DEPARTMENT OF THE INTERIOR
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A gravity survey of parts of Quadrangles 26E, 26F, 27E, and 27F, Northeastern Arabian Shield, Kingdom of Saudi Arabia

by

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A GRAVITY SURVEY OF PARTS OF QUADRANGLES 26E, 26F, 27E, AND 27F, NORTHEASTERN ARABIAN SHIELD, KINGDOM OF SAUDI ARABIA

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ABSTRACT

A gravity survey using nearly 800 stations was conducted over an area of about 13,400 km^2 located in the northeast part of the Arabian Shield. The stations were set on spot elevations of relative high density and shown on high-quality 1:50,000-scale topographic base maps.

The error in a gravity reading due to uncertain elevation is estimated to be less than 0.33 mgal. Determination of station coordinates was aided by helicopter-mounted LORAN-C navigation units. The cost/time factors involved in the survey compared favorably with commercial surveys done with inertial-guidance systems but without the 1:50,000-scale maps. As topographic-map coverage becomes available, gravity surveys should be run over the entire Arabian Shield.

The Arabian Shield is generally comprised of Proterozoic sedimentary rocks metamorphosed to varying degrees and intruded by plutonic rocks. The northeastern Shield is traversed by the north-trending Nabitah mobile belt, a zone of flexing, faulting, shearing, and mineralization. The complete Bouguer gravity field defines the boundary of the mobile belt, as well as a tectonic platelet that has undergone especially conspicuous thrusting and other types of deformation within the mobile belt.

Many plutons intruded the metamorphic rocks in the survey area. The youngest rocks are peraluminuous, contain anomalously high tin and tungsten concentrations, and are similar to other tin and tungsten-bearing granites elsewhere. Pronounced gravity lows are associated with these plutons, but not all of a pluton or its associated mineralized rocks may crop out. Thus, gravity surveys of areas with similar plutonism are important in the study of plutonic mineralization.

Quaternary deposits are distributed along mountain fronts and wadis. Gravity lows are commonly associated with the wadis, but their low amplitude suggests alluvial thicknesses of less than 25 m. This implies that the valleys are not

structurally controlled by extension and that the alluvial aquifers, from which nearly all domestic water is produced, are relatively thin.

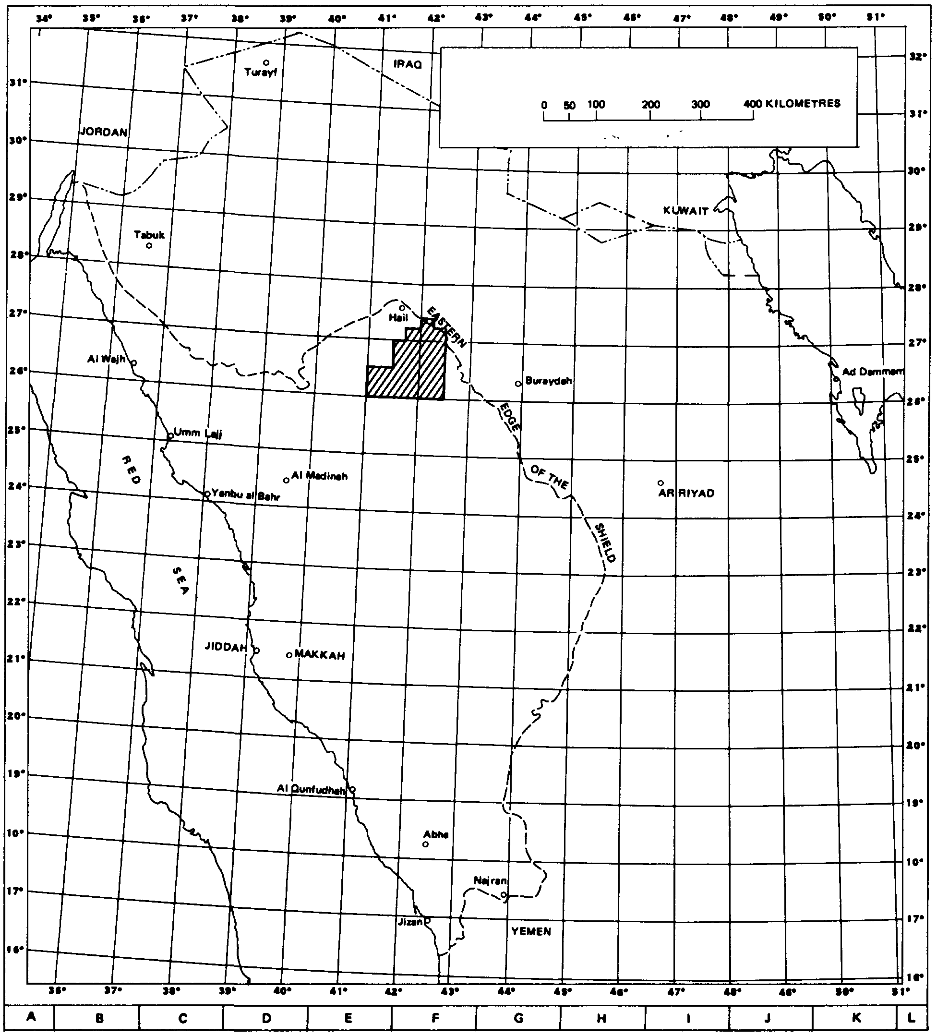
The greatest complete Bouguer anomaly is associated with basaltic lava flows located in the northeastern part of the survey area. The thickness of the basalt in outcrop does not account for the anomalies with the highest amplitudes, but the latter may be due to the presence of a basalt-filled vent. Those anomalies that are present do not define the basalt flows well, but the largest free-air anomaly occurs over the southwestern margin of the Salma Caldera, located about 15 km from the basalt flows. The source of the free-air anomaly is unknown, but it may be related to another hidden basaltic vent.

