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A test of the telluric-electric profiling method at the tin-bearing Greisen area of Jabal As Silsilah, Kingdom of Saudi Arabia

by

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A TEST OF THE TELLURIC-ELECTRIC PROFILING METHOD AT THE TIN-BEARING GREISEN AREA OF JABAL AS SILSILAH, KINGDOM OF SAUDI ARABIA

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ROBERT J. KAMILLI, CHARLES J. ZABLOCKI, AND MOHAMMED O. HAJNUR

ABSTRACT

Fine-scale, telluric-electric geophysical profiling is the geophysical method of choice for locating buried, possibly mineralized granite cupolas at the Silsilah tin deposit (lat 26°06' N., long 42°40' E.; MODS 3262). This method is accurate, rapid, and inexpensive. In this study, it proved to be more accurate than the more costly and time-consuming induced-polarization technique.

For this study, six traverses measured electrical fields (a qualitative measurement of rock resistivity) at 27 and 270 Hz across grounded electrodes spaced 50 m apart. Little difference was seen between the 27- and 270-Hz profiles, suggesting that only one frequency may be necessary for similar studies in the future.

This method is able to identify and distinguish among unroofed granite cupolas, cupolas with their aplite-pegmatite carapaces intact, strong (quartz-rich) greisens, weak (relatively quartz-poor) greisens, dikes, faults, and pervasively argillized rock, such as that encountered at Silsilah.

Two electrical anomalies probably represent buried cupolas: one is located at 7.8 East, 4.8 to 5.35 North; the other is located at 7.8 East, 5.6 to 5.9 North. They should be the first targets for any additional drilling of this prospect.

This method could be useful in the evaluation of other mineral prospects in the region, especially tin-tungsten and disseminated-gold prospects, both of which are spatially and genetically associated with the apexes of small igneous cupolas.

INTRODUCTION

In the course of 1:100,000-scale geological mapping of the Jabal as Silsilah quadrangle (26/42D), E. A. du Bray identified a tin-greisen deposit in the southwest sector of the igneous Silsilah ring complex (lat 26°06' N., long 42°40' E.), about 150 km west-southwest of Buraydah (fig. 1) (du Bray, 1983; 1984). The Saudi Arabian Mineral Occurrence Documentation System (MODS) number is 3262. Exploration and prospect evaluation was carried out by the Riofinex Geological Mission (Parker and others, 1984), and detailed studies of ore genesis were conducted by Kamilli (1987). These studies include detailed mapping of the

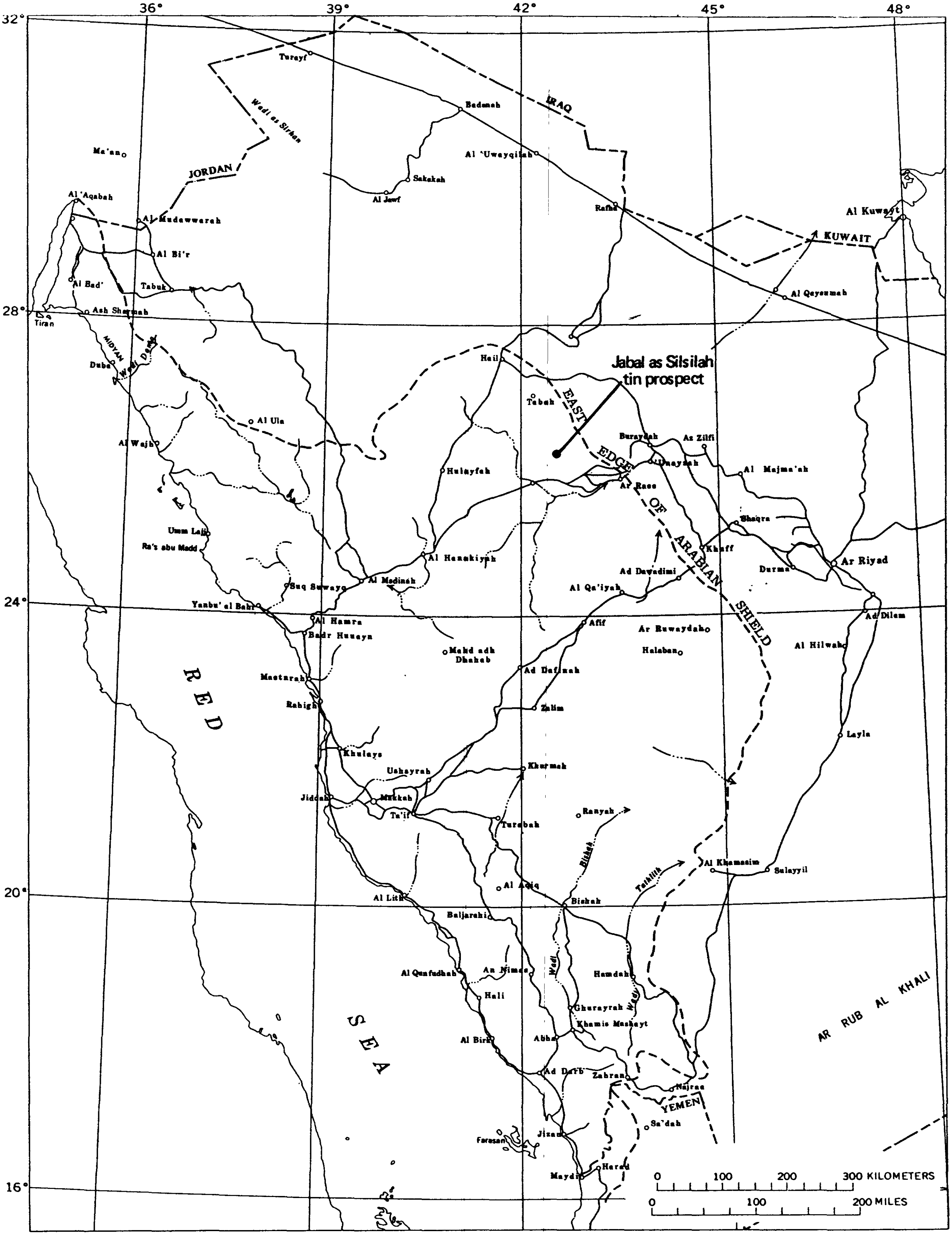

Figure 1.--Index map of western Saudi Arabia showing the location of the Silsilah ring complex.

surface and trenches, high-density surficial and near-surface rock-chip sampling, diamond and rotary-percussion drilling, detailed geophysical surveys, and studies of paragenesis, mineralogy, geochemistry, petrology, and fluid inclusions.

The information acquired from these studies afforded the opportunity to assess the utility of the telluric-electric (TE) profiling technique as a rapid, albeit qualitative, means of characterizing the geoelectric properties of rocks in this type of setting. Accordingly, six TE profiles were made along survey lines and trenches over a five-day period in 1984, while subregional-scale audio magnetotelluric (AMT) studies were being carried out in and around the Silsilah ring complex (Zablocki and others, 1985). Detailed (1:500 scale) geological maps of the trenches allowed precise correlation of the TE data with the geology along 37 percent of the profiles. For those geophysical lines not close to a trench, geological information was used from 1:5000-scale surface mapping, which was then compiled at a scale of 1:10,000 (pl. 1). In this report, we discuss the findings from this study and appraise the usefulness and limitations of this natural-source field technique.

ACKNOWLEDGMENTS

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TECHNIQUES

Except for one experimental traverse, all previous investigations with the telluric-electric profiling technique in the Kingdom have been made using large-spacing (to 500 m) bipoles and micropulsation electromagnetic energy at 0.033 Hz as a source. This arrangement permitted the rapid investigation of subsurface structures to depths of several kilometers over large areas. See, for example, Flanigan and Zablocki (1984); Zablocki and others (1985). The details of this technique have been described previously by Zablocki and others (1984). For this study, the technique was modified so that electromagnetic energy produced by spherics (distant lightning discharge in the lower atmosphere) was used as a source, and the resulting fields measured at 27 and 270 Hz across grounded electrodes spaced 50 m apart. This modified procedure obtained better definition of the geoelectric responses to shallow and relatively small-dimension features of contrasting resistivity. The two frequencies were selected because of the good quality and consistent signal levels obtained in this part of the electromagnetic spectrum. Also, because depth of penetration of electromagnetic waves is inversely proportional to the square root of frequency, the order of magnitude difference in frequency allowed us to evaluate the utility of obtaining useful information at relative depth differences of approximately 3 to 1 ($1/\sqrt{10}$).

As in previous TE profiling studies, the relative electric-field amplitude ratio was determined while the 3-electrode array was leapfrogged along a traverse. This ratio was then multiplied by the previous ratio to produce a relative amplitude profile of the electrical-field component in the traverse direction. The magnitude of the electric-field ratio at a given location is proportional to the square root of the ratio of the resistivities in the region of each electrode pair.

Accordingly, the resulting profile will reflect the gross electrical characteristics of the underlying rocks. It should be remembered that this technique provides only qualitative information about the electrical properties of the rocks along individual straight-line profiles. Absolute determination of resistivity would require using the AMT method or other resistivity-measuring techniques. Accordingly, unless resistivities are determined at one or more locations along parallel traverses, the electric-field amplitudes can not be tied together to produce contoured maps of the data.

GEOLOGIC SETTING AND PROSPECT GEOLOGY

INTRODUCTION

The Silsilah tin deposit is located in the northeastern part of the late Proterozoic Arabian Shield in the Afif terrane (Stoeser and Camp, 1985). This terrane is a microplate consisting of late orogenic, intracratonic granites, intermediate felsic volcanic rocks, and molassic sediments that overlie a poorly known crystalline basement. The terrane contains both peralkaline and peraluminous granites that were emplaced late in the Pan-African orogeny (Stoeser and Camp, 1985). The rocks of the Silsilah ring complex are similar to other late Proterozoic granites in the region, all of which have been assigned to the Abanat suite (Cole, 1985a; 1985b).

PROSPECT GEOLOGY

The Silsilah tin deposit is composed of disseminated cassiterite with minor wolframite in pervasively altered quartz-topaz greisens at the top of small (300-400 m in diameter) cupolas within the Silsilah igneous ring complex. The complex is a circular feature composed of ring dikes and intrusions that rise as much as 300 m above a relatively flat peneplain that has a general elevation between 810 and 860 m above sea level (fig. 2).

The ring complex is about 12 km in diameter. Although the structure appears to be a cauldron, there is no evidence for resurgence. Roobol and White (1986) suggest that the pluton has the shape of a flat-topped belljar, and was formed by the subsidence of a large, roughly circular block of the country rock into the magma. In the case of Silsilah, the pluton passes upward into vertical ring dikes. They also hypothesize that the presence of dikes with a tuffaceous component indicates the former existence of a volcanic edifice, now eroded away. The rocks that comprise the complex, from oldest to youngest, are alkaline dacite, comendite, peralkaline granite, and peraluminous granite and aplite (du Bray, 1984). The alkaline dacite (ad) (fig. 2) is composed of fine-grained sodic plagioclase and Fe-Ti oxides. It is locally tuffaceous and vesicular, suggesting that some of the magma represented by these rocks may have vented.

The Silsilah comendite (sc) (fig. 2) is a porphyritic peralkaline rock composed of quartz, alkalic feldspar, albite, arfedsonite, and opaque oxides. Phenocrysts of quartz and alkalic feldspar are present in a micrographic groundmass.

The Fawwarah granite (fg) (fig. 2) is a peraluminous, medium-grained rock composed of quartz, albite, generally perthitic alkalic feldspar, trioctahedral micas (biotite, ferrophengite, zinnwaldite), muscovite, and traces of fluorite and

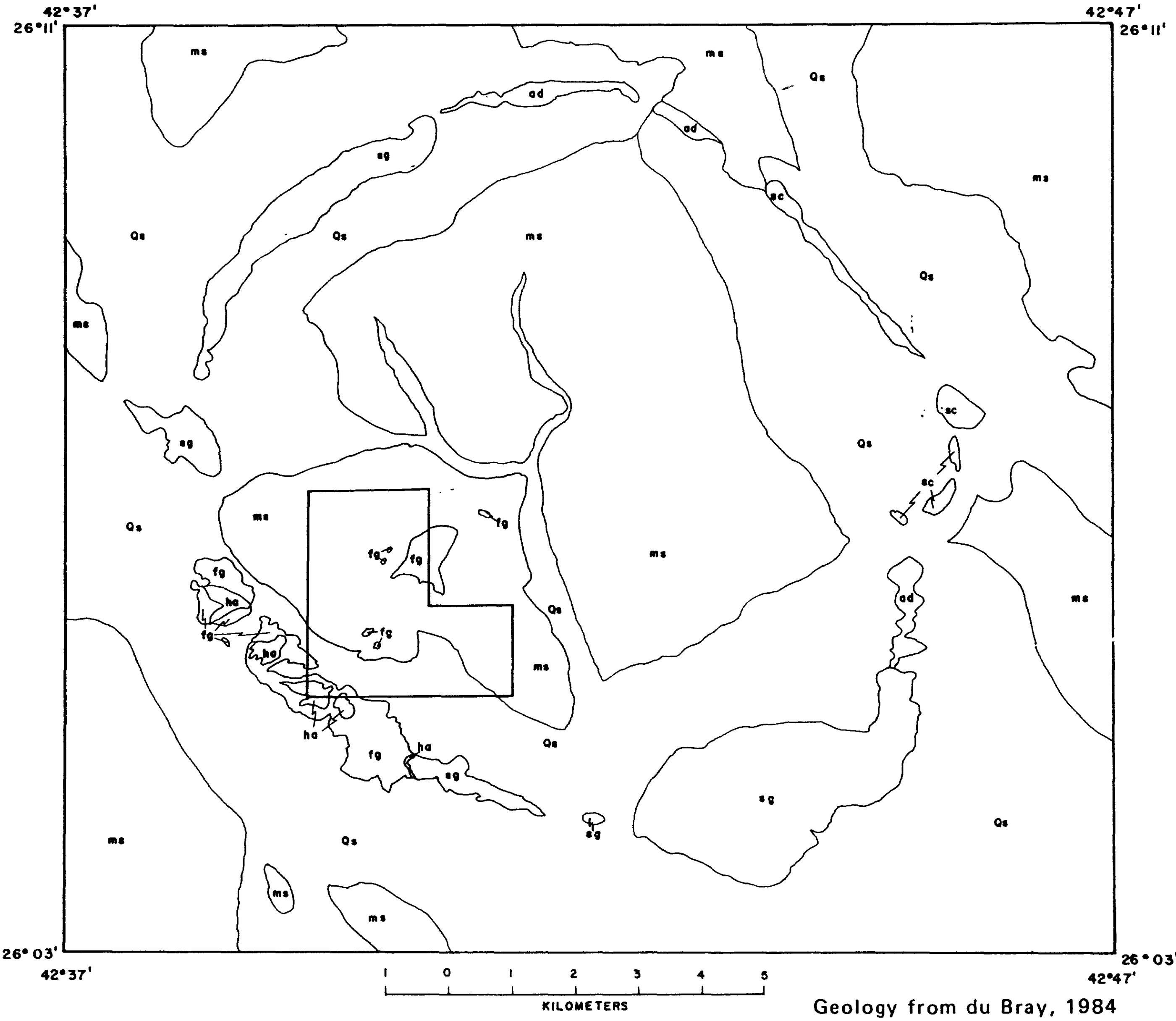

Figure 2.--Simplified geological map of the Silsilah ring complex. Symbols are as follows: Qs - surficial deposits; ha - Hadhir aplite; fg - Fawwarah granite; sc - Silsilah comendite; ad - alkaline dacite; ms - Murdama sandstone. Inner boundary shows the area covered by plate 1.

topaz. A U-Pb zircon age obtained by John Stacey indicates that the Fawwarah granite was emplaced at 587 ± 8 Ma (du Bray, 1984). This granite is found within the ring structure as well as in individual cupolas inside the ring (fig. 2 and pl. 1). Each Fawwarah intrusion has an aplitic carapace, named the Hadhir aplite (ha) (du Bray, 1984), and commonly contains layered pegmatites near the contact with the underlying Fawwarah granite.

Pegmatites are also present as isolated pods from about 10 to 100 cm across throughout the granite. The pegmatites of the greisen zones inside the ring contain green topaz crystals (1 cm), as well as trioctahedral micas, chiefly zinnwaldite. The micas commonly are found as dendritic, