITS--Unconsolidated sand, silt, and gravel in wadi channels and outwash plains. Older alluvial deposits (Qao) in abandoned channels of Wadi Sa'diyah

Qs_2 Qs_1 SABKHAH DEPOSITS--Calcareous, gypsiferous, and saline silt, clay, and sandy mud deposited in restricted shallow basins with surfaces just above mean high-tide level; surface characterized by thin salt crusts formed by evaporation of seawater introduced during storm tides and by subsurface seepage through porous sand and reef limestone. Sabkhah deposits of two ages mapped: Qs_2, modern deposits in basins of active deposition closer to the coast; and Qs_1, older, inactive deposits at higher topographic levels due to Quaternary uplift. Both deposits partly buried by eolian and alluvial sand

Qrl CORAL-REEF LIMESTONE--Submarine reef limestone consisting chiely of coral and coral debris with calcareous organic material and minor sand; active coral growth

Qrb BACK-REEF DEPOSIT--Submarine coral-reef limestone and quartz and carbonate sand; deposited behind the active fringing reef in shallow areas of sand deposition and limited coral growth; derived in part from the combined alluvium of Wadi Sa'diyah and Wadi Sa'yah

Qrt_3 Qrt_2 Qrt_1 CORAL-REEF LIMESTONE--Subaerial reef limestone terraces, chiefly coral and coral debris; also includes minor beach sand. Probably uplifted by Quaternary faulting as described in the Shu'ayba and Al Ghalah quadrangles (Pallister, unpub data)

Qt WADI TERRACE DEPOSITS--Partly eroded, poorly consolidated sand, silt, and gravel; unit forms channel-crossbedded, poorly sorted deposits near major drainages in eastern part of quadrangle. Probably deposited during early to middle Holocene pluvial cycle (Whitney, 1980). Locally greater than 5 m thick

Tba BATHAN FORMATION--Coarse, polymictic boulder conglomerate, poorly exposed as an isolated boulder-lag deposit at Harrat Tuffil. The Bathan formation unconformably underlies Pliocene alkali olivine basalt dated at 3.25±.05 Ma and unconformably overlies Shama rhyolite dated at Jabal abu Shidad at 19.2±0.9 Ma. Contains angular to moderately rounded boulders of Precambrian granite, gneiss, diorite, and amphibolite as much as 2 m across and Tertiary volcanic and hypabyssal rocks of the Shama rhyolite and Sita formation. Produced by first major, rapid uplift of Red Sea Escarpment during middle or late Miocene (Schmidt and others, in press)

Ts SHUMAYSI FORMATION--Light-tan to dark-maroon, quartz arenite, hematitic quartz arenite, hematitic claystone, and ironstone; contains sparse water-laid tuff beds in some outcrops near Jabal Sita. Sandstone composed chiefly of angular, strained, and multi-domain quartz grains in a clayey or hematitic matrix; grainsize distribution commonly bimodal with peaks at ~0.4 mm and ~ 0.1 mm diameters; trace-mineral grains chiefly amphibole, zircon, magnetite, and rutile; XRD analysis showing kaolinite and pyrophyllite as major matrix minerals suggests a rhyolitic ash component. Sandstone west of Jabal abu Shidad is crossbedded, contains zones that are cemented by authigenic quartz, and contains numerous mollusk and worm burrows and molds. Unit underlies and is locally interbedded with volcanic rocks of the Sita formation near Jabal Sita. Unconformably overlies Precambrian rocks of the Baish(?) igneous suite east of Jabal Sita and near Jabal abu Shidad; deformed with Sita formation; locally intruded by basalt and plagioclase megacrystic diabase dikes of the Damm dike swarm east of Jabal Sita. Maximum exposed thickness ~ 150 m east of Jabal Sita. Unit can be traced discontinuously north into the Makkah and Al Jumum quadrangles where fossil and pollen analyses of samples from the middle member of the Shumaysi formation define an early Eocene (Cuisian) age (Moltzer and Binda, 1981). Probably correlates with Ayyanah sandstone of the Jizan group (Schmidt and others, 1982)

Jdo DOLOMITE AND DOLOMITIC LIMESTONE--Light- to medium-gray, resistant, well-bedded, very fine to fine-grained, dolomitized clastic and bioclastic limestone and minor sandy or ferruginous dolomite. Some beds contain abundant but poorly preserved fossil debris. XRD analyses yield dolomite/calcite ratios of 98:2. Unconformably overlies Sa'diyah formation amphibolite as a west-southwest dipping, internally undeformed, homoclinal ridge at the single mapped exposure southeast of Harrat Tuffil. Intruded by several, 1- to 2-m-thick, Tertiary(?), primitive tholeiite sills that are probably cogenetic with the Damm dike complex. Tentatively correlated with Jurassic Hanifa Formation as described by Powers and others (1966). No other Jurassic rocks have been reported in the Tihamat province (Red Sea coastal plain) of southwestern Saudi Arabia north of approximately lat 17° N. Minimum thickness approximately 30 m, top not exposed

SA'DIYAH FORMATION

Metasedimentary rocks of the Sa'diyah formation are chiefly para-amphibolite, quartzite, schist, and marble that structurally underlie, but are locally interlayered with, the Baish(?) igneous suite, and probably are the oldest rocks in the quadrangle. They are lithologically similar and are exposed in a similar geologic setting to the Sabya formation of Fairer(unpub data) with which the Sa'diyah is tentatively correlated. The reference area for the Sa'diyah is between Harrat Tuffil and Wadi Sa'diyah in the southeastern part of the quadrangle. Individual reference localities for the three map units are given below. Metasedimentary rocks within the Baish group are assigned oceanic island-arc or eugeosynclinal depositional environments free of continental detritus (Prinz, 1981), and quartzofeldspathic gneiss within the Baish group was probably derived from trondhjemite protoliths of an immature island-arc tectonic setting (D. L. Schmidt, oral commun., 1982). These types of quartz-rich rocks and schists are recognized and mapped within the Baish(?) igneous suite, and a few examples are present within the Sa'diyah formation. However, the presence of aluminosilicates (kyanite and andalusite) indicates a pelitic protolith for some of the Sa'diyah formation rocks, and the presence of potassium feldspar, muscovite but not paragonite (confirmed by XRD), and trace minerals characteristic of granites indicates a granitic or arkosic (not trondhjemitic) source for others. These factors suggest that a source of continental material was present during deposition of the Sa'diyah formation. Evidence for continental detritus and interlayering of the Sa'diyah formation and Baish(?) igneous suite suggests that the Sa'diyah was deposited in a miogeosynclinal tectonic setting. The age of the Sa'diyah formation is not directly known.

sa PARA-AMPHIBOLITE--Dark-gray to black, strongly foliated, fine-grained epidote-amphibole and epidote-quartz-amphibole rocks, generally plagioclase-free; porphyroblasts of epidote or blue-green amphibole common. Interlayered with subordinate quartzite, schist, marble, and orthoamphibolite (metabasalt). Possibly derived by amphibolite-grade metamorphism from an argillaceous, siliceous dolomite or limestone protolith. Reference locality: lat 20°39' N., long 39°50' E. Thickness unknown due to possible repetition by folding and due to a lack of stratigraphic facing indicators

sm MARBLE--White to gray, resistant, foliated, fine-grained quartz and biotite-muscovite-quartz marble and cm- to mm-scale layered amphibole marble. Recumbently folded at outcrop scale. Contains thin, sandy, relict beds generally parallel to foliation. Probably derived from sandy limestone and interbedded limestone, graywacke, and pelitic rocks. Metamorphosed to amphibolite facies. Structurally overlies and is interlayered near top of Sa'diyah formation quartzite unit. Maximum structural thickness ~ 250 m at reference locality in southwestern Jabal al Ghamdiyah at lat 20°42' N., long 39°49' E.

sq QUARTZITE--White to light-pink; weakly to moderately foliated; granoblastic to schistose; commonly lineated; medium to fine grained. Three major rock types identified: 1) andalusite-kyanite-muscovite quartzite, rutile-muscovite-kyanite quartzite, muscovite-kyanite quartzite, and muscovite-quartz schist (metapelites); 2) magnetite quartzite (metachert?); and 3) feldspathic (microcline and (or) plagioclase) quartzite or quartzofeldspathic gneiss that contains minor or trace amounts of fluorite, hornblende, allanite, titanite, zircon, garnet, and magnetite and that was probably derived from granitic or arkosic protoliths. An epidote-garnet and magnetite-epidote-amphibole-quartz skarn (××××), 1 to 3 m thick, is present along the contact of feldspathic quartzite with marble and amphibolite near lat 20°41' N., long 39°47' E. Unit also contains: kaolinite-quartz schist and quartz claystone (derived from muscovite-quartz schist); quartz-kyanite-muscovite-plagioclase schist (metatrondhjemite?); biotite-muscovite-quartz-plagioclase schist with relict plagioclase phenocrysts (meta-andesite?); minor quartz-bearing plagioclase-epidote-amphibole-chlorite schist and hornblende-plagioclase amphibolite (metabasalt); and garnet-biotite granite-gneiss, granite mylonite, and trondhjemite gneiss. Polymetamorphosed at amphibolite facies; deformed kyanite porphyroblasts in some samples indicate multi-phase deformation during metamorphism. Map patterns suggest that unit structurally overlies Sa'diyah para-amphibolite and marble, and underlies, but locally interfingers with, the Baish(?) igneous suite. Thickness unknown due to possible repetition by folding and intrusion by granite gneiss to the east. Reference localities near lat 20°46' N., long 39°48' E. and lat 20°41' N., long 39°47' E.

IGNEOUS AND META-IGNEOUS ROCKS

Tb_2 ALKALI BASALT (PLIOCENE)--Medium-gray; fine grained; intergranular; nonvesicular to moderately vesicular; olivine, olivine-plagioclase, and clinopyroxene-olivine-plagioclase porphyritic to glomeroporphyritic. Classified as alkali basalt of the sodic-alkali basalt series of Irvine and Baragar (1971) (fig. 1). Chemically similar to some alkali basalts in Damm dike swarm (Td) and with LREE enrichments typical of rift-related magmas (figs. 1, 2). Exposed only as a shield volcano at Harrat Tuffil. Flow features generally obscured by weathering, but poorly preserved flow fronts, channels, and differences in phenocryst type and abundance indicate several flows at Harrat Tuffil. A single flow traveled ~ 12 km south of the eruptive center, probably along a paleostream channel. Upper flow in vent area dated by whole-rock K-Ar at 3.25±0.5 Ma. Unconformably overlies Bathan conglomerate, Shama rhyolite, and Precambrian gneiss and granite. Typically <10 m thick except in vent areas

Tb_1 ALKALI BASALT (MIOCENE)--Medium-gray; fine grained; intergranular to subophitic; locally diktytaxitic; nonvesicular to moderately vesicular; olivine, olivine-plagioclase, and subordinate clinopyroxene-olivine-plagioclase porphyritic to microporphyritic. Classified as alkali basalt of the sodic-alkali basalt series of Irvine and Baragar (1971) (fig. 1). Olivine commonly iddingsitized and vesicles and intergranular spaces filled by calcite in some flows; flow features obscured by more intense weathering than at Harrat Tuffil. Chemically similar to the Pliocene alkali basalt at Harrat Tuffil and to some alkali basalts in the Damm dike swarm (figs. 1, 2). Crops out chiefly at Harrat ad Damm as a remnant of flows that once filled a paleovalley in Precambrian rocks; this volcanic field is now topographically inverted due to more rapid erosion of valley-wall rocks. Minor outcrops atop hills north of Jabal Sita are remnants of more widespread flows. Clinopyroxene from Harrat ad Damm dated by K-Ar at 11.3±0.6 Ma. Harrat surface ~ 110 m in elevation above bed of Wadi ad Damm. This indicates an average rate of erosional downcutting of ~10 m per Ma

