DEPARTMENT OF THE INTERIOR
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GEOLOGIC INTERPRETATION OF GEOPHYSICAL DATA FOR THE WADI AL JARIR AND AL JURDHAWIYAH QUADRANGLES, SHEETS 25/42 C and D, KINGDOM OF SAUDI ARABIA

by

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CONTENTS

ILLUSTRATIONS
[Plates are in pocket]

TABLE

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ABSTRACT

Interpretations of aeromagnetic and gravity data made in support of geologic mapping clearly outline the near-surface shape of Proterozoic granitic units in the Wadi al Jarir (25/42 C) and Al Jurdhawiyah (25/42 D) 1:100,000-scale quadrangles of the northern part of the Arabian Shield. The aeromagnetic data show marked correlation with the surface geology, and the resulting interpretation defines nine magnetic provinces inferred to reflect bodies of granitic rock possessing homogeneous magnetic properties. Several magnetic lineations of possible structural significance are identified and probably relate to Najd faulting. Older structures of the Hijaz tectonic cycle cannot unequivocally be defined.

Four of the younger granitic bodies are interpreted to be tabular in cross-section and of finite thickness on the basis of magnetic anomalies defined by high-amplitude, short-wavelength, positive anomalies along the southern margin of the body and counterpart negative anomalies along the northern margin. One of these bodies, a granodiorite porphyry in the northwestern part of the Al Jurdhawiyah quadrangle, is estimated to be from 4 to 7 km thick on the basis of calculations of gravity data. Older granites possess no edge anomalies and therefore are interpreted to extend to greater depth. Peralkaline granites are distinctively nonmagnetic and are identifiable in the aeromagnetic data as areas of little magnetic relief.

Correlation of aeromagnetic data and mineral deposit information provide justification for some prospecting guides. Small granodiorite-porphyry plutons with distinct edge anomalies in Murdama metasediments commonly are associated with copper-gold-bearing quartz veins. Vein orientations in these and most other known deposits in the north-

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eastern Shield cannot be sensibly related to the stress field of the Najd fault system, and are believed to predate the Najd or to have been governed by local factors. Small, weakly magnetic targets such as the Baid al Jimalah West tungsten deposit are not indicated by the regional magnetic data.

INTRODUCTION

A geologic interpretation was made of aeromagnetic data and a gravity profile within the Wadi al Jarir (25/42 C) and Al Jurdhawiyah (25/42 D) quadrangles, located in the northern part of the Arabian Shield. The two quadrangles are contiguous and cover about 5,580 km^2 between lat 25°00' and 25°30' N., long 42°00' and 43°00' E. (fig. 1, plate 1). Scintillation data recorded along the aeromagnetic flight paths have been separately analyzed for the region (J. L. Irvine and F. Bin Abri, written commun., 1980; F. Bin Abri, written commun., 1981).

This report is based on studies conducted in accordance with a work agreement between the Saudi Arabian Ministry of Petroleum and Mineral Resources and the U. S. Geological Survey (USGS). The investigations were made under subproject 5.02.04 in support of field geologic mapping and studies of petrogenesis and mineral potential of the granitic rocks of the Arabian Shield (Stoeser and Elliott, 1980; Cole, 1981; Young, 1982).

Objectives of the geophysical study were to provide information about the regional structural framework and the distribution of granitic rocks in the area and to detect any evidence of geologic structures or older crystalline basement that formed during the Hijaz tectonic cycle (Greenwood and others, 1974; Stoeser and Elliott, 1980). Field investigations for this study were conducted during seven days in May 1980 and laboratory measurements of magnetic susceptibility were completed in Jiddah during the same month.

Other geophysical investigations and observations in the northern part of the Shield have been reported by various workers for regional data compilations and small-scale reconnaissance studies of magnetic anomalies associated with the Najd fault system (Flanigan and Akhras, unpub. data; Andreasen and Petty, 1974; Andreasen and others, unpub. data; Kiilsgaard, 1975; Moore, 1979).

Kleinkopf wishes to thank H. R. Blank, Jr., D. L. Schmidt, D. B. Stoeser, and E. J. Young for outlining and discussing geologic problems of the region; Cole was added as an author following his review of an earlier draft of the manuscript. Blank and M. E. Gettings provided technical support and suggestions for conducting the geophysical interpretation. Derivative aeromagnetic-data maps (plate 3a to 3d)

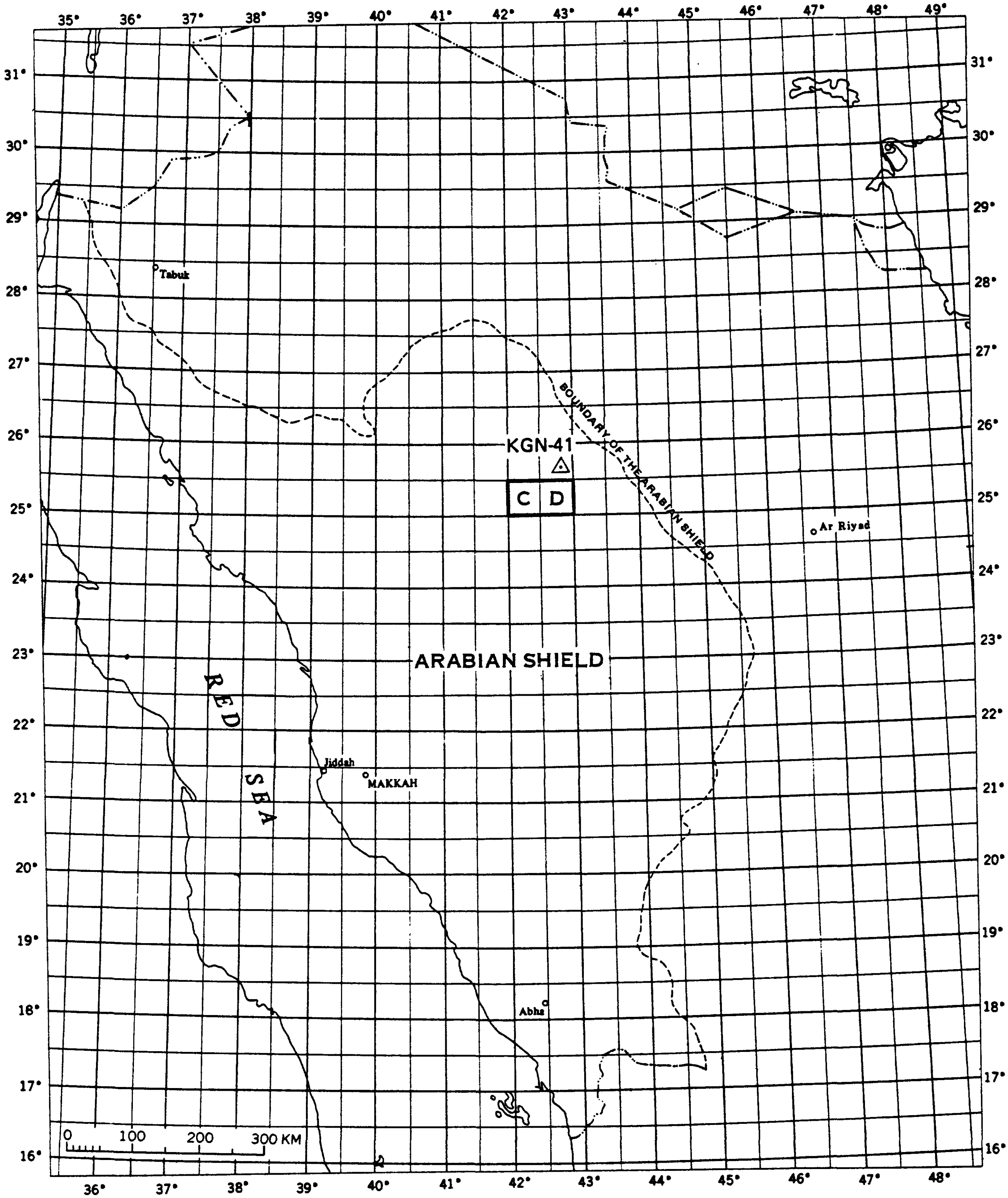

Figure 1.--Index map of western Saudi Arabia showing the locations of aeromagnetic map sheet 85 and the two included quadrangles: C = Wadi al Jarir, sheet 25/42 C (Young, 1982); D = Al Jurdhawiyah, sheet 25/42 D (Cole, in press). Location of reference gravity station KGN-41 (Flanigan and Akhras, unpubl. data) is indicated by triangle.

were made under contract to the USGS by Phoenix Corporation of McLean, Virginia, U.S.A., as described in a following section.

Mineral localities referred to in this report are recorded in the Mineral Occurrence Documentation System (MODS) data bank and identified by a unique 5-digit locality number (MODSxxxxx). For simplicity, the leading (zero) digit has been dropped in the text. Inquiries regarding this data bank may be made through the Office of the Technical Advisor, Saudi Arabian Deputy Ministry for Mineral Resources, Jiddah, Kingdom of Saudi Arabia.

GEOPHYSICAL DATA

Aeromagnetic data

Total-intensity magnetic data were obtained from regional aeromagnetic-scintillation surveys of the Arabian Shield conducted during 1966-67 (plates 1, 2). The surveys were done by a consortium of geophysical companies consisting of Aero Service Corporation, Hunting Geology and Geophysics Limited, Lockwood Survey Corporation Limited, and Arabian Geophysical and Surveying Company (Andreasen and Petty, 1974). The flying and data compilation were supervised by the Bureau de Recherches Geologiques et Minieres (BRGM). The part of the survey covering the study area (sheet 85, plate 1) was flown 150 m above terrain along northeast-southwest-oriented flight lines that were spaced about 800 m apart.

The total-intensity data were reduced to residual total-intensity data and referred to an arbitrary datum. The unit of magnetic intensity used in this report is the nanotesla (nT) in the International System, which is equivalent to the gamma in the centimeter-gram-second system (Parasnis, 1968). The data reduction procedures are those described by Andreasen and Petty (1974). The residual data were obtained by removing a regional linear gradient, which is composed mostly of the geomagnetic gradient of the Earth's main field but includes diurnal variations and instrument drift. The average gradient for the Shield was estimated to be 3.9 nT/km for the north magnetic component and 1.2 nT/km for the east magnetic component. These values compared favorably with the magnetic north and east components of the International Geomagnetic Reference Field (IGRF) for the year 1967.300, which are 3.70 and 1.17 nT/km, respectively (Andreasen and Petty, 1974). Other parameters of the Earth's main field for the study area were a mean declination of 1°43' and a mean inclination of 36°19' (Vestine and others, 1947).

Gravity profile

Gravimetric observations were made along a profile line trending north-northeast across the central part of the study area (plate 1, fig. 2). Helicopter transport from station to station minimized the travel time. The profile was designed to determine the gravity response of a large granodiorite porphyry pluton, to compare this response with that of the granodiorite-monzogranite unit in the Wadi al Jarir quadrangle, and to examine the gravity discontinuity across the major fault zone of the region. The stations were located in areas of low relief in order to minimize the terrain effects on the gravity data. All gravity measurements were completed in 10 total hours on two consecutive days.

A high-precision gravity meter was used, and readings were taken at 25 stations spaced approximately 3 km apart along the profile. The gravity readings were referenced to base station KGN-41 at lat 25°44.17' N., long 42°55.57' E. (fig. 1), one of 42 primary gravity stations established previously at first-order geodetic stations in the Kingdom of Saudi Arabia (Flanigan and Akhras, unpub. data). The station altitudes were determined using paired, precision barometric altimeters; readings were corrected for variations in atmospheric pressure, as well as for temperature and relative humidity, which were simultaneously measured at each station. Station 1, located near the middle of the profile line (fig. 2), was tied to the primary elevation and gravity control at KGN-41 and served as a field-control point because it could be readily reoccupied every 1 to 2 hours using a minimum of helicopter time.

GEOLOGIC SETTING

Rocks in the study area consist of upper Proterozoic layered rocks of the Murdama group and the Al Jurdhawiyah group (Muller, 1975; Cole, in press), which are intruded by large plutons of calc-alkaline and peralkaline granite, and by minor gabbro and diorite. No layered or plutonic rocks of the area are known to be older than the Murdama group, although Cole believes that the oldest plutonic rocks of the area (units bht and bhgd, plate 1) may predate deposition of the Murdama. On the presumption, however, that the magnetic character of the study area may contain components related to extensive subsurface rocks and structures that predate the Murdama group, the following brief summary of the geologic history of the Arabian Shield is presented for background.

The Arabian Shield and the counterpart Nubian Shield in northeastern Africa were formed during the approximate period 1000 Ma to 550 Ma in four widely recognized phases (Greenwood and others, 1976; Schmidt and others, 1979; Fleck and others, 1980; Hadley and Schmidt, 1980; Stoeser and Elliott, 1980). Evidence for the first phase is preserved only in western and southwestern Saudi Arabia and consists of primitive mafic and intermediate volcanic rocks and immature sediments that were most probably formed and deposited in an ensimatic basin adjacent to converging lithospheric plates. These layered rocks comprised the juvenile Arabian-Nubian Shield and were intruded by comagmatic(?) diorite-gabbro batholiths during the approximate period 915 Ma to 810 Ma ago (Fleck and others, 1980). All units were probably compressed into north-trending fold-fault belts when the first-phase subduction-arc system was accreted to the Archean craton of Africa (Greenwood and others, 1982/1983).

The second phase of continent formation is represented throughout the southeastern, central, north-central, and northwestern parts of the exposed Arabian Shield by thick successions of intermediate volcanic rocks and immature sedimentary rocks with subordinate mafic and felsic volcanic units, carbonate layers, and conglomerate beds that contain cobbles of the first-phase diorite-gabbro plutonic suite. These rocks are generally referred to as the Halaban-Hulayfah group and are believed to have been generated and deposited in oceanic or (proto)continental-marginal basins adjacent to second-phase subduction zone(s) (Schmidt and others, 1979; Greenwood and others, 1982/1983). Deposition of the Halaban-Hulayfah group began approximately 780 Ma ago and continued until about 700 Ma ago (Greenwood and others, 1982/1983) and during that interval the layered rocks were intruded by comagmatic(?) diorite-tonalite-trondhjemite batholiths. The second phase of Shield evolution was terminated during a protracted interval from about 690 Ma to 650 Ma ago when most of the principal structures of the craton were formed. The evolved crust of the first and second phases was compressed in an east-west direction, folded and intensely faulted, regionally metamorphosed (greenschist and local amphibolite grades), and intruded by large volumes of buoyant quartz diorite-granodiorite-monzogranite magma along north-trending zones of weakness in gneiss domes and batholiths (Schmidt and others, 1979; Greenwood and others, 1982/1983). The structural and magnetic imprint of this profound deformational-magmatic episode (sometimes referred to as the Hijaz tectonic cycle; Greenwood and others, 1976) is reflected in the north-trending fabric of much of the central and western Arabian Shield.

The third phase of crustal evolution somewhat overlaps the cessation of the second phase in time, and seems to have begun as early as 670 Ma ago with the deposition of Murdama group sediments (and minor volcanic rock) in a marine basin northeast of the matured crust of the previous two phases (Schmidt and others, 1979). Much of the Murdama is a thick, monotonous, thinly bedded sequence of medium- and fine-grained volcaniclastic siltstone and subgraywacke that were derived chiefly from the layered and plutonic rocks of the earlier phases, and deposited in a subsiding but tectonically quiescent basin (Hadley and Schmidt, 1980). This basin was subsequently compressed in an east-west direction to produce broad folds of general northerly trend, possibly synchronous with weak regional greenschist-grade metamorphism (Cole, in press). The Al Jurdhawiyah group rests unconformably on the folded and eroded Murdama terrane and on diorite and granodiorite of uncertain age. In contrast to most parts of all older layered sequences, the Al Jurdhawiyah group was chiefly deposited under subaerial conditions. It consists for the most part of volcanic conglomerate and laharic breccia derived from contemporaneous andesite-dacite volcanic and pyroclastic rocks that were extruded from local eruptive centers. Alteration to greenschist-facies assemblages is pervasive, but the new minerals show no dimensional fabric and probably grew during lithification rather than during a subsequent regional metamorphic event. The Al Jurdhawiyah group is only gently folded except in the neighborhood of younger high-angle faults that trend in an easterly direction (Cole, in press and unpublished data). The age of these rocks is not yet known, but Cole believes they may be contemporaneous with gently deformed, thick successions of rhyolite in the northern Shield that have been called the Shammar group (Bramkamp and others, 1963; Brown and others, 1963; Delfour, 1977; Schmidt and others, 1979). The Murdama and Al Jurdhawiyah groups in the northeastern Arabian Shield are intruded by numerous large bodies of calc-alkaline granodiorite and monzogranite that generally have simple ellipsoidal outcrop shapes, typically lack internal fabric, and are believed to be about 640 Ma to perhaps 610 Ma old (Stoeser and Elliott, 1980; Cole, unpublished data).

The fourth and final phase of formation of the Arabian Shield spans the period of time from about 600 Ma to 550 Ma ago. During this episode, highly fractionated peraluminous, alkaline, and peralkaline granites and contemporaneous(?) gabbro were generated and emplaced chiefly in the eastern and northern Shield (Stoeser and Elliott, 1980). At about the same time, the Najd transcurrent fault system was formed by the last major Proterozoic stress regime that affected the entire Shield. This system consists of three or four major northwest-trending strands with aggregate left-lateral displacement of as much as 300 km (Moore, 1979; Schmidt and others, 1979). Localized terrestrial basins bounded by Najd-system faults were formed and these accumulated clastic debris, carbonate, and basalt which constitute the Jibalah group (Delfour, 1977; Hadley and Schmidt, 1980). Rapid cessation of tectonic and magmatic processes is documented by planation of the Shield rocks and subsequent deposition of highly mature Cambrian and Ordovician Wajid Sandstone and Saq Sandstone (Hadley and Schmidt, 1980).

The geology of the study area (sheet 85) consists of the folded Murdama group in the northwestern part of its depositional basin, and a superimposed depositional basin of the younger Al Jurdhawiyah group. A relict volcanic vent for the Al Jurdhawiyah lavas is defined by the outcrops of gabbro (gbn) and diorite (dr) and the sub-radial andesite dike swarm near the Jarrar ancient mine (MODS 0958; plates 1, 2). Miscellaneous porphyritic rocks (plate 1) in dikes and plugs probably also represent source conduits for Al Jurdhawiyah rocks (Cole, 1981). The nearest outcrops of the Halaban-Hulayfah group are located at Nuqrah about 30 km west of the study area near lat 25°20' N., long 41°40' E. (plate 2; Delfour, 1977). Massive tonalite (bht) and granodiorite (bhgd) along the eastern boundary of the study area (plate 1) are older than the Al Jurdhawiyah group and may predate the Murdama group, but the latter relationship is not yet established (Cole, 1981). In either case, these rocks probably belong to the 690 to 650 Ma-old suite of plutons formed at the end of the second phase (Hijaz cycle). Quartz diorite (bhqd) with primary igneous foliation and massive leucotonalite (to) along the southern boundary of the study area (plate 1) are younger than the Murdama group, but may be older than the Al Jurdhawiyah group (Cole, 1981; Young, 1982). Granodiorite porphyry (gdp), granodiorite granophyre (bhgg), and at least part of the granodiorite-monzogranite (gdmg) units (plate 1) are younger than all layered rocks in the area and probably represent the 640 to 610 Ma-old calc-alkaline granite suite. The perthite granite unit (apg, pg; plate 1) and the peraluminous microcline-albite granite (mag; plate 1) that generated the Baid al Jimalah West tungsten deposit (MODS 2661) are the youngest rocks in the study area and both are about 575 Ma old (C. E. Hedge and J. S. Stacey, written commun., 1982). The only significant fault in the area traverses the southwestern part of sheet 85 (plates 1, 2) and was mapped on the basis of localized deformation and offset contacts and structures by Cole (1981). Regional studies have long recognized this trace as the northernmost major strand of the Najd fault system (Bramkamp and others, 1963; Brown and others, 1963; Mytton, 1970; Moore, 1979). This section of the Najd fault is unusual because it trends N. 75° W. rather than the typical N. 40°-50° W., and because the zone of local deformation is less than 50 m wide (Cole, unpublished data).

ROCK MAGNETISM

Forty-two samples of various granitic rocks were collected in the study area for magnetic-susceptibility measurements (table 1). Magnetic susceptibilities in this report are stated as dimensionless values in SI (International System) units x 10^{-4} (Parasnis, 1968). They were core-drilled and then analyzed using a magnetic-susceptibility bridge in the USGS laboratories in Jiddah. At a few locations, where samples could not be readily obtained, _in situ_ measurements were made on flat outcrops by means of a sample coil connected to the magnetic-susceptibility meter. Although less

Table 1.--*Magnetic susceptibilities of granitic rocks in the study area*

[Rock symbols, sample numbers, and magnetic province numbers as on plate 1]

Sample number	Magnetic province (plate I)	Magnetic susceptibility*		Lithology
D1	I	464		Granodiorite porphyry (gdp)
D2	I	107		Granodiorite porphyry (gdp)
D3	I	147		Granodiorite porphyry (gdp)
D4	I	164		Granodiorite porphyry (gdp)
D5	I	35		Granodiorite porphyry (gdp)
D6	I	895		Rhyodacite
D7	VII	0	(altered?)	Perthite granite (pg)
D8	VII	113		Perthite granite (pg)
D9	VII	118		Perthite granite (pg)
D10	V	39		Perthite granite (pg)
D11	VIII	486		Biotite-hornblende granodiorite granophyre (bhgg)
D12	VI	286		Biotite-hornblende granodiorite (bhgd)
D13	V	9	(altered?)	Biotite-hornblende tonalite (bht)
D14	V	394		Biotite-hornblende tonalite (bht)
D15	V	526		Biotite-hornblende tonalite (bht)
D16	V	407		Biotite-hornblende tonalite (bht)
D17	V	470		Biotite-hornblende tonalite (bht)
D18	IV	382		Granodiorite porphyry (gdp)
D19	IV	200		Granodiorite porphyry (gdp)
D20	IV	82		Granodiorite porphyry (gdp)
D21	IV	168		Granodiorite porphyry (gdp)
D22	III	778		Biotite-hornblende quartz diorite (bhqd)
D23	II	54		Granodiorite-monzogranite (gdmg)
D24	II	50		Granodiorite-monzogranite (gdmg)
D25	II	22		Granodiorite-monzogranite (gdmg)
D26	II	128		Granodiorite-monzogranite (gdmg)
D27	II	218		Granodiorite-monzogranite (gdmg)
D28	II	96		Granodiorite-monzogranite (gdmg)
D29	IX	80		Granodiorite-monzogranite (gdmg)
D30	IX	176		Granodiorite-monzogranite (gdmg)
D31	IX	312		Granodiorite-monzogranite (gdmg)
D32	IX	6	(altered?)	Granodiorite-monzogranite (gdmg)
D33	IX	153		Granodiorite-monzogranite (gdmg)
D34		202		Granodiorite-monzogranite (gdmg)
D35		28		Felsic dike
D36		22		Aplite dike
D37		62		Felsic dike
D38		15		Granodiorite-monzogranite (gdmg)
D39		137		Granodiorite-monzogranite (gdmg)
D40		174		Granodiorite-monzogranite (gdmg)
D41		140		Granodiorite-monzogranite (gdmg)
D42		316		Granophyric granite

* Dimensionless values in SI (International System) units x 10^{-4} (Parasnis, 1968).

precise, the *in situ* measurements provided a useful estimate of the susceptibilities.