INTRODUCTION

This report presents the results of a regional gravity survey conducted in the northeastern part of the Proterozoic Arabian Shield (fig. 1). The method of acquisition of the complete Bouguer gravity anomaly and a geologic interpretation are described herein; the nature and interpretation of the free-air gravity is also discussed. Both the gravity and generalized geology are presented at a scale of 1:250,000 and figure 1 B shows the 1:250,000-scale geologic map coverage for the area of this study. The purpose of the survey is to delineate regional gravity trends; this will help interpret geologic structures, delineate lithologies, and possible mineral deposits. In particular, this survey will help define some layered rocks that have been intruded by peraluminous plutons that are chemically similar to plutons elsewhere in the world and that are associated with deposits of tin or tungsten (Kellogg and Smith, 1986; du Bray and others, 1982).

The gravimetrically surveyed area covers about 13,400 km^2 and includes nearly 800 base and gravity stations, which corresponds to a station interval of about 4 km. The stations were set on spot elevations shown on high-quality topographic base maps and the location of these spot elevations was greatly aided by a helicopter-mounted LORAN-C navigational system. Terrain corrections were calculated and the gravity data were reduced by computer. The gravity survey and data reduction was performed by an all-Arab crew from the Geophysics Section, of the U.S. Geological Survey Mission, Jeddah. The cost effectiveness of this "in-house" survey compared favorably to that of commercial surveys that used inertial-guidance systems controlled by satellite surveying systems instead of the 1:50,000-scale topographic maps with spot elevations.

(A)



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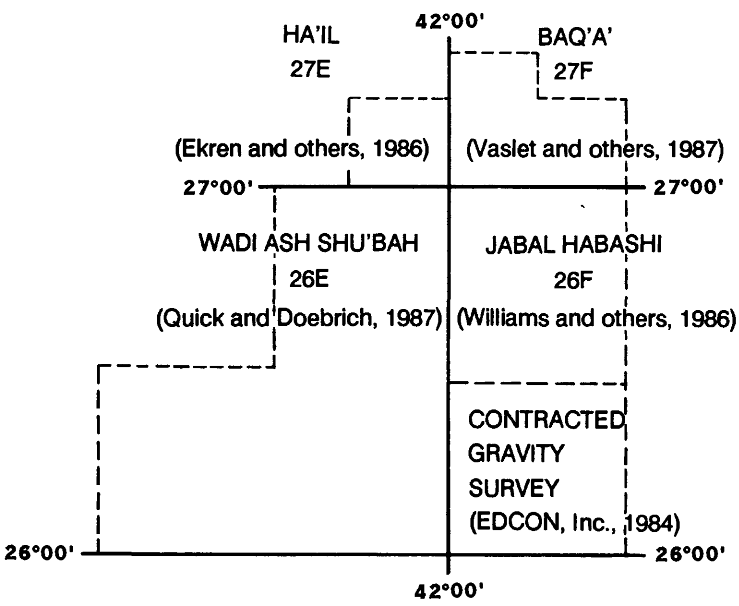

Figure 1.--(A) Index map of Saudi Arabia showing the area covered by the Survey (hachured polygon) described in this report. (B) Index map of the area of gravity coverage showing the 1:250,000-scale geologic quadrangles used in the gravity interpretation.

The gravity survey was done in accordance with the Ninth Extension to the Work Agreement between the Directorate General of Mineral Resources (DGMR), Jeddah, Saudi Arabia and the United States Geological Survey (USGS) Mission under Subproject 6.11.03.

ACKNOWLEDGMENTS

M. O. Hajnur did much of the field measurements, data reductions, including terrain corrections, and computer processing. L. V. Balboda and B. L. Talibsao did much of the drafting and manuscript preparation. K. S. Kellogg and M. D. Kleinkopf offered valuable suggestions for improving the manuscript. The superb field and administrative support provided by the USGS Mission is greatly appreciated.

Additional key factors in the success of the survey were the acquisition of 1:50,000-scale quadrangle maps by H. B. Merghalani of the DGMR and the skill and professionalism of the helicopter pilots (headed by H. Edwards) of Special Flights, Inc.

GRAVITY METHOD

The details of gravity surveys appear in Dobrin (1960). The gravity measurements are done by weighing a small mass at various known points on the earth's surface. At a given station,the mass weighs more or less depending upon the density and distribution of mass about the station and after certain corrections are applied. Corrections to the measurements are applied to compensate for the elevation above sea level datum, the attraction of rocks between the station and sea level datum, terrain, and geographic latitude. A fully corrected reading is referred to as "the complete Bouguer anomaly"; a free-air anomaly is obtained when the effect on rocks between datum and station altitude is not corrected. Complete Bouguer anomalies are usually negative over continental crust.

The present gravity survey is referenced to absolute-gravity base station number KGN-41. This station's geographic coordinates (located by LORAN-C) are latitude 25° 44.0' N. and longitude 42° 55.6' E. The base station's observed gravity is 978,779.694 mgal. Gettings (1984) adjusted the original data of Flanigan and Akhrass (1972) to fit this value to the International Gravity Standardization Net of 1971 (Morelli and others, 1971) at Jeddah. While several gravity surveys in the northeast part of the Shield are referenced to station KGN-41, it has not been precisely tied to the Jeddah base.

GEOGRAPHIC COORDINATES

The gravity survey was compiled on 1:50,000-scale topographic maps prepared by Aero Asia Surveys of Seoul, Korea for DGMR. The DGMR furnished the USGS with paper copies of the pertinent maps and were subsequently photographically transferred to mylar bases. The maps have spot elevations scattered generously across them and selected sites were occupied by helicopter for gravity observations.

The geographic coordinates for gravity stations were determined by helicopter-mounted LORAN-C navigational systems and checked against the scaled coordinates of the sites marked on 1:50,000-scale topographic base maps. Differences in horizontal coordinates obtained from the maps and from the LORAN-C ranged from 0 to 185 m. Gravity values change with latitude, but the errors introduced by using LORAN-C are negligible for the purpose of a regional survey.