Tr SHAMA RHYOLITE--Light-gray, white to tan or pink, or, where perlitic, black to green rhyolite and dacite; flow banded and flow folded; spherulitic, vitroclastic, locally eutaxitic or brecciated; fine grained; contains sparse phenocrysts of quartz, quartz and plagioclase, or quartz, plagioclase, and sanidine; chemically classified as rhyolite and dacite (fig. 1 and Laurent, 1976); forms rhyolite ash, rhyolite tuff-breccia, rhyolite and dacite flow rock, welded tuff, and perlite. Best exposed at reference area at Jabal Shama and at Jabal abu Shidad. Perlite discontinuously exposed along base of ash flow at Jabal Shama; possibly hydrated basal vitrophyre. Sample from Jabal abu Shidad dated by whole-rock K-Ar at 19.2±0.9 Ma (Gettings and Stoeser, 1981). Unconformably overlies and intrudes Baish(?) igneous suite and is faulted against Shumaysi formation near Jabal abu Shidad; unconformably overlain by Bathan formation and Pliocene alkali basalt at Harrat Tuffil. Probably correlates with Liyyah rhyolite of the Jizan group of Schmidt and others (in press). Thickness variable but locally exceeds 100 m

Tv SITA FORMATION--Two bimodal suites of 1) alkali basalt and trachyte and 2) minor subalkaline basalt and rhyolite (figs. 1, 3). Alkali basalt is dark gray to greenish gray; fine grained; moderately to severely altered (chloritic or zeolitic); vesicular or amygdaloidal; hyalopilitic to intergranular or subophitic; contains phenocrysts of olivine or olivine and plagioclase. Trachyte is medium to light gray; slightly to moderately altered; trachytic; contains phenocrysts of hornblende and albite or clinopyroxene and albite. Subalkaline basalt has color and alteration similar to the alkali basalt but is fine grained, commonly aphanitic, or contains phenocrysts or microphenocrysts of plagioclase and clinopyroxene. Rhyolite is light gray, fine grained, and contains sparse feldspar phenocrysts; very minor component of formation and may correlate with Shama rhyolite. Each rock type forms lava flows interbedded with reddish-gray to purple volcaniclastic rocks (tuff-breccia and water-laid tuff), graywacke, laminated limestone, and shale. Formation best exposed south and east of Jabal Sita. Lower, predominantly clastic and volcaniclastic part of section conformably overlies and is locally interbedded with Shumaysi formation southeast of Jabal Sita; unconformably overlain by Miocene alkali basalt north of Jabal Sita. Intruded by cogenetic, subvertical, locally sheeted, north- to northwest-trending, aegirine(?)-plagioclase porphyritic trachyte to mugearite(?) dikes and by plagioclase-megacrystic diabase dikes of the Damm dike complex. Whole-rock sample of trachyte(?) dated by K-Ar at 21.1±2.1 Ma (Gettings and Stoeser, 1981). Water-laid tuff and limestone probably correlate with Baid formation of the Jizan group of Schmidt and others (1982). Top eroded but thickness probably locally exceeds 300 m

DAMM DIKE COMPLEX

Chiefly hypabyssal rocks intruded in parallel to subparallel dike swarms (Damm dike swarm member) and in dikes, sills, and minor flows at Jabal Sita (Dike and sill member). Complex is named after Wadi ad Damm in the northeastern and central parts of the quadrangle.

Td DAMM DIKE SWARM MEMBER--Two bimodal suites of 1) alkali basalt and hawaiite to trachyte and comendite, and 2) tholeiitic basalt to dacite and rhyolite (figs. 1, 3). Alkali basalt and hawaiite are dark gray to gray, intergranular to subophitic or ophitic (diabasic), fine grained, and contain plagioclase megacrysts. Comendite is light-gray, fine- to medium-grained, quartz-sanidine-albite granophyre with arfvedsonite(?) phenocrysts. Trachyte is gray, fine grained, and contains phenocrysts in a felted (trachytic) albite-rich groundmass. Tholeiitic basalt is similar in appearance to alkali basalt and hawaiite, but is commonly finer grained and contains phenocrysts or microphenocrysts of olivine, plagioclase, or clinopyroxene, or clinopyroxene and plagioclase. Rhyolite is light gray, but weathered surfaces are commonly tan to brown; forms fine- to medium-grained quartz-albite-sanidine granophyre or very fine to fine-grained pilotaxitic rhyolite with phenocrysts or microphenocrysts of plagioclase, or quartz and plagioclase, or sanidine(?), quartz, and plagioclase. Dacite is similar in appearance to the pilotaxitic rhyolite, but contains phenocrysts of plagioclase, or quartz and plagioclase, or clinopyroxene, hornblende, and plagioclase. All dikes are variably altered and metamorphosed to greenschist facies. Member forms a swarm of generally northerly trending dikes that intrude all pre-Bathan rocks in the quadrangle except the youngest parts of Shama rhyolite and the gabbro and monzogabbro unit. Dikes average 1 to 2 m wide, are more abundant inward from the margins of the swarm, and locally form a sheeted dike complex (100 percent dike rock); dikes typically parallel to subparallel and vertical to subvertical; split-dikes locally common; sparse cross-cutting dikes occur and tend to follow regional northeast-trending structural patterns. Both alkaline and subalkaline dikes appear to be coeval because they intrude one another. Most dikes are in a north- to northeast-trending swarm that follows the western boundary of the granite gneiss from Wadi ad Damm north through Jabal al Ghamdiyah, or in a separate northwesterly trending swarm in the Jabal Sita area. Dike swarms predate: Miocene alkali basalt of Harrat ad Damm dated at 11.3±0.6 Ma; large, northwesterly trending gabbro to monzogabbro dikes dated at 21.7±0.5 Ma and 24.4±1.2 Ma; and small gabbro plutons near Jabal Sita dated at 26.7±4.6 Ma (Gettings and Stoeser, 1981). Most dikes (~90 percent) of the swarm predate Burgatinah diorite dated by hornblende K-Ar at 26.8±0.4 Ma, 27.8±0.9 Ma, and 27.2±0.4 Ma, but some dikes (~10 percent) intrude the diorite; plagioclase separated from a plagioclase-megacrystic hawaiite dike is dated at 43.5±0.7 Ma and the Eocene (~ 50 Ma) Shumaysi sandstone unconformably overlies some dikes but is intruded by sparse plagioclase-megacrystic dikes southeast of Jabal Sita; these data indicate periodic intrusion during a period of regional tension from ~ 50 Ma to ~20 Ma. Dike-swarm member probably represents conduits for volcanic rocks of the Sita formation that are correlated with formations of the Jizan group of Schmidt and others (1982)

Th DIKE AND SILL MEMBER--Distinctive, dark-gray to gray alkali basalt to hawaiite (fig. 1); intergranular to subophitic (diabasic), fine grained; 5 to 15 percent oscillatory zoned labradorite megacrysts typically 0.5 to 1 cm across. Similar plagioclase-megacrystic hawaiite recognized as the final stage of Tertiary and Quaternary harrat volcanism throughout Saudi Arabia by Coleman and others (unpublished data). Forms dikes, sills, and subordinate flow rock and flow breccia. Dikes and sills form an intrusive complex, which is probably the subvolcanic zone of an alkali basalt to hawaiite volcano. Septa of rhyolite of Sita formation locally present between dikes. Variably altered and incipiently metamorphosed to lower greenschist facies. Forms dikes in Jabal Sita region that intrude some Sita volcanic rocks, but most dikes probably predate latest Sita volcanism. Best exposed in canyons cutting flanks of Jabal Sita. Plagioclase from a chemically similar plagioclase-megacrystic hawaiite dike in Damm dike swarm near Jabal Burgatinah dated by K-Ar at 43.5±0.7 Ma

Tgb GABBRO AND MONZOGABBRO--Dark-gray to gray, blocky to bouldery weathering, hypidiomorphic-granular, fine- to medium-grained olivine, clinopyroxene, olivine-clinopyroxene, hornblende-clinopyroxene, and hornblende gabbro, and clinopyroxene-hornblende and biotite-hornblende monzogabbro. Fresh except for slight alteration of olivine to smectite and (or) serpentine, and limited uralitization of pyroxene and hornblende, saussuritization of plagioclase, and chloritization of biotite. Unit forms small plutons and 10- to 100-m-thick northwesterly trending dikes with resistant, recrystallized host-rock margins producing dual-rib or "railroad-track" weathering patterns; produces prominent aeromagnetic lineaments. Dikes crosscut Damm dike swarm and are overlain by Miocene alkali basalt at Harrat ad Damm dated by K-Ar at 11.3±0.6 Ma. Similar dike in the Al Lith quadrangle to the southeast dated by plagioclase K-Ar at 21.7±0.5 Ma and clinopyroxene K-Ar at 24.4±1.2 Ma; however, whole-rock K-Ar dates are anomalously old (100-200 Ma) due to contamination by excess radiogenetic argon from Precambrian host rocks (Pallister, unpublished data). Small plutons near Jabal Sita dated by whole-rock K-Ar at 26.7±4.6 Ma (Gettings and Stoeser, 1981)

Tdr BURGATINAH DIORITE--Gray, medium-grained, hypidiomorphic-granular biotite-clinopyroxene-hornblende and hornblende quartz diorite, biotite-hornblende diorite, and biotite-hornblende monzodiorite. Shows limited saussuritization of plagioclase and alteration of mafic minerals to chlorite or smectite. Chemically equivalent to dacite (fig. 1). Positive europium anomaly (fig. 2) suggests diorite is crystal accumulation produced by fractionation of rhyolite that forms dikes in the Damm dike swarm and flows in the Shama and Sita formations. Intrudes most (~90 percent) dikes of Damm dike swarm but is intruded by sparse (5 to 10 percent) tholeiitic diabase, plagioclase-megacrystic diabase (hawaiite?), and plagioclase-clinopyroxene-hornblende porphyritic dacite dikes, and by cogenetic hornblende quartz micro-diorite dikes; therefore, coeval with late dike swarm intrusion of both alkaline and subalkaline magma; dated by hornblende K-Ar at 26.8±0.4 Ma, 27.8±0.9 Ma, and 27.2±0.4 Ma. Forms prominent spire at Jabal Burgatinah and prominent normally polarized aeromagnetic anomaly

Tan ANORTHOSITE--Light-gray, medium- to coarse-grained, hypidiomorphic-granular, biotite-, clinopyroxene-, and hornblende-bearing anorthosite. Pyroxene is uralitized and biotite is chloritized, but hornblende and plagioclase are fresh; hornblende is strongly pleochroic, from dark green to brown, and is zoned. Intrudes most (~90 percent) dikes of Damm dike swarm but is intruded by sparse (5 to 15 percent) mafic dikes; therefore, coeval with late phase of Damm dike swarm intrusion; dated by hornblende K-Ar at 26.5±0.4 Ma. Exposed 4 km northwest of Jabal Burgatinah; produces prominent normally polarized aeromagnetic anomaly

gd GRANODIORITE (PRECAMBRIAN)--Light-gray to pink, massive, medium- to coarse-grained; contains pink phenocrysts or oikocrysts of microperthitic orthoclase. Biotite granodiorite (fig. 4) with trace muscovite, allanite, titanite, apatite, and zircon. Plagioclase partly sericitized and shows oscillatory zoning, quartz recrystallized to multi-domain grains. Intruded by sparse (10 to 15 percent) plagioclase-megacrystic diabase (hawaiite?) and fine-grained mafic dikes of Damm dike swarm. Exposed along northern border of the quadrangle

gs SYENOGRANITE (PRECAMBRIAN)--Pinkish-gray, massive to weakly foliated, medium-grained, allotriomorphic granular to granoblastic, alaskitic syenogranite (fig. 4). Partly sericitized plagioclase and microperthitic orthoclase, quartz recrystallized to multi-domain grains. Occurs only as a small (<1 km^2) pluton that intrudes amphibolite of the Baish(?) igneous suite and granite-gneiss 3 km southeast of Sa'diyah village. Cut by 5 m wide northerly trending bull quartz vein

gr MONZOGRANITE (PRECAMBRIAN)--Pinkish-gray, massive to schistose, fine- to medium-grained, allotriomorphic granular to granoblastic or gneissic, peraluminous, muscovite-garnet-bearing and garnet-muscovite-biotite-bearing monzogranite and monzogranite gneiss (fig. 4). Sericitized plagioclase and microperthitic microcline, quartz recrystallized to multi-domain grains. Crops out in small areas east of Jabal Shama and east of Harrat Tuffil. Spatially associated with aluminous rocks of Sa'diyah quartzite unit; monzogranite could be an old source rock for Sa'diyah quartzite but is probably younger

gn GRANITE GNEISS (PRECAMBRIAN)--Light- to dark-gray, moderately to strongly foliated, fine- to medium-grained, granoblastic or gneissic, locally mylonitic, commonly banded, biotite monzogranite orthogneiss and minor hornblende-biotite monzogranite orthogneiss (fig. 4); fresh to strongly sericitized and zoned plagioclase, perthitic to nonperthitic microcline, quartz recrystallized to strained multi-domain grains. Intruded by subalkaline, alkaline, and peralkaline dikes of Damm dike swarm, especially common along the western margin of the gneiss. Part of a large batholith exposed along eastern margin of the quadrangle and in the adjacent Wadi Sa'diyah quadrangle (Wier and Hadley, 1975). Intrudes and recrystallizes Baish(?) amphibolite and hornfels in the southeastern part and Sa'diyah quartzite in the central part of the quadrangle; faulted against Baish(?) rocks along Bir ad Damm fault where apparent diapiric(?) rise and counter-clockwise rotation of the batholith produced a large synformal drag fold in adjacent Baish rocks. Age not directly known, but similar granites in the same tectonic belt near At Taif are dated by Rb-Sr at 595±20 Ma (Nasseef and Gass, 1977)

BAISH(?) IGNEOUS SUITE

Metabasaltic rocks of the Baish(?) igneous suite consist of orthoamphibolite and hornblende hornfels, and quartzofeldspathic gneiss and schist. The former represent cogenetic metadiabase, metabasalt, and metagabbro; the latter represent metatonalite or metatrondhjemite. Rocks of this suite structurally overlie but are locally interlayered with the Sa'diyah formation. Quartzofeldspathic gneiss and schist are derived from trondhjemite and tonalite (fig. 4). Metabasalt, metadiabase, and metagabbro are chemically tholeiitic basalt (fig. 1) and have REE patterns with LREE depletions typical of mid-ocean ridge or immature island-arc basalt (fig. 2). Felsic metavolcanic rocks are not present in the quadrangle, although dacitic (fig. 1) rocks occur in the Baish group of Al Lith quadrangle to the southeast. Intermediate composition andesites are not present, indicating bimodal Baish(?) chemistry. Baish(?) metabasalts are tholeiitic and similar to ocean-floor basalts in terms of minor- and trace-element chemistry and REE; similar conclusions are stated by Reischmann and others (1982). Metavolcanic rocks that apparently overlie the Baish(?) amphibolite in the adjacent Wadi Sa'diyah quadrangle are dated by Rb-Sr at 821±19 Ma (Kröner and others, 1982). Brown, magmatic hornblende from quartz diorite in the northeastern part of the quadrangle is dated by K-Ar at 804±8 Ma. Metamorphic amphiboles from metagabbro and metatrondhjemite yield recrystallization ages of 672±10 Ma and 678±7 Ma. A three-point isochron for Baish(?) metabasalt from the Al Lith quadrangle of Hadley and Fleck (1979) yielded a date of 1165±110 Ma; however, the total range in $^{87}Rb/^{86}Sr$ was less than 0.12 and the date is equivocal. The suite is clearly older than 804±8 Ma; it is probably between 800 and 880 Ma old (Reischmann and others, 1982). The suite is tentatively correlated with the lithologically and chemically similar Baish group (Prinz, in press; Fairer, unpub data), which is also intruded by tonalite and diorite dated at 895±173 Ma and 853±72 Ma (Fleck and others, 1980) and by tonalitic gneiss of the An Nimas batholith dated by the zircon uranium-lead (U-Pb) method at 816±4 Ma (Cooper and others, 1979).

