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Reconnaissance geology of the Al Abanat quadrangle, sheet 25/42B, Kingdom of Saudi Arabia

by

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

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ABSTRACT

The Al Abanat quadrangle, located approximately mid-way between An Nuqrah and Buraydah, contains layered and intrusive rocks that represent the major phases of Proterozoic geology in the northeastern Arabian Shield. Low-potassium metavolcanic rocks of the Dhiran meta-andesite were intruded 690 Ma to about 670 Ma ago by (possibly cogenetic) low-potassium mafic and intermediate rocks of the Suwaj suite. Both units were probably formed by partial melting of oceanic lithosphere above a southwest-dipping subduction zone. The Dhiran-Suwaj terrane was deformed and metamorphosed during a regional orogenic event that may have coincided with the termination of subduction.

The orogenic uplift shed abundant fine-grained sandstone (Murdama group) into fault-bounded, subsiding marine basins. The Ata fault, which forms one of the Murdama basin boundaries, is well exposed in this area and its features suggest it was a major left-slip structure prior to Murdama time, but was re-activated as a dip-slip fault during sedimentation. The unlithified Murdama deposits were penecontemporaneously deformed during basin-subsidence and then regionally folded along north-south trends. This period of regional folding appears to pre-date and overlap with intrusion of batholithic granitic rocks of the Khishaybi suite, probably at about 650 Ma.

Regional north-south extension and calc-alkaline volcanic activity began at about 640 Ma and produced voluminous andesitic volcanic and volcaniclastic deposits of the Jurdhawiyah group. Primary volcanic materials and their rapidly eroded detritus were deposited in elongate, fault-bounded basins that were partly shallow-water marine and partly terrestrial. The Lughfiyah-Shuhban reverse fault system was active during a brief interval in late Jurdhawiyah time. This deformation was closely followed by intrusion of elliptical bodies of Idah suite granodiorite porphyry, 620 Ma to 615 Ma ago, that may have been cogenetic with the Jurdhawiyah volcanic rocks.

The succeeding 30-Ma interval was characterized by uplift, erosion, and probable planation. During a subsequent period of regional cratonic extension from about 585 to 570 Ma, high-silica, evolved granites of the Abanat suite were intruded in ring dikes and composite plutons of the Asmar complex (dominantly peraluminous) and the Ahmar complex (peralkaline). The Asmar complex partially intruded its coeval rhyolitic volcanic cover (Samra rhyolite).

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Mineral potential in the Al Abanat quadrangle is indicated by ancient gold and copper workings and by geochemical anomalies and favorable geologic settings. Auriferous quartz veins at the Al Khaymah locality contain local rich pockets and the stibnite-rich veins at Umm Jirfan contain local high values of gold and silver. Copper is associated only with the Dhiran-Suwaj terrane and is concentrated in a splay of the Ata fault at Mibari. Tin and granitophile elements are locally enriched in fluorite-bearing rocks of the Abanat suite and the Samra rhyolite.

INTRODUCTION

Reconnaissance geologic mapping of the Al Abanat quadrangle, sheet 25/42 B, was conducted as part of a regional program to study the lithologic, stratigraphic, and structural features of the Arabian Shield to provide a rational basis for mineral exploration activities. The area of investigation is a 30-minute square of latitude and longitude, approximately 50 km by 55 km, whose northwestern corner is the intersection of 26°00'00" N. and 42°30'00" E. Figure 1 shows the location of the Al Abanat quadrangle, surrounding quadrangles, and regional geographic features mentioned in this report.

Fieldwork was initiated in December, 1980 following interpretation of aerial photographs, Landsat imagery, aeromagnetic and aero-radiometric maps, and existing reports and Mineral Occurrence Documentation System (MODS) files. The Al Abanat quadrangle was mapped at the same time as the adjoining Uqlat as Suqur quadrangle to the west (sheet 25/42 A). The majority of this work was performed by helicopter, although ground traverses were added in areas that warranted additional detail. Thirteen days of fieldwork were completed in the Al Abanat quadrangle by the middle of February, 1981, but further work was suspended during administrative assignment. Fieldwork was resumed and completed in December, 1983 following two additional days of helicopter-supported work. In all, 15 days were spent on field investigations, and approximately 190 sites were described and sampled.

Cultural and geographic data are based on information released in 1984 from the Aerial Survey Department, Saudi Arabian Ministry of Petroleum and Mineral Resources (MPMR). Geographic names used in this report are based in these data and conform to the official transliteration (less diacritical marks) for the Kingdom of Saudi Arabia.

Representative samples of igneous-rock units were analyzed for major- and trace-elements, and various groups of trace-elements were determined for representative samples of layered-rock units and samples collected at known or suspected sites of mineralization. Conclusions arising from study of these results are incorporated in this report. However, the raw data are tabulated separately in the project Data File (Cole, 1984c), and are also stored in the Rock Analysis Storage System computerized data base of the United States Geological Survey (USGS) in Jiddah.

Lithologic descriptions and interpretations of sedimentology, igneous crystallization history, and structural/metamorphic history are based on hand-specimen descriptions, microscopic studies of approximately 150 thin sections, and analysis of rock slabs stained for potassium feldspar. Modal mineral content for holocrystalline igneous rocks was determined on these stained slabs by standard point-count methods.

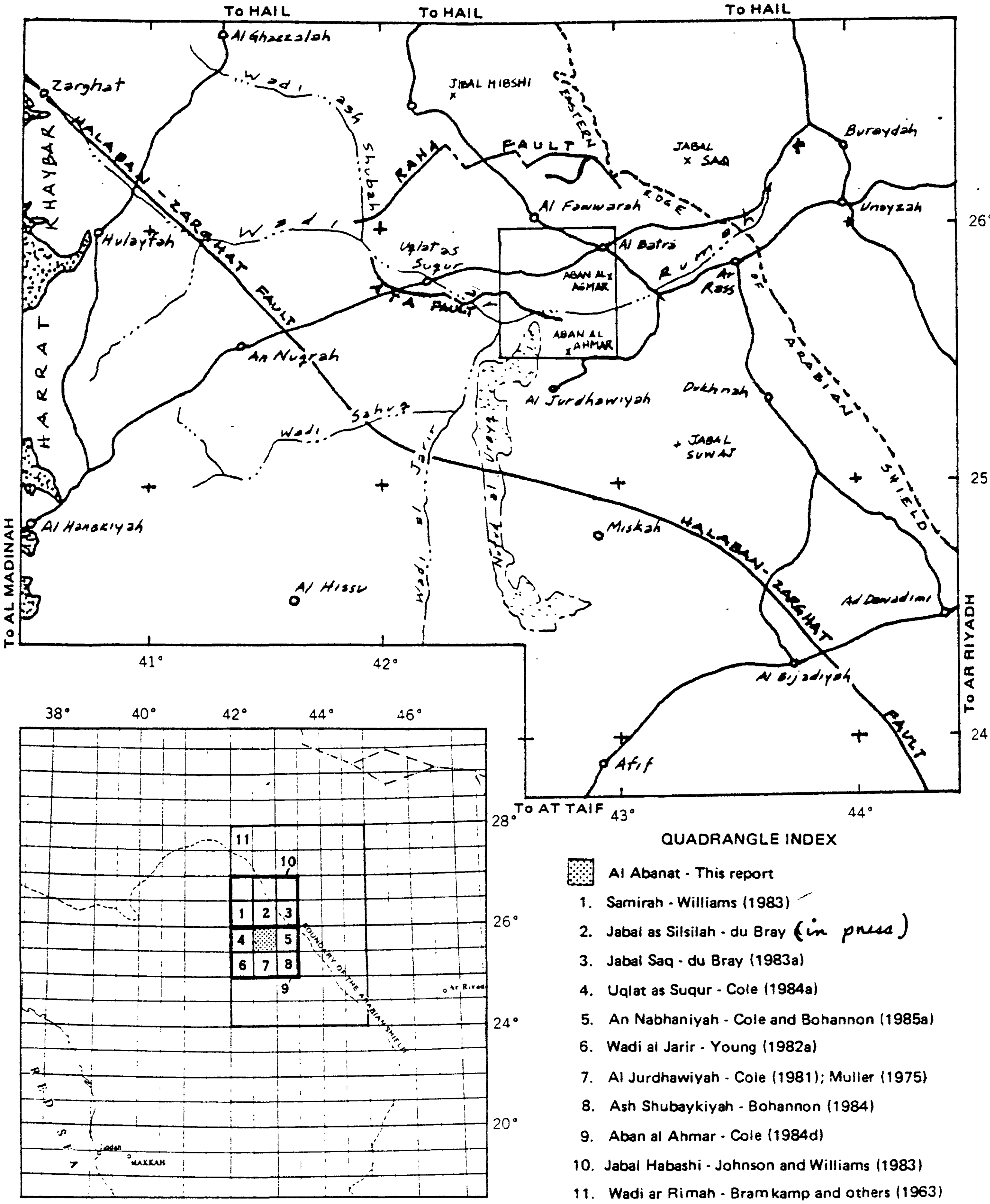

Figure 1.--*Location maps for the Al Abanat quadrangle and vicinity. Geographic and geologic features mentioned in text are illustrated in upper diagram; surrounding quadrangles and references are shown in lower diagram.*

GEOGRAPHY AND GEOMORPHOLOGY

The town of Al Batra is the principal commercial center and established settlement within the quadrangle (approximately 800 inhabitants) and is located at the intersection of the Al Madinah-Buraydah highway, the highway to Al Fawwarah and Samirah, and the highway to Ar Rass and Ar Riyadh (fig. 1). Most areas of the quadrangle are accessable on the ground via a network of established, ungraded desert tracks, but the major drainage channels and eolian dune fields restrict travel. As of early 1984, telecommunication and first-aid facilities were only available outside the quadrangle in the nearby towns of Uqlat as Suqur, An Nabhaniyah, and Al Fawwarah (fig. 1). A high-voltage power line crosses the quadrangle from the sub-station at Al Batra west to Uqlat as Suqur, and numerous branch lines have been constructed to serve the various villages and farms.

The name of this quadrangle derives from the local term for the two major mountain groups in the area; Al Abanat is the collective (plural) term for Aban al Asmar ("the dark") north of the Wadi ar Rumah drainage channel and Aban al Ahmar ("the red") south of the channel. The highest peaks in these mountain groups are 1243 m and 1315 m above sea level, respectively, whereas the altitudes of most areas of the quadrangle are 800 to 730 m.

The easily eroded Murdama sandstone north of Wadi ar Rumah forms a nearly planar, south-sloping surface that drains into Wadi ar Rumah via the well developed dendritic channels of Wadi Thadij-Shaib Maraghan and Wadi Ata. These channels are aggraded as a result of low runoff and low gradients; the average altitude along the northern quadrangle boundary is about 800 m and Wadi Thadij joins Wadi ar Rumah at an altitude of about 718 m. The topography and drainage south of Wadi ar Rumah are more variable due to the eolian sand fields of Nufud al Urayq and Nufud al Maysariyah and the mountainous terrain of Aban al Ahmar, Jabal Idah (1028 m), and Samra Khaytan (1060 m). Drainage is toward the north along various channels but runoff does not reach Wadi ar Rumah because it is ponded in sabkhah basins south of the eolian sand fields.

Wadi ar Rumah drains a basin that includes most of the northeastern Shield as far west as Harrat Khaybar and as far south as Afif (fig. 1). Its principal southern tributary, Wadi al Jarir, joins the main channel at an altitude of 735 m at the western quadrangle border and the Rumah channel slopes systematically down to about 703 m at the eastern boundary. The width of the channel is typically about one to two kilometers and alluvial terrace deposits are locally preserved along its margins. However, drainage is constricted southeast of Ata village, probably as a result of Pleistocene migration of eolian sand in Nufud al Maysariyah, and the Rumah channel is 50 to 100 m wide and eroded in bedrock.

PREVIOUS INVESTIGATIONS

Systematic reconnaissance geologic mapping of the Al Abanat area was first conducted under the USGS program to produce 1:500,000-scale geologic maps of the Shield in the late 1950's and early 1960's (Bramkamp and others, 1963). Reconnaissance mapping at 1:100,000-scale was begun in the middle 1970's in the southern one-third of the Al Abanat quadrangle and the area to the south (Muller, 1975), but this work was superceded by Cole (1981) and the present report.

Adjoining quadrangles were mapped by Young (1982), du Bray (1983a, in press) Williams (1983), Bohannon (1984), Cole (1984a) and Cole and Bohannon (1985a). Compilations of this information at 1:250,000-scale have been completed by Johnson and Williams (1984) and by the author (Cole, 1984d).

Magnetic and radiometric data were acquired for the Al Abanat quadrangle during regional airborne surveys of the northern Shield in the mid-1960's (ARGAS, 1967; Andreasen and Petty, 1974). Kleinkopf and Cole (1982) interpreted aeromagnetic data for the region immediately south of the quadrangle, and similar techniques were used in this study. Reconnaissance gravity measurements (Flanigan and Akhras, 1972, unpub. data) were recently supplanted by a regional gravity survey conducted by the USGS (M. Kane, written comm., 1984).

Mineral resource investigations in the quadrangle prior to 1981 were limited to brief examinations of the ancient workings at Al Jurayyir (MODS 3267), Shaib al Jurayyir (MODS 1604), and Umm Jirfan (MODS 959)(Mytton, 1970; Muller, 1975; Begg, 1980). Additional ancient workings and mineral occurrences were discovered during this project and are described in the section on Economic geology, but the more substantial workings at Al Khaymah (MODS 3941) were studied in greater detail (Smith and Samater, 1985; Cole, 1985, unpub. data). Drainage-sediment geochemical reconnaissance was completed for this quadrangle in 1982 and interpreted in 1983, but no new (unknown) targets were defined (W. Miller and R. Samater, written comm., 1983). The granitic rocks at Aban al Asmar and Aban al Ahmar were included in a study of the uranium-thorium potential of the young granites of the northeastern Shield (Stuckless and others, 1982a, b).

Isotopic ages for most of the regional units have been established by uranium-lead analysis of zircon (Cole and Hedge, 1985, unpub. data) and by rubidium-strontium whole-rock isochron techniques (Stuckless and others, in press). Topical studies of Quaternary geology include examination of the Wadi ar Rumah drainage system (Hötzl and others, 1978), and regional stratigraphy and age determinations (Whitney, 1983, unpub. data).

ACKNOWLEDGMENTS

Reconnaissance geologic mapping of the Al Abanat quadrangle was performed by the author as part of a work agreement between the USGS and the Saudi Arabian MPMR. This report completes the specific activities of subproject 2.01.19 of the annual work program for the Saudi Arabian Deputy Ministry for Mineral Resources (DMMR).

Chemical analyses were obtained from the DMMR-USGS Chemical Laboratory under the supervision of K. J. Curry. Ahmed Hamdan al Bathli (USGS) determined modal mineral content of samples of intrusive rocks. Excellent logistic support was provided during the course of this study and for that, I am indebted to P. Togans, USGS Field Services Officer and his staff, and to the personnel of the DMMR Special Flights Service.

GEOLOGIC SETTING

The area of the Al Abanat quadrangle covers part of the northeastern Arabian Shield that formed during the late Proterozoic Eon between about 700 and 570 Ma (Cole, 1984a, d; Cole and Hedge, 1985, unpub. data). Regional synthesis and isotopic data indicate that, prior to 700 Ma, no continental-type crust existed in this area, but the events of the succeeding 130 Ma produced a mature, continental crust by successive episodes of magma generation and consequent volcanic activity and intrusion (Cole, 1984d; Johnson and Williams, 1984; Stuckless and others, in press; Cole and Hedge, 1985, unpub. data). The major geologic events of the Al Abanat quadrangle are defined by three regional unconformities, four principal intrusive suites, and by folds and faults that formed during two principal periods of deformation.

The geology of this part of the Shield is interpreted in terms of four major rock-forming episodes that can be characterized as: 1) creation, orogenic deformation, and erosional denudation of primitive crust in an ensimatic magmatic arc; 2) partial melting of this crust and intrusion of batholithic granite bodies; 3) widespread, dispersed generation of calc-alkaline magmas that were extruded on the protocontinental crust and intruded into it; and 4) localized partial melting of the matured lithosphere and the production of coeval granite and rhyolite. Cole (1984d) has estimated from regional evidence that the respective episodes formed approximately 35, 15, 40, and 10 percent of the Proterozoic crust of the northeastern Shield.

The earliest episode is represented in this quadrangle by mafic metavolcanic rocks of the Dhiran meta-andesite and the coeval(?) mafic intrusive rocks of the Suwaj suite. These rocks, designated the Dhiran-Suwaj terrane (Cole, 1984a), are interpreted to have formed together in an ensimatic magmatic arc at a convergent plate boundary between about 700 and 670 Ma (Cole and Hedge, 1985, unpub. data). This primitive crust was regionally folded along northerly trends, thickened, and metamorphosed during an orogenic event, and the debris shed from this uplift was deposited in north-trending basins to form the Murdama group. The end of this first crust-forming episode is marked by regional folding of the Murdama sediments, and is inferred to pre-date about 655 Ma (Cole, 1984d; Cole and Hedge, 1985, unpub. data).

Rocks formed during the second episode are defined as the Khishaybi suite (Cole and Bohannon, 1985a) and crop out along the eastern quadrangle border. These leucocratic rocks consist chiefly of biotite monzogranite and syenogranite and form several elongate batholithic intrusions that are exposed over thousands of square kilometers east and south of this quadrangle (Cole and Hedge, 1985, unpub. data). Evidence from the adjoining An Nabhaniyah quadrangle indicates the Khishaybi granites may have formed in part by large-scale partial melting of the Dhiran-Suwaj terrane (Cole and Bohannon, 1985a). The Khishaybi intrudes sediments of the Murdama group but its absolute age and relation to younger layered rocks are unknown.

A pronounced, regional unconformity surface above the Murdama group and the Dhiran-Suwaj terrane marks a period of erosion that pre-dates the third major crust-forming episode. Voluminous calc-alkaline andesite and minor dacite of the Jurdhawiyah group were extruded on this surface and deposited in several fault-bounded, epicontinental basins along with abundant volcaniclastic conglomerate and sandstone that were eroded from contemporaneous volcanic piles (Cole, 1984a, d). The Jurdhawiyah group deposits are inferred to be younger than the Khishaybi suite granites because the layered rocks are not intruded by them, although the relationship has not been firmly established. Both the Jurdhawiyah and the Khishaybi, however, are widely intruded by numerous elliptical bodies of calc-alkaline granodiorite and related diorite and granite of the Idah suite (Cole, 1984a, d), which was emplaced during a brief interval between about 620 and 615 Ma (Cole and Hedge, 1985, unpub. data). On the basis of similarity in composition and compositional range, Cole (1981, 1984a, d) concludes the Jurdhawiyah group and the Idah suite originated from similar sources at about the same time, and they together comprise the third major episode of crust formation.

The last major Proterozoic events of this region follow a protracted interval of uplift and erosion during which the crust of the northeastern Shield adjusted (isostatically) to the preceeding, widespread intrusion of the Idah suite (Cole, 1984a, d). Beginning at about 585 Ma, evolved granitic magmas were generated at dispersed sites and intruded to high levels in the crust and locally into coeval deposits of rhyolite. This latter situation is documented in this quadrangle by the Samra rhyolite and the subjacent intrusive rocks of the Asmar complex. Similar granites in the region are defined in this report as the Abanat suite, and they were emplaced between about 585 and 570 Ma in the northeastern Shield (Stuckless and others, in press; Cole and Hedge, 1985, unpub. data).

PROTEROZOIC LAYERED ROCKS

Volcanic and sedimentary rocks are exposed in about two-thirds of the Al Abanat quadrangle and are mapped and distinguished from each other on the basis of lithology and position relative to three major unconformities. Rocks mapped with the Dhiran meta-andesite, the Murdama group, and the Jurdhawiyah group are classified according to the definitions established by Cole (1984a) in the adjoining quadrangle to the west. Sparse outcrops of layered rock beneath the Murdama group on the west flank of Jibal Zalma (Aban al Asmar) are correlated with the Mafic granulite unit defined by Cole and Bohannon (1985a) in the area to the east on the basis of lithologic similarity and stratigraphic position. The youngest layered rocks in the quadrangle are defined in this report as the Samra rhyolite.

Descriptive terminology for clastic and chemical sedimentary rocks is based on the classification scheme of Folk (1968). The lithologic terminology for volcanic rocks is based on normative mineralogy (Irvine and Baragar, 1971) calculated from existing chemical data (Cole, 1982, 1984c) or, in the absence of such data, on phenocryst content (Streckeisen, 1978). Textures and names for pyroclastic rocks are based on the definitions of Fisher (1961, 1966) and Fisher and Schmincke (1984). In the following descriptions, "epidote" refers to any of the minerals epidote, zoisite, or clinozoisite; and "calcite" refers to all common carbonate minerals.

The Dhiran meta-andesite and the Mafic granulite unit contain the only regionally metamorphosed rocks in the quadrangle; the Dhiran is variably schistose and recrystallized to blastic assemblages of greenschist-grade minerals but primary textures are generally preserved, whereas the Mafic granulite contains no relict minerals or textures and consists chiefly of anhydrous phases. Primary minerals in the Murdama and Jurdhawiyah groups and in the Samra rhyolite are altered and (or) replaced by chlorite, epidote, calcite, and quartz, but the textures and mineral assemblages are consistent with diagenetic alteration (Schiffman and others, 1984) and they are not described as metamorphic rocks. Contact metamorphic effects are notable at the margins of most of the younger intrusions, as described below.

DHIRAN META-ANDESITE

The oldest layered rocks in the Al Abanat quadrangle are mapped as the Dhiran meta-andesite (Cole, 1984a), which contains member-rank sub-units of schistose sodic metadacite and marble, and sparse biotite-hornblende schist. These rocks south of Wadi ar Rumah were originally mapped with foliated intrusive rock as the Saydun formation of Muller (1975), but this term has been abandoned. The internal stratigraphy of the Dhiran has been disrupted by deformation and metamorphism. The subdivisions are described below in order of decreasing abundance, and no stratigraphic position is implied.

The Dhiran crops out in the southwestern part of the quadrangle, south of the Ata fault, where it is widely intruded by Foliated quartz diorite of the Suwaj suite. It is unconformably overlain by the Jurdhawiyah group at several localities in this quadrangle, and it is also overlain by the Murdama group, although that relationship is best displayed in the area immediately to the west (Cole, 1984a).

Most of the Dhiran consists of dark green to black, fractured and weakly schistose metavolcanic rock (da) that has the approximate composition of andesite (Cole, 1984b, c). Bedding and primary structures are generally absent, but the original volcanic texture of the rock is indicated by sparse phenocryst relics (pyribole and minor plagioclase), by common amygdules and zones of amygdular rock, and by alternations of massive and autoclastically brecciated flow rock. Outcrops typically display irregular, braided seams of granulated and recrystallized rock that are rich in secondary quartz, epidote, and chlorite; these seams are variably oriented, but locally define a weak foliation where they are sub-parallel.

Primary igneous textures are variably preserved in the meta-andesite, but the minerals have completely recrystallized to assemblages of porphyroblastic chlorite, epidote, and calcite, acicular (but weakly oriented) actinolite, and granular quartz, sodic plagioclase (oligoclase), and sphene. Relict plagioclase phenocrysts are unzoned and variably replaced by epidote, sericite, and calcite, and probably lost calcium during recrystallization. Original mafic phenocrysts are totally replaced by actinolite, chlorite, epidote, and sphene but are inferred chiefly to have been hornblende on the basis of preserved cleavage traces. Sparse primary augite is preserved in a few samples.

The meta-andesite contains sparse, unmapped bodies of biotite-hornblende schist in the area of Al Ukhaydirat. Some mafic rocks in the Dhiran are coarsely crystalline and sub-equigranular, and resemble the Diorite and Metagabbro units of the Suwaj suite; they probably represent thin sills or dikes.

Sodic metadacite member

Schistose, phenocryst-rich rocks of the Sodic metadacite member (dq) regionally comprise about 10 percent of the Dhiran (Cole, 1984a). However, the only occurrence of this member in the Al Abanat quadrangle is at lat 25°44' N. on the western boundary. The map pattern is generalized because the original contact between sodic metadacite and meta-andesite has been structurally disrupted (Cole, 1984a).

The rock is characterized by its gray-brown color, well developed chlorite-muscovite schistosity, and by the presence of 30 to 40 percent relict phenocrysts of sodic oligoclase (2 to 4 mm in diameter) and sparse, embayed quartz. Mafic minerals (or their relics) are very rare and potassium feldspar makes up less than about 5 percent of the rock. In addition to the fine-grained and oriented chlorite and muscovite, the matrix consists of granular quartz, sodic plagioclase, epidote, and sphene, and irregular porphyroblastic calcite.

Marble member

A singular, irregular bed of pink-gray to rose-brown siliceous marble (dm) is mapped within the Dhiran south of Dib Khulayf and about one kilometer west of the Ata fault. Discontinuous pods and lenses of marble are present in the Dhiran in the quadrangle to the west as well (Cole, 1984a), and they are locally associated with thin bodies of hornblende schist.

The marble bed contains rootless, isoclinal folds and a faint foliation defined by alternating cm-scale layers that are rich in quartz or calcite. This planar fabric is brecciated and the resulting fragments are separated by veins of sparry, white calcite. Sparse, fractured grains of magnetite are present in the marble and suggest a similarity to listwänite within the Ata fault, but this marble unit appears to be structurally isolated within the Dhiran.

MAFIC GRANULITE

High-grade metamorphic rocks that consist chiefly of anhydrous calc-silicate minerals are exposed as irregular and discontinuous inclusions in the Hamar granite in the An Nabhaniyah quadrangle to the east, where they are defined as the Mafic granulite unit (gnl; Cole and Bohannon, 1985a). Typical granulites in that area consist of mosaic grains of labradorite, diopside, sphene, quartz, and calcite, with variable amounts of scapolite, orthopyroxene, garnet, or epidote, depending on bulk composition.

Mafic granulite in this quadrangle crops out only on the west side of Jibal Zalma. These rocks are fine- to medium-grained and granular but contain 2- to 10-cm layers defined by variations in grainsize and composition. This layering describes irregular to isoclinal folds at the scale of the outcrop and a broad antiform that appears to plunge toward the north. The Mafic granulite unit is inferred to underly the Murdama group to the west because of its discordant structure, its significantly higher metamorphic grade, and because the Murdama locally contains clasts of similar rock, but the unconformity is not exposed. The age relation of the Mafic granulite unit and the Dhiran meta-andesite is not known because the two crop out in separate areas.

Mafic granulite west of Jibal Zalma consists of about 75 percent porphyroblastic scapolite, 15 to 20 percent equant diopside, minor amounts of calcite, sphene, wollastonite, apatite, and pyrite, and a trace of vesuvianite. The absence of plagioclase is attributable to its complete replacement by scapolite in the presence of carbonate-rich fluid; partial replacement is common in the plagioclase-bearing rocks of this unit east of Aban al Asmar (Cole and Bohannon, 1985a). The presence of wollastonite+diopside and the absence of free quartz in the rocks of the Jibal Zalma area indicate higher metamorphic tempertures than the typical plagioclase+diopside+calcite+quartz assemblage of this unit (Winkler, 1974).

MURDAMA GROUP

Fine-grained marine sedimentary rocks correlated with the Murdama group, as defined by Cole (1984a), are exposed in about half of the Al Abanat quadrangle. The basal unconformity of the group is rarely exposed in this quadrangle but exposures in the area to the west clearly show that the Murdama rests on the Dhiran meta-andesite and contains abundant cobbles derived from the Suwaj intrusive suite. The Timiriyat conglomerate and the Limestone unit are discontinuous but characteristically form the lower part of the group (Cole, 1984a).

The Murdama in the Al Abanat quadrangle is interpreted to have been deposited in two discrete basins, separated by a paleo-ridge of Dhiran-Suwaj rocks (fig. 2). North of Wadi ar Rumah, the main Maraghan basin includes all of the Murdama north of the Ata fault, west of the unconformity above the Mafic granulite unit at Jibal Zalma, east of the Bakrah arch (Darat al Jibu area), and north into the adjoining quadrangle (du Bray, in press). The northern part of the smaller Jarir North basin is exposed in the vicinity of Al Lughfiyah in the southwestern corner of the Al Abanat quadrangle (fig. 2).

The Murdama group consists of three formations. In this quadrangle and throughout the northeastern Shield, the Sandstone unit is dominant and consists of fine-grained, thinly bedded, calcareous feldspathic volcanic arenite. The basal Timiriyat conglomerate is sparsely preserved along the margin of the Jarir North basin but has not been identified in the Maraghan basin. The Limestone unit is exceptionally thick at the margin of the Jarir North basin but is very rare in the Maraghan basin. These features emphasize the individualistic depositional histories and resulting stratigraphic successions in the various Murdama basins; the following sections describe the formation-rank Murdama units as they are exposed in each of the basins.

The age of the Suwaj suite indicates the Murdama group is no older than about 670 Ma and the group is probably no younger than about 655 Ma, based on the apparent age of quartz diorite that intrudes it (Muwashsham pluton of Johnson and Williams, 1984) 30 km north of this quadrangle (Cole and Hedge, 1985 unpub. data). The Murdama group is unconformably overlain by the Jurdhawiyah group on the north flank of Jibal Zalma, north of Al Lughfiyah, north of Jabal Idah, and at numerous other localities in the northeastern Shield (Cole, 1984d).

Timiriyat conglomerate

Coarse, polymict conglomerate at and near the base of the Murdama group was defined as the Timiriyat conglomerate (Mtc)(Cole, 1984a). Similar rock in equivalent stratigraphic position in this quadrangle has only been identified in a few localities in the southwestern part of the quadrangle, near Al Lughfiyah village. These deposits mark the northern preserved margin of the Jarir North depositional basin. The original thickness of the unit is unknown because the base is not exposed and because post-depositional slip on the reverse faults of the Lughfiyah-Shuhban system (fig. 2) have disrupted the section.

Undeformed Timiriyat conglomerate is preserved in low outcrops along the northwestern margin of the playa lake basin northwest of Al Lughfiyah. The contact with the overlying Limestone unit is covered by coarse colluvium, but bedding in the two units is generally conformable. The conglomerate consists of well sorted and rounded granules and rare pebbles in a sparse sandy matrix; bedding is weakly defined by variations in average clast size and degree of sorting. Most clasts consist of textural varieties of meta-andesite, and other materials include quartz, felsic metavolcanic rock, epidote and epidote aggretgates, and plagioclase. Rare clasts of quartz-orthoclase granophyre are also present and are the only Timiriyat detritus that contain potassium feldspar.

All clasts in the Timiriyat are altered to assemblages of sericite, chlorite, epidote, quartz, and calcite, although detrital epidote indicates some of the alteration took place in the source terrane. Much of the original intraclast void space is filled with granular chlorite and sparse epidote.

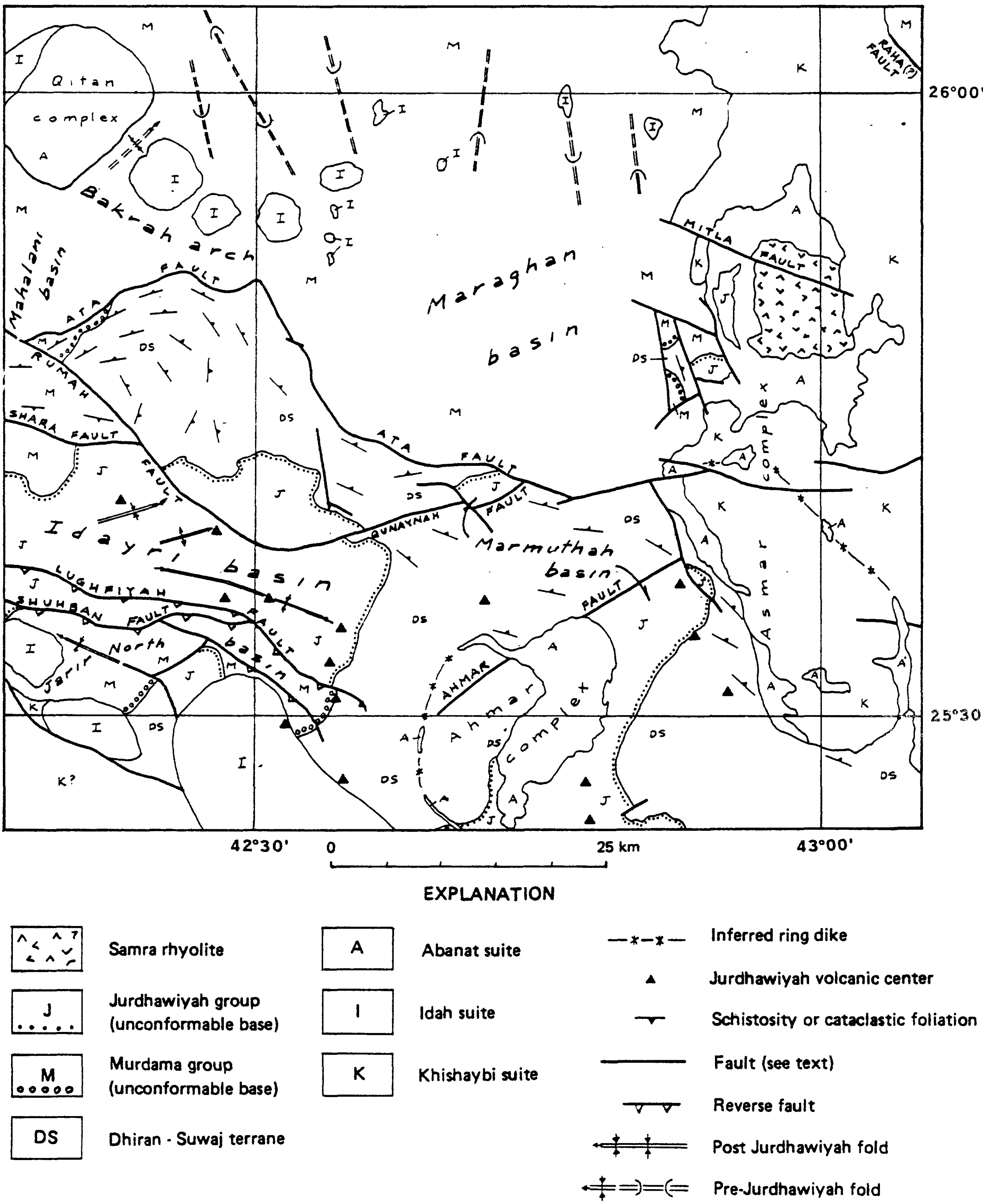

Figure 2.--*Simplified structural sketch map for the Al Abanat quadrangle and surrounding areas.*

The conglomerate beneath the Limestone unit in the hanging-wall block of the Lughfiyah fault is similar to the foregoing description in terms of clast lithology and alteration mineralogy, but it contains more pebbles and cobbles and a few meter-scale blocks of folded silicic volcanic rock. The conglomerate at this site also has a moderate chlorite-muscovite schistosity that is roughly parallel to the contact with the overlying beds of the Limestone unit.

Limestone

Well bedded, siliceous calcite limestone (Ml) forms a thick unit near the base of the Murdama group at the northern margin of the Jarir North depositional basin (fig. 2) that is continuous for more than 10 km to the west in the hanging-wall of the Lughfiyah-Shuhban fault system (Cole, 1984a, d). In this quadrangle, the Limestone unit appears to rest conformably on Timiriyat conglomerate, but unconformably overlies Dhiran meta-andesite a few kilometers to the west (Cole, 1984a).

The Limestone unit west of Al Lughfiyah village consists of two thick, lower beds (each about 70 m) that are brown to black and pervasively recrystallized. Above these beds, alternating layers of limestone and impure limestone (several millimeters to tens of centimeters thick) are more typical and are tan, dark brown, gray, and blue-white. The original depositional thickness of the Limestone unit is unknown because disharmonic contortions and isoclinal folds are common, but its geometric thickness is about 1500 m.

Most limestone consists of granular micrite with varying amounts of clastic quartz, plagioclase, and rock fragments (felsic volcanic rock, Murdama sandstone, granophyre, and rare meta-andesite). These contaminants locally form the nucleii for ooliths that are concentrated in beds. Coarse, sparry calcite fills sigmoidal veins and minor gash fractures at various places throughout the unit, but is particularly common in proximity to the major faults. North and east of Jabal Idah, the limestone has largely recrystallized to mosaic-granular, white to pale blue calcite marble as a result of contact heating by the Idah suite granodiorite porphyry pluton; calc-silicate minerals were not detected.

The rocks in the hanging-wall block of the Lughfiyah fault (fig. 2) exposed in the hill immediately north of Al Lughfiyah village show some additional features of the Limestone unit that are too small to depict at the scale of the map. The limestone here is intensely fractured and veined by sparry calcite, and it contains several lensoid blocks (approximately 1 to 15 m in long dimension) of non-carbonate materials that are interpreted as disrupted segments of competent, bedded or intrusive rocks. Several blocks consist of calcite-cemented pebble conglomerate; the pebbles are very well rounded and sorted and consist wholly of silicic volcanic rock and quartz. Other blocks consist of red-brown, internally contorted, microcrystalline rhyolite(?); the contortions appear to have formed during flow of the rhyolite magma (into dikes, sills, or subareal flows) and not as a result of disruption within the limestone, because the fabric in the rhyolite blocks is not conformable with the enclosing limestone fabric.

In the Maraghan basin, limestone is only mapped in two thin layers northeast of Thadij village. These beds are blue-gray, laminated, sparsely oolitic, and contain about 10 percent detrital plagioclase and volcanic rock fragments. The enclosing Murdama sandstone contains abundant calcite cement, which implies stratigraphic proximity to the base of the group, as deduced by Cole (1984a) from the geology of the Bakrah arch (fig. 2).

Sandstone

The Sandstone unit of the Murdama group (Ms) forms the overwhelming bulk of the deposits in the Maraghan basin, north of Wadi ar Rumah, and is continuous in outcrop across the Bakrah arch with deposits in the Mahalani basin of the adjoining quadrangle to the west (fig. 2; Cole, 1984a). Sandstone is not mapped in the Jarir North basin in this quadrangle, but it interfingers with and overlies the Limestone unit to the west and south (Cole, 1984a, d).

The sandstone is poorly exposed throughout the quadrangle due to pervasive centimeter-scale fracture, fine-scale laminar bedding, variable calcite cement, and modern disruption by deposition of gypsum in near-surface veins. In the broad, sparsely drained areas of Iblat Utayy and Iblat Ata, outcrop is largely absent and float fragments are generally less than a few centimeters in diameter; many observations of sandstone in the Maraghan basin are based on examinations of modern trench excavations and spoil piles at water wells.

Bedding in Murdama sandstone is thin, planar, and continuous, where observed. Linear outcrop ridges and hollows are characteristically parallel to the measured strike of bedding, and some resistant beds (particularly near Darat al Jibu) can be traced continuously for several kilometers. The pattern indicated on the geologic map for "trace of bedding" is based on these data and indicates that regional bedding in the Maraghan basin is irregular, disharmonious, and not systematic, and probably the result of soft-sediment folding during deposition (Cole, 1984a).

Sandstone is fine- to medium-grained, immature, calcite-cemented volcanic arenite and is characteristically pale green to brown-green on fresh and weathered surfaces. The four dominant clast materials (in order of decreasing abundance) consist of: 1) meta-andesite (microporphyritic or trachytic varieties with abundant plagioclase crystals and chlorite-epidote pseudomorphs of mafic grains); 2) felsic volcanic rock fragments (microcrystalline quartz-plagioclase aggregates with relict eutaxitic, spherulitic, and felted textures); 3) broken plagioclase grains; and 4) quartz and "granitic" rock fragments (phaneritic aggregates of quartz and plagioclase and(or) potassium feldspar, and quartz-orthoclase granophyre). As a very general average, these four clast types make up about 45, 35, 10, and 10 percent of the rock, respectively. Limestone fragments and detrital biotite and epidote grains are locally present in amounts of 1 to 5 percent, but potassium feldspar, hornblende, and pyroxene grains are virtually absent.

Post-depositional alteration is widespread in the Sandstone unit, although it is not always possible to distinguish these effects from source-terrane alteration (in particular, within-clast replacement by chlorite, epidote, and sericite). Calcite is the most common alteration product and replaces the matrix and clasts, and locally makes up as much as 50 percent of the rock. Cubic pyrite grains (altered to iron oxide) are disseminated throughout the rock and are distinctive in outcrop. Thin, irregular veins filled with combinations of quartz, calcite, epidote, and chlorite are common and locally abundant. Murdama sandstone locally possesses a weak compaction fabric (aligned long-axes of clasts and braided intergranular films of chlorite and sericite) that produces a weak sheen on parting surfaces, and some thin quartz veins are ptygmatically folded perpendicular to this fabric. This is not a metamorphic fabric, however, because chlorite and sericite are bent and not aligned, and the clasts do not appear to be deformed.

A contact-metamorphic zone several hundred meters wide surrounds intrusions of the Idah suite. Hornfelsed sandstone is dark green to dark brown, indurated, and more resistant to erosion than elsewhere, and it contains disseminated brown biotite, granular magnetite, and sparse porphyroblastic cordierite. Similar effects are present near intrusions of the Khishaybi and Abanat suites, although the contact zone is generally narrower.

JURDHAWIYAH GROUP

Layered rocks of the Jurdhawiyah group are exposed chiefly in the southern part of the quadrangle and consist of andesite and dacite flow rock and flow breccia, abundant volcaniclastic conglomerate and sandstone, and sparse beds of tuff and polymict conglomerate. Cole (1984a) defined the Jurdhawiyah and its subdivisions from the adjoining area to the west; correlation to the outcrops in this quadrangle are firmly established from continouus outcrop and lithostratigraphic similarity of the units.

The base of the Jurdhawiyah is marked by a regional unconformity that truncates the Dhiran-Suwaj terrane and folded beds of the Murdama group. This surface is generally planar but local undulations of several tens of meters to a maximum of about 250 m are common. The trace and orientation of the unconformity and the distribution of the Polymict conglomerate member (derived from pre-Jurdhawiyah sources) indicate the Jurdhawiyah was deposited in two discrete basins in this quadrangle. The Idayri basin (fig. 2) is a simple synclinal structure that extends westerly from Nufud al Urayq for a distance of at least 50 km (Cole, 1984a, d). The Marmuthah basin (fig. 2) is defined by the Jurdhawiyah deposits at Samra Khaytan, Jibal al Qunaynah, and possibly Jibal Zalma that outline a southwest-trending trough that extends beyond the quadrangle (Cole, 1981, 1984d). Although the Idayri basin is largely preserved intact, the Marmuthah basin is divided by a horst of Dhiran-Suwaj rock that was uplifted along the Ahmar and Qunaynah faults, and is intruded by the Ahmar complex.

The subdivisions of the Jurdhawiyah group are established by lithologic homogeneity, local stratigraphic relations, and utility as reconnaissance map units. The group is regionally characterized by lateral and vertical lithologic variation and consists of overlapping and interbedded lensoid sheets of the various rock types. Therefore, the subdivision units of the Jurdhawiyah do not form a simple stratigraphic sequence in individual sections, within depositional basins, nor between basins.

The following order of description does imply a strict depositional chronology for the units, but it is based on their general stratigraphic tendencies (Cole, 1984a, d). The Andesite unit typically occupies a near-basal position in the group, and the Polymict conglomerate member and the Volcaniclastic conglomerate unit are also most abundant near the base of msot sections. The Volcaniclastic sandstone unit is thin but persistent near the base of the Marmuthah basin (Samra Khaytan area and south; Cole, 1981), although it is most common and thickest in the upper part of the Idayri basin (Cole, 1984a). Thin beds of the Lapilli tuff member are present at various stratigraphic positions within the group.

The Jurdhawiyah is younger than the Murdama group and older that the Idah suite (Cole, 1984a, d), but its age relative to the Khishaybi suite (Cole and Bohannon, 1985a) has not been firmly established because the two units are not in contact. The Khishaybi was inferred to be younger by Cole (1981; biotite monzogranite unit), chiefly because the Polymict conglomerate member of the

Jurdhawiyah lacks clasts that are as felsic as the Khishaybi granites. This report and the regional synthesis by Cole and Hedge (1985 ...) conclude that the Khishaybi is older than the Jurdhawiyah, and that the absence of clasts in the Polymict conglomerate member only indicates the Khishaybi was not unroofed during Jurdhawiyah deposition.

Andesite

The Andesite unit (Ja) consists of hornblende and augite andesite and minor hornblende dacite that make up a small part of the Jurdhawiyah group in this quadrangle. The greatest section of flow rock and flow breccia is located north of the Al Khaymah mineral locality, where it appears to fill a broad paleochannel at the base of the group. Typical andesite contains abundant phenocrysts of plagioclase, pyroxene, and amphibole and is locally amygdaloidal, structureless, or autoclastically brecciated. These features are well displayed by the thin beds at Jibal al Qunaynah, the isolated hills southeast of Mazari al Jarrariyah, and at Jabal Bidan near the western quadrangle boundary.

About half of the Andesite unit is flow breccia that consists of angular blocks in a fine-grained, igneous andesite matrix. Flow breccia is difficult to distinguish from volcaniclastic conglomerate in outcrop because of matrix alteration and similar weathering characteristics. However, clasts in flow breccia are generally more uniform in terms of composition and texture than those in the Volcaniclastic conglomerate unit, and breccia can locally be identified by the presence of amygdules in the matrix. Andesite flows are generally structureless, but relict bedding can be inferred from amygdaloidal zones and from contacts between brecciated and non-brecciated rock.

Andesite is typically dark brown and brown-green and coated with thick desert varnish. Phenocrysts (3-15 mm in diameter) make up 5-25 percent of the rock and consist of augite, augite-plagioclase, augite-plagioclase-hornblende, hornblende-plagioclase, and (rarely) plagioclase alone. Magnetite is a ubiquitous phenocryst and hypersthene is locally present in the more mafic andesites (Cole, 1982, 1984c), but these minerals are rarely identifiable in hand specimen.

Labradorite-andesine is the typical phenocryst plagioclase and many crystals have a spongy form due to globular inclusions of primary melt; normal and delicate oscillatory zoning are characteristic. Augite is pale green to colorless, equant, euhedral, and fresh, whereas hypersthene is generally replaced by serpentine and chlorite. Phenocryst hornblende is strongly colored (red-brown or locally brown-green), pleochroic, and subhedral and many crystals are surrounded by a reaction rim of augite and magnetite.

The matrix of both the andesite flow rock and the matrix of flow breccia consists of tabular plagioclase, granular pyroxene, disseminated magnetite, and various recrystallization products (epidote, chlorite, calcite, and rare sphene and quartz). Relict vesicles are most commonly filled by concentric layers of quartz, epidote, and chlorite and (locally) by irregular patches of calcite or andradite garnet.

Volcaniclastic conglomerate

Most of the Jurdhawiyah group in this quadrangle consists of poorly bedded, poorly sorted pebble to boulder conglomerate (Jc). Clasts are texturally varied but fairly uniform in composition and consist of several kinds of fresh andesite, porphyritic intrusive rocks (andesite and dacite composition), and tuff. Because it is generally not feasable to determine the process of clast fragmentation (volcanic versus epiclastic), use fo the descriptive term "volcaniclastic" follows the definition of Fisher (1966).

Bedding within the unit is poorly defined by variations in average clast size and degree of sorting; better evidence is obtained from thin, lensoid sheets of interbedded volcaniclastic sandstone. Individual conglomerate beds (2-20 m thick) are continuous for hundreds of meters to several kilometers along strike. Clasts range from very angular to subrounded and are typically 5-20 cm in diameter, although boulders 60-120 cm in diameter) are not uncommon; rounding increases with clast size. Sorting is typically poor throughout the unit, but individual beds are characterized by a more limited range of clast sizes.

Clasts consist of porphyritic, amygdaloidal, fragmental, aphanitic, and tuffaceous materials whose composition and textures are similar to rocks in the Andesite and Lapilli tuff units and to the Plagioclase porphyry unit of intrusive rocks. Clasts and matrix are generally green and brown-green; red-brown fragments are less common. Near basin margins, volcaniclastic conglomerate may contain 5-10 percent clasts of Murdama sandstone, Suwaj intrusive rocks, and(or) Dhiran meta-andesite. Conglomerate in the footwall block of the Lughfiyah fault north of Al Lughfiyah village contains notable clasts of Murdama limestone (about 10 percent) and sparse cobbles recycled from the Timiriyat conglomerate.

Alteration is variable within the matrix and from clast to clast, and indicates some of the alteration occurred prior to deposition. All alteration is minor, however, and consists of sparse chlorite, epidote, calcite, and minor granular sphene.

Polymict conglomerate member.--Cole (1984a) defined the Polymict conglomerate member for distinctive conglomerate beds that contain at least 25 percent clasts of pre-Jurdhawiyah rock. The outcrop characteristics of this member are similar to those of the Volcaniclastic conglomerate unit; the geologic map indicates beds of polymict conglomerate only where they were clearly identified. Additional beds may be present elsewhere, but the known distribution indictes the Polymict conglomerate member is only typical of the lower few hundred meters of the Jurdhawiyah group (Cole, 1984a, d). In this quadrangle, the best exposures are located at the eastern foot of the Samra Khaytan ridge at the margin of the Marmuthah basin (fig. 2). A thin boulder bed was also identified on the northern margin of the Idayri basin, south of the Mibari mineral locality.

Bedding, sorting, and clast rounding characteristics of the Polymict conglomerate member are similar to those described for the Volcaniclastic conglomerate unit, and typically 50 percent of the clasts consist of Jurdhawiyah andesite and lapilli tuff, and rocks of the Plagioclase porphyry unit. At Samra Khaytan, polymict conglomerate crops out at the base of the group in an irregular bed 5-25 m thick; several similar layers are present a few hundred meters higher in the section. The dominant pre-Jurdhawiyah clasts here consist of Suwaj quartz diorite, tonalite, and sparse granodiorite and Suwaj dike rocks (see also Cole, 1981). Polymict conglomerate south of the Mibari locality is exposed only as a bouldery rubble that contains clasts of Suwaj quartz diorite and cataclastic granophyre, Dhiran meta-andesite, and sparse Murdama sandstone.

Volcaniclastic sandstone

Medium- to coarse-grained sandstone and pebbly sandstone comprise the Volcaniclastic sandstone unit (Js) and make up a minor part of the Jurdhawiyah group in this quadrangle. The sandstone forms mappable, well bedded, lenses that are several hundred meters thick, contain interbedded lenses of volcaniclastic conglomerate (2-20 m thick), and that generally interfingew with the conglomerate. Volcaniclastic sandstone is thickest and most continuous near the base of the Marmuthah basin (below the Samra Khaytan ridge) and along the north side of the Idayri basin at the western quadrangle boundary (Cole, 1984a).

Bedding within the sandstone is generally planar, regular, and continuous for hundreds of meters to several kilometers along strike. Typical beds are 5-20 cm thick (rarely, one meter) and locally display millimeter-scale laminations, although internal uniformity is more common. Graded beds and cross-stratification are rare. Facing directions are commonly indicated by channels in the bottoms of sandstone beds and by shallow channels filled with overlying volcaniclastic conglomerate. Rain-drop imprints indicate periods of subaerial deposition and are particularly common on the tops of laminated, tuffaceous siltstone beds in the southern Marmuthah basin. Observations of these features throughout the region consistently indicate the Jurdhawiyah group is right-side-up, and are inconsistent with Muller's interpretation that the Jurdhawiyah east of Aban al Ahmar forms an overturned syncline.

Volcaniclastic sandstone (immature andesite arenite and feldspathic andesite arenite) is typically pale green to pale brown, coarse to medium grained, and moderately to poorly sorted. Clasts are angular to sub-angular in the sand-sized fractions, but disseminated pebbles and cobbles are sub-rounded. Most clasts consist of volcanic rock fragments similar to those described for the Volcaniclastic conglomerate unit, and detrital hornblende, augite, and plagioclase are also common (derived from porphyritic volcanic and hypabyssal intrusive rocks). Rare detrital quartz and plutonic rock fragments have only been identified from beds at the base of the Jurdhawiyah group. Volcaniclastic sandstone is cemented by chlorite and granular epidote and by sparse calcite.

Lapilli tuff member.--Pyroclastic volcanic rocks form thin, continuous beds at various positions within the Jurdhawiyah group and are defined as the Lapilli tuff member by Cole (1984a). These beds are chiefly andesitic throughout the region (based on phenocryst compositions; see Cole, 1984a), although dacitic tuff is present south of the Al Khaymah ancient mines near the western quadrangle boundary. Lapilli tuff is interbedded with the Volcaniclastic sandstone and conglomerate units.

Andesitic lapilli tuff may be more common than indicated on the geologic map because its color and outcrop style are similar to the Volcaniclastic conglomerate unit. Dacitic tuff, however, is typically red-brown or orange-red and forms conspicuous marker beds. All tuff beds are 3-20 m thick and consist of 10-30 percent lapilli-sized, variably flattened, pumice fragments in a matrix of ash-sized pyroclasts and phenocrysts of plagioclase, hornblende, and rare augite.

Welding is generally weak in the tuff beds and a pervasive planar fabric is not typical (Cole, 1984a, d). Relict shards and pumice fragments are slightly flattened and molded onto each other, onto phenocrysts, and onto lithic fragments. Post-emplacement alteration, other than devitrivication, is also slight and is most typically indicated by sparse chlorite, calcite, and clay(?) minerals in the groundmass.

SAMRA RHYOLITE

Recrystallized rhyolitic volcanic rocks are exposed in the central, highest parts of the Aban al Asmar mountains and are defined in this report as the Samra rhyolite. The name is derived from Jabal as Samra, located on the eastern quadrangle boundary between the right-hand (al Ayman) and left-hand (al Aysar) upstream tributaries of Shaib al Mitla. The base of the Samra is not exposed (intruded by the Asmar complex) and the top is eroded, but the minimum thickness is estimated to be about 1500-2000 m from bedding geometry.

The Samra rhyolite is interpreted to be comagmatic with the intrusive rocks of the Asmar complex because: 1) it is only exposed in proximity to the complex; 2) it is thickest within an interpreted caldera boundary; and 3) it is chemically and mineralogically similar to the rocks of the Asmar complex. Samra rhyolite (73-77 percent silica) is weakly peraluminous and enriched in fluorine, lithium, rubidium, beryllium, and (locally) zinc (Stuckless and others, 1982a; Cole, 1984c; Cole and Bohannon, 1985b). On the basis of general compositional traits and inferred age, the Samra is similar to the Humaliyah formation 90 km to the west (Cole, 1984a) and possibly to the Raha formation 60 km to the north (du Bray, in press; Johnson and Williams, 1984).

Typical Samra rhyolite forms blocky, fractured outcrops that are black or very dark red-brown due to thick desert varnish. Primary bedforms are rare and difficult to detect because of the pervasive and variable joint sets. Faint, planar fabric that is parallel to sparse flattened lapilli or to elongate gas cavities is inferred to represent bedding. At outcrop scale, bedding is also inferred from faint color boundaries and ledges that mark discontinuities in the trend or orientation of joint sets. From these features, bedding in the Samra describes a crudely circular basin within Aban al Asmar, and most beds dip less than 20 degrees. Intrusive contacts with several members of the Asmar complex are generally parallel to inferred or measured bedding and suggest that magma invaded these planes of weakness during intrusion.

Fresh rhyolite is salmon-orange to brick-red, very fine grained, largely structureless, and contains 10-30 percent disseminated phenocrysts (0.5-3.0 mm in diameter) of orange orthoclase/sanidine and clear quartz. Fine-grained magnetite and biotite locally form phenocrysts, and albite and green hornblende are present in a few samples. Abundant, coarse-grained zircon and equant grains and irregular patches of fluorite are characteristic of the Samra, whereas apatite and sphene are rare. A few samples contain altered xenoliths of plagioclase-hornblende rock that resembles tonalite or diorite of the Suwaj suite.

The matrix of the Samra rhyolite consists of fine-grained quartz, orthoclase, albite, and accessory minerals and displays a wide variety of primary and recrystallization fabrics. The major minerals are commonly intergrown in an equigranular mosaic, although granophyric and myrmekitic textures are locally pervasive. Relict shards are rarely preserved. This widespread recrystallization of the Samra matrix (and the scarcity of primary bedforms) makes identification of the depositional process (extrusion versus pyroclastic flow) difficult. However, several well bedded layers of lapilli tuff and graded ash are exposed north of Jibal al Mishanniyah and are enclosed within more typical, structureless rhyolite. Their presence suggests most of the Samra was deposited as uniform, crystal-rich ash.

The Samra rhyolite is devitrified and recrystallized, but otherwise slightly altered. Quartz and the feldspars are fresh and biotite is moderately replaced by granular magnetite, muscovite, and sparse chlorite. Secondary fluorite is locally common and generally present in minor amounts. One sample collected north of the Mitla fault at the western margin of the contains abundant fluorite and irregular patches of probable topaz; the presence of topaz in hydrothermally altered rhyolite has been confirmed in samples from the adjoining quadrangle to the east (Cole and Bohannon, 1985a). Quartz veins are uncommon in the Samra but some contain primary muscovite and fluorite.

PROTEROZOIC INTRUSIVE ROCKS

Approximately one-third of the Al Abanat quadrangle is underlain by Proterozoic intrusive rocks that were intruded during five well defined Proterozoic magmatic events and range in composition from gabbro to leucocratic granite (Cole, 1984d; Cole and Hedge, 1985, unpub. data).The various intrusive rocks are distinguished from each other on the basis of bulk composition, mineralogy, texture, degree of deformation and alteration, magnetic signature, intrusion style, outcrop form, and contact relations with the major layered-rock units of the area. These rocks were mapped, classified, and described as sub-units of four regional intrusive suites that have been defined from age relationships to the layered rocks and from general similarities in the features listed (Cole, 1984a; Cole and Bohannon, 1985a). The youngest intrusive rocks of the region are classified within the Abanat suite, which is defined in this report.

The Suwaj suite (Cole, 1984a) consists chiefly of mafic rocks that intrude the Dhiran meta-andesite, are overlain by the Murdama group, and were emplaced approximately 690-670 Ma ago (Cole and Hedge, 1985, unpub. data).The Khishaybi suite (Cole and Bohannon, 1985a) consists of leucocratic, fine-grained biotite monzogranite and syenogranite that intrude the Murdama and are inferred to be older than the Jurdhawiyah group. The Idah suite (Cole, 1984a) consists of calc-alkaline-series granodiorite (and related diorite and granite outside this quadrangle) that intruded both the Murdama and Jurdhawiyah groups about 620-615 Ma ago (Cole and Hedge, 1985, unpub. data).The Abanat suite consists of leucocratic, evolved granitic rocks that were chiefly intruded 585-570 Ma ago (Stuckless and others, in press; Cole and Hedge, 1985, unpub. data)in composite plutons and ring structures.

The age relationships among these suites are clear and well established, but relative ages for the compositional sub-units of the suites cannot be stated in all cases because they commonly form discrete intrusions. Furthermore, relative age relations between two plutons cannot necessarily be inferred to apply throughout the geographic domain of the suite. Therefore, sub-units are described in the following sections in order of known relative age or, arbitrarily, from mafic to felsic within any suite. Dike rocks are difficult to classify because of their limited extent, but are described with their host plutonic rocks on the general assumption that they are cogenetic.

The abundant west-trending dikes that intrude the Murdama group in the Maraghan basin (fig. 2) could be related to either the Khishaybi suite or the Idah suite and thus are not differentiated on the geologic map. They are described with the rocks of the Khishaybi suite, however, because they do not intrude the Jurdhawiyah group. Numerous dikes and plugs of the Plagioclase porphyry unit and plugs of the Gabbronorite unit are interpreted to represent eroded conduit intrusions that fed the flows and pyroclastic deposits of the Jurdhawiyah group, and are described under the heading: Jurdhawiyah-contemporary intrusive rocks.

Rock compositions are stated according to the recommendations of the International Union of Geological Sciences by its Subcommission on Systematics of Igneous rocks (Streckeisen, 1976). Modal mineral content (determined from potassium-stained slabs) was modified in some cases to correct for fine-grained or granophyric groundmass intergrowths. Plagioclase in leucocratic rocks was checked in thin section and included with "alkali feldspar" for rock classification (Streckeisen, 1976), if average extinction angles were more negative than -10° (sections normal to {010} and {001}).

SUWAJ SUITE

The Suwaj suite includes the oldest intrusive rocks in the quadrangle and they are chiefly exposed in the region southwest of the Ata fault where they intrude layered rocks of the Dhiran meta-andesite. The Suwaj pre-dates deposition of the Murdama group, based on unconformity relations exposed in adjoining areas (Cole, 1984a, d) and based on common fragments of Suwaj-type granophyre in Murdama sandstone. The Suwaj suite is characterized by: 1) mafic composition (fig. 3); 2) low potassium content relative to rocks of similar silica content (Cole, 1982, 1984b, c); 3) moderate to strong alteration; 4) presence of cataclastic seams or pervasive fluxion structure; 5) distinctive magnetic signature; 6) scarcity of cogenetic dikes; and 7) poor exposure (Cole, 1984a).

Most recognized sub-units of the Suwaj (Cole, 1984d) are exposed in this quadrangle and they include the Metagabbro, Foliated quartz diorite, Diorite, Tonalite, and Granodiorite granophyre units and sparse dikes.

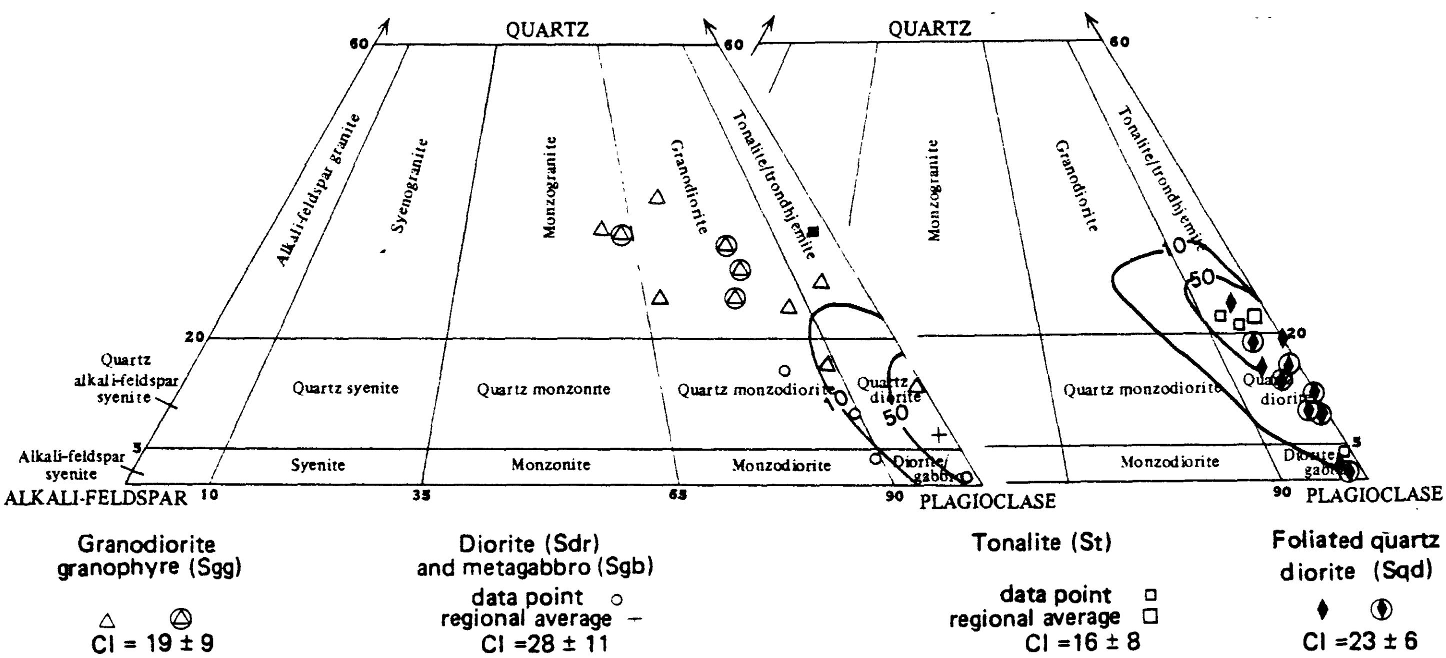

Figure 3.--*Modal composition diagram for rocks of the* Suwaj suite. *Analyses for the Al Abanat quadrangle (circled or indicated as data point) are compared to regional data for the suite (Cole, 1984d) and to regional average color index (CI; ± one-sigma standard deviation). For units with abundant analyses, contours enclose 10 and 50 percent of the population. Rock-name fields and triangle poles defined by Streckeisen (1976).*

Metagabbro

The black, conical hill west of Jibal Mihayyiwah consists of hornblende metagabbro (Sgb) that is assigned to the Suwaj suite on the basis of its deformation and alteration. It is intruded to the east by perthite granite of the Abanat suite, but its age relative to other Suwaj units is unknown. Altered hornblendite and hornblende gabbro are contained in quartz diorite on the east bank of Shaib Jarrar west of Mazari umm Arta (too small to indicate on map), and suggest that metagabbro is older than or coeval with the Foliated quartz diorite unit.

Metagabbro is dark green-brown, medium- to fine-grained, and consists of about 55 percent dark green hornblende, 35 percent anhedral, equant grains of andesine (local labradorite cores), minor brown biotite, and apatite and magnetite. The rock does not possess a primary or secondary foliation, but thin seams of granulated, recrystallized rock cemented by secondary epidote, quartz, and chlorite are common on the outcrop. The internal fabric of the metagabbro is weakly cataclastic, as indicated by crushed and bent grains. Plagioclase is widely replaced by saussurite, hornblende by actinolite, chlorite, and sphene, and biotite by chlorite and prehnite.

Foliated quartz diorite

The most widespread rock of the Suwaj suite in this quadrangle consists of biotite-hornblende quartz diorite (Sqd) that typically has a moderate to pervasive foliation defined by cataclastic fluxion structure (Higgins, 1971). It is exposed in a triangular area between the Ata fault, Al Lughfiyah village, and Shaib Jarrar and is probably the dominant bedrock beneath eolian sand of Nufud al Urayq, based on continuity of the magnetic fabric from exposed areas (ARGAS, 1967).

Foliated quartz diorite is probably included in (intruded by) the Tonalite unit west of Al Hinayniyah village, although the contact is not exposed. A short distance south of this quadrangle, Foliated quartz diorite is intruded by the Granodiorite and Granodiorite granophyre units of the Suwaj suite (Cole, 1981, 1984d). These observations and the more pervasive deformation of the Foliated quartz diorite unit indicate that it is one of the oldest Suwaj units. Zircon separated from a sample collected at the southern flank of Samra Khaytan defines a concordia-intercept emplacement age of 689±5 Ma (Cole and Hedge, 1985, unpub. data).

Rocks of this unit are generally exposed in small, isolated knobs and rocky plains and are typically gray-green in color. Intrusive contacts with rocks of the Dhiran meta-andesite are not well exposed, but are generally sharp and planar; xenoliths are rare and contact-metamorphic effects are not notable. The cataclastic foliation is defined by subparallel, steeply inclined, braided seams of crushed, granulated, and recrystallized rock that are 1-5 cm thick. In most localities, these seams separate lensoid blocks of less-deformed rock that are 5-10 cm thick, although the cataclasis is more widely spaced west of Aban al Ahmar and the extent of outcrop is much greater. Within several kilometers of the trace of the Ata fault, the foliation is locally more intense and plagioclase augen are contained in a pervasive planar fabric that is generally parallel to the fault trace.

Slightly deformed samples indicate that the original quartz diorite was medium grained, had a weak primary foliation defined by tabular plagioclase, and consisted of about 55 percent andesine, 23 percent hornblende (plus pyroxene?), 15 percent quartz, 0-5 percent biotite, and minor orthoclase, sphene, and magnetite. Figure 3 indicates the limited compositional range of this unit and the minor amount of orthoclase in all samples. Plagioclase and hornblende are both subhedral, whereas quartz is interstitial and tends to poikilitically enclose earlier minerals.

The deformed quartz diorite consists of fractured and bent grains of plagioclase, hornblende, and biotite that are locally granulated and elongate in the cataclastic fabric. Quartz forms irregular, lenticular aggregates of strained and undulatory grains. Moderate to intense alteration is typical: plagioclase is replaced by sericite, epidote, and calcite; hornblende by actinolite, chlorite, and secondary sphene; and biotite by chlorite and prehnite. Deformation probably overlapped with this alteration in part, because some of the secondary minerals are also bent and fractured.

Diorite

Melanocratic rocks of the Diorite unit (Sdr) are widespread in the Suwaj suite southeast of this quadrangle (Bohannon, 1984; Cole, 1984d), but are only exposed beneath the Jurdhawiyah unconformity in the vicinity of the Mibari South mineral locality. These rocks, and those in the Diorite unit a few kilometers west (Cole, 1984a) are compositionally and mineralogically similar to typical rocks of the unit in the region, but are generally fine-grained. The relative age of diorite in this quadrangle is unknown, but it is locally intruded by rocks of the Granodiorite, Granodiorite granophyre, and possibly the Tonalite units of the Suwaj elsewhere in the region (Cole, 1984d).

The diorite is exposed in low hills south of the Wadi ar Rumah channel. The rock is typically dark brown or brown-green, fine- to medium-grained, and equigranular to diabasic. Sparse, minute plagioclase phenocrysts are disseminated in a matrix consisting of about 65 percent plagioclase laths (indeterminate composition), 28 percent mafic silicate (totally replaced by chlorite, sphene, epidote, and minor scapolite), 5 percent equant magnetite, and a few percent intergranular quartz. Cataclastic seams are not as common in these rocks as in other units of the Suwaj suite.

Tonalite

Rocks of the Tonalite unit (St) crop out in low hills in the southeastern corner of the quadrangle and form the northernmost exposures of a large and homogeneous body of biotite-hornblende tonalite that extends for more than 40 km to the southeast (Cole, 1981, 1984d; Bohannon, 1984). Tonalite appears to intrude the Diorite unit in adjoining areas (Bohannon, 1984; Cole, 1984d) and post-dates the Foliated quartz diorite unit, but is intruded by the Granodiorite unit south of this quadrangle (Cole, 1981, 1984d).

Tonalite is snow-white to light tan in outcrop and weathers to produce a bright white colluvium that is a useful recognition trait. The rock is medium to coarse-grained, equigranular, and the mafic minerals are typically aggregated into spherical clusters, 1-2 cm in diameter. The composition of tonalite is gradational to that of Foliated quartz diorite unit (fig. 3) because some samples contain little quartz, but rocks of the two units are easily distinguished on the basis of texture and mineralogy. Average tonalite consists of about 65 percent subhedral, weakly zoned plagioclase (andesine-calcic oligoclase), 20 percent quartz, 8 percent hornblende, 7 percent brown biotite, sparse orthoclase, large crystals of sphene and magnetite, and minor apatite and zircon. Hornblende is generally more common than biotite but the latter is dominant in a few samples. Quartz and orthoclase are interstitial to plagioclase and the mafic minerals and typically form poikilitic grains that enclose the latter.

Cataclastic deformation in the Tonalite unit is generally mild and confined to wide-spaced, irregularly oriented seams of crushed and recrystallized rock. Some outcrops are distinctly bladed and appear to reflect a weak but nearly pervasive fracture set that has a similar orientation to fluxion structure in the Foliated quartz diorite unit. Plagioclase, hornblende, and biotite in the Tonalite unit are slightly bent and locally fractured and quartz is variably strained. Alteration is generally slight; primary minerals are partly replaced by sericite, chlorite, and granular epidote.

Granodiorite granophyre

Leucocratic intrusive rocks with distinctive granophyric texture have been identified within the Suwaj suite and are defined (Cole, 1984a) as the Granodiorite granophyre unit (Sgg). Three small bodies are exposed in the Al Abanat quadrangle; two that intrude the Foliated quartz diorite unit near the Mibari mineral locality, and a poorly defined body that is included in rocks of the Khishaybi suite south of Jibal Zalma. On a regional basis, similar granodiorite and leucocratic granophyre are the youngest rocks of the Suwaj suite (Cole, 1984a, d).

Granodiorite granophyre is poorly exposed, but its presence can be inferred by its distinct pale orange to white colluvium. The rocks vary systematically in texture and bulk composition from leucocratic, medium-grained granodiorite (abundant, equant plagioclase phenocrysts) to leucocratic, coarse-grained syenogranite and orthoclase granite (sparse plagioclase phenocrysts and common quartz phenocrysts), but the coarsely granophyric groundmass and low percentage of mafic minerals is common to all rocks of the unit.

The granodiorite granophyre bodies near the Mibari mineral locality consist of about 55 percent stubby oligoclase phenocrysts in a granular to granophyric groundmass of 20 percent quartz and 15 percent orthoclase, and 10 percent primary mafic minerals (probably hornblende; totally replaced by epidote, chlorite, and granular sphene). Moderate cataclastic deformation is common (fractured and bent plagioclase, undulatory quartz, and thin cataclastic seams), but the body at the Mibari mineral locality also contains abundant, thin, variably oriented veins of quartz, epidote, and calcite with malachite and chrysocolla.

Leucocratic granophyre crops out adjacent to the terrace gravel deposits on the north bank of Wadi ar Rumah near Mibari and cobbles of this distinctive rock (with pervasive cataclastic fabric) are contained in the Polymict conglomerate member of the Jurdhawiyah group nearby to the southwest. The inclusion of leucocratic granite in the Khishaybi suite body (south of Jibal Zalma) is an unusual rock that consists solely of equigranular quartz and orthoclase, 1-2 percent coarse, euhedral sphene, and abundant stout prisms of zircon. The single sample examined lacks granophyric texture, but is included with this unit because it pre-dates the Khishaybi suite and it has a moderately cataclastic fabric.

Dike rocks

Dike rocks are characteristically rare in the Suwaj suite (Cole, 1984d) and are only present in the Tonalite unit near the southeastern corner of this quadrangle. The dikes are typically 0.5-1.0 m thick, trend toward the north, and consist of altered, subporphyritic hornblende(?) andesite; unmapped dikes are thin, irregular, and discontinuous and consist of pink, saccharoidal aplite. Mafic minerals in all of these dikes are replaced by chlorite and epidote and plagioclase is widely replaced by saussurite.

KHISHAYBI SUITE

Fine grained, leucocratic granitic rocks of the Khishaybi suite (Cole and Bohannon, 1985a) are exposed along the eastern border of the quadrangle and form the western margin of a voluminous composite intrusive body that extends many tens of kilometers to the north, east, and south (Cole, 1984d; Cole and Hedge, 1985, unpub. data). Two sub-units of the Khishaybi are exposed in this quadrangle; the Hamar monzogranite (the dominant unit of the suite) and the younger Dilaymiyah syenogranite. Hamar monzogranite intrudes the Murdama group along the eastern margin of the Maraghan depositional basin (fig. 2) but does not intrude the Jurdhawiyah group, which is interpreted to be younger. Farther to the east, the Hamar and the Dilaymiyah are intruded by elliptical bodies of the Idah suite that were emplaced 620-615 Ma ago (Cole and Hedge, 1985, unpub. data).

Rocks of the Khishaybi suite are characterized by: 1) poor outcrop; 2) monzogranite to syenogranite composition (fig. 4); 3) low color index; 4) prevalence of biotite over hornblende; 5) common allanite and late-stage muscovite; 6) equigranular to subporphyritic textures; 7) diffuse cataclasis; 8) irregular intrusive form; and 9) very weak magnetic signature (Cole and Bohannon, 1985a). Primary intrusive fabric is rare in rocks of the Khishaybi suite, although the Hamar monzogranite locally has a faint foliation defined by concentrations of biotite and irregular lenses of pegmatite-aplite and, in these localities, the Hamar also contains disseminated garnet, cordierite, and fibrolitic sillimanite. Dikes are moderately common in the Khishaybi and typically trend in a westerly direction in this region; these are described separately at the end of this section.

Hamar monzogranite

The Hamar monzogranite (hmg; Cole and Bohannon, 1985a) is continuously exposed along the eastern quadrangle border from Al Batra to Al Hinayniyah, except where it has been intruded by the younger Asmar complex (Abanat suite). The reference locality for the Hamar is located about 5 km northeast of the northeastern corner of this quadrangle along Shaib al Hamar (Cole and Bohannon, 1985a); the unit was first mentioned as the "Hamrah monzogranite" by du Bray (1983a; unofficial transliteration) prior to the definition of the Khishaybi suite.

The Hamar is generally only exposed in flat, bald slabs and in small channels and is typically pale gray to pale tan or pink. In this quadrangle, most of the rock is fine grained and equigranular biotite monzogranite, although medium-grained and sparsely porphyritic varieties are also present. These textural variations are completely gradational over distances of several meters.

Typical Hamar consists of an equigranular, hypidiomorphic intergrowth of oligoclase, orthoclase, and quartz in roughly equivalent amounts (fig. 4). Orthoclase and, less commonly, oligoclase and quartz, form slightly larger phenocrysts in inequigranular rocks, and most of the measured variation in modal composition (fig. 4) reflects variations in the proportions of these phenocryst minerals. Myrmekitic intergrowths of oligoclase and quartz are common in small lobate masses that project into orthoclase grains. Small globules of quartz are also intergrown with both feldspars on a larger-scale and produce a spongy texture that is typical of the Hamar.

Euhedral, tabular, red-brown biotite is the characteristic and dominant mafic mineral in the Hamar and it is locally accompanied by sparse green hornblende. Euhedral magnetite, apatite, and zircon are common accessory minerals, but zoned, brown-to-yellow allanite is characteristic to the unit and generally present. Coarse flakes and irregular grains of muscovite are locally common in the Hamar, but its textural habit suggests the mica grew following magmatic crystallization. These mafic and accessory minerals only make up about 5 percent of the rock.

South of Wadi ar Rumah and west of Wadi umm Arta, the dark minerals in the Hamar are aggregated into clusters (0.5-1.5 cm in diameter) that are disseminated throughout the rock. These clusters consist of biotite, cordierite (and its alteration products), and subsolidus muscovite.

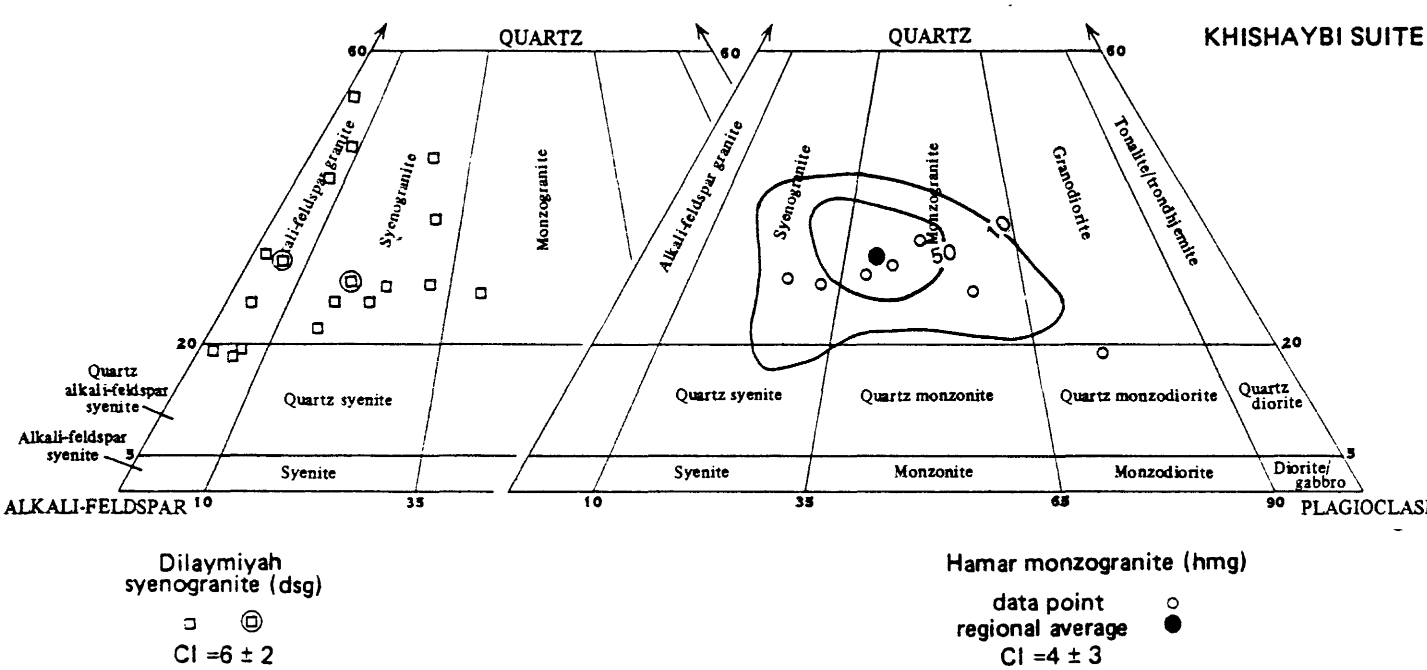

Figure 4.--*Modal composition diagram for rocks of the* Khishaybi suite. *Analyses for the Al Abanat quadrangle (circled or indicated as data point) are compared to regional data for the suite (Cole, 1984d) and to regional average color index (CI; ± one-sigma standard deviation). For units with abundant analyses, contours enclose 10 and 50 percent of the population. Rock-name fields and triangle poles defined by Streckeisen (1976).*

Weak cataclasis is a regional characteristic of the unit (Cole, 1984d). This type of deformation is generally not apparent in outcrop, but is clearly expressed by undulatory extinction in quartz, bent and kinked grains of biotite and muscovite, and by less common cracked or bent grains of feldspar.

Dilaymiyah syenogranite

Very coarse grained, equigranular, leucocratic ferro-edenite syenogranite (dsg) is exposed only in the northeastern corner of the Al Abanat quadrangle, but is continuous with more extensive intrusions to the east that have been defined as the Dilaymiyah syenogranite (Cole and Bohannon, 1985a). This syenogranite intrudes the Hamar monzogranite in irregular masses and is, itself, intruded by slightly younger phases of the Khishaybi suite. The reference locality of the Dilaymiyah syenogranite is near the village of Ad Dilaymiyah, located about 20 km east of Al Batra on the Qassim highway; the unit defined by Cole and Bohannon (1985a) includes the rocks mapped as "Dharaymeeah syenogranite" by du Bray (1983a; unofficial transliteration).

The Dilaymiyah is slightly more resistant to erosion than the Hamar monzogranite and forms low bouldery outcrops along minor drainage divides. The characteristic rock color is orange-brown or red-brown and the texture is dominated by large, equant grains of perthitic orthoclase (0.5-1.5 cm in diameter). Quartz is also coarse-grained and has a waxy, brown or gray luster. The composition of Dilaymiyah syenogranite is not as variable as suggested by the data in figure 5 (scatter is chiefly due to coarse minerals and small stained slabs), but typical rocks consist of 45 to 75 percent perthitic orthoclase, 25 to 40 percent quartz, 5 to 25 percent subhedral sodic oligoclase, and a few percent each of red-brown biotite and strongly colored ferro-edenitic amphibole. Accessory minerals include magnetite, allanite, apatite, and zircon.

Sodic oligoclase forms independent, subhedral crystals and myrmekitic intergrowths are common where plagioclase and orthoclase are in contact. Biotite and amphibole are locally enclosed in feldspar grains and are interpreted to have nucleated prior to feldspars. Quartz is generally equant and interstitial to the other minerals, although it is graphically intergrown with orthoclase in subporphyritic rocks near the margins of intrusions and in west-trending dikes that penetrate the Hamar monzogranite.

The Dilaymiyah syenogranite has a weak cataclastic fabric similar to that in the Hamar monzogranite. Slight post-intrusion alteration is indicated by sericite in plagioclase and by diffuse granular hematite in feldspars and on the margins of magnetite grains.

Dike rocks

Most dike rocks associated with the Khishaybi suite consist of microgranite and granite porphyry. North of Al Batra town, brick-red dikes within the Hamar monzogranite can be traced eastward into the Dilaymiyah syenogranite, from which they differ only by finer grainsize, granophyric and subporphyritic texture, and their lower average color index. South of Wadi ar Rumah and east of Shaib Jarrar, dikes in the Hamar consist of biotite- and muscovite-bearing microgranite and aplite that are interpreted to be cogenetic and coeval with the Hamar.

Several of these dikes and a few of the Dilaymiyah syenogranite dikes north of Al Batra are intensely crushed and silicified and the resulting microbreccia is cemented by drusy quartz and laminated hematite. Granitic wall rock marginal to these dikes is also fractured and locally granulated and stained with hematite.

Numerous, thin dikes intrude the Murdama group within the Maraghan depositional basin (fig. 2) and they generally trend in a westerly direction but form an arcuate swarm that is concave to the north. These dikes consist of microgranite, granite porphyry, and porphyritic latite and diabase that are variably altered and recrystallized. They are probably coeval with the Khishaybi suite because they do not intrude the Jurdhawiyah group, they are typically more altered (and locally fractured) than Jurdhawiyah-contemporary intrusive rocks, and because they appear to have selectively intruded the Murdama group west of the main Khishaybi batholith.

Rocks of similar compositional diversity (aplite and diabase/andesite) are associated with discrete central intrusions of the Idah suite in the area between An Numaniyah and Darat al Jibu, but such dikes typically form crossing sets within and marginal to their cogenetic host plutons (Cole, 1984a, d). In all, the dikes within the Maraghan basin are similar to the assemblage mapped as "Deformed and altered dike rocks" in the adjoining quadrangle to the west (Cole, 1984a), but more study is necessary to establish reliable criteria for distinguishing such dikes from those related to the Idah suite. Therefore, dikes attributed to the Khishaybi suite and to the Idah suite are indicated on the geologic map with the same symbol.

JURDHAWIYAH-CONTEMPORARY INTRUSIVE ROCKS

Small plugs, dikes, and local sills of mafic and intermediate rock form a recognizable assemblage of intrusions on the basis of composition, texture, mineralogy, and their spatial association with deposits of the Jurdhawiyah group. The coeval units of Plagioclase porphyry and Gabbronorite were defined by Cole (1984a) and are interpreted to represent the eroded remains of intrusive conduits that channeled magma to contemporaneous lava flows and pyroclastic eruptions during Jurdhawiyah time. Gabbronorite intrusions have only been identified on the margins of the Marmuthah depositional basin (fig. 2), whereas Plagioclase porphyry dikes and plugs are common along the margins of both the Marmuthah and Idayri basins.

Gabbronorite

Three small intrusions in the southern part of the quadrangle consist of two-pyroxene gabbronorite and olivine gabbro (gbn) that contain slightly altered primary igneous minerals. Similar mafic rocks are also exposed south of this quadrangle in the center of a relict Jurdhawiyah volcano and, thus, the Gabbronorite unit is interpreted to have intruded during Jurdhawiyah time (Cole, 1981, 1984d). All rocks of this unit are black to blue-gray in outcrop and the intrusions are associated with strong bipolar magnetic anomalies (ARGAS, 1967; Cole, 1984d).

The outcrops 4 km west of Al Hinayniyah village consist of medium grained hypersthene-augite gabbronorite that has a weakly aligned fabric defined by adcumulus plagiocalse laths (zoned bytownite). South and west of this intrusion, unmapped augite basalt dikes within Suwaj tonalite pass upward into mafic flow rocks that are mapped as the base of the Jurdhawiyah group. On the southeastern margin of the Samra Khaytan ridge, similar gabbronorite with about 10 percent olivine intrudes Foliated quartz diorite (Suwaj suite) at the base of the Jurdhawiyah group. The third representative of the Gabbronorite unit is isolated from the Jurdhawiyah group and intrudes the Dhiran meta-andesite" east of Nufud al Urayq, 4 km north of Al Ghadya village. This body consists of medium grained olivine gabbro that has a faint cumulus layering defined by alternating laminae rich in labradorite and olivine.

Labradorite and bytownite are the typical feldspars, are generally euhedral, and are unzoned or weakly zoned. Olivine and the two pyroxenes are typically euhedral and equant, and are present in variable amounts. Magnetite forms octahedral crystals, and minor late-stage titaniferous biotite is locally present. Most minerals are fresh and only olivine is replaced by fibrous serpentine and granular magnetite.

Plagioclase porphyry

Stocks, plugs, and tabular bodies of the Plagioclase porphyry unit (pp) intrude the layered rocks of the Jurdhawiyah group and consist of andesite and minor dacite (Cole, 1982, 1984b, c). They are common in two areas: at the southern margin of the Marmuthah depositional basin (fig. 2) north of Samra Khaytan; and at the southern margin of the Idayri basin between Al Lughfiyah village and Jabal Bidan.

Plagioclase porphyry is red-brown in outcrop and forms spheroidal weathered boulders. The porphyry is characterized by abundant phenocrysts (typically 25 percent; 0.5-3.0 cm in diameter) and the mineral assemblages in individual intrusions consist of plagioclase-augite, plagioclase-augite-hornblende, plagioclase-augite-hypersthene, augite-hypersthene, hornblende, or (rarely) plagioclase alone. Clasts with similar mineralogy and texture are common in the Jurdhawiyah group Volcaniclastic conglomerate, and indicate that Plagioclase porphyry was intruded during Jurdhawiyah deposition.

The typical phenocryst plagioclase is normally zoned, euhedral labradorite-andesine and some crystals enclose globular masses of devitrified magma. Augite is characteristically euhedral, colorless, and simply twinned. Hornblende generally has strong color and pleochroism and is locally surrounded by a reaction corona of pyroxene and magnetite. The crescent-shaped intrusion east of Jabal Bidan is more felsic (probable dacite) than the unit average and contains phenocrysts of sodic andesine, brown biotite, and minor hornblende and orthoclase.

Groundmass minerals consist of felted laths of andesine and calcic oligoclase, equant grains of augite and magnetite, local hornblende, and alteration minerals (probably derived from primary glass). Post-emplacement alteration is variable in intensity, but most rocks contain some secondary calcite, epidote, chlorite, and sericite, and hypersthene is generally replaced by serpentine, magnetite, and chlorite.

IDAH SUITE

Numerous circular to elliptical plutons of biotite-hornblende granodiorite porphyry in the Al Abanat quadrangle are assigned to the Idah suite (Cole, 1984a) on the basis of their close similarity to the defining features of the suite: composition and mineralogy, intrusive form, outcrop style, magnetic expression, contact metamorphism, texture, and association with mineralized quartz veins. Four subdivisions of the Idah are recognized regionally, but only the Granodiorite porphyry sub-unit is exposed in this quadrangle. Zircon from a sample of the circular pluton at Darat al Jibu defines a concordia-intercept age of 614±7 Ma that corresponds to five other ages determined for the suite in the northeastern Shield (621-614 Ma; Cole and Hedge, 1985, unpub. data).

Granodiorite porphyry

Eleven bodies of biotite-hornblende granodiorite porphyry (Igdp) are mapped in this quadrangle and most are intruded into the Murdama group in the area north of the paved Al Madinah-Buraydah highway. All plutons are simple circular to elliptical structures that are less than about 12 km^2 in area. The granodiorite porphyry at Jabal Idah in the southwestern quadrangle corner is the northern margin of a large elliptical body that is about 600 km^2 in area. Outcrop is generally poor within and at the margins of these plutons, but the contacts are inferred to be steep from magnetic data (ARGAS, 1967; Kleinkopf and Cole, 1982; Cole, this report) and by comparison to the exposed contacts of the larger body at Jabal Idah (Cole, 1984a).

Granodiorite porphyry is light gray or pale brown, structureless, medium grained, porphyritic to subporphyritic, and characteristically contains disseminated, discoid mafic inclusions (2-15 cm in diameter) that are rich in hornblende, biotite, augite, and accessory minerals. The distinctive porphyry texture is due to about 20 percent equant phenocrysts of zoned andesine-oligoclase (2-10 mm in diameter) that have blue-gray cores (abundant inclusions of magnetite, hornblende, and biotite) and white rims.

Mineralogy, bulk composition, and texture are uniform throughout individual intrusions and compare well between intrusions. Measured modal composition varies from quartz-poor granodiorite and monzogranite to quartz monzodiorite chiefly as a function of the percentage of phenocryst plagioclase and average color index (Cole, 1984d, fig. 6b). In general, these rocks contain 35-45 percent andesine-oligoclase (phenocrysts plus groundmass), 12-20 percent quartz, 7-15 percent orthoclase, and 7-10 percent each hornblende and biotite. Magnetite, zircon, and apatite are typical accessory minerals and augite is present in minor amounts in the cores of hornblende grains, particularly in the more mafic samples.

Plagioclase phenocrysts have delicate oscillatory zones and irregular zones in their cores; the oligoclase rim is commonly marked by a distinct change toward a more sodic plagioclase. Hornblende is dark green-brown, subhedral, and generally more common than red-brown biotite. Quartz and orthoclase tend to be irregular and fill the interstices between these other minerals. Myrmekitic intergrowths of quartz and oligoclase are locally present between plagioclase and orthoclase grains. Most samples of granodiorite porphyry are unaltered, except for minor sericite and calcite in plagioclase and chlorite in hornblende and biotite.

Dike rocks

Aplite and diabase dikes are regionally common in granodiorite porphyry plutons (Cole, 1984a, d). Most are contained within these plutons (few extend more than one kilometer from the pluton border) and they are interpreted to be cogenetic with the central intrusions. These types of dikes form crossing swarms that trend toward the northeast and northwest in the larger plutons between Darat al Jibu and An Numaniyah village.

The felsic dike that intrudes Jurdhawiyah group rock on the south side of Jabal Idah is a distinctive, brick red, granophyric syenogranite that merges downward with a subhorizontal sheet beneath the flat roof of the granodiorite porphyry pluton. This distinctive cap phase forms mappable masses in the adjoining quadrangle to the west that are defined as the Granophyre member of the Granodiorite porphyry unit (Idah suite; Cole, 1984a).

ABANAT SUITE

The Abanat suite, defined in this report, comprises the youngest Proterozoic intrusive rocks of the region and consists chiefly of leucocratic, alkali-rich, siliceous, and highly evolved granitic rocks. Typical intrusions of the Abanat suite form elliptical to circular bodies, composite plutons, and ring dikes and many show structural and textural features that indicate they were emplaced at shallow depth, locally into a cogenetic cover of rhyolitic volcanic rock. Contacts with country rock are knife-sharp, external contacts are generally vertical or dip steeply outward, and xenolithic inclusions are rare. Abanat suite granites are regionally associated with radiometric anomalies and are typically non-magnetic (ARGAS, 1967); the magnetic border of individual intrusions, however, is marked by high-frequency anomalies due to contact metamorphism.

Rocks of the Abanat suite are resistant and form the highest mountains of this quadrangle and of the northeastern Shield (Cole, 1984d). The suite is characterized by a restricted composition and compositional range (fig. 5) and essentially all of the rocks are alkali-feldspar granites in which perthitic orthoclase and quartz are the dominant minerals. Mafic phases and accessory minerals rarely make up more than about 7 percent of Abanat suite granites; abundant primary fluorite and coarse, prismatic zircon are virtually diagnostic of the suite. These granites are also characterized by regional enrichment in rubidium, fluorine, beryllium, zirconium, and rare-earth elements; by local enrichment in lithium, zinc, and copper; by marked europium anomalies; and by depletion in strontium, calcium, barium, and magnesium (Cole, 1982, 1984b, c; Stuckless and others, 1982a, b, in press; Elliott, 1983; W. Miller and R. Samater, written comm., 1984).

Mineralogy, major-, and minor-element traits and isotopic features of Abanat suite granites further define two subsets that are compositionally gradational, although their genetic relationship is not presently clear (Elliott, 1983; Stuckless and others, in press). Nevertheless, the two end-member prototypes can be defined as reference standards for the purpose of comparison, and these prototype compositions are referred to as "peralkaline" and "peraluminous" in accord with common usage (Stuckless and others, 1982a, b, in press; Elliott, 1983; Cole, 1984a, d).

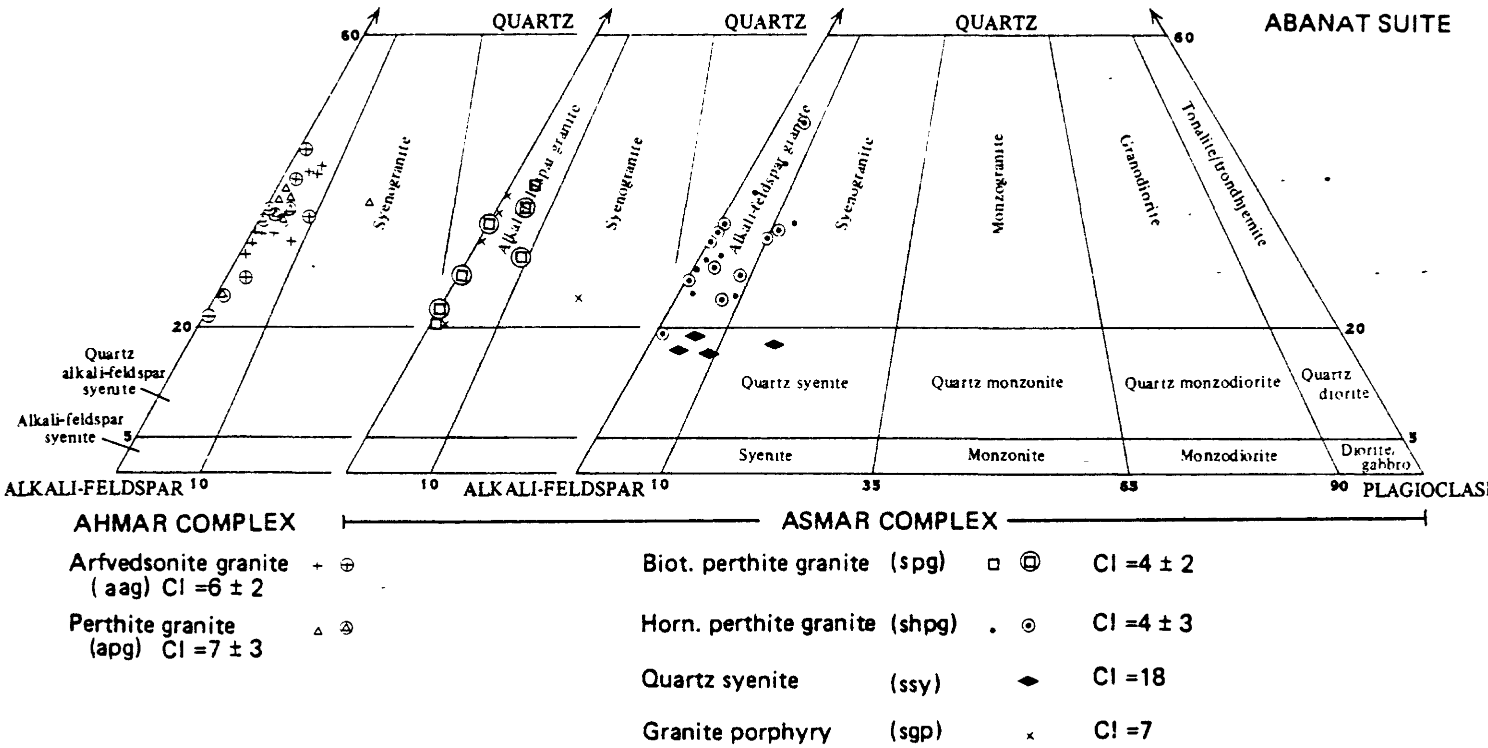

Figure 5.--*Modal composition diagram for rocks of the Abanat suite. Analyses for the Al Abanat quadrangle (circled) are compared to regional data for the Ahmar and Asmar complexes (Cole, 1982; Cole and Bohannon, 1985b) and to regional average color index (CI; ± one-sigma standard deviation). Rock-name fields and triangle poles defined by Streckeisen (1976).*

Most peralkaline granites of the Abanat suite are coarse grained, equigranular, and consist of quartz and a single perthitic feldspar (sodium-potassium orthoclase inverted from primary sanidine) that indicates relatively dry (hypersolvus) crystallization. Mafic minerals are typically interstitial and anhedral, nucleated during the final stages of solidification, and are enriched in sodium; aegirine and sodium amphibole (katophorite-arfvedsonite series) are diagnostic and iron-biotite is common. Accessory minerals include magnetite, zircon, fluorite, and local rare minerals (aenigmatite, bastnaesite). Peralkaline granites are especially enriched in niobium, yttrium, light rare-earth elements, lead, and some tin. Isotopic traits of strontium, lead, and oxygen indicate peralkaline granites did not interact with evolved crustal materials during genesis (Stacey and Stoeser, 1983; Stuckless and others, in press.

Peraluminous granites of the Abanat suite are typically medium to coarse grained, inequigranular and commonly porphyritic. Phenocrysts of quartz, albite, potassium orthoclase, and sparse mica in a granular groundmass of the same minerals indicate relatively wet (subsolvus) crystallization. Biotite, zinnwaldite, and(or) muscovite are diagnostic minerals and are locally accompanied by sparse cordierite, garnet, or sillimanite. Accessory minerals include magnetite, fluorite, and coarse zircon and some samples also contain hornblende, apatite, topaz, or cassiterite. Peraluminous granites are especially enriched in lithium, boron, tin, and some tungsten and zinc; rare-earth element patterns are typically flat or concave upward. Isotopic traits of strontium, lead, and oxygen indicate peraluminous granites incorporated some evolved crustal material during genesis (Stacey and Stoeser, 1983; Stuckless and others, in press.

In this quadrangle, the Abanat suite is represented by the composite Asmar complex (dominantly peraluminous), the composite Ahmar complex (peralkaline), and by a regional swarm of peralkaline rhyolite dikes defined as the Sanidine porphyry unit (Cole, 1984a). The suite name is derived from Al Abanat, the geographic term that collectively refers to the mountains of Aban al Asmar and Aban al Ahmar on the eastern side of the quadrangle.

Granites of the Abanat suite intrude all other rocks in the area and represent the last major Proterozoic magmatic event of the northeastern Shield. The Ahmar complex defines a six-point rubidium-strontium whole-rock isochron age of 574±5 Ma (Stuckless and others, in press), which is typical of the suite. Additional age determinations by rubidium-strontium and uranium-lead methods for peralkaline and peraluminous granites correlated with the Abanat suite (Cole, 1984d; Cole and Hedge, 1985 unpubl. data) closely define its age in the interval between 585 and 570 Ma (Stuckless and others, in press; Cole and Hedge, 1985 unpubl. data; J. Stacey, written comm., <u>in</u> du Bray, 1984).

Asmar complex

Intrusive rocks of the Asmar complex are defined in this report to consist of six lithologically distinct members that make up the composite pluton at Aban al Asmar and a partial, elliptical ring dike that is exposed south of Wadi ar Rumah and in adjoining quadrangles (fig. 2; Cole, 1981, 1984d; Cole and Bohannon, 1985a).

The ring dike south of Wadi ar Rumah and the composite pluton at Aban al Asmar are both elongate toward the north (parallel to the Khishaybi-Murdama contact) and are approximately 25 by 15 km in dimension. The ring dike consists wholly of the Hornblende perthite granite member, whereas the composite pluton to the north consists of nested, arcuate bodies of several granite members. The Rhyolite porphyry member forms irregular plugs, sheets, and dikes on the west side of Aban al Asmar that pre-date the Quartz syenite member.

The composite pluton at Aban al Asmar is interpreted to represent the root zone of a volcano that erupted the Samra rhyolite. The Samra is thick and extensive in the center of the mountain range and probably accumulated within a central caldera depression. The inferred caldera margin is arcuate and defined by elongate bodies of the Rhyolite porphyry, Quartz syenite, and Granite porphyry members and probably by the arcuate bodies of Biotite perthite granite and Hornblende perthite granite members at the north and south ends of the pluton. The fact that Samra rhyolite is only preserved in four small blocks outside of this caldera margin probably indicates that uplift accompanied intrusion of the Asmar complex. This concept is also supported by the observation that the external Samra rhyolite blocks are tilted and structurally lower than the Samra within the caldera.

<u>Biotite perthite granite member.</u>--Equigranular, coarse-grained, tan to pale pink biotite perthite granite (<u>spg</u>) is exposed in an arcuate mass at the northern end of the Asmar complex. Its very well exposed contact with the Samra rhyolite is sharp, generally planar, and dips gently toward the center of the composite pluton, more-or-less parallel to bedding in the rhyolite. Contacts with the surrounding Khishaybi suite are poorly exposed, but the age relationship is clear from blocky inclusions of Hamar monzogranite and truncated Dilaymiyah syenogranite dikes.

The Biotite perthite granite member is intruded by a stock of the Granite porphyry member east of Rawdat Qiradan village and by related porphyritic dikes at the west end of Jabal al Manjuri.

The rock consists of large, euhedral to subhedral crystals of orthoclase perthite, coarsely subhedral quartz, sparse primary albite, and about 4 percent green biotite, magnetite, fluorite, and zircon. Biotite forms subhedral flakes that are vermicularly intergrown with quartz in places. Fluorite is colorless to pale purple and forms coarse equant grains and irregular interstitial patches; its textural habit is consistent with primary crystallization from the melt.

Hornblende perthite granite member.--Very coarse grained, equigranular, tan to pale pink and orange biotite-hornblende perthite granite (shpg) is exposed at the southern end of the composite intrusion at Aban al Asmar. Similar rock forms whaleback knobs and ridges southward from Jabal Najjabah to Mazari umm Arta and beyond (Cole and Bohannon, 1985a), and define a discontinuous ring dike south across Wadi ar Rumah (fig. 2). Hornblende perthite granite intrudes the Jurdhawiyah group and older rocks, and is intruded by flat-lying sheets of the Granite porphyry and Quartz syenite members, west and north of Jibal umm Burayqi.

The Hornblende perthite granite member is mineralogically and texturally similar to the Biotite perthite granite member at the north end of the Asmar complex, but it typically contains minor amounts of dark green, sub-calcic hornblende. Biotite in this member is mostly brown rather than green, and vermicular intergrowths with quartz have not been noted. Fluorite is less common in this member than in the Biotite perthite granite member.

Intrusion breccia member.--The contact between the Hornblende perthite granite member and the Samra rhyolite is a thick zone consisting of a megalithic intrusion breccia (sbr) that is widely exposed at Jibal umm Burayqi and to the north. The breccia is about 30 percent granite in the form of tabular sheets, 1-10 m thick, that enclose large slabs of Samra rhyolite (fig. 6). These sheets generally dip gently northward toward the center of the composite pluton and are approximately parallel to measured and inferred bedding in the Samra rhyolite. Thus, emplacement of Hornblende perthite granite was guided by weak bedding planes as it moved upward and intruded the Samra.

Rhyolite porphyry member.--Irregular plugs and subvertical dikes of brick red, fine-grained, moderately porphyritic rhyolite (srp) intrude country rocks along the western margin of the composite pluton at Aban al Asmar and also intrude the Samra rhyolite north of the Mitla fault. Rhyolite porphyry is intruded by the Quartz syenite member, but is not in contact with the granite members. Rhyolite porphyry contains about 10-20 percent phenocrysts of orthoclase perthite and quartz (2-4 mm in diameter) in a fine-grained, equigranular to granophyric groundmass of the same minerals. Magnetite, fluorite, zircon, and disseminated hematite are present in minor amounts. Sparse radial aggregates of muscovite are present in a few samples, but mafic silicate minerals are absent. Some rock in the larger plugs north of Jibal Zalma is flow-banded.

Two east-northeast-trending dikes that intrude Foliated quartz diorite (Suwaj suite) east of Shaib Jarrar and west of Mazari umm Arta are correlated with this member on the basis of mineralogy and lack of deformation, and may be related to emplacement of the Hornblende perthite granite member in the ring dike a short distance to the northeast.

Figure 6.--*Oblique aerial photograph of the Intrusion breccia member of the Asmar complex. View toward the north from canyon north of Jibal umm Burayqi. Note crude planar fabric (gentle dip to north-northwest) defined by tabular blocks of Samra rhyolite (dark) surrounded by sheets of Hornblende perthite granite member (light).*

Quartz syenite member.--Gray, richly porphyritic, medium-grained biotite-hornblende quartz syenite (ssy) forms a steep-sided stock west of Jibal al Mishanniyah and a gently dipping sheet north of Jibal umm Burayqi. This member intrudes Samra rhyolite and the Hornblende perthite granite and Rhyolite porphyry members and is inferred to be younger than the Biotite perthite granite member. It is not in contact with the Granite porphyry member, but both were probably emplaced at the same time around the outer margins of the composite pluton at Aban al Asmar.

The Quartz syenite member contains substantially less quartz and more mafic minerals than any other member of the Asmar complex (fig. 5) and is distinctive in outcrop. It consists of 40-60 percent phenocrysts of strongly perthitic orthoclase (5-15 mm in diameter), minor quartz and albite in a medium-grained, equigranular groundmass. Green hornblende, brown biotite, magnetite, zircon, and apatite are abundant, sphene and allanite are rare, and fluorite has not been detected. Sparse augite is present as irregular inclusions in hornblende and orthoclase.

Granite porphyry member.--Leucocratic, subporphyritic to inequigranular biotite orthoclase granite and biotite syenogranite (sgp) forms a small, north-trending stock and several thick dikes at the northwestern corner of Aban al Asmar, and a northward dipping sheet 3 km west of Jibal umm Burayqi. These various bodies intrude all other members of the Asmar complex except the Quartz syenite member, which is nowhere in contact.

Granite porphyry is pale gray to pale pink and is distinctly lighter in color than other members of the complex. It contains 10-20 percent phenocrysts of orthoclase perthite, quartz, and rare oligoclase (3-5 mm in diameter) in a fine grained, equigranular matrix consisting of the same minerals plus about 7 percent biotite, magnetite, zircon, fluorite, apatite, and rare allanite and green hornblende. These minor and accessory minerals tend to be aggregated in irregular clusters that are disseminated throughout the rock.

Ahmar complex

The Ahmar complex is defined in this report to include the dominantly peralkaline granitic rocks of the composite, zoned pluton at Aban al Ahmar, along the south-central border of the quadrangle. The southern half of the pluton was mapped by Cole (1981) and his constituent units ("biotite- and hornblende-bearing perthite granite", "arfvedsonite perthite granite", and "rhyolite porphyry") are equivalent to the Perthite granite, Arfvedsonite granite, and Rhyolite porphyry members, respectively, defined in this report. The Perthite granite member forms the core of the pluton and the Arfvedsonite granite member forms a marginal rim and partially preserved roof carapace; both granite members intrude each other, the contact between them is locally gradational, and they are interpreted to be coeval. The Rhyolite porphyry member forms irregular and circumferential dikes in country rock east of the zoned pluton, and a discontinuous ring dike to the west (Sinaf Aba al Haddar and isolated outcrop in Nufud al Urayq) that is not concentric with the zoned intrusion (fig. 2).

The pluton is elongate toward the east-northeast (20 km long by about 7 km wide) and intrudes across the structural trends of the Jurdhawiyah group and the Dhiran-Suwaj terrane. The northwestern border of the body truncates the trace of the Ahmar fault but is generally parallel to it and it is likely that the fault influenced the shape of the intrusion. The contact between the outer Arfvedsonite granite member and country rock is generally steep and dips outward, but the dip decreases at the southern margin and merges with a sub-horizontal, southward-plunging roof contact (Cole, 1981). This outer contact is generally sharp and smooth, although irregular apophyses are present due west of Dulay Rashid village (fig. 7). Excellent exposures in this locality also show that granite sheets in country rock grade into the Rhyolite porphyry member by decrease in average grainsize.

The inner contact between the two granite members generally follows the trend and orientation of the outer contact, although the dip is typically less steep. This contact is most clearly marked by a change in rock color that is quite apparent from a distance; in detail, the contact is generally gradational, locally interfingering, and locally marked by small pegmatite cavities lined with well formed quartz and arfvedsonite crystals. The boundary between the granites is smooth and regular along the eastern and northern sides of the pluton, but is highly irregular and more difficult to define in the northwestern zone where it is locally marked by mutually penetrating dike sets.

Figure 7.--*Photograph of the intrusive margin of the Ahmar complex. View toward the north from bottom of canyon north of Shaib al Hayyas, along the outer margin of the Arfvedsonite granite member (light), showing local irregularities where it intrudes rocks of the Jurdhawiyah group (dark). Altitude at skyline is about 500 m higher than camera location.*

Numerous dikes of white, pink, and dark red-brown, fine-grained granite intrude both granite members (not mapped). These bodies are generally less than one meter thick, locally zoned, planar or curved and lensoid, variably oriented, and are rarely continuous for more than a few hundred meters. The dark red-brown dikes in particular are 2-3 times more radioactive than other rocks of the complex, they contain substantial specular hematite and unidentified heavy minerals, and they are particularly enriched in niobium, yttrium, tin, copper, and beryllium and contain local high values of arsenic, molybdenum, and silver (Cole, 1984c).

Perthite granite member.--The core phase of the pluton consists of moderate red, coarse-grained, equigranular biotite perthite granite (apg). Near contacts with the Arfvedsonite granite member and along the crest of the range (near the inferred roof contact), the perthite granite is medium to fine grained, equigranular to granophyric, brick red, and contains abundant disseminated hematite. The more typical coarse-grained rocks are composed of strongly perthitic orthoclase and equant quartz grains and sparse laths of albite. Red-brown biotite (typically replaced by hematite) is the principal mafic mineral and it is locally accompanied by minor, strongly colored sub-calcic hornblende, fluorite, magnetite, zircon, and sparse apatite and allanite. Rocks of the Perthite granite member are chemically metaluminous and generally contain less total iron than those of the Arfvedsonite granite member (Stuckless and others, 1982a; Cole, 1982, 1984c).

The hypersolvus texture indicates perthite granite crystallized from a water-poor magma and that albite was only saturated during the final stages of consolidation. Fluorite forms equant, anhedral grains that are interstitial to quartz and orthoclase and most likely also crystallized from the last fraction of melt. The primary sodium-potassium feldspar exsolved albite at temperatures below the solidus, and this unmixing was accompanied by the crystallization of fine, granular hematite that produces the distinctive red color of this granite. The textural association of this hematite with feldspar exsolution suggests that the iron was originally incorporated in the lattice of the magmatic feldspar.

Arfvedsonite granite member.--The rim phase of the composite pluton consists of very coarse grained, equigranular, tan perthite granite (aag) that contains the diagnostic sodium-rich minerals arfvedsonite(-katophorite) and aegirine. It forms a sheath that is about 1.5 km thick along the eastern margin, no more than about 200 m thick along the roof axis (Cole, 1981), and discontinuous along the western margin. The Arfvedsonite granite member is intruded by the Rhyolite porphyry member at Sinaf Aba al Haddar, but grades into dikes of the latter at some localities.

Arfvedsonite granite consists of large, equant crystals of orthoclase perthite and subhedral gray quartz (fig. 5). Minor and accessory minerals (average 7 percent) include zoned, anhedral arfvedsonite, anhedral aegirine, equant fluorite, magnetite, stout, prismatic zircon, and rare bastnaesite(?). Arfvedsonite, aegirine, and fluorite commonly occur together in the interstitial spaces between quartz and orthoclase grains and are interpreted to have crystallized from the last fraction of magma. Arfvedsonite and fluorite locally form vermicular intergrowths and occur in pegmatitic cavities at the interface between the two granite members. The Arfvedsonite granite member is somewhat finer grained and granophyric within a few meters of the country rock contact, contains orthoclase and anorthoclase together, and contains abundant sodium-rich minerals (pyriboles and unidentified silicates).

Rocks of this unit are marginally to moderately peralkaline; in comparison to the Perthite granite member, the Arfvedsonite granite member is enriched in total iron, sodium, fluorine, lithium, total rare-earth elements, lead, yttrium, zirconium, tantalum, and hafnium and contains local high values of tin, molybdenum, zinc, and silver (Stuckless and others, 1982a; Cole, 1982, 1984c). These elemental enrichments suggest that more of the last liquid in the composite pluton was concentrated toward the exterior during progressive crystallization. The textural evidence that sodium- and iron-rich arfvedsonite and aegirine crystallized late indicates they did not form until the residual magma had reached sufficient concentration. Thus, the boundary between the two granite members probably does not reflect separate bodies of magma, but rather a diffusion interface within the residual, interstitial melt. From the observation that iron is contained in feldspar and magnetite in the Perthite granite but in sodium pyriboles and magnetite in the Arfvedsonite granite, it seems the diffusion interface may also have been influenced by variations in oxygen fugacity.

Rhyolite porphyry member.--Rocks of the Rhyolite porphyry member (arp) form dikes in the vicinity of the composite pluton at Aban al Ahmar and consist of brick-red, peralkaline rhyolite. Thin and irregular dikes intrude the Jurdhawiyah group along the east side of the mountain range, generally dip toward the pluton center at moderate angles, and form part of a concentric swarm that continues around the southern end of the pluton (Cole, 1981). The singular dike northwest of the pluton at the Hadiyah North mineral locality is generally concentric with this swarm, but its dip is unknown.

Rhyolite porphyry also forms a thick, elliptical ring dike (tens to hundreds of meters wide) that is discontinuously exposed west of the composite pluton (fig. 2), south of Sinaf Aba al Haddar. Farther south, the trace of the ring dike defines an ellipse that is nearly as large as the composite pluton, is oriented along similar axes, and probably indicates a buried body of similar granite west of Aban al Ahmar (fig. 2).

Rhyolite porphyry has a uniform composition but variable texture; most is very fine grained and contains 10-20 percent phenocrysts of orthoclase and embayed quartz (1-5 mm in diameter) in an equigranular or granophyric groundmass. Some dikes are sparsely porphyritic and the groundmass texture ranges from flamboyantly granophyric to spherulitic to (rarely) equigranular. Textural and compositional flow banding is common and some of the spherulites are flattened and elongated in the plane of flow; these features indicate rhyolite porphyry magma was viscous.

Minor and accessory minerals generally consist of zircon (locally very abundant), fluorite, magnetite, some brown biotite or arfvedsonite, and unidentified, fine-grained minerals. Dikes with spherulitic texture contain abundant granular aegirine and radial-fibrous riebeckite. Although they have not been sampled in detail, rhyolite porphyry dikes appear to be the most peralkaline rocks of the complex, and they are notably enriched in the elements that characterize the Arfvedsonite granite member (particularly lanthanum, niobium, yttrium, and zirconium; Cole, 1982, 1984c).

SANIDINE PORPHYRY

The Sanidine porphyry unit of the Abanat suite (Cole, 1984a) was defined for a regional swarm of thick, bright orange to brick red, richly porphyritic dikes that consist of weakly peralkaline rhyolite. These dikes (2-5 m thick) extend southwestward from near An Numaniyah village, south of Darat al Jibu, and west of this quadrangle for an aggregate distance of about 80 km (Cole, 1984a). They intrude the Idah suite (620-615 Ma; Cole and Hedge, 1985), but are not offset by faults that are interpreted to have moved in latest Proterozoic time (Cole, 1984a), and thus are assigned to the Abanat suite.

Sanidine porphyry has uniform texture and consists of 30-50 percent phenocrysts of sanidine and glomerophenocrysts of sanidine and albite (8-12 mm in diameter) and smaller, embayed quartz in a fine-grained, granular to granophyric groundmass. Accessory minerals are sparse and consist of biotite, magnetite, zircon, and unidentified minerals that probably contain rare-earth elements (Cole, 1984a).

STRUCTURAL UNITS

Listwänite and Cataclastic megabreccia are discontinuously exposed along the trace of the Ata fault from Ata village to the west-central quadrangle boundary. These units are structurally bounded and have no stratigraphic context; their distinct characteristics are the result of emplacement during movement on the Ata fault.

CATACLASTIC MEGABRECCIA

Heterogeneous, deformed rocks of the Cataclastic megabreccia unit (mbr) are only exposed at the western quadrangle boundary in an elongate lens approximately 200 m wide and 1000 m long. The unit is characterized by lensoid blocks of cataclastically deformed rock, 1-10 m long, that make up 70-80 percent of the outcrop. These blocks are contained in a weakly foliated, serpentine-rich heterogeneous matrix that contains smaller blocks and fragments of deformed rock. In the area to the west, this serpentine foliation is parallel to the trace of the Ata fault and dips steeply toward the north (Cole, 1984a).

The exotic blocks in the megabreccia appear to be chiefly derived from Dhiran meta-andesite, Suwaj-type diorite, quartz-bearing plutonic rock (Suwaj quartz diorite or granodiorite?), and a quartz-bearing sandstone similar to the Murdama (rare). These rocks typically have a pervasive cataclastic fluxion structure (Higgins, 1971) and crushed primary mineral grains; brecciation post-dates this fluxion structure, however, because the cataclastic fabric is not conformable among the blocks nor between the blocks and the enclosing serpentine foliation. The cataclastic blocks were also altered and recrystallized following structural emplacement, as indicated by undeformed crystals and radial aggregates of epidote, coarsely crystalline calcite, and unstrained chlorite.

LISTWÄNITE

Most of the trace of the Ata fault south and east of Dib Khulayf is marked by low ridges of pale rose-brown listwänite (lw), a rock consisting of dolomite, silica minerals, and relict serpentine, spinel, and magnetite that is interpreted to have formed by wholesale replacement of ultramafic rock. These ridges are 0.5-250 m thick and can be traced for several kilometers in outcrop. Listwänite locally contains a weak foliation defined by cataclastic fracture and parallel zones of silica- and dolomite-dominant replacement. This foliation is parallel to the trace of the fault and generally dips steeply toward the north. Subsidiary faults in the Dhiran-Suwaj terrane south of the Ata fault between Shaib Mibari and Dib Baham also contain some listwänite, mylonite, and small lenses of serpentinite.

Listwänite consists of rose-brown (sideritic?) dolomite (iron-stained granules and elongate porphyroblasts), colorless dolomite (rhombic crystals and coarse mosaics in veins), gray quartz and chalcedonic silica, and variable amounts of relict serpentine (fig. 8). Fractured octahedral grains of bottle-brown spinel are present in most samples and are locally accompanied by some fractured grains of magnetite. Spinel is marginally replaced by magnetite (fig. 8) and magnetite is widely replaced by hematite. Talc and brucite are intergrown with serpentine in some of the less altered samples.

Listwänite fabric is typically complex and indicates that replacement of the original serpentine-rich rock occurred continuously during repeated movement on the fault surface. Mosaic dolomite crystals in thin, irregular veins are least deformed (strain twinning); they cut across dislocated patches that are variably replaced by sideritic dolomite and chalcedonic quartz. Relict serpentine is locally kinked and twisted.

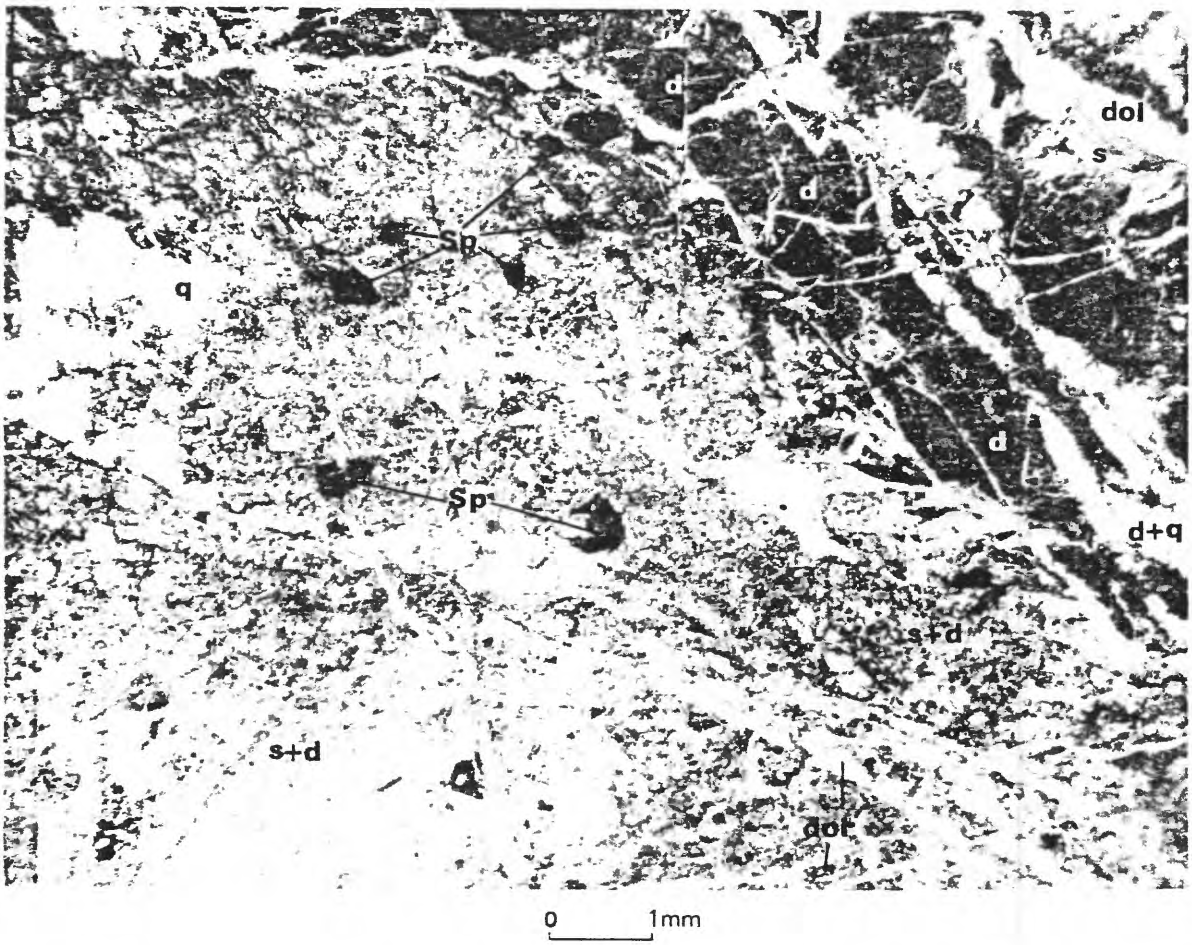

Figure 8.--*Photomicrograph of listwänite showing relict spinel grains (dark gray; Sp). Planar fabric is defined by serpentine (s) replaced by spongy, iron-stained dolomite (d) and strained quartz (q); veins of colorless, twinned dolomite (dol) post-date this fabric, but are also strained.*

QUATERNARY DEPOSITS

Surficial deposits are widespread due to low topographic relief and restricted runoff. These materials are only mapped where bedrock geology could not be reasonably inferred. Quaternary deposits consist of two older units (alluvial fan and apron deposits and terrace gravel deposits) that contain weak soil profiles, eolian sand deposits in Nufud al Urayq and Nufud al Maysariyah, and modern deposits of saline silt in playa basins (sabkhah deposits) and alluvium (Cole, 1984a, d). Two additional units of intermediate age are also exposed in this area and consist of lithified alluvium preserved in a few canyons at Aban al Ahmar, and lacustrine marl deposits in deflation hollows in Nufud al Urayq.

The interpretation of Quaternary geology in this region is based on comprehensive reconnaissance and carbon-14 age determinations by Whitney 1983 unpub. data. His work with the author in this area indicates that the oldest alluvial fan and terrace gravel deposits were probably formed during the Pleistocene Epoch as a result of increased precipitation, weathering, and runoff that correlate with interglacial episodes in the northern hemisphere. Most of the eolian sand accumulated during the intervening arid, glacial episodes prior to the beginning of the Holocene Epoch about 100,000 years before present (B.P.). Increased precipitation during the Holocene interglacial episode is inferred from older lacustrine deposits that formed in Nufud al Urayq between 33,000 and 22,000 years B.P., and it is probable that the lithified alluvium at Aban al Ahmar was deposited at the same time. Subsequent aridity is inferred from the encroachment of eolian sand (Nufud al Maysariyah) on the Wadi ar Rumah channel southeast of Ata village. Younger lacustrine deposits (9000 to 5000 years B.P.; Whitney, 1983) in modern deflation basins of Nufud al Urayq indicate that the last major period of sand accumulation occurred prior to 9000 year B.P. Present-day arid conditions date from about 5000 years B.P. and the landscape has only been slightly modified since then.

ALLUVIAL FAN AND APRON DEPOSITS

Moderately sorted deposits of gravel, sand, and boulders (Qf) have accumulated adjacent to the high mountain ranges of Aban al Asmar and Aban al Ahmar in the eastern part of the quadrangle. The surfaces of alluvial fan and apron deposits are covered with a lag gravel that has thick desert varnish on clasts derived from the Jurdhawiyah group and the Samra rhyolite; deposits derived from Abanat suite granites are pink or red in color and lack this desert varnish. Modern, incised channels in these deposits locally expose a red-orange, slightly cohesive soil at a depth of about 20 cm.

TERRACE GRAVEL DEPOSITS

Inactive deposits of gravel and sand (Qt) are preserved in terraces 1-3 m above the modern channel of Wadi ar Rumah and record the position of the former floodway. These terrace gravel deposits are typically dark brown and are armored by a lag deposit of moderately well rounded cobbles and pebbles of quartz, felsic volcanic rock, and other durable materials. Many cobbles have been faceted by wind erosion and volcanic rock clasts are coated with desert varnish. Red-orange, clayey cohesive soil is present at a depth of 10-20 cm. Evaporation of capillary groundwater has produced thin crusts of white carbonate and sulfate minerals on top of some terraces.

Only one terrace bench is preserved along most of the Wadi ar Rumah course, but the constricted waterway southeast of Ata village has cut three benches in Murdama sandstone bedrock. The surface of the upper bench is 3 m above the channel bottom and is capped by terrace gravel deposits on the north bank and covered by eolian sand on the south bank. The middle bench, at a height of about one m, has no associated lag gravel deposit. The lowest bench is the modern channel bottom.

LITHIFIED ALLUVIUM

Several of the major canyons within Aban al Ahmar contain deposits of lithified, coarse sandy conglomerate and interbedded arkose (Qo). The best exposures are in the canyons north and south of Shaib al Hayyas on the east side of the mountain range, but similar deposits are present on the western side near Al Fayyadah village and on the north side of Sinaf Aba al Haddar. The alluvium is typically red-brown, consists entirely of granitic materials derived from the Ahmar complex, and the top is locally as much as 25 m above the modern streambed; the base is not exposed. Planar-bedded arkose (2-10 cm thick) alternates with variably cross-bedded conglomerate and conglomeratic sandstone that form lensoid beds 20-50 cm thick. Clasts are typically angular and sorting is moderate. This alluvium is friable, but is moderately cemented by calcite and is exposed in vertical cliff-faces where it has been eroded by modern runoff.