INTERPRETATION TECHNIQUES

The aeromagnetic data were interpreted using qualitative and semiquantitative techniques. The results of the two techniques were combined for the final conclusions.

The qualitative studies of the region were based on several approaches beginning with the definition of a magnetic signature or character observed over areas in which the geology is known. The magnetic signatures include parameters such as amplitude of anomalies relative to background levels, wavelength (breadth) of anomalies, and persistence of magnetic gradient zones; the latter typically indicate fault zones or dikes. The magnetic map was spectrally colored in increments of 100 nT to highlight prominent positive and negative features and to determine their amplitudes relative to adjacent magnetic levels. In another qualitative approach, the axes of elongate positive and negative features were marked to form a lineation map. This procedure emphasizes trend continuity, helps define boundaries between magnetic provinces, and enhances the correlation of magnetic signatures with outcrop geology.

In the semiquantitative studies, measurements were made of steep gradients along the flanks of magnetic anomalies to estimate depth of source (Peters, 1949; Vacquier and others, 1951; Zietz and Andreasen, 1967). For the elliptical granodiorite porphyry unit in the north-central part of the study area (plate 1), theoretical profile models (Blank and Andreasen, 1980) were used to estimate the shape and relative thickness of the body.

In another semiquantitative approach, the magnetic data were processed by computer to aid in resolving subtle magnetic features and in identifying their sources. Four interpretive magnetic maps were prepared under contract to USGS by the Phoenix Corporation (plates 3a-d). The data used for the production of the interpretive maps consisted of values hand digitized from the residual total-intensity map (plate 1) at the intersections of an arbitrary 1-km-square grid. The interpretive maps include rotation-to-pole (plate 3a); band-pass filter (low cut, 0.015 cycles per km and high cut, 0.15 cycles per km; plate 3b); low-pass filter (cutoff wavelength, 8 km; plate 3c); and residual-field (total intensity minus low-pass filter; plate 3d).

The magnetic interpretations are discussed in terms of magnetic anomalies, which are defined as detectable perturbations and variations in the geomagnetic field. These are anomalies inferred to be caused by contrasts of total magnetizations of rocks in the upper few kilometers of the Earth's crust. Anomalies are assumed to reflect total magnetizations, which are vector sums of the Earth's present induced field and remanent magnetization acquired by the rocks during crystallization or recrystallization at a time in the geologic past when the field direction was different from that of the present. If remanent magnetization is present, it is significantly less than the induced magnetization. Bodies of reversely-magnetized rock, which would be indicated by anomaly pairs with the positive anomaly on the north and the negative anomaly on the south, are not present in the study area. In the interpretations presented, remanent magnetization in directions not parallel with the present field of the Earth is considered negligible.

GEOLOGIC INTERPRETATION OF GEOPHYSICAL DATA

Discussion

The interpretations delineate nine magnetic provinces inferred to relate to granitic sources and identify a number of magnetic lineations of possible structural significance. Of the interpretations for the two quadrangles, the more definitive are those for the Al Jurdhawiyah quadrangle, for which the magnetic patterns are less complex and correlate more clearly with particular types of granites.

The effects of topography on the interpretations are considered negligible. The relief of the area is low except for a few mountains that rise as much as 400 m above the nearly flat desert surface, particularly in the Al Jurdhawiyah quadrangle.

Six types of aeromagnetic maps covering the study area were used in the investigations. The aeromagnetic studies were made principally at a scale of 1:100,000, which was the scale of the geologic mapping. Because the magnetic data contain considerably more detail than could be assimilated for this report, only major magnetic features are discussed. The residual total-intensity magnetic data superimposed on the geology (plate 1, scale 1:100,000) serve as the principal reference map. The 1:500,000-scale regional total-intensity map (plate 2) provides a wider perspective of the study area in terms of magnetic setting, extensive linear magnetic features, sharply contrasting magnetic patterns, and probable extent of major magnetic units beyond the boundaries of the study area. The four 1:100,000-scale interpretative maps (plates 3a-d) help isolate and enhance anomalies of interest, aid in outlining the magnetic provinces thought to define boundaries of granitic bodies, provide ideas on depth significance of anomaly sources, and define and evaluate magnetic lineations.

The rotation-to-pole operation (plate 3a) removes the dipolar effect, and the resulting anomalies are shifted to positions more directly over the magnetic source. The angle of magnetic inclination for this part of the Shield is about 37°, and on the total-intensity map the negative part of a dipolar anomaly will be detected more nearly over the magnetic source than the positive part. The rotation operation helps clarify the interpreted boundary of the magnetic source.

The band-pass and low-pass filtering in the frequency domain (plates 3b,c) remove the higher frequency components in order to resolve and study the long-wavelength anomalies. The residual-field interpretative map (plate 3d) was derived by subtracting the low-pass filter data (plate 3c) from the total-intensity data (plate 1). The residual-field map emphasizes subtle anomalies and enhances the identification and evaluation of possible geologic sources.

An inspection of the total-intensity map (plate 1) shows that the rocks underlying the study area are variably magnetic. The range of magnetic intensities is not great, and all values are between 5,400 and 6,400 nT. In more than 50 percent of the study area, the gradients are low and intensities range from 5,800 to 5,900 nT; these intensities provide a background level in areas adjacent to marked high- or low-intensity anomalies. Most of the high-amplitude anomalies are associated with granitic rocks, particularly along the boundaries of granitic masses inferred to have finite thicknesses. The metasedimentary and metavolcanic rocks of the Murdama and Al Jurdhawiyah groups generally show weak magnetic responses, which typically are expressed as nearly featureless fields having from 20- to 40-nT-amplitude anomalies in the form of closures or noses in the contours. Petrographic studies suggest that the reason for low magnetic intensity is that the lower greenschist-facies assemblages in the rocks of the Murdama and Al Jurdhawiyah groups include almost no magnetite; sites of former opaque minerals are preserved only by granular sphene and local hematite. The majority of high-amplitude anomalies (greater than 100 nT) that occur over outcrops of metasedimentary-metavolcanic rocks are inferred to be caused by shallow subcrops of granite. In some places, small bodies of gabbro, diorite, or miscellaneous porphyritic rocks in dikes and plugs (plate 1) within the sequence of metavolcanic and clastic rocks of the Al Jurdhawiyah and Murdama groups may be the sources of the anomalies.

Magnetic lineations

A number of prominent lineations are inferred to reflect either fault or fracture zones, some of which may be associated with Najd faulting. Regional geologic maps show that the study area is located along the northeastern edge of the Najd fault system (Bramkamp and others, 1963; Brown and others, 1963; Moore, 1979), and a major rock discontinuity (labeled IIe on plate 1) in the southwestern part of the study area is defined by the magnetic data and confirmed by mapping (Cole, in press). In studies of regional petrology, Stoeser and Elliott (1980) identified this same zone as a boundary between their Hijaz-Najd and Hail-Dawadimi regions, based on different layered rock assemblages and the relative abundance of late Proterozoic granite to the north. Clearly, the geology of areas north and south of this zone are distinctly different. As discussed in the preceeding section on Geologic Setting, the oldest rocks of the study area are the Murdama group that postdates the Hijaz tectonic cycle, or perhaps the somewhat older tonalite and granodiorite that may possess Hijaz-cycle structures. Therefore, lineations related to the Hijaz cycle would not be expected to be major elements of the magnetic fabric of sheet 85.

In a Shield-wide structural analysis of fault and shear patterns of the Najd fault system, Moore (1979) recognized master faults that strike northwest and synthetic Riedel shears that are oriented about 15° to the master fault direction and have the same sense of movement as the main shear set. Moore (1979) suggested that magnetic lineations that do not correlate with mapped faults may reflect subsurface conjugate Riedel shear zones along which there is no surface expression of the trace of the master fault. No zones of secondary fractures were mapped in the area, but such distributed zones of offset may account for the lack of a prominent surface trace of the magnetically defined Najd fault through the Wadi al Jarir quadrangle.