ba METADIABASE AND METABASALT--Very dark gray to gray, massive to schistose, fine- to medium-grained, amphibolite, epidote amphibolite, quartz amphibolite, or hornblende hornfels derived chiefly from diabasic and basaltic protoliths; also minor metatonalite and metagabbro. Metamorphosed to lower to upper amphibolite facies; multiply deformed. Structurally overlies Sa'diyah formation but is locally interlayered with Sa'diyah quartzite and para-amphibolite; intruded by metagabbro and by metatonalite (quartzofeldspathic gneiss unit). Structural thickness probably exceeds 3 km

bg METAGABBRO--Dark-gray to gray, massive to foliated, hypidiomorphic-granular to granoblastic, fine- to medium-grained, variably recrystallized and locally mylonitic or gneissic hornfels derived from hornblende, clinopyroxene-hornblende, or orthopyroxene-clinopyroxene-hornblende olivine gabbro, hornblende tonalite, and biotite tonalite. Chemistry (fig. 1) and olivine-hypersthene reaction textures define tholeiitic composition of olivine gabbro. Metamorphosed to greenschist to amphibolite facies, locally retrograded to lower greenschist facies; weakly to moderately deformed. Intrudes and was deformed with Baish(?) metadiabase and metabasalt. Forms isolated outcrops in southeastern and northwestern parts of quadrangle; coincides with prominent positive polarity aeromagnetic anomaly in southeast

bq QUARTZOFELDSPATHIC GNEISS--White to light-gray or light-tan, weakly foliated or lineated, granoblastic (relict hypidiomorphic-granular) to schistose, fine- to medium-grained, variably recrystallized and locally mylonitic or gneissic, epidote-quartz, epidote-muscovite-plagioclase-quartz, and plagioclase-quartz gneiss; unit also contains muscovite-quartz, sericite-plagioclase-microcline, and calcite-quartz-sericite-epidote schist, and subordinate quartz-plagioclase and hornblende-plagioclase hornfels, hornblende-biotite tonalite gneiss, and tonalite mylonite. Metamorphosed to greenschist to amphibolite facies, moderately to highly deformed; derived chiefly from recrystallized tonalite and trondhjemite (fig. 4) of the Baish(?) metagabbro unit; interlayered with amphibolite of the Baish(?) metadiabase and metabasalt unit

bag METADIABASE-METABASALT AND METAGABBRO COMPLEX--Intrusive complex consisting of rocks of metadiabase and metabasalt unit intimately intruded by and deformed with rocks of metagabbro unit. Contains Precambrian metadiabase dike swarm in the northeast; folded on a regional scale adjacent to Bir ad Damm fault, perhaps during emplacement of granite gneiss

ECONOMIC GEOLOGY

Perlite at Jabal Shama (MODS01166) was described by Laurent (1976), who concluded that certain reserves of 105,000 tons and possible reserves of 1 million tons exist. The perlite has relatively low expansion coefficients (2.8 to 5.6), but could be suitable as light aggregate in the manufacture of plaster or lightweight concrete.

Sparse barite veins (MODS03065) were discovered in the lower Shumaysi formation near Jabal Sita. These deposits may have been derived from brines produced during proto-Red Sea rifting 50 to 20 Ma ago.

A small skarn, 1 to 3 m thick, is present along the contact of feldspathic quartzite and marble near lat 20°41' N., long 39°47' E.; however, no economic mineralization was noted and pyrite-rich quartzites in the same area are also very poor in metals of economic interest.

Relatively small deposits of the Sa'diyah formation marble (MODS03066) are jointed at the surface but may be of interest for local use as building stone or for cement. The Jurassic(?) dolomite is locally quite pure and may be useful locally.

Little is known about the ground water resources of the region. Wells in Wadi ad Damm, Wadi al Kargah, and Wadi Sa'diyah produce water for local consumption. It is possible that ground water is trapped in fault basins or paleochannels in the coastal plain, such as near Harrat Tuffil.

ENTRY INTO MINERAL OCCURRENCE DOCUMENTATION SYSTEM (MODS)

Mineral localities referred to in this report are recorded in the Mineral Occurrence Documentation System (MODS) data bank and are identified by a unique five-digit number. Inquiries regarding this data bank may be made through the Office of the Technical Advisor, Saudi Arabian Deputy Ministry for Mineral Resources, Jiddah.

The Jabal Shama perlite MODS entry was updated and the Shumaysi barite and Jurassic(?) dolomite deposits have been entered in the data bank to Mini-MODS standards as files 03065 and 03066, respectively.

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Note: Tgb and Td are shown in red on geologic map (plate 1).
K-Ar dates calculated using the following decay constants: $\lambda_\varepsilon=0.5811 \times 10^{-10} y^{-1}$, $\lambda_\beta=4.962 \times 10^{-10} y^{-1}$, $^{40}K=0.01167$ atom %. Dates reported by Gettings and Stoeser (1981) are recalculated to these constants.

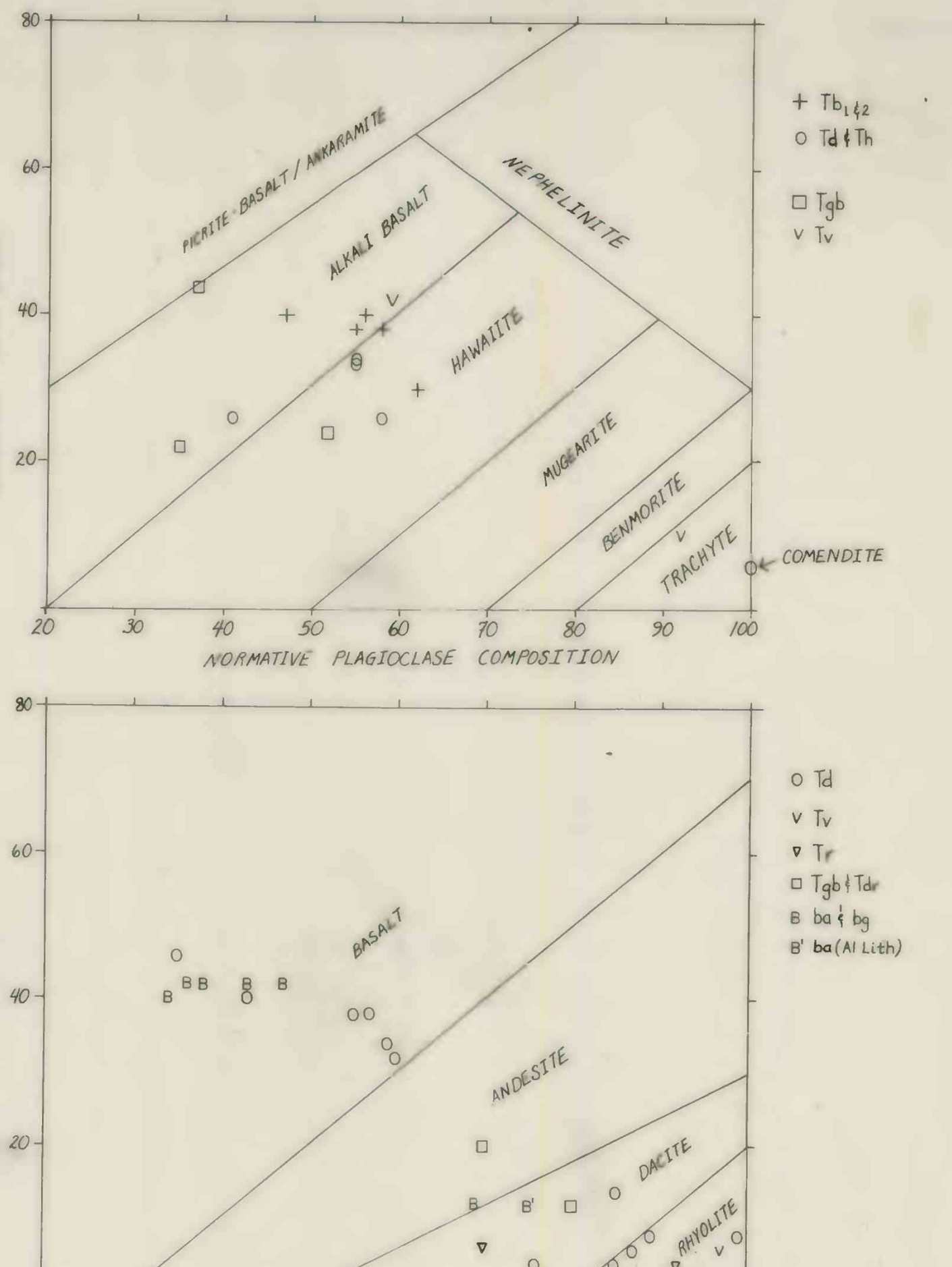

Figure 1.--Volcanic classification diagrams of Irvine and Baragar (1971) showing distribution of rocks of the Harrat Tuffil quadrangle and one rock from the adjacent Al Lith quadrangle (point B'). The upper diagram shows rocks classified as members of the sodic series of the alkaline basalt suite according to the criteria of Irvine and Baragar; the lower diagram shows subalkaline rocks. Normative plagioclase is defined as 100 x [(ab + 5/3 ne)/(an + ab + 5/3 ne)]; normative color index is defined as ol + opx + cpx + mt + il + hm. Plots are in percent cation equivalents. Unit symbols are defined in Description of map units.

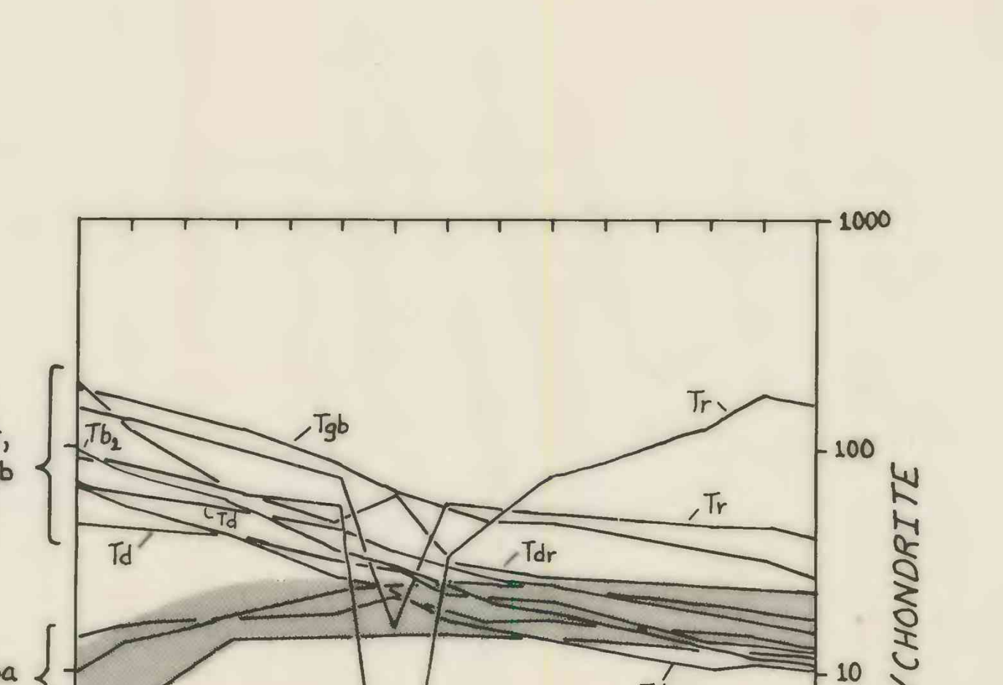

Figure 2.--Chondrite-normalized rare-earth element (REE) diagrams for rocks of the Harrat Tuffil quadrangle. The shaded field shows average mid-ocean ridge basalt (Schilling, 1971; Frey and others, 1974). REE are plotted in order of atomic number on the abscissa; only analyzed elements are labeled. Unit symbols are defined in Description of map units.