The gravity survey also included the northwest corner of a gravity survey contracted to EDCON, Inc. (1984) (Lakewood, CO 80226, USA) by the DGMR. The EDCON (1984) survey covered an area that extended from the southwest part of the Jabal Habashi quadrangle (fig. 1 b) northward to about latitude 26° 24' N. The contracted survey used a doppler-satellite technique to establish the coordinates of control points and the inertial-guidance system of the survey helicopter established coordinates for gravity stations between the control points. While no limits of accuracy for the doppler elevations were cited by the contractor, the limits are considered to be acceptable. The maximum difference in elevation determined by repeated occupancy of a station by a helicopter with an inertial-guidance system was 0.6 m; most differences were less than 0.1 m. The EDCON (1984) gravity measurements were reduced using the same constants as those of the present survey data.

The accuracy of the 1:50,000-scale topographic maps and, hence, the accuracy of the spot elevations plotted on them, was tested by comparing them with elevations determined by the survey helicopter's inertial-guidance system during the contractor's survey. The map elevations were obtained by simply interpolating between topographic contours wherever a contractor's station was plotted. Figure 2 shows these statistical differences in elevations at 266 such points. The interpolated map elevations have a standard deviation of ± 4.54 m compared to the inertial-guidance system data; the arithmetic mean is -1.7 m. The gravity gradient is about 0.2 mgal per vertical meter; therefore, about two thirds of the gravity stations have apparent equivalent gravimeter-elevation errors of about 0.9 mgal and an arithmetic mean of about -0.34 mgal. However, it must be kept in mind that the topographic-map elevations interpolated from between contours for this test are more error-prone than the site elevations plotted on the same map. The real error in gravity values introduced by the spot elevations would, therefore, seem to be considerably less than indicated by figure 2.

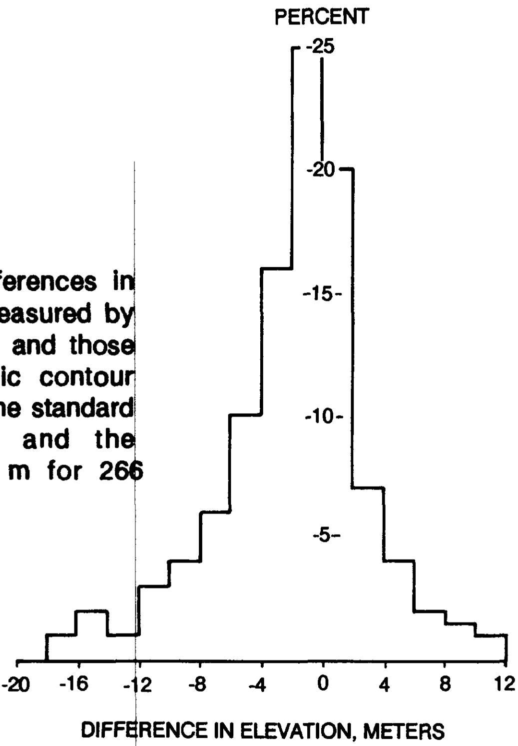

Figure 2.-The distribution of differences in elevation between those measured by an inertial guidance system and those estimated from topographic contour maps at the same point. The standard deviation is ± 4.54 m and the arithmetic mean is - 1.7 m for 266 points.

TERRAIN CORRECTIONS

Terrain corrections were applied to the simple Bouguer anomalies out to zone M (15,864 m) of the Hammer charts (see Dobrin, 1960). Stations surrounded by several meters of flat terrain and, hence, with no A-zone corrections on the Hammer charts were selected for metering and zones B-D were estimated at the metered site. Stations with total terrain corrections of more than about 1.5-2.0 mgal were computed from zones D-M, as were representative stations selected at random across the region. Terrain corrections were applied to the remaining stations by estimating zones D-M by comparison with nearby stations that already had terrain corrections applied.

The terrain corrections were as much as 7 mgal, but most stations required considerably less correction, the average correction being about 0.3 mgal. Redundant terrain corrections indicate that the correction error is about one tenth the total correction. The average error for a given terrain correction is, therefore, only a few hundredths of a milligal, which is negligible in a regional survey.

GEOLOGY

The geology of the area covered by the gravity survey of quadrangles 26E, 26F, 27E, and 27F has been mapped at a scale of 1:250,000 (fig. 1B). The geology has been simplified by combining rock units of similar density for the purpose of gravity interpretation (fig. 3); the general geology is discussed below.

The Arabian Shield (fig. 1A) is characterized by Proterozoic (older than 570 Ma) rocks that presently constitute a stable cratonic platform. The northern and eastern flanks of the Shield are unconformably overlain by relatively flat-lying sedimentary rocks of Phanerozoic age.

The Proterozoic rocks are comprised of volcanic and sedimentary rocks intruded by a suite of plutonic rocks that range in composition from gabbro to granite. Many of the older rocks in the survey area were profoundly deformed during formation of the Nabitah mobile belt, a north-trending suture zone that has undergone flexing and faulting between two converging crustal plates (Stoeser and Camp, 1984). The plates collided at about 650-700 Ma, leaving rocks that tended to be more deformed and metamorphosed than subsequently formed rocks.

Volcanic and sedimentary rocks that have been subjected to various grades of metamorphism are characteristic of the layered rocks of the Shield. Those rocks formed before about 680 Ma tend to be calc-alkaline and formed within oceanic island arc complexes (Greenwood and others, 1976). Those that formed later in the Proterozoic were chemically more mature (calc-alkaline to alkaline) and more clastic, indicating development of mature island-arc complexes along a continental margin (Roobol and others, 1983). Stoeser and Camp (1984) have also shown that sutures such as those found along the mobile belt were formed by accretion of microplates of tectonically emplaced oceanic crust that tended to form linear zones of mafic complexes. It may be inferred that the basic deformed and accreted rocks (older than about 650 Ma, on the average) are more dense and, hence, produce gravity anomalies with higher amplitudes than the younger, less basic, and less metamorphosed continental rocks.

Felsic plutons intruded the Precambrian basement rocks throughout much of the Proterozoic era and so modern outcrops of intrusive rocks comprise more than 50 percent of the present land surface in the surveyed area. The history of the plutons is somewhat analogous to that of the volcanic and sedimentary rocks because plutons older than about 680 Ma are chemically more primitive, have a more basic composition (generally dioritic and tonalitic), and are more deformed than the younger plutons. The last episode of plutonism was essentially post-orogenic (about 610-570 Ma). Caldera-derived volcanic rocks are also associated with this period (Kellogg, 1985), during which time the cratonization of the Shield was completed. The composition of these later plutons is generally felsic (granitic and granodioritic) and chemically highly evolved. The younger plutons were emplaced at relatively

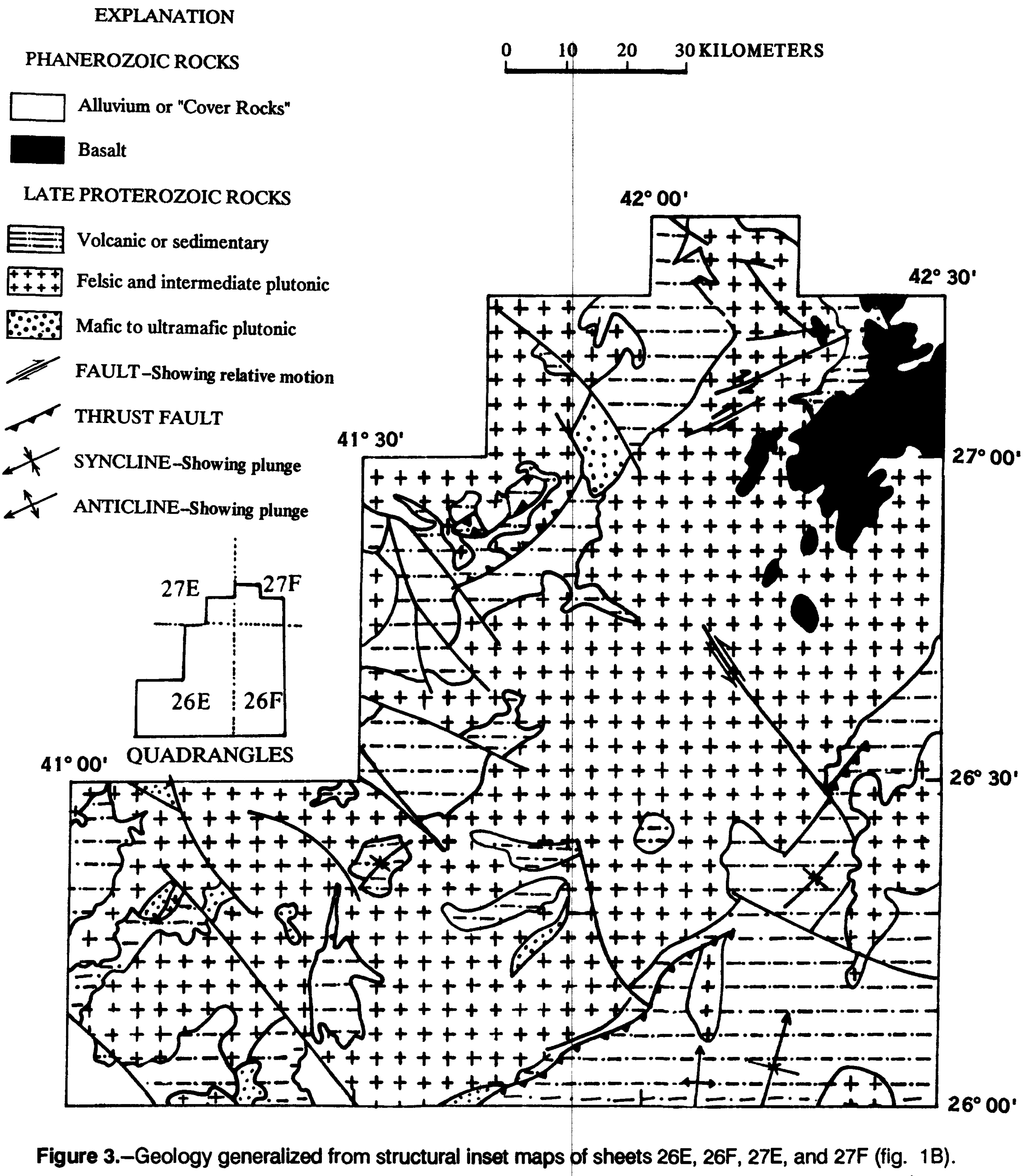

Figure 3.–Geology generalized from structural inset maps of sheets 26E, 26F, 27E, and 27F (fig. 1B).

high levels in the earth's crust, although ring structures are evident above some plutons that have not been unroofed. Hydrothermal alteration accompanied emplacement of some of these younger plutons; tin greisens, tungsten stockworks, and radiation anomalies are also evident (Greenwood and Brown, 1973; Jackson, 1986; Richter and others, 1985).

The main structural features of the Arabian Shield are associated with regional east-west plate convergence. Two of the most prominient features are the Nabitah mobile zone, which contains thrusts and high-angle faults, as well as the Najd system of north-west trending and left-lateral transcurrent faults (Johnson and others, 1987) (fig. 3).

Phanerozoic rocks unconformably cover the Proterozoic rocks in the extreme north and northeast part of the survey area. During early Cambrian time, the Shield was eroded to a peneplane and a sequence of clastic and carbonate platform rocks were deposited during much of the Phanerozoic era. The Paleozoic platform rocks were gently warped during formation of the Hail arch (quadrangle 27 E; fig. 1B), beginning in the Permian and continuing into the Tertiary; the range of this tectonic activity may have extended farther southward into the area of the gravity survey.

Beginning in the Tertiary period, basalt was extruded in the northeast part of the survey area (fig. 3). The composition of the extrusion is generally alkali-olivine basalt and it formed lava flows, cinder cones, and tuff rings.

The cover rocks are the main source of sediments for the An Nafud sand sea to the north of the Arabian Shield. Quaternary deposits also overlie rocks of the Shield as alluvium in wadis and along the fronts of highlands as terraces and gravel sheets.

DENSITY

Gravity measurements corrected for elevation and terrain respond not just inversely to the square of the distance to a causitive body, but directly to the density of the body as well. Therefore, the lithologies reported in the study area (fig. 1B) have been generalized here on the basis of the densities shown in figure 4, which are estimated with knowledge of intrinsic mineral densities for these types of rocks (Birch and others, 1942) and from relative gravity anomalies.

Some parameters that affect the density of rocks include inherent mineral composition and processes that increase density, such as diagenesis and age. Volcanosedimentary rocks possess a significant amount of porosity and so may be subject to compaction and increasing density with the passage of time. This concept is evident when the estimated densities for Proterozoic volcanosedimentary rocks are compared (fig. 4) to those of Phanerzoic sedimentary rocks: the older rocks have undergone compaction and metamorphism, and are considerably more dense.

On the other hand, plutonic rocks are inherently less porous and, therefore, are not subject to large increases in density. Gravity anomalies that exhibit contrasts between different plutonic rocks may be produced by inherent differences in composition. Plutons older than about 680 Ma may be more basic and more dense than the younger plutons, which are generally more felsic and less dense.

Compared with rhyolit and other felsic rocks, basalt contains a higher percentage of heavy minerals and many of the flows exhibit high densities, giving rise to relatively strong gravity anomalies. However, some basaltic deposits are composed of cinders or are highly fractured flows and so may be correspondingly less dense.

Quaternary deposits are mostly unconsolidated and of such low density that they are gravimetrically anomalous in relation to the other rocks. The Phanerozoic rocks possess the next lowest density, but few gravity stations were established on them. Granitic plutonic rocks are intermediate in density, about 2.67 g/cm^3, which is characteristic of an average sialic crust. For this reason, most gravity surveys (including this one) are reduced to complete Bouguer anomalies using 2.67 g/cm^3 as an average crustal density. Proterozoic volcanosedimentary rocks are also estimated to be intermediate in density, but the rocks older than about 680 Ma may be more dense than the younger volcanosedimentary rocks. Compact Quaternary basalt flows, some gabbros, and the more intensely metamorphosed Proterozoic rocks are generally estimated to be the densest of the rock groups shown in figure 4.

GEOLOGIC INTERPRETATION OF THE GRAVITY FIELD

Plate 1 shows the complete Bouguer gravity field superimposed on the generalized geology of parts of quadrangles (1:250,000-scale) 26E, 26F, 27E, and 27F (fig. 1). The location (but not the complete Bouguer values) of each station is shown on the map. The contour interval is 1 mgal and every fifth contour isopach is numbered. All values are negative because the corrected gravity is less than the theoretical gravity; enclosed lows are hachured.

GRAVITY LOWS

The most prominient lows on the map are associated with plutons because they are essentially all embedded in higher density metasedimentary and metavolcanic rocks. The anomalous lows located over plutons are particularly evident in quadrangle 26F (Jabal Habashi, fig. 1), where plutons were also delineated by magnetic surveys (Richter and others, 1985) and where most of the place names ascribed to these plutons have been retained on plate 1. The ages of these plutons