Magnetic provinces

The magnetic provinces are labeled by Roman numerals I through IX on the maps (plates 1 to 3), and they are defined principally on the basis of anomaly patterns and interpretations of mapped geology. Parameters of the anomalies used include amplitude, wavelength, and configuration. A province is assumed to represent granitic rocks of homogeneous magnetic composition and character. The granitic masses may be single intrusions, groups of intrusions, or a single phase within larger plutons or batholiths. Thus, each magnetic province is inferred to define the near-surface outline of a given granitic mass beneath alluvium, and locally beneath outcrops of rocks of the Murdama and Al Jurdhawiyah groups.

Magnetic province I

Major rock type: Granodiorite porphyry (gdp)
Magnetic susceptibility: 184×10^{-4}, average of 5 samples ranging from 35×10^{-4} to 464×10^{-4}

Total-intensity aeromagnetic and geologic map (plate 1): A pronounced arcuate pattern of anomalies define a large, elliptical area. Surface geology (Cole, in press) defines a uniform body of granodiorite, the outline of which coincides closely with the magnetic boundaries outlined for province I. A swarm of comagmatic diabase dikes is present in a west-northwest zone, but appears to have no influence on total magnetic intensity. The forms of the gravity and magnetic profiles across the province (fig. 2) suggest that the mass may have a finite thickness. The broad positive anomaly along the southern boundary of the province and the major negative anomalies along the northern boundary are similar to theoretical magnetic models for a plate or disk source (Andreasen and Zietz, 1967; Blank and Andreasen, 1980). The concentration of isolated high-amplitude anomalies extending beyond the southern and northern geologically defined boundaries of the province may indicate either extensions of granodiorite in the subsurface or more mafic phases along the contact zones as is suggested by the geologic mapping. Cole (in press) also suggests that these broadened anomalies may reflect a contribution from layered rocks in contact metamorphic zones as wide as 1 km that contain abundant biotite and magnetite. However, enrichment of magnetite in zones of contact metamorphism cannot be the sole cause because the extended zones of anomalies are limited to two locations along the border of the granodiorite body.

Using the gravity data, the thickness (T) of the inferred plate of granodiorite was calculated to be 4.2 km, assuming a vertical cylinder of finite thickness having its top at ground surface. The thickness was calculated using the expression (M. E. Gettings, written commun., 1980):

$$T=[\Delta g/2(41.9)\Delta\rho][1-41.91\Delta\rho R/(\Delta g-41.91\Delta\rho R)]$$

where Δg is the Bouguer gravity anomaly in milligals (14.2), $\Delta\rho$ is the density contrast in g/cm^3 (0.1), and R is the radius of the mass in km (10). The density contrast of 0.1 g/cm^3 was estimated using measurements made in the laboratory of samples of granodiorite and Murdama and Al Jurdhawiyah group rocks: three granite samples averaged 2.64 g/cm^3 (2.63, 2.60, and 2.68 g/cm^3), and four samples from the Murdama and Al Jurdhawiyah groups averaged 2.74 g/cm^3 (2.74, 2.76, 2.75, and 2.70 g/cm^3). This calculated thickness is inferred to be a minimum figure. If an average crustal density of 2.67 g/cm^3 were assumed for the granodiorite, then calculations using a density contrast of 0.07 g/cm^3 would yield a thickness of 7.1 km. Therefore, it seems geologically reasonable to infer a thickness ranging from 4 to 7 km for the granodiorite mass.

Magnetic lineations Ia, Ib, and Ic mark nearly continuous northeast trends across province I and may represent faults

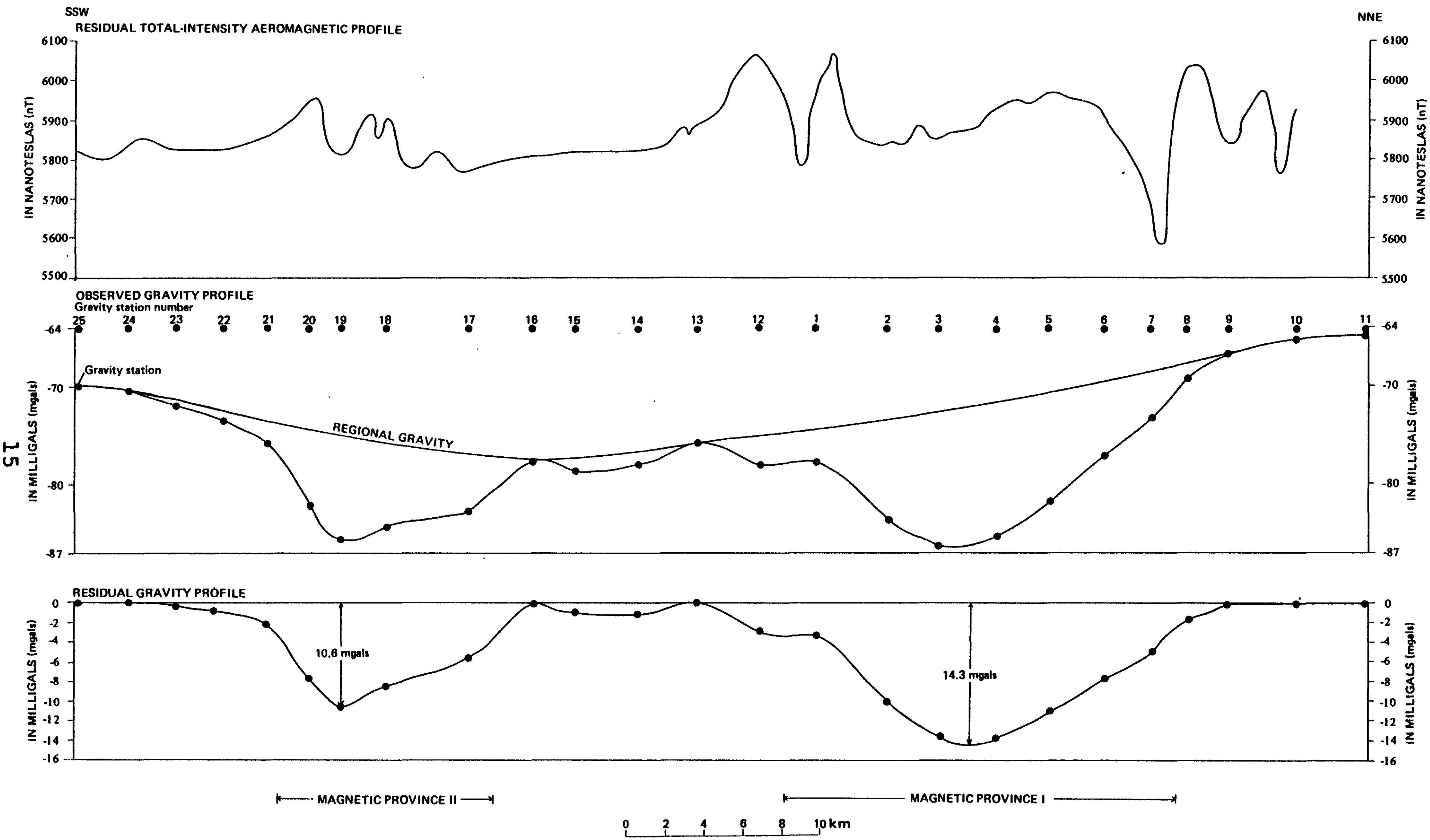

Figure 2.--Aeromagnetic and Bouguer gravity profiles of the Wadi al Jarir and Al Jurdhawiyah quadrangles, sheets 25/42 C and D. See plate 1 for line of profile. Magnetic interpretation by Kleinkopf, 1981.

or fractures in the granodiorite. Near the southwestern end of lineation Ic, a high-amplitude positive anomaly is aligned along the trend. The source of the anomaly may have been controlled by this postulated fault or fracture zone inferred from lineation Ic. Magnetic lineation Id trends slightly west of north and intersects province I. It may reflect a shallow fault in bedrock beneath sands of the Nafud al Urayk, which is located in the central part of sheet 85.

Regional total-intensity aeromagnetic map (plate 2): The perspective of the smaller scale emphasizes the continuity of high-amplitude anomalies outlining province I. The group of sharp anomalies at the northwestern end of province I and just north of the study area suggests small intrusions along the northwestern contact of the granodiorite unit, and this is supported by geologic mapping (Cole, unpublished data).

Interpretative maps (plate 3a-d): Magnetic lineations Ia, Ib, and Ic are substantiated on the rotation-to-pole and the residual-field interpretative maps, but only Ia and Ic show coherence on the band-pass and low-pass filter maps; lineation Ib may be related to a near-surface source, whereas lineations Ia and Ic may be related to deeper fractures. The fact that lineation Id is well defined on all four interpretative maps, particularly on the low-pass filter map, suggests that it represents a deep zone of deformation.

Magnetic province II

Major rock type: Granodiorite-monzogranite (gdmg)

Magnetic susceptibility: 95×10^{-4}, average of 6 samples ranging from 22×10^{-4} to 218×10^{-4}

Total-intensity aeromagnetic and geologic map (plate 1): Province II is characterized by pervasive, complex patterns of west- to west-northwest-trending anomalies and may represent a distinct intrusive phase in the widespread granodiorite and monzogranite (gdmg) unit. The province boundaries are defined by anomaly-trend changes and steep-gradient zones. A characteristic of the granodiorite-monzogranite rocks in the field (E. J. Young, written commun., 1980) is their lack of gneissic texture and a ubiquitous presence of small inclusions of fine-grained diorite or quartz diorite. The magnetic trends may reflect diorite and quartz diorite concentrated along west-northwest zones of cataclasis. In some cases, the magnetic trends are parallel with swarms of mafic and felsic dikes, but, because this is not a consistent relationship, the magnetic patterns probably are not related predominantly to the dikes.

The magnetic profile across the eastern part of the province (fig. 2) shows a positive high-frequency anomaly at the southern edge of the province; however, unlike province I, there is no distinct negative anomaly at the northern edge, which would be characteristic of a tabular source. The marked gravity low is similar in form to the gravity anomaly across province I. Using the same expression as for province I and setting the Bouguer gravity anomaly equal to 10.6 mgals, and R equal to 5.5 km, an estimated thickness for the inferred granodiorite-monzogranite of 3.6 km is calculated for a density contrast of 0.1 g/cm^3; a contrast of 0.07 g/cm^3 yields a thickness of 7.1 km. The asymmetry of the gravity low and the weakness of magnetic gradients on the north suggest that the inferred body may be tapered toward the north. In cross section, the body may approximate an inverted trapezoid. From comparisons with theoretical magnetic models, it is speculated that the base dips about 30° beneath the body from the north; on the basis of the gravity data, the maximum thickness may be near station 19, where the negative anomaly is greatest.

Magnetic lineations IIa, IIb, and IIc were defined from subtle deflections of contours and alignments of high gradient zones within the province. The lineations may reflect either zones of deformation related to antithetic faulting of the Najd system or north-trending faults of the older Hijaz tectonic cycle; the latter hypothesis, however, would require the rock of province II to be older than the Murdama group. Lineation IId is inferred to reflect a zone of faulting or fracturing along the northern side of province II. Lineation IId appears to terminate at lineation Id.

Lineation IIe is interpreted to be an expression of the major Najd fault across the southwestern part of the study area, and this master fault zone is inferred to be the contact on the southern side of the granodiorite-monzogranite mass defined as province II. Using broad regional observations of the magnetic data, several authors (Andreasen and others, unpub. data; Moore, 1979) have also postulated the presence of Najd faulting in this general area. Recent geologic studies in the Al Jurdhawiyah quadrangle (as summarized in the Geologic Setting section) define the fault-zone trace on the basis of localized minor fracturing, and on truncation of quartz diorite plutons and structural discontinuities in the Murdama group (Cole, in press).

Regional total-intensity aeromagnetic map (plate 2): The small-scale perspective emphasizes the distinctive magnetic signature of province II. The magnetic expression of the Najd fault zone (lineation IIe) can be traced to the east-southeast and to the west-northwest, where it appears to bifurcate near the western edge of the study area and develop a splay that trends northwest. This splay bounds an elongate basin in the 1:250,000-scale Nuqrah quadrangle that contains a well preserved section of the latest Proterozoic Jibalah group (Delfour, 1977).

Interpretative maps (plate 3a-d): Magnetic lineations IIa and IIb are well expressed on the rotation-to-pole and residual-field maps. The band-pass filter data show expression of IIc, and on the low-pass filter map lineations IIa and IIc are apparent. Lineation IId is expressed on all of the maps. Lineation IIe is expressed on all of the maps by prominent alignments of anomalies and gradient zones along the trace of the Najd fault zone in this area.

Magnetic province III

Major rock type: Biotite-hornblende quartz diorite (bhqd)

Magnetic susceptibility: 778 x 10^{-4} (1 sample)

Total-intensity aeromagnetic and geologic map (plate 1): The fact that high-amplitude positive and negative anomalies form an arcuate cluster suggests that the quartz diorite (bhqd) mass enlarges with depth. A tabular mass of unspecified thickness is inferred.

Regional total-intensity aeromagnetic map (plate 2): The magnetic expression of province III extends south of the study area, and high gradients suggest that the granite is bounded on the south by the Najd fault (lineation IIe).

Interpretative maps (plate 3a-d): The rotation-to-pole and residual-field anomalies mirror the total-intensity anomalies. The band-pass and low-pass filter data are devoid of high-frequency anomalies and show a single west-southwest-trending magnetic trough, which has unknown significance.

Magnetic province IV

Magnetic rock type: Biotite-hornblende granodiorite porphyry (gdp)

Magnetic susceptibility: 208 x 10^{-4}, average of 4 samples ranging from 82 x 10^{-4} to 382 x 10^{-4}

Total-intensity aeromagnetic and geologic map (plate 1): The magnetic patterns are similar to those for province I. Well-developed positive and negative closures in arcuate patterns are inferred to define the edge of a tabular granodiorite porphyry (gdp) body. The gentle gradients away from the high-amplitude border anomalies suggest that the width of the mass increases with depth. The high-frequency anomalies at the northwestern end may reflect either a subsurface extension of the granodiorite porphyry (gdp) beyond the main body or possibly separate intrusions along the contact of the granite. Intrusive rock at depth is suggested by biotite-bearing hornfelsed metasediments northwest of the surface granodiorite porphyry contact (Cole, in press). Magnetic lineation IVa, although discontinuous, may have structural significance; it appears to mark a boundary beneath (or within) layered rocks to the northeast of the province.

Regional total-intensity aeromagnetic map (plate 2): Steep gradients in arcuate patterns suggest that the southwestern border of the granodiorite is located just beyond the study area.

Interpretative maps (plate 3a-d): All maps show good definition of province IV. The band-pass and low-pass filter data favor rounding off the northwestern end and not extending the granodiorite porphyry northwest of the main mass. Magnetic lineation IVa is well defined on the residual-field map and poorly defined on the rotation-to-pole map. However, the band-pass filter map suggests that the southwestern part of the lineation has a deep source within the granodiorite porphyry.