LACUSTRINE MARL DEPOSITS

Snow-white, thinly laminated calcareous marl (Ql) is exposed in a few of the interdune deflation hollows within Nufud al Urayq, and formed during two periods (Whitney, 1993, unpubl. data). Probable late Pleistocene lacustrine marl (>31,000 years B.P.; southernmost age locality, pl. 1) rests on eolian sand and is largely covered by later sand; this deposit is less than 1.5 m thick and its partial outcrop indicates the center of the lake basin was not coincident with the present-day deflation basin. Similar deposits elsewhere in the dune field formed during the Holocene wet period (9000-5000 years B.P.); their outcrop coincides with present-day deflation basins, they are not covered by dune sand, and radiocarbon ages confirm the Holocene age (Whitney, 1993, unpubl. data; northern two age localities, pl. 1).

EOLIAN SAND DEPOSITS

The extensive dune fields of Nufud al Urayq and Nufud al Maysariyah consist of wind-blown sand (Qe) that covers large tracts south of Wadi ar Rumah. These deposits chiefly form large barchanoid-cluster and star dunes (70-100 m high) that are light gray (due to a lag coating of coarse quartz and feldspar sand), moderately vegetated, and inactive. Smaller, active barchan dunes consist of medium to fine sand that has a typical red-orange color (due to a higher proportion of oxidized, iron-bearing minerals); these dunes are sparsely vegetated and rest on the older, larger dunes.

SABKHAH DEPOSITS

Thin deposits of light-colored saline silt, carbonate, and sulfate minerals (Qs) are present in several localities in the quadrangle where drainage is restricted or internal. Most of these deposits are associated with the low-gradient channels of Wadi Ata, Shaib Maraghan, and Shaib Jarrar or with protected hollows marginal to the Nufud al Maysariyah dune field. Several of the playa basins in Shaib Maraghan and Wadi Thadij have linear, west-trending, downstream boundaries that coincide with dikes of the Khishaybi suite; these dikes impede the flow of groundwater and surface runoff and allow silt to accumulate on their upstream sides.

The playa basin west of Al Lughfiyah village in the southwestern corner of the quadrangle contains relatively thick deposits of calcareous silt and some bedded halite. An intermittent lake forms during the rainy winter months.

ALLUVIUM

The modern, intermittently active drainage channels of the quadrangle contain moderately sorted deposits of gravel, sand, and minor silt (Q). Bedrock is locally exposed within the channels and indicates these deposits are probably less than a few meters thick. The breadth and extent of the alluviated floodways are clearly relics of past periods of higher discharge, most likely those of the Pleistocene interglacial intervals (Whitney, 1993 unpub. data; Cole, 1984a). Modern runoff is carried in thin, discontinuous rivulets, and the relict floodways are presently aggrading.

STRUCTURAL GEOLOGY

The principal structural elements in the Al Abanat quadrangle are folds in the Murdama group and faults that vary widely in style, scale, and inferred histories of movement. Relations between these structures, the regional unconformities within the layered rocks, and the major intrusive units indicate three periods of widespread deformation during the Proterozoic. The earliest is recorded by deformation and low-grade metamorphism of the Dhiran meta-andesite. The second coincides with the major episode of displacement on the Ata fault, the formation of cataclastic fabric in part of the Suwaj suite, and the beginning of Murdama deposition; these first and second regional events may have been progressive parts of a protracted orogeny (Cole, 1984a, d; Cole and Hedge, 1985 unpub. data). The third regional event is indicated by folding in the Murdama group, which Cole (1984a) has demonstrated took place during terminal deposition while the Murdama was saturated with water.

Post-Murdama units are only locally deformed. The Lughfiyah-Shuhban reverse fault system was principally active during the terminal stages of Jurdhawiyah deposition and produced minor folds in that group (Cole, 1984a). Most of the other faults in the quadrangle were chiefly active during post-Jurdhawiyah time and the amounts of displacement are relatively minor.

FOLDS

Dhiran meta-andesite is structurally massive and contains few folds, but locally possesses a faint schistosity. In contrast, the Sodic metadacite and Marble members and unmapped bodies of biotite-hornblende schist are intensely schistose and contain some rootless, isoclinal folds. Regional evidence suggests that the Dhiran was widely deformed and metamorphosed, but the Meta-andesite does not record the folding because of its mechanical competence (Cole, 1984a, d).

Folds of diverse scale, style, and orientation are common in the Sandstone and Limestone units of the Murdama group (Cole, 1984a). The diversity and disharmony of medium- and small-scale folds (wavelengths less than about 2 km) and the absence of axial-planar cleavage or schistosity suggest these structures formed during soft-sediment deformation.

Bedding in the Murdama north of the Al Madinah-Buraydah highway defines large, steep-limbed, north-trending folds whose axial traces are spaced approximately 5-7 km apart (fig. 2). Folds that close to the north are probably anticlines if they may be compared with similar structures to the west (Cole, 1984a) where sedimentary facing direction has been more reliably determined. These larger structures diminish toward the south and are replaced by highly irregular and disharmonic kilometer-scale contortions in the area south and west of An Numaniyah village. The structure of the Murdama south of the paved highway is largely unknown because of pervasive fine-scale fracture and very sparse outcrop.

Structural, stratigraphic, and magnetic data indicate that a pre-Murdama basement ridge (Bakrah arch, fig. 2) underlies the area surrounding Darat al Jibu (Cole, 1984a). The Bakrah arch separates the main depositional centers of the Murdama in this region (Maraghan and Mahalani basins, fig. 2) and the Murdama was thinner and more calcareous on the Bakrah arch than in the basins (Cole, 1984a). The highly irregular folds near the arch probably reflect soft-sediment slumping that accompanied sporadic uplift of the basement block on the Ata fault and buried structures.

Layered rocks of the Jurdhawiyah group are essentially unfolded in this quadrangle. The synclinal form of bedding in the area east of Jabal Bidan and along the Samra Khaytan ridge chiefly reflects the original geometry of the Idayri and Marmuthah depositional basins, respectively. Reverse-slip on the Lughfiyah fault (south block displaced up and over the north block) at the end of Jurdhawiyah deposition increased the dip of bedding on the south side of the Idayri basin (locally overturned), and produced minor, local folds.

FAULTS

High-angle faults are common in the southern two-thirds of this quadrangle and are related to several regional fault systems that were active during various periods of Proterozoic deformation. Fault surfaces are rarely exposed, but their map traces are based on the following inferrential evidence. Fault traces indicated with a solid line (pl. 1) are partly exposed, generally coincide with a magnetic lineament, and(or) are readily inferred from structural or stratigraphic truncations in the bounding blocks. Faults indicated by dashed lines are not exposed, but coincide with magnetic lineaments and are required by the exposed geology. Faults indicated by long-and-short dashes are chiefly inferred from magnetic lineaments and are only compiled where local geology suggests a fault.

Ata fault system

The Ata fault is a major, continuous, northwest-trending structure that extends from Ata village at least 110 km beyond the quadrangle boundary (Cole, 1984a, d). It juxtaposes the Dhiran-Suwaj terrane to the south against the Maraghan depositional basin of the Murdama group to the north, coincides with a boundary between very dissimilar magnetic terranes, and is marked by listwänite, cataclastic megabreccia, and serpentinite along its trace. Several shorter fractures southwest of the main Ata trace near the Mibari mineral locality and Jibal al Qunaynah also contain listwänite and serpentinite and are included as part of the Ata fault system.

The main Ata fault is irregular and sinuous in plan, but appears to dip uniformly toward the north at 70-85°, as inferred from cataclastic foliation in listwänite. Most of the subsidiary faults also dip steeply toward the north and east, although measured fluxion structure is locally as shallow as 45°. The trends of these faults and their dip directions are regionally concordant with the dominant trend of cataclastic fluxion structure in the Foliated quartz diorite unit of the Suwaj suite and with weak schistosity in the Dhiran meta-andesite. Thus, the deformed fabric in the Dhiran-Suwaj terrane may be genetically related to the earliest movement on the Ata fault.

The displacement history of the Ata fault described by Cole (1984a) is consistent with the geology in the Al Abanat quadrangle. The Ata was an active down-to-the-north normal fault in this area during Murdama deposition and formed the structural margin of the Maraghan basin. During Jurdhawiyah time, parts of the Ata system were re-activated as down-to-the-south faults during formation of the Idayri depositional basin, only to be reversed again (down-to-the-north) at the end of Jurdhawiyah deposition (Cole, 1984a). This type of slip-reversal relationship may apply to the southeast-trending faults at Jibal al

Qunaynah; the main Ata fault is down-to-the-south with regard to the Murdama and Jurdhawiyah groups, but the subsidiary faults that truncate the Jurdhawiyah are down-to-the-north. Other faults of the Ata system (near the Mibari mineral locality) were abandoned during later Jurdhawiyah deposition and are unconformably overlain by it.

Lughfiyah-Shuhban fault system

The high-angle, reverse Lughfiyah fault and related normal faults in the southwestern corner of this quadrangle are the eastern extensions of the Lughfiyah-Shuhbah fault system defined in the area to the west (Cole, 1984a). The Lughfiyah was active at the end of Jurdhawiyah deposition in the Idayri basin and its movement pre-dates intrusion of the Idah suite. However, the Lughfiyah-Shuhban system also coincides in part with the northern structural margin of the Jarir North depositional basin of the Murdama group (fig. 2), and Cole (1984a, d) concludes that precursor faults were active during Murdama time. As with the Ata fault system, the implied sense of slip must have been antithetic during the two main phases of movement; down-to-the-south during Murdama deposition and down-to-the-north following Jurdhawiyah deposition.

The master structure of the system is the Lughfiyah reverse fault and is well exposed in the hills immediately north of Al Lughfiyah village. It is a strongly cleaved fracture zone (0.5-3.0 m thick) that dips 75^{o} to the south. The total displacement cannot be established from present data, but must be on the order of a few kilometers (basal Murdama juxtaposed with lower Jurdhawiyah). The upper plate (south block) consists of intensely fractured, veined, and recrystallized Murdama limestone and moderately schistose cobble conglomerate correlated with the Timiriyat conglomerate (basal Murdama). Schistosity in the Timiriyat is inferred to pre-date the fault because it is generally parallel to the contact with limestone and is offset and re-oriented in the fracture zone of the Lughfiyah fault. The Jurdhawiyah Volcaniclastic conglomerate north of the fault contains 5-10 percent clasts of Murdama limestone and some sandstone, and probably indicates the Lughfiyah fault was also active during early Jurdhawiyah sedimentation.

The subsidiary faults of the Lughfiyah-Shuhban system formed in response to major displacement on the Lughfiyah fault (Cole, 1984a). Displacements on these structures are estimated to be no more than a few hundred meters (section A-A', pl. 1) and they merge with and terminate in the master fault. Dip-slip is typical, although the fault that passes along the south side of the playa basin west of Al Lughfiyah (S2 fault of Cole, 1984a) has a rotational component of offset; it is down-to-the-north in this quadrangle and becomes down-to-the-south along strike to the west (Cole, 1984a).

Other faults

Most other faults of the quadrangle are neither as well exposed nor is their movement history as closely constrained as the Ata and Lughfiyah-Shuhban fault systems. The Qunaynah and Ahmar faults are sub-parallel and trend east-northeast, and each forms the boundary of a down-faulted, synclinal block of Jurdhawiyah group deposits. The block between the two faults consists of Dhiran-Suwaj terrane that was probably uplifted during Murdama deposition in the Maraghan basin. Conversely, the same block must have been structurally depressed during Jurdhawiyah deposition in the Marmuthah basin that surrounds it; there is no evidence of a pre-Jurdhawiyah source terrane within the basin.

The fact that the north and south margins of the Marmuthah basin (exposed at Jibal al Qunaynah and southwest of Samra Khaytan) are subparallel to the Qunaynah and Ahmar faults, respectively, suggests that the block of Dhiran-Suwaj terrane may have dropped to form a graben during Jurdhawiyah time. Magnetic lineaments in the Dhiran-Suwaj terrane beneath Nufud al Urayq have similar east-northeast trends and may reflect additional block faults within the Marmuthah basin (graben).

The present structural position of the Dhiran-Suwaj block indicates the Qunaynah and Ahmar faults must have been re-activated with the opposite sense of slip after Jurdhawiyah time. Most likely, the re-activation occurred in association with the main period of movement on the Lughfiyah-Shuhban fault system, which coincides with the end of Jurdhawiyah deposition in the adjoining Idayri basin (Cole, 1984a). The Ahmar fault is truncated by the intrusive rocks of the Ahmar complex and, therefore, is older than 574±5 Ma (Stuckless and others, in press).

Several faults in the quadrangle have moved in latest Proterozoic time, although the amount of displacement appears to have been quite small. The Mitla fault displaces the Samra rhyolite and intrusive rocks of the Asmar complex and is exposed in a col at the head of Shaib al Mitla al Ayman and in a silicified zone south of Rawdat Qiridan. The fault zone is about 2-3 m wide and consists of breccia that is cemented by hematite and quartz. The offset of the magnetic boundary between Murdama and Hamar monzogranite near Rawdat Qiridan suggests about 2 km of left-slip, whereas the offset of the Samra rhyolite can be interpreted as a few hundred meters of either left-slip or down-to-the-north displacement. The preferred interpretation is that the Mitla fault had moderate left-slip following intrusion of the Hamar (Khishaybi suite) and was re-activated as a dip-slip structure following emplacement of the Asmar complex (Abanat suite).

Other faults near Jibal Zalma, north of Jibal umm Burayqi, and along Wadi ar Rumah at Jabal Najjabah are inferred to post-date the Asmar complex, but the amount of required displacement is minor and is most probably dip-slip. The fault north of Jibal umm Burayqi is exposed in the quadrangle to the east and is a minor cataclastic fracture zone (quartz-hematite-epidote cementation) that has displaced the Intrusion breccia member down-to-the-south (Cole and Bohannon, 1985a). The indicated fault contact north of Jabal Najjabah between Hornblende perthite granite (Asmar complex) and Hamar monzogranite (Khishaybi suite) is certainly more complicated than shown, but exposures are very sparse near the Wadi ar Rumah floodway.

STRUCTURAL EVOLUTION

The structural history of the Al Abanat quadrangle is largely similar to the adjoining area to the west, where Cole (1984a) presents considerable evidence for four deformational events. These are: 1) folding and metamorphism of the Dhiran-Suwaj terrane prior to Murdama deposition; 2) soft-sediment deformation of the Murdama prior to Jurdhawiyah deposition; 3) faulting during and after Jurdhawiyah time, most strongly displayed by the Lughfiyah-Shuhban reverse fault system; and 4) regional extension and local block-faulting during intrusion of Abanat suite granites and associated volcanic activity. The end of each major event is defined by a regional unconformity (Cole, 1984a, d).

The Dhiran-Suwaj terrane represents the earliest-formed protocontinental crust of the region and the two units have been interpreted as cogenetic volcanic and intrusive rocks formed from subducted oceanic crust (Cole, 1984d; Cole and Hedge, 1985, unpub. data). The limited compressional folding of the Dhiran, the ductile deformation of the Foliated quartz diorite, and regional metamorphism of the Dhiran are consistent with the high heat-flow and tectonic setting of magmatic arc environments (convergent plate boundaries), but further work is needed to establish a genetic relationship among these features.

Cole (1984d) and Cole and Hedge (1985, unpub. data) have documented the onset of regional transcurrent slip on the Halaban-Zarghat fault (fig. 1) prior to deposition of the Murdama group, and suggest that the Ata fault initially formed at the same time under similar regional stress conditions. The southern part of the Halaban-Zarghat fault is similar to the Ata fault in that it forms the boundary between markedly different geologic and magnetic terranes and it contains serpentinite, listwänite, and mylonite gneiss along its trace (Delfour and others, 1982). The fact that foliation in the Dhiran and cataclastic fabric in the Foliated quartz diorite unit are conformable with the Ata fault suggests that these three structures may have formed together during the initial phase of strike-slip displacement on the Ata fault.

Initial deposition of the Murdama group is interpreted to be the result of orogenic uplift that accompanied the deformation of the Dhiran and intrusion of the Suwaj suite. Murdama deposition was accompanied by vertical displacement on the Ata fault and on the precursor to the Lughfiyah-Shuhban fault system (Cole, 1984a). That part of the Ata fault that bounds the Maraghan basin in this quadrangle was probably not as active as segments that bound the Mahalani basin to the west, because the basal Timiriyat conglomerate is absent from the Maraghan basin but abundant in the Mahalani basin (fig. 2).

The variable, small-scale folding of the Murdama sandstone is largely the result of soft-sediment deformation, but the north-trending folds along the northern quadrangle boundary suggest a regional, east-west compressional stress system whose origin is uncertain (Cole, 1984a, d). A similar stress regime is inferred from the east-west dikes of the Khishaybi suite, which intrude the Maraghan basin. It is also likely that this regional east-west compression induced the second major episode of left-slip on northwest-trending Halaban-Zarghat fault, because it displaces the Murdama and Khishaybi but not the Jurdhawiyah (Cole, 1984d; Cole and Hedge, 1985, unpub. data).

The regional unconformity at the base of the Jurdhawiyah group marks the end of the second major structural event and the onset of the third. This younger event is characterized by active dip-slip on faults that bounded and defined the Marmuthah and Idayri depositional basins of the Jurdhawiyah. Regional north-south to northwest-southeast extension is inferred during early Jurdhawiyah time because the basin-bounding faults are perpendicular to these trends and because basin margins were intruded by Plagioclase porphyry dikes and plugs that erupted Jurdhawiyah volcanic products. The general lack of pre-Jurdhawiyah clastic debris in the group also suggests these basins subsided in relation to stable basin-margin blocks.

The regional extensional stress system was superceded in late Jurdhawiyah time by local northward-directed compression, as expressed by displacement on the Lughfiyah-Shuhban reverse fault system (Cole, 1984a, d). The compression is indicated by several kilometers oftratigraphic displacement across the Lughfiyah master fault, by local overturned Jurdhawiyah beds in the footwall, and by kilometer-scale chevron folds beneath the fault surface west of this quadrangle (Cole, 1984a). These effects are local to the Idayri basin and have no counterpart in other Jurdhawiyah basins (Cole, 1984d). Post-Jurdhawiyah offset on the Qunaynah and Ahmar faults, which raised the Dhiran-Suwaj horst through the Marmuthah basin deposits, may have occurred at this time to accommodate crowding from the southwest as a result of Lughfiyah fault displacement.

Intrusions of the Idah suite truncate these folds and faults and appear to have been emplaced during regional structural quiescence; the Idah forms simple, cylindrical bodies and the rocks lack directional fabric (Cole, 1984d; Cole and Hedge, 1985, unpub. data). Widespread intrusion of these plutons appears to have stabilized the crust of the northeastern Shield and fundamentally altered its internal density structure (Cole, 1984a, d; Cole and Hedge, 1985, unpub. data). During the 30-Ma interval following Idah-suite intrusion (about 615-585 Ma; Cole and Hedge, 1985, unpub. data), no rocks are known to have formed. It appears that post-Idah isostatic adjustment lead to epierogenic uplift, erosion, and planation. This interval was also probably characterized by prolonged weathering because most pre-615 Ma rock units are characterized by poor outcrop and weak topographic expression, whereas the post-585 Ma Samra rhyolite and the intrusive rocks of the Abanat suite are topographically prominent.

Emplacement of the Abanat suite was accompanied by weak north- to northeast-trending extension. This tectonic setting is inferred from the orientation of the Sanidine porphyry dike swarm, the minor faults that offset the Asmar complex, and similar structures in the region (Cole, 1984d). Both the Asmar and Ahmar complexes consist of nested and intersecting, elliptical ring structures whose major axes trend toward the north-northwest and north-northeast, respectively (fig. 2). Although these features may also be due to the influence of regional stresses, it is more likely that the orientation of the Asmar ring structures is inherited from the shape of the mechanical margin of the Khishaybi terrane, and that the Ahmar ring structures derive from zones of weakness subparallel to the Ahmar fault.

ECONOMIC GEOLOGY

Minor ancient gold workings are present in a number of geologic environments in the Al Abanat quadrangle, but only those of Al Khaymah and possibly Umm Jirfan are sufficiently extensive to suggest mineral potential. Disseminated and stockwork-hosted copper minerals are associated with a few fractures of the Ata fault system in the Suwaj suite, and minor copper-bearing sulfides were extracted from Dhiran meta-andesite in Suwaj diorite. Potential exploration areas for tin and granitophile elements are defined on the basis of favorable geology and geochemical reconnaissance, but no sites of concentration have yet been defined.

Mineral locality names are spelled as they are listed in the MODS data base, and may differ slightly from the official transliterations of geographic features shown on the map.

GOLD

Four areas of ancient workings have been located in the quadrangle and the principal commodity extracted is known or inferred to be gold. The geologic setting of the minor workings at Al Jurayyir and Shaib al Jurayyir are similar to other gold deposits in the region (Kleinkopf and Cole, 1982; Boyle and Howes, 1983; Cole, 1984a, d) because they follow quartz veins in the Murdama near Idah-suite intrusive stocks. The veins at the Al Khaymah ancient workings are generally similar to this regional deposit type, but they contain more gold and less arsenic and antimony and the deposit is hosted by the Jurdhawiyah group (Smith and Samater, 1985). Umm Jirfan represents a third type of gold deposit; it is hosted by rocks of the Suwaj suite, the veins are characterized by abundant stibnite and minor pyrite, and silver is a significant associate of gold.

The Al Jurayyir occurrence (MODS 3267) is located on the northern quadrangle boundary, north of An Numaniyah village, and extends into the adjoining quadrangle for 3-4 km (Mytton, 1970; du Bray, in press). The workings consist of short, irregular trenches and dumps along quartz veins. These veins generally trend due north within the small stock of Idah suite granodiorite porphyry and in the hornfelsed Murdama country rock and consist of medium-grained, vuggy quartz, brown carbonate, and sparse relics of pyrite. Vein quartz is locally brecciated and cemented by hematite. A single composite sample of vein material contained trace amounts of gold and silver and 700 ppm arsenic.

The Shaib al Jurrayir occurrence (MODS 1604) is located 4 km west of Thadij village and was briefly described by Mytton (1970) and visited by the author. Exposures are poor, but there appear to be 3-4 en echelon trenches (30-40 m long, 1 m wide) that trend N. 35-50° E. Thin quartz veins are similar to those at Al Jurayyir but are more thoroughly brecciated and cemented by hematite. A single composite sample of vein material from spoil piles contained 5 ppm gold, minor copper, and 20 ppm tin. No plutonic body is exposed in the area, but magnetic data (ARGAS, 1967) suggest a buried stock may be present immediately to the east.