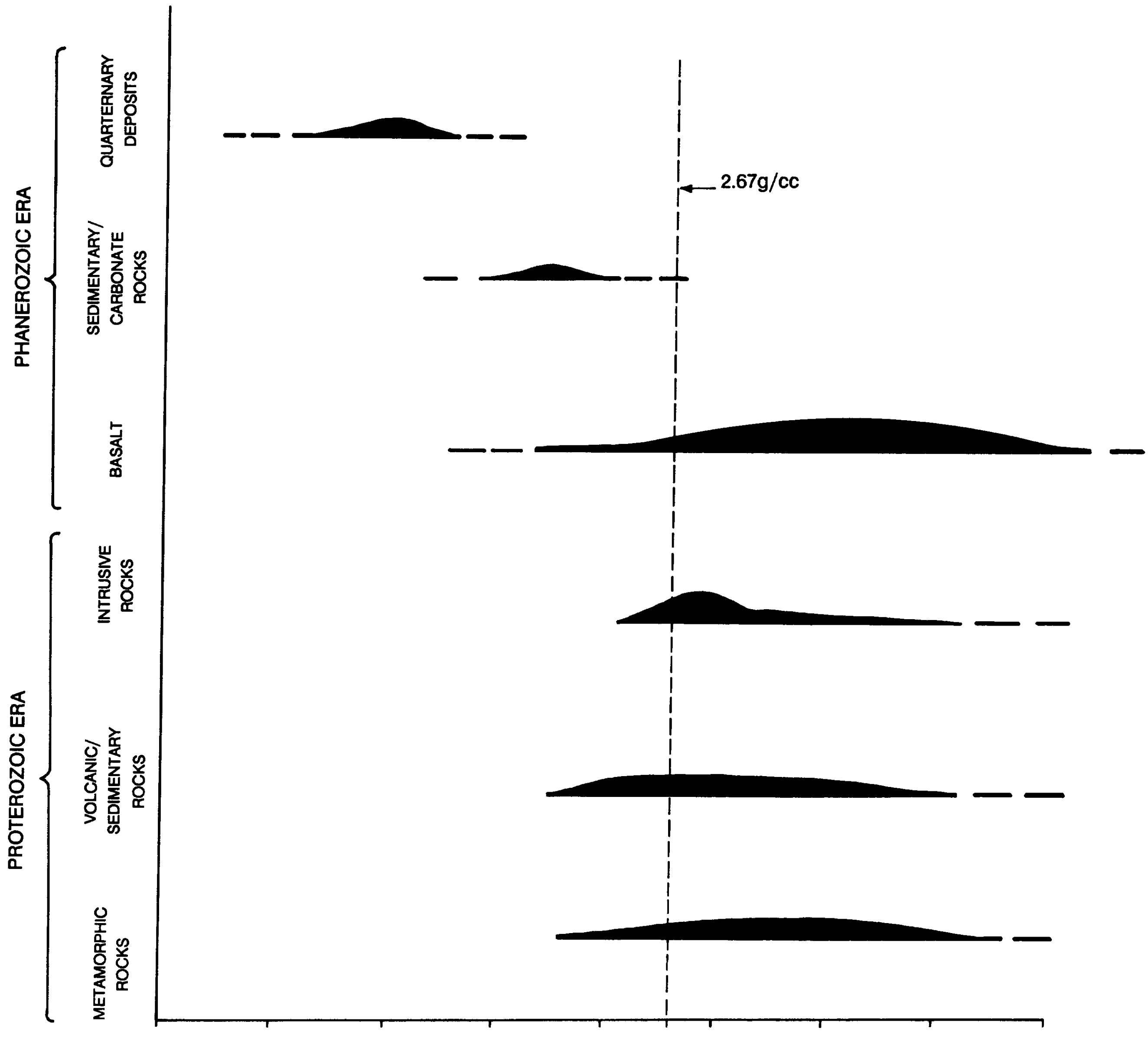

Figure 4.--Estimated relative densities for generalized lithologies in the area of the gravity survey. Reference density is 2.67 g/cc, which is average for the earth's continental crust (granite). Estimated relative density (X-axis) increases to the right.

(in 26F) range from older than 680 Ma for the more chemically primitive and mafic ones to younger than about 600 Ma for the postorogenic plutons, which are generally more highly evolved and may be associated with tin-tungsten type mineral deposits. Samirah pluton, for example, is older than the Mahalani, Awin, Nimrian, and Klab plutons. The Qutn, Gusal, Hudub, and Salma plutons are postorogenic and younger than the four plutons mentioned above. The complete Bouguer anomalies do not distinguish the plutons by age, at least at this regional scale, but more closely spaced surveys might show some differences.

Gravity anomalies that are as low as -80 to -95 mgal are associated with plutonic rocks in Wadi Ash Shu'bah (quadrangle 26E). The lows are enclosed by a pair of -80-mgal contours at about latitude 26° 10' N. and longitude 41° 50' E., the -90-mgal contour along the same latitude but at longitude 41° 32' E., the -90-mgal contour farther west along the map border at about latitude 26° 15' N. and longitude 41° N., the -95-mgal low at Jibal Munaysifan, and the anomaly enclosed by the -85-mgal contour at about latitude 26° 55' N. and longitude 41° 30' E. These anomalies do not distinguish the plutonic rocks by age. Neither quadrangle 27E (Hail) nor 27F (Baq'a) contain any significant gravity lows associated with plutonic rocks, except for the low over the Salma caldera. This low is associated with relatively young plutonic rocks. The low appears to be shifted somewhat south-east from where the center of the caldera is indicated to be, and over the southern lobe of the Salma pluton, judging by the annular outcrops (Kellogg, 1985).

Quaternary deposits are distributed throughout the study area but there are few conspicuous gravity lows associated with them. Two exceptions are the -85-mgal anomaly at Wadi Qahad located in the southwest corner of the area (fig. 5) and the -90-mgal anomaly located at Sha'ab Hafan (latitude 26° 40' N. and longitude 41° 45' E.). These anomalies are estimated to be about 3 mgal more than the regional level. Assuming a density contrast of about 0.8 g/cm^3 between the Quaternary deposits and the underlying Proterozoic bedrock, and modelling the Quaternary deposits as a horizontal cylindrical slab of infinite radius (Dobrin, 1960), the maximum thickness for these deposits is about 90 m. However, most of the other anomalies associated with Quaternary deposits, are considerably less than 3 mgal, suggesting that most Quaternary deposits are no more than about 25 m thick. The relatively thin Quaternary deposits and the absence of steep gravity gradients at valley sides indicates that the valleys are not primarily down-dropped blocks formed during tectonic extension.

GRAVITY HIGHS

Most of the prominent gravity highs are located over layered Proterozoic rocks and Tertiary basalt flows (plate 1). A very broad high occupies the entire southeast corner of the study area, except over the Qutn pluton and two small granite bodies. The anomaly is as much as -60 mgal (shown in the inset structural sketch map of figure 5) and encloses the Nabitah mobile belt. This broad high is associated with the layered Proterozoic rocks that are evidently more dense than the rocks within the belt. There are considerably more felsic to intermediate-composition intrusive rocks within the belt (fig. 5) and the rocks are apparently of relatively low density, causing a net decrease in gravity values within the mobile belt. Another broad high (more than -60 mgal) is centered near latitude 27° 00' N. and longitude 41° 45' E. This high is inside the Nabitah belt but it is located over rocks that are generally similar to those southeast of the belt (i.e., layered Proterozoic rocks associated with thrusting and some rocks of relatively high metamorphic grade). The rocks bounded by thrust faults and associated with this broad gravity high are here referred to as a "platelet". There are four other significant gravity highs located within the mobile belt. Three of them are situated over mostly volcanic and sedimentary rocks: a -75-mgal anomaly near latitude 26° 30' N. and longtitude 41° 45' E.; a -70-mgal anomaly near latitude 26° 15' N. and 41° 45' E.; and a -60-mgal anomaly at Sha'ib Akbad near latitude 26° 15' N. and longitude 41° 10' E. The latter gravity high is relatively extensive and is situated near outcrops of mafic to ultramafic rocks of relatively small areal extent. A fourth maximum high (about -65 mgal) is situated on the north bank of Wadi Ar Rimah at about latitude 41° 40' E. This high is located over intrusive rocks, although outcrops of both volcanosedimentary and metamorphic rocks crop out within a few kilometers of it.