Magnetic province V

Major rock type: Biotite-hornblende tonalite (bht)

Magnetic susceptibility: 449×10^{-4}, average of 4 samples ranging from 394×10^{-4} to 526×10^{-4}

Total-intensity aeromagnetic and geologic map (plate 1): The province is defined by patterns of elongated and steep-gradient anomalies that trend west to west-northwest. The province is inferred to outline the near-surface distribution of tonalite (bht) in the study area. The magnetic susceptibility of 449×10^{-4} is greater than that determined for most of the other granites. Anomaly amplitudes generally range from 50 to 100 nT, as compared to 100 to 200 nT for the granodiorite porphyry of provinces I and IV; these provinces have magnetic susceptibilities of only 184×10^{-4} and 192×10^{-4}, respectively. The differences are interpreted to result from the geometry of the granodiorite bodies in provinces I and IV. Because the tonalite of province V does not show high-amplitude, edge anomalies along the contacts, it is inferred to be of infinite thickness.

An area containing outcrops of biotite-hornblende granodiorite (bhgd) is included in province V on the basis of magnetic signature. This slightly younger granodiorite (both bhgd and bht pre-date the basal conglomerate of the Al Jurdhawiyah group; Cole, in press) may be underlain at shallow depth by older tonalite.

The boundary between province V and the younger granodiorite (province VI) is marked by a pronounced change in magnetic trend, from west-northwest in province V to predominantly southwest in province VI. The anomaly trends appear to bear little correlation to the distribution of dikes in either province, and the relationship of the magnetic grain to possible incipient fracture patterns is unknown.

A second area included in province V lies midway along the eastern edge of the study area and is inferred to be underlain largely by tonalite. Exposures of tonalite beneath the unconformity at the base of the Al Jurdhawiyah group are recorded by Cole (in press) in that area. A troughlike magnetic low (lineation Va) extends about 17 km to the west, then abruptly turns northwest to intersect the edge of province I. This magnetic feature may reflect a shallow structural trough, which is deepest in the area of closed contours 5 km west of the province V boundary. The trough corresponds roughly with the axis of a gentle syncline in the Al Jurdhawiyah group volcaniclastic rocks. However, a suggestion of a buried magnetic source appears as an ill-defined dipolar anomaly at the southern edge of the trough (approximately lat 25°17' N., long 42°17' E.).

Regional total-intensity aeromagnetic map (plate 2): The regional patterns suggest that the tonalite of province V underlies the continuous area outlined east and southeast of the study area. The magnetic trough, lineation Va, may reflect a buried graben beneath the rocks of the Al Jurdhawiyah group. Steep-gradient zones are present in the magnetic data within tonalite for a distance of several kilometers east of the study area; these zones pass westward along strike into the broad Va lineation.

Interpretative maps (plate 3a-d): The distinction between provinces V and VI is clearly defined on the four interpretative maps by profound changes in anomaly trends along their boundary. The band-pass and low-pass filter data show discrete smooth anomalies across the province. The troughlike character of the linear magnetic low (Va) is emphasized in the band-pass and low-pass filter data. The residual-field data enhance the dipolar anomaly, and the rotation-to-pole data show a single positive anomaly that defines the location of the source along the southern side of the trough.

Magnetic province VI

Major rock type: Biotite hornblende granodiorite (bhgd)

Magnetic susceptibility: 286 x 10-4 (1 sample)

Total-intensity aeromagnetic and geologic map (plate 1): Magnetic province VI is defined by patterns of elongated high-frequency anomalies with trends that range from south to west. Only minor west-northwest trends typical of province V are present. The magnetic patterns suggest that the granodiorite (bhdg) of province VI may be present southwest of its outcrop area beneath less magnetic rocks of the Al Jurdhawiyah group. In addition, two high-amplitude positive anomalies, having intensities that exceed 6,000 nT, are unique and likely reflect shallow mafic bodies consisting of diorite and gabbronorite that underlie an eroded eruptive center that produced andesitic rocks of the Al Jurdhawiyah group (Cole, in press).

Regional total-intensity aeromagnetic map (plate 2): The perspective of the regional map emphasizes the distinct magnetic character of province VI and indicates that the granodiorite (bhgd) barely extends beyond the limits of the study area.

Interpretative maps (plate 3a-d): The band-pass and the low-pass filter data show nearly coincident, paired positive anomalies that define a west-northwest trend. One of these anomalies is centered in the southwestern part of province VI, and the other is just southeast of province VI. Their paired appearance may be fortuitous; nevertheless, they probably reflect bodies of granodiorite at shallow depth beneath the Al Jurdhawiyah group rocks.

Magnetic province VII

Major rock type: Perthite granite (pg and apg)

Magnetic susceptibility: 116×10^{-4}, average of 2 samples measuring 113×10^{-4} and 118×10^{-4}

Total-intensity aeromagnetic and geologic map (plate 1): Magnetic province VII is inferred to define the approximate limits of the Aban al Ahmar pluton, part of which is located in the northeastern part of the Al Jurdhawiyah quadrangle. The magnetic signature of this province is a near lack of magnetic expression as compared to adjacent areas. The magnetic field has low relief and mostly shows single-contour anomalies over outcrops of the perthite granite core (pg) and the nearly continuous arfvedsonite perthite granite shell (apg). These granites appear to extend southwest in the subsurface beneath rocks of the Al Jurdhawiyah group, as shown in the geology (Cole, in press). The higher gradients in this area are probably related to contact effects.

Regional total-intensity aeromagnetic map (plate 2): The perspective of the small scale emphasizes the lack of high-gradient anomalies as compared to adjacent areas. The Aban al Ahmar pluton extends about 10 km north of the study area.

Interpretative maps (plate 3a-d): The rotation-to-pole map clearly outlines the province in relation to adjacent areas. The other maps show southwest trends in the magnetic data but are not definitive across this narrow province.

Magnetic province VIII

Major rock type: Biotite-hornblende granodiorite granophyre (bhgg)

Magnetic susceptibility: 486 x 10^{-4} (1 sample)

Total-intensity aeromagnetic and geologic map (plate 1): The magnetic patterns in province VIII consist of medium- and some high-amplitude anomalies that trend northwest. The province is inferred to be underlain by a mass of granodiorite granophyre (bhgg). Near the border of province I, the anomaly amplitudes exceed 300 nT. As discussed earlier with regard to province I, the source of these high-amplitude, northwest-trending anomalies is very likely either mafic intrusions, concentrations of magnetite due to contact metamorphism, northward protrusions of the granodiorite porphyry (gdp), or some combination of these. The amplitudes of the anomalies diminish to the east, and the western contact of the granodiorite granophyre (bhgg) is indistinct in the magnetic patterns.

Regional total-intensity aeromagnetic map (plate 2): The extent of the granodiorite granophyre beyond the study area is not clear because the magnetic patterns to the north are variable.

Interpretative maps (plate 3a-d): The rotation-to-pole and residual-field data enhance north- and northwest-trending anomalies. The band-pass and low-pass filter data isolate correlated west-northwest-trending positive anomalies. The positive anomalies are nearly centered over the granodiorite granophyre as inferred from the geology (plate 1). The magnetic gradients on the western sides of the highs approximate the inferred western contact of the granodiorite granophyre.

Magnetic province IX

Major rock type: Granodiorite-monzogranite (gdmg)

Magnetic susceptibility: 180 x 10^{-4}, average of 4 samples ranging from 80 x 10^{-4} to 312 x 10^{-4}

Total-intensity aeromagnetic and geologic map (plate 1): Magnetic province IX appears to represent a wedge-shaped unit of granodiorite-monzogranite (gdmg) that has a distinct magnetic signature in comparison to the remainder of the map unit. The province is isolated as an area of strong northwest-trending magnetic lineations within a broader area of mostly west- to west-northwest-trending lineations.

The magnetic susceptibility of 180 x 10^{-4} is almost twice that of province II (95 x 10^{-4}), although both provinces are defined within massive granodiorite-monzogranite that covers more than 75 percent of the Wadi al Jarir quadrangle. The higher amplitude anomalies indicate that the granodiorite-monzogranite in province IX is more magnetic than it is in province II. Field observations lead us to believe that province IX is a more mafic phase (quartz diorite) of the map unit.