The Al Khaymah prospect (MODS 3941) is located along the western boundary of the quadrangle north of Wadi ar Rumah and was discovered by the author in 1981. The following description is summarized from the report of systematic channel sampling and geochemical reconnaissance in the area by Smith and Samater (1985). Al Khaymah consists of a large ancient excavation (2 m wide, 75 m long) at the southern end of the field and four smaller workings (various trenches 20-50 m long) that are distributed northward along the dominant vein trend (N. 5-15^{o} W.) over a distance of about 4 km. The host rocks are Jurdhawiyah volcanic and volcaniclastic rocks, which contain sparse contact-metamorphic biotite near the southern working. The vein at this locality is 40-100 cm thick, dips about 80^{o} west, and consists of coarsely crystalline, vuggy quartz, minor ankerite, and widely disseminated grains of sulfide minerals (pyrite, chalcopyrite, and local bornite and covellite) with prominent granules of free gold. Secondary hematite and copper minerals are common, especially where the margins of the vein are slightly brecciated. The veins in the northern workings are generally thinner (10-40 cm), shorter, and less continuous, but are otherwise similar.

Al Khaymah is unusual because of the abundance of free gold in comparison with the sparse ancient workings. Composite channel samples typically contain 3 ppm gold and very sporadic values of 40-65 ppm are not unusual. However, Smith and Samater (1985) were unable to estimate an average grade because of high sample and analytical variance. Associated elements include copper and minor zinc, but silver is characteristically less than 3 ppm and arsenic and antimony are generally not present in detectable amounts.

Although Al Khaymah differs from typical gold occurrences in the northeastern Shield (Cole, 1984a, d), it is similarly interpreted to be genetically related to an Idah suite stock (Cole, 1985; Smith and Samater, 1985). The presence of a buried intrusive body is indicated by a circular magnetic anomaly near and southeast of the main working, by sparse diabase dikes that cut some veins, and by faint recrystallization of the Jurdhawiyah host rocks.

The Umm Jirfan occurrence (MODS 959) is very poorly exposed on the alluvial apron north of Aban al Ahmar, but has been repeatedly visited because of its abundant stibnite and local high values of gold and silver (Mytton, 1970; Muller, 1975; Begg, 1980; Cole, this report). The main workings are located about 1 km west of a small hill (Foliated quartz diorite, Suwaj suite) and consist of two discontinuous main trenches (about 150 m long) that are sub-parallel and trend approximately N. 20^{o} W., and small pits and trenches that are interpreted to form a cross trend (N. 60^{o} E.; Mytton, 1970; Muller, 1975). Granite grindstones are common near the dumps, and a probable ancient village site is located about 1.5 km east of the quartz diorite hill. A large area on the alluvial apron north and east of these exposed workings (indicated by pattern on the map) appears hummocky and pitted and may have been excavated, although the surface has been reworked by runoff and covered by sheet sand.

Veins are not exposed at Umm Jirfan but the material in spoil piles indicates that most are less than a few centimeters thick, consist of greasy, gray-black quartz that is brecciated and annealed, and contain abundant granular to bladed stibnite, sparse pyrite and galena, and secondary hematite, brown carbonate, and antimony minerals. Begg (1980) reported high values of 115 ppm gold, 12 ppm silver for a grab sample of vein quartz. Results for grab samples by Mytton (1970), Begg (1980), and the author all indicate considerable gold (2 samples at 2-5 ppm, 8 samples at 10-30 ppm, and one sample each at 78 and 115 ppm) and silver (5 samples at 2-5 ppm, 5 samples at 10-20 ppm, and one sample at 26 ppm) in association with high antimony values. Arsenic, copper, lead, and zinc are generally minor.

COPPER

Two minor copper occurrences were discovered in the course of this project in the Dhiran-Suwaj terrane. At the Mibari locality, mineralization is associated with cataclastic rock in a subsidiary of the Ata fault system that is unconformably overlain by the Jurdhawiyah group. Both Mibari and Mibari South probably pre-date the Murdama group as well because they are confined to the Dhiran-Suwaj terrane, and because most copper deposits in the Arabian Shield are contained in pre-Murdama host rocks (Johnson and Vranas, 1984).

The Mibari locality (MODS 3944) coincides with a complex braided fracture zone at the south end of a south-trending splay of the Ata fault system, 6.5 km east of the Al Khaymah occurrence on the north bank of Wadi ar Rumah. The host rocks are blocks of Dhiran meta-andesite that are irregularly intruded by fine-grained, orange-pink, microporphyritic granodiorite granophyre of the Suwaj suite. The granophyre is riddled with stockwork veinlets of gray quartz that contain chalcocite, sparse pyrite, and variable amounts of orthoclase. Secondary hematite and copper minerals are common. The veinlets are exposed for a distance of about 2 km along a N. 70° W. trend that follows the irregular trace of later fractures. These fractures are thin, coated with epidote and chlorite, display irregular slickenside lineations, and locally contain some redeposited copper minerals.

Spot and composite rock samples collected by Smith and Samater (1985) contain variable amounts of copper (300 to about 10,000 ppm), minor zinc, and local amounts of molybdenum (100 ppm maximum). Precious metals are characteristically present in amounts less than 1-2 ppm.

The Mibari South occurrence (MODS 3943) is located on the south bank of Wadi ar Rumah, on a southwestward continuation of the Mibari trend, but no cataclastic zone is present. Mibari South consists of two subparallel trenches (30 and 40 m long) along thin veins that trend N. 65-85° W. The host rocks are poorly exposed, but include Suwaj diorite and irregular inclusions of Dhiran meta-andesite. The veins are chiefly fractured quartz and calcite and contain small gossanous pods and masses that are stained by secondary copper minerals. Smith and Samater (1985) report a maximum value of about 1.6 percent copper and 500 ppm zinc for gossanous material.

TIN AND RARE METALS

One mineral locality and several geochemical/geological anomalies are associated with intrusive rocks of the Abanat suite and suggest the possibility of local enrichment in the granitophile elements. Regional drainage-sediment geochemical surveys define three principal anomalous zones on the basis of strongly correlated abundances of trace elements (W. Miller and R. Samater, written comm., 1984): 1) copper, lead, boron, and tin in the Murdama north of the paved highway; 2) beryllium, tin, niobium, lead, and local zinc and molybdenum in the drainages of Aban al Asmar; and 3) niobium, lanthanum, beryllium, yttrium, and tin in the drainages of Aban al Ahmar.

The first zone is a low-grade regional anomaly that covers much of the central Maraghan depositional basin, and it overlaps with an independently defined zone that has Landsat-spectral characteristics correlated with hydrothermal limonite (G. Raines, written comm., 1983). The Meshaheed deposits (MODS 1266; gold, minor molybdenum, and base metals; Smith and Samater, 1984) and the Silsilah tin deposit (MODS 3262; du Bray, 1984) are contained in these overlapping anomaly zones, as are numerous small gold deposits. Quartz veins are locally abundant in the Murdama in this area although most lack sulfide minerals or anomalous trace metals (Cole, 1984c). However, one quartz vein sampled east of Darat al Jibu between two small stocks of Idah suite granodiorite porphyry contained 50 ppm tungsten, 20 ppm molybdenum, and 10 ppm boron. Further work is needed throughout the anomalous zones to evaluate the potential for mineralization above buried intrusions.

The second anomalous zone corresponds to the peraluminous intrusive rocks of the Asmar complex and to the coeval Samra rhyolite. No specific sites of mineral enrichment have been detected, but further work is warranted because the complex formed by multiple intrusions by fluorine- and trace-element-rich magmas. These intrusions recrystallized the Samra rhyolite, and it locally contains porphyroblastic topaz, muscovite, and fluorite.

The third anomalous zone corresponds with the Ahmar complex and is characterized by those elements that are typically enriched in peralkaline granites. Late-stage dikes and the outer contact zones are more radioactive than other parts of the pluton and are relatively enriched in niobium, lanthanum, fluorine, and (locally) tin and zinc. Quartz-fluorite veins in some fracture-controlled canyons are also enriched in these elements (MODS 2733).

The Hadiyah North silver occurrence (MODS 3942) is believed to be related to the Ahmar complex because the shallow, circular, ancient pits there were excavated along the contact between Dhiran meta-andesite and a radioactive, rhyolite granophyre dike. This dike, located about 4 km north of the Sinaf Aba al Haddar dike ridge, is correlated with the Rhyolite porphyry member of the Ahmar complex on the basis of its bulk composition, orientation, and enrichment in lanthanum and niobium. Exposures are poor and the relationship of veins to the dike is unknown. Silver (3 ppm) and molybdenum (7 ppm) were detected in carbonate-rich quartz-vein material that was sampled from the pit-spoil piles (Cole, 1984c).

SUMMARY AND REGIONAL IMPLICATIONS

The geologic history and crustal evolution outlined here for the northeastern Shield (fig. 9) are based on the geologic framework established in this and adjoining quadrangles (Cole, 1981, 1984a), on regional compilations and summaries (Cole, 1984d; Johnson and Williams, 1984), and on recent age determinations (Stuckless and others, in press; Cole and Hedge, 1985, unpub. data). This region consisted of oceanic crust prior to about 700 Ma, which evolved to a continental shield by repeated intrusion and deformation in a limited interval during the latest Proterozoic (700-570 Ma).

The Dhiran meta-andesite and the intrusive rocks of the Suwaj suite are interpreted as the products of a magmatic arc that formed above a southwest-dipping, ensimatic subduction zone between about 700 and 670 Ma (Cole, 1984d; Cole and Hedge, 1985, unpub. data). Although the Suwaj consistently intrudes the Dhiran, both units were probably comagmatic and broadly coeval because their composition, compositional range, and inferred primary mineralogy are similar (Cole, 1984a, d). These low-potassium, mafic intrusive and volcanic rocks are similar to the oldest rock assemblages elsewhere in the Shield that have also been interpreted as remnants of ensimatic magmatic arcs (Schmidt and others, 1979; Greenwood and others, 1982; Roobol and others, 1983; Stoeser and Camp, in press). However, the Dhiran-Suwaj terrane (700-670 Ma) is considerably younger than most of these similar assemblages (Fleck and Hadley, 1982; Calvez and others, 1983; Stacey and others, 1984; Cole and Hedge, 1985, unpub. data) and probably formed from a discrete, short-lived magmatic arc. The volcanic and intrusive rocks of the Ar Rayn area in the easternmost Shield were formed in an even younger arc at about 650 Ma (Roobol and others, 1983; Stacey and others, 1984; Stoeser and Camp, in press).

The cause(s) of regional metamorphism, folding, and initiation of the Ata fault are not certain, but these three events appear related in space and time and probably represent deformation of the primitive Dhiran-Suwaj crust when subduction ceased at about 670 Ma (Cole, 1984a, d; Cole and Hedge, 1985, unpub. data). Other workers have recognized this pre-Murdama, regional orogenic event and its coincidence with the end of arc processes (Schmidt and others, 1979; Letalenet, 1979; Calvez and others, 1983; Stacey and others, 1984; Stoeser and others, 1984; Cole and Hedge, 1985, unpub. data). Several proposed models for the tectonic setting during this event differ mainly in their assumptions about the types of crustal plates involved in the deformation, and further work is needed to evaluate these models.

The voluminous clastic debris of the Murdama group is interpreted to represent the erosional stripping of the orogenic uplift (Cole, 1984a, d). Initial deposition, therefore, probably began at about 670 Ma and filled several marine basins whose margins are defined by faulted uplifts of the Dhiran-Suwaj terrane. The Ata fault (reactivated as a dip-slip structure) on the southern margin of the Maraghan basin and the early Lughfiyah-Shuhban fault system on the northern margin of the Jarir North basin (fig. 2) were active during this period. Gentle regional folding produced north-trending warps in late Murdama time, which probably pre-dates 655 Ma (Cole and Hedge, 1985, unpub. data).

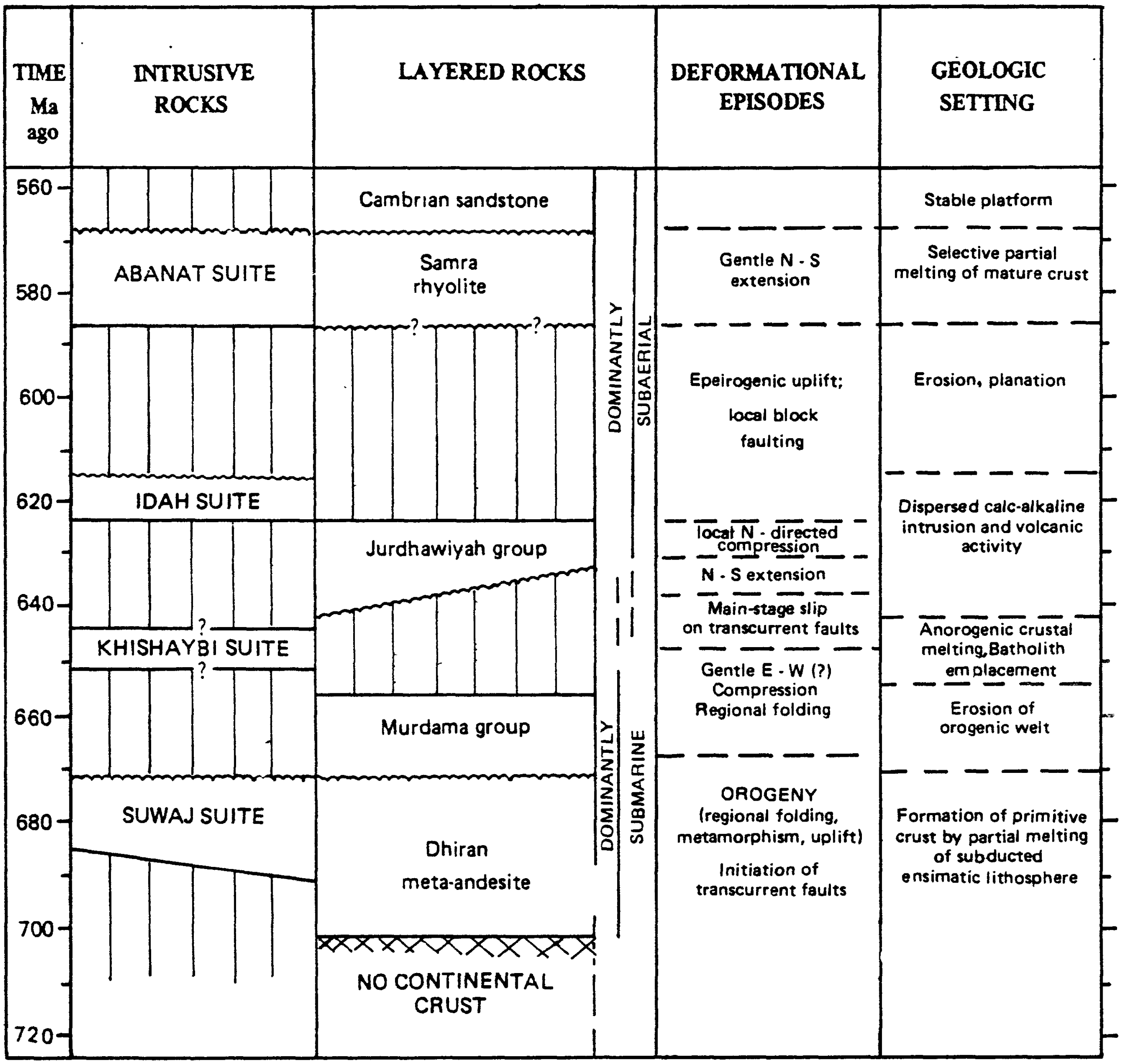

Figure 9.--*Interpreted geologic evolution of rock units and structural events for the Al Abanat quadrangle and vicinity. Absolute time scale is based on Stuckless and others* (in press) *and Cole and Hedge* (1985 unpubl. data)*; see text for discussion.*

The leucocratic granitic rocks of the batholithic Khishaybi suite were emplaced following this folding, but its age and tectonic setting are not certain. The Khishaybi is probably not much younger than Murdama (both pre-date the Jurdhawiyah group; fig. 9), and its intrusion may even have overlapped with the gentle east-west compression that produced the Murdama folds. This suggestion is supported by the dominant westerly trend of Khishaybi dikes, by the brecciation of some of these dikes, and by the diffuse cataclasis typical of all Khishaybi granites (Cole and Bohannon, 1985a).

The regional unconformity at the base of the Jurdhawiyah group marks the initiation of a markedly different geologic setting in the northeastern Shield (Cole, 1984a). The group consists of calc-alkaline volcanic rocks (dominantly andesite) that must have originated from sources beneath the Murdama crust (for example, Gill, 1981; Cole, 1984d); therefore, these volcanic and contemporaneous volcaniclastic deposits represent the addition of new material to that crust. Furthermore, Jurdhawiyah basins are controlled by high-angle block faults that generally trend east-west and indicate contemporaneous crustal extension in a north-south to northwest-southeast direction, transcurrent to Murdama structural trends. Deposition and subsidence during Jurdhawiyah time were probably rapid and discontinuous, based on the abundance of coarse clastic debris, lensoid bedding units, and the lateral and vertical facies changes that characterize the group. The distribution and variability of the Andesite unit and the Lapilli tuff member indicate that contemporaneous volcanic activity was sporadic in various areas. Jurdhawiyah volcanic centers, deduced from the Plagioclase porphyry and Gabbronorite plugs and dikes, are clustered along the margins of the basins and their locations were probably controlled by the extensional bounding faults.

Post-Jurdhawiyah deformation is generally minor and limited to tilting and block-faulting. The Lughfiyah-Shuhban reverse fault system, however, produced some folding and overturning in response to local, northward-directed compression (Cole, 1984a). Displacement on this fault system, estimated to be several kilometers from stratigraphic offset of the Murdama and Jurdhawiyah groups, may have been sufficient to drive the uplift of the Dhiran-Suwaj horst, bounded by the Qunaynah and Ahmar faults.

Widespread intrusion of calc-alkaline plutonic rocks of the Idah suite between about 620 and 615 Ma (Cole, 1984d; Cole and Hedge, 1985 unpub. data) post-dates deformation of the Jurdhawiyah group, and probably coincides with a time when regional stress was largely neutral (Cole, 1984a, d). Although the Idah is clearly younger, it is probably cogenetic with compositionally similar Jurdhawiyah volcanic rocks and, together, these rocks may have formed from a significant episode of partial melting in the lower crust or upper mantle. The Jurdhawiyah and Idah are similar to voluminous calc-alkaline assemblages elsewhere in the world in terms of their average composition, compositional range, mineralogy, and trace element chemistry (Gill, 1981; Cole, 1982, 1984a, b, c, d). However, the broadly dispersed pattern of intrusion and volcanic activity shown by these two units (that is, the absence of regional linear trends) is inconsistent with a simple, Andean-type subduction model. A closer analog to the Jurdhawiyah-Idah assemblage may apply from the complicated pattern of Cenozoic intrusion and volcanic activity in the western United States (Gill, 1981).

The 30-Ma interval that followed intrusion of the Idah suite (about 615-585 Ma) was characterized by epeirogenic uplift, weathering, and planation (Cole, 1984a), probably as a result of isostatic adjustment to the preceding period of magma generation. Intrusion of the leucocratic, evolved granites of the Abanat suite began at about 585 Ma and lasted until about 570 Ma (Stuckless and others, in press; Cole and Hedge, 1985 unpub. data). Composite plutons with nested, ring-shaped multiple intrusions are characteristic of the suite and these bodies are inferred to have been emplaced at very shallow depths. The Asmar complex was partly emplaced into its cogenetic volcanic cover (Samra rhyolite), and the Ahmar complex granites are typically very fine grained, granophyric, and quenched along its subhorizontal roof contact (Cole, 1981, this report).

Geochemical, geochronologic, and isotopic studies of the Abanat suite granites indicate the peralkaline, peraluminous, and intermediate varieties were all formed at about the same time and that distinctions among them may be related to differences in the partially melted source materials (Stuckless and others, 1982a, b, 1984; Cole and Hedge, 1985 unpub. data). The source terrane for the Ahmar complex must have been chemically and isotopically primitive (similar to the Dhiran-Suwaj terrane), whereas the Asmar complex peraluminous granites must have had some interaction with evolved crustal materials (Khishaybi suite or perhaps the Murdama group) during genesis.

DATA STORAGE

Unpublished data generated in the course of DMMR sub-project 2.01.19 and summarized and incorporated in this report are available for examination at the Jiddah office of the USGS. They are cataloged as DMMR Data-File USGS-DF-04-34, which contains:

* Map (1:100,000-scale) showing station locations, station/sample numbers, secondary (dirt) roads, and station altitudes (barometric; superceded by information released in 1984 by the MPMR Aerial Survey Department, Riyadh); paper copy in file; stable-base mylar stored separately

* Computer tabulation of digitized station locations (latitude-longitude)

* Computer tabulation of chemical data for all samples analyzed and collected from this quadrangle; original analytical data sheets also stored in file

* Photocopies of original field notes, including total-count radioactivity measurements (semiquantitative)

* Contact black-and-white prints, 1:60,000-scale aerial photography with original field notations

* Modal composition data for plutonic rocks (original analyses, tabulated percentages, and triangular composition diagrams)

* Thin sections and stained rock slabs (stored separately)

Entries into Mineral Occurrence Documentation System

MODS 959	Umm Jirfan	updated bibliography
MODS 1604	Shaib al Jurayyir	updated bibliography
MODS 3267	Al Jurayyir	updated bibliography
MODS 3941	Al Khaymah	new entry (5/84), Au-Cu workings
MODS 3942	Hadiyah North	new entry (5/84), Ag workings
MODS 3943	Mibari South	new entry (5/84), Cu workings
MODS 3944	Mibari	new entry (5/84), Cu occurrence

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