The highest amplitude gravity anomaly in the area is associated with the basalt flows located in the northeastern part of the survey area (plate 1) and is centered on the minus 55-mgal contour (located at about latitude 27° 00' N. and longitude 42° 15' E.). Assuming a density contrast between the basalt and underlying Proterozoic rocks of no more than 0.4 g/cm^3 and a positive residual anomaly of about 5 mgal at the gravity maximum, and by modelling the basalt as an infinite slab, it appears that the flow rocks are at least 300 m thick. This thickness seems excessive if we assume that the basalt flowed across a relatively flat pre-eruptive surface. Therefore, the center of the gravity high appears to be a source-vent for basalt that extends to a significant depth.

STRUCTURE

The gravity field not only generally defines the boundary of the Nabitah mobile belt, but it also locates the boundary along zones of compressive deformation. The southeastern boundary of the belt (inset, plate 1) is located along thrust faults, folds, and rocks that are more intensely metamorphosed than most and delineated by gravity highs. The platelet defined by the gravity field in the northern part of the survey area is also associated with thrusts, folds, and relatively intensely metamorphosed rocks. The folding away from the belt boundary, however, is not particularly well delineated by the gravity field, which indicates that this folding occurred in relatively homogeneous rocks without a significant density contrast. Folding along the boundary and the platelet, however, were accompanied by faulting and metamorphism that produced density contrasts.

The many northwest-striking Najd faults in the area are not particularly well delineated by the gravity field, which indicates that this faulting does not produce a significant density contrast. One exception may be the left-lateral fault located in the eastern part of the survey area that extends from near the Nimrian pluton to near the Klab pluton. This weak gravity trend may continue northwest to a point near the Salma pluton and may be continuous with the Najd fault that continues to the northwest. Another exception may be associated with a fault that bounds the northeast side of Wadi Qahad. This fault may bound a graben so that a thicker accumulation of alluvium than usual has been deposited in the wadi.

FREE-AIR ANOMALIES

The concept of isostasy (Dobrin, 1960) presupposes that topographic highs located over broad areas with a radius of 100-200 km or more are compensated at depth by being less dense. This effect is manifested by the presence of complete Bouguer anomalies that are nearly always negative over sialic continents and are positive over mafic oceanic crusts. A positive free-air anomaly indicates over-compensation by greater-than-"normal" densities at depth; conversely, a negative anomaly indicates under compensation.

While the complete Bouguer gravity-anomaly map (pl. 1) shows the distribution of anomalies, figure 5 shows the distribution of positive free-air anomalies over the same area. The negative complete Bouguer anomaly indicates the "usual" continental crust, although the values are less negative than those measured in most surveys conducted on continents. The positive free-air values, however, indicate that the part of the earth's subcrust in question is more dense than usual, that is, the area appears to be overcompensated. These characteristics seem to be manifestations of an eroded but stable cratonic shield containing rocks at depth that may have relatively high densities approaching those of oceanic crustal rocks.

The free-air anomaly map (fig. 5) generally has low relief, except for anomalous highs located on the southwest flank of Salma Caldera, at the platelet, and at Sha'ib Akbad. The plutons (pl. 1) with prominient low Bouguer anomalies have only low-amplitude free-air anomaly lows (fig. 5).

The free-air anomaly with the greatest amplitude (fig. 5) is situated on the southwest flank of Salma caldera. The complete Bouguer anomaly with the highest amplitude, as discussed previously, is located about 15 km to the southeast, and may be a source vent for basalt. The cause of the free-air anomaly is unknown, but it may be related to extrusion vents filled with relatively dense rocks.

Both the free-air anomalies at the platelet and at Sha'ib Akbad have complete Bouguer-anomaly counterparts (as previously discussed). The highs at the platelet are associated with relatively deformed high-density rocks that apparently extend to a considerable depth. The free-air anomaly located at Sha'ib Akbad also indicates the presence of relatively dense rocks at depth.

FREE AIR AND GEOLOGIC MAP

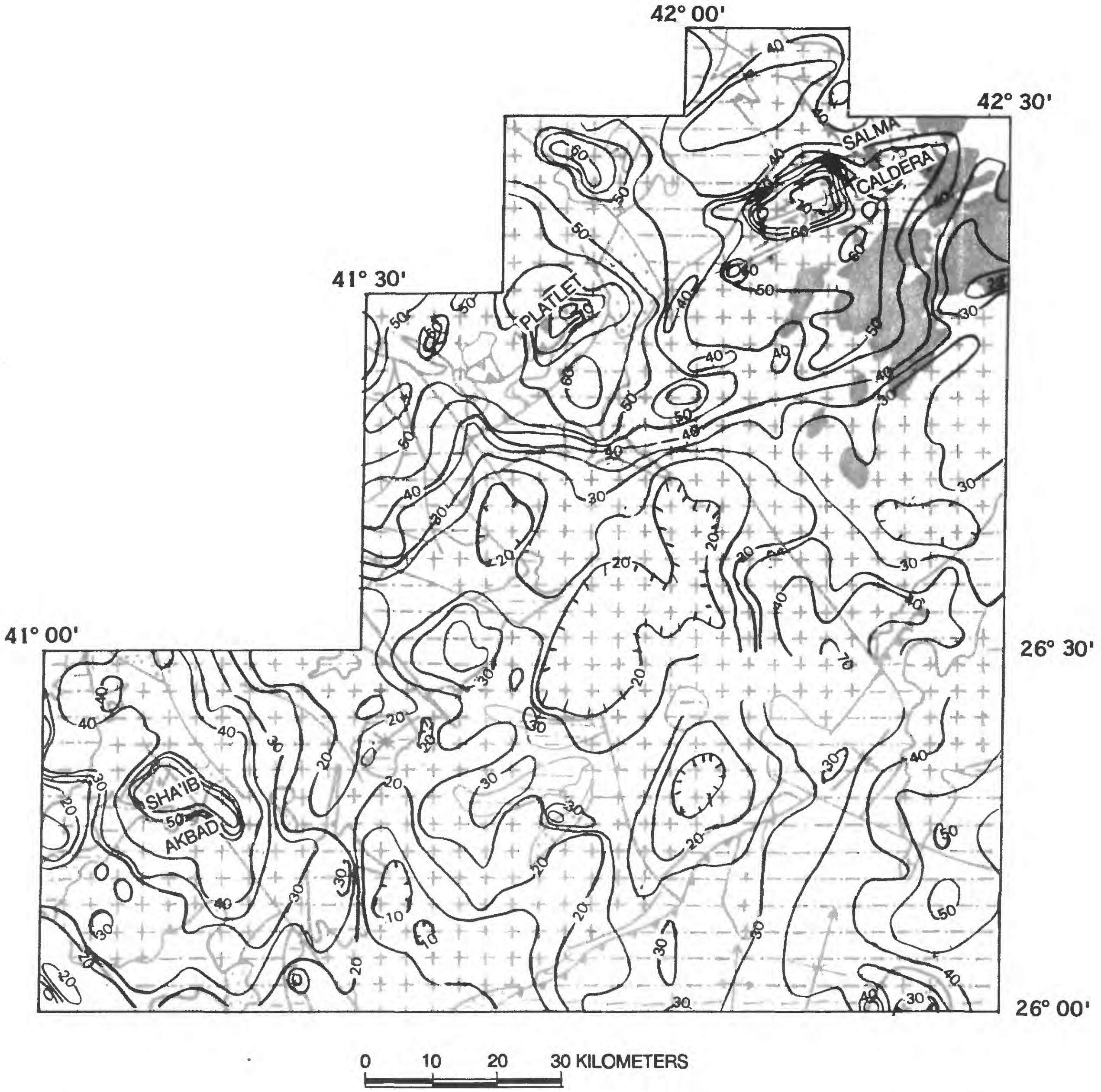

Figure 5.-Free-air anomaly map of parts of sheets 26E, 26F, 27E, and 27F. Contour interval is 5 mgal and low areas are hachured; all values are positive.

SUMMARY AND CONCLUSIONS

A gravity survey that included almost 800 gravity stations was conducted by helicopter over an area of about 13,400 km^2. The locations of the gravity stations were selected from spot elevations plotted on 1:50,000-scale topographic maps. The task of horizontal location of the stations on the ground was greatly aided by a helicopter-mounted LORAN-C navigational system. The equivalent gravimetric accuracy of the spot elevations is thought to be well within about 0.33 mgal. The resulting gravity data was reduced to complete Bouguer and free-air anomaly maps. The lithology from the 1:250,000-scale geologic quadrangle maps of the area was generalized into six rock types. The relative densities of these rock types were estimated or deduced from the gravity field and geologic interpretations were made.

Quaternary deposits are distributed throughout the area in wadis and along highland fronts. Gravity lows, however, are not conspicuous over these deposits and their thickness seems to be mostly less than about 25 m with a maximum thickness of about 90 m. The lack of obvious gravity lows over alluvium in valleys indicates that the valleys were not formed by down-dropping during structural extension.

Gravity lows are also closely associated with some plutons, which are generally of two kinds: older, more chemically primitive plutons and the younger, postorogenic ones, which elsewhere in the world are associated with mineral deposits. The gravity field does not distinguish between the two general types of plutons, but may, nevertheless, be an important tool in locating buried plutons. The Nabitah mobile belt is a zone of deformation located between major tectonic plates of the Arabian Shield. The belt is important because many known mineral deposits are associated with it, and the gravity field generally defines the boundary of the belt. The gravity field in the study area, however, is relatively low over the belt. The overall density of the belt rocks appears to be lowered by the preponderance of relatively low-density felsic intrusive rocks, thus lowering the overall gravity values across the interior of the belt.

A conspicuous gravity high (pl. 1) is situated over a platelet contained within the mobile belt and is associated with thrusted mafic and metamorphic rocks. Another prominient high is situated over Sha'ib Akbad where mafic and ultramafic rocks crop out.

The most prominent complete Bouguer gravity high in the survey area is situated over basalt flows. Calculations indicate that the thickness of the exposed basalt is not sufficient to account for the observed anomaly. The anomaly, therefore, may be due to the presence of a volcanic vent. The most prominient free-air anomaly in the area is located 15 km northwest of the basalt anomaly on the flanks of the Salma caldera. Outcrops at the caldera edge do not reveal the cause of the free-air anomaly, which may be due to the presence of some deep-seated high-density rocks.

Numerous Najd faults strike northwest across the eastern part of the Arabian Shield, including the Nabitah mobile belt. These faults, however, have little expression in the gravity field.

The gravity survey described above is significantly more efficient than a survey run with Doppler inertial-guidance systems. This and other gravity surveys has proved to be important in the interpretation of regional geology, but only about 20 percent of the Arabian Shield has gravity coverage. We recommend, therefore, complete coverage of the Arabian Shield in this manner as the topographic maps of the Arabian peninsula become available.

DATA STORAGE

All field and laboratory data for this report, including field gravimeter readings, field and topographic maps, photographs, terrane corrections, and computer printouts of reduced data are stored in Data File USGS-DF-09-04 in the Jeddah office of the U.S. Geological Survey Saudi Arabian Mission.

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

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