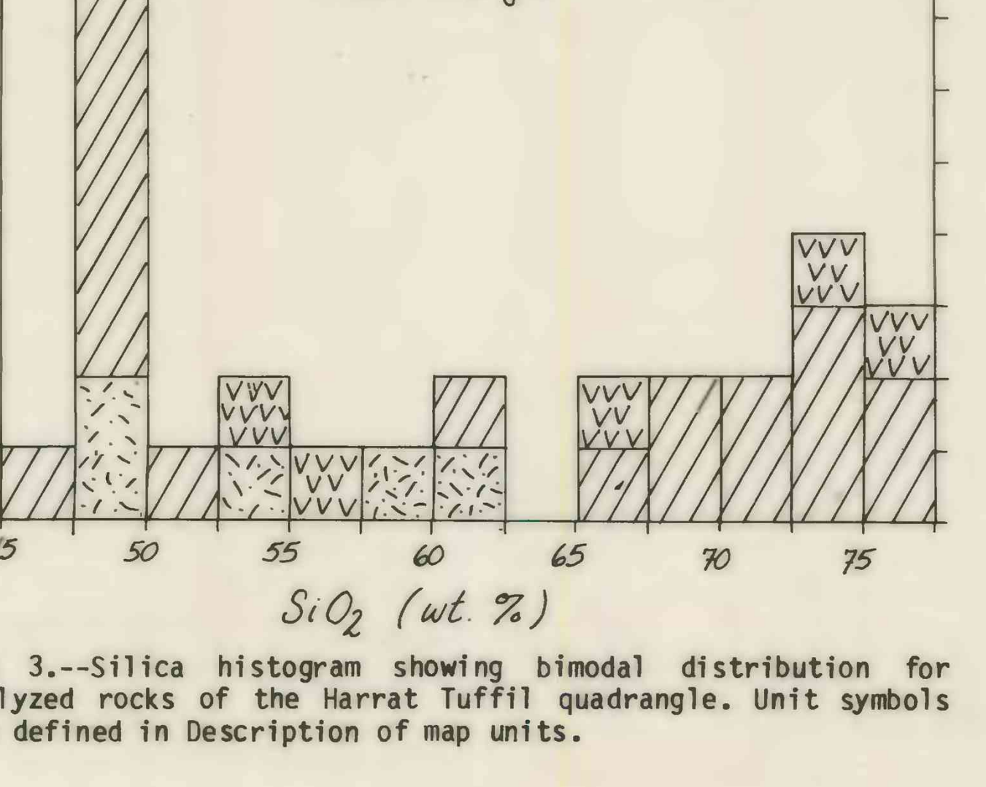

Figure 3.--Silica histogram showing bimodal distribution for analyzed rocks of the Harrat Tuffil quadrangle. Unit symbols are defined in Description of map units.

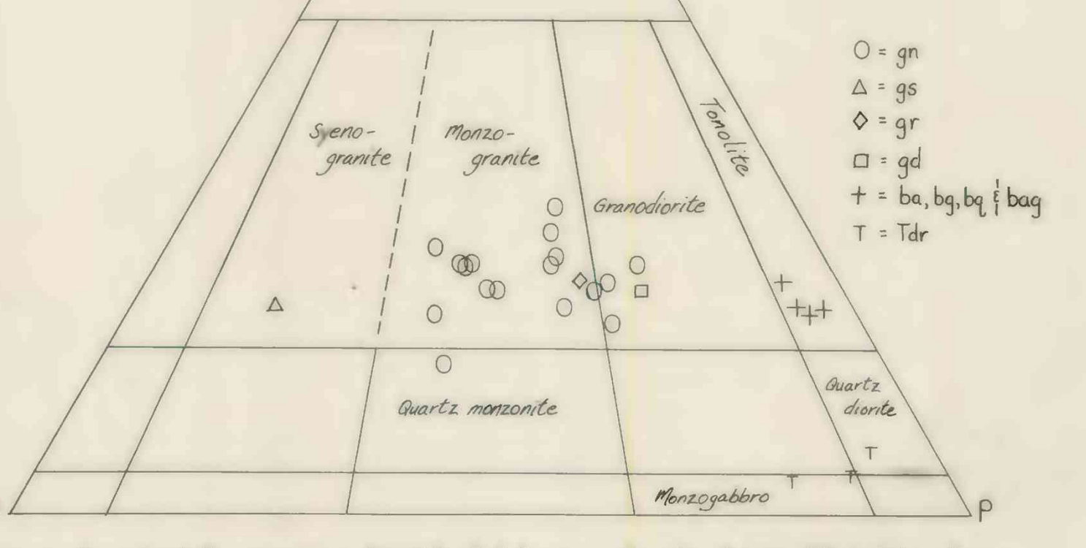

Figure 4.--Modal quartz-alkali feldspar-plagioclase (Q-A-P) classification diagram for rocks of the Harrat Tuffil quadrangle. Divisions are from Streckeisen (1973). Only plutonic rocks in the Baish(?) igneous suite are plotted. Unit symbols are defined in Description of map units.

EXPLANATION FOR RECONNAISSANCE GEOLOGIC MAP OF THE HARRAT TUFFIL QUADRANGLE, SHEET 20/39 B, KINGDOM OF SAUDI ARABIA

by John S. Pallister 1983