The source of the prominent northwest-trending negative feature (magnetic lineation IXa) near the center of the province was not detected in the field. A small mafic dike crops out along the anomaly axis and another dike, although parallel to the axis, crops out about 1.5 km to the southwest. However, the northwest-trending dikes mapped at the surface are few in comparison to the swarms of northeast-trending dikes, particularly in the southern part of the province where the northeast-trending dikes are abruptly terminated near lineation IXa. The southern boundary of the province is marked by magnetic lineation IXb, inferred to reflect a fault or fracture zone that extends both west-northwest and east-southeast of the province.

Another prominent negative feature (lineation IXc) of almost 200 nT amplitude, is similar to lineation IXa but is east of the province boundary. Lineation IXc trends west-northwest and is subparallel with lineation IXa and IXb. It extends east-southeast and crosses the boundary of province I. Lineation IXc may be related to Najd deformation that occurred subsequent to the emplacement of the granodiorite porphyry of province I.

Regional total-intensity aeromagnetic map (plate 2): When viewed from a regional perspective, the magnetic patterns of province IX define a kidney-shaped area just north of the study area, which has an arcuate configuration of anomalies. Although arcuate structures were not recorded in reconnaissance geologic mapping (Bramkamp and others, 1963), they may be present in the subsurface.

Interpretative maps (plate 3a-d): The rotation-to-pole and residual-field data show pronounced northwest trends. The band-pass and low-pass filter data have broad, positive anomalies that trend northwest and arc to the north near the edge of the study area. All of the interpretative maps show good resolution of magnetic lineation IXb, inferred to reflect a fault or fracture zone that marks the southern boundary of the province.

MAGNETIC PATTERNS RELATED TO MINERAL DEPOSITS

Localities of known mineralization within sheet 85 are plotted on plate 1, and on plate 2 with similar data for the surrounding region (compiled from MODS; Mytton, 1970; Cole, in press; Young, 1982; and Cole, unpublished data). Previous efforts to summarize and categorize the mineral deposits of the northeastern Shield were based on fewer data (Greenwood and others, 1974; Muller, 1975) or were focused on more specific structural controls (Moore and Al Shanti, 1981). These reports tend to emphasize an assumed importance for the Najd fault system with regard to the localization, orientation, and formation of ore-bearing zones, but our present study suggests that other factors are probably more important in this region north of the principal Najd zones.

All of the 30 deposits compiled on plate 2 (which represent the principal ancient workings and known sites of base- and precious-metals in the region) are systems of mineralized quartz veins; stratiform, syngenetic deposits are unknown from this part of the Shield, probably because the depositional environments of the Murdama and Al Jurdhawiyah basins were not favorable to the deposition of massive sulfides. Characteristic metals in most of the deposits are known (or inferred) to be copper and gold, although tungsten-tin are dominant at Jabal al Koom (MODS 1066) and at Baid al Jimalah West (MODS 2661; Cole and others, 1981), gold and antimony occur together at Wagt (MODS 1269; Mytton, 1970) and at Umm Jirfan (MODS 0959), and lead-zinc-silver-(tin) are the dominant metals at Baid al Jimalah East (MODS 0960; Cole and others, 1981). Furthermore, most all of these vein systems are relatively simple fracture-fillings; cataclasis as a part of or subsequent to ore formation is only a notable feature at Al Habla East (MODS 1286), Jabal Thara (MODS 1086), part of the Ash Shumta district (MODS 1108 and others), and possibly at Baid al Jimalah East (MODS 0960). Of these, only Al Habla East is genetically related to a fault that is parallel to the local Najd trend (Cole, unpublished data). If the undeformed fracture-filling veins were related to regional deformation of the Najd system, they would be expected to be oriented along a N. 75° E. trend in the region north of the main fault (lineation IIe, plate 2; Moore, 1979). As shown on the compilation of plate 2, however, this trend is clearly a minor one for the deposits of the northeastern Shield.

We suggest rather that many of the vein-controlled deposits are genetically related to the emplacement of the later felsic plutons of the area. On plate 2, mineral localities 1, 2, 3, 5, 6, 10, 11, 14, 16, 17, 19, 21, 24, and 25 share the following common characteristics: Mineralized copper-gold-bearing quartz veins are present in plutons or in narrow contact-hornfelsed envelopes of Murdama metasediment. These plutons are generally granodiorite porphyry (gdp on plate 1) or are mineralogically and texturally similar to the porphyry and are characterized by high-amplitude magnetic anomalies localized on the contact zones. These plutons are most likely about 620 Ma old (Cole, unpublished data) and therefore predate the probable onset of Najd-fault deformation by at least 30 million years. The prominent trend of veins in these localities is essentially due north and may reflect the influence of a regional (residual?) stress pattern in the Murdama basin at the time of emplacement, or this northerly trend may have been governed by weak cleavage that formed during folding of the Murdama group. Several other vein deposits of similar type in the area (localities 9, 18, 20, 28, 29; plate 2) may belong to the same episode of ore formation but have not been eroded deeply enough to expose the granodiorite-porphyry-type pluton; however, magnetic anomaly patterns imply that a body may be present in the subsurface.

The best example of a young mineralized vein system that might have been formed at the same time as the Najd transcurrent fault system is the Baid al Jimalah (East and West) district (locality 7; plate 2). The source granite was emplaced about 575 Ma ago and geologic and isotopic factors indicate contemporaneous ore formation (Cole and others, 1981; J. S. Stacey, written commun., 1982). The Baid al Jimalah district is located about 15 km from the trace of the major Najd fault, and minor fractures in the surrounding Murdama group have a parallel trend of about N. 75° W. and slight left-lateral offsets. The vein systems in the Baid al Jimalah district, however, have a dominant trend of N. 60° W. and are principally undeformed open-space fillings; only the last minor veins of the East and West deposits show signs of cataclastic deformation (Cole and others, 1981). Therefore, it appears that the Najd system did not have a significant effect on the orientation of Baid al Jimalah veins.

In summary, study of regional aeromagnetic data have indicated a significant prospecting guide for vein-controlled copper-gold deposits: small granodiorite-porphyry-type plutons emplaced in Murdama group rocks and characterized by high-amplitude edge anomalies. This work also suggests that a relationship between ore formation and the Najd fault system cannot be substantiated in the region north of the principal fault zone (lineation IIe; plate 2). Furthermore, regional magnetic data are not accurate at a sufficiently large scale to detect small, weakly magnetic hosts such as the Baid al Jimalah granite and, because this deposit does not bear a simple relationship to regional structures or magnetic anomalies, prospecting may need to rely more heavily on sound geologic mapping.

CONCLUSIONS AND RECOMMENDATIONS

Characteristic magnetic patterns were found to differentiate areas of exposed granitic rocks having subtle petrologic differences, and interpretations of magnetic data in support of geologic mapping in other quadrangles of the northern Arabian Shield seem justified. Initially, the aeromagnetic data for the late Proterozoic granites in the northern Shield should be studied as a unit at a small scale to form a framework for 1:100,000- and 1:250,000-scale interpretations done concurrently with geologic mapping and smaller-scale compilations.

The detection of a distinct gravity low shown on the profile across the granodiorite porphyry mass (magnetic province I) supports the utility of gravity surveys to aid in delineating the configuration of many of the granitic bodies in the third dimension. The gravity profile also substantiates the interpreted shape deduced from the strong edge anomalies in the magnetic data.

Followup studies to evaluate possibilities for mineral deposits may be appropriate along border zones of some granitic bodies and in the areas of magnetic lineations. Areas recommended for further evaluation are those in which inferred satellitic intrusions and contact metamorphism are concentrated, particularly where geochemical anomalies are also present. Notable examples include the clusters of high-amplitude, short-wavelength anomalies along the northern and southern sides of the large granodiorite porphyry mass (province I) and at the northwestern end of the granodiorite porphyry in magnetic province IV. Magnetic lineations that are marked by anomalously low values, particularly IIe, IXa, and IXc, may reflect altered (demagnetized) rock generated by ore-forming processes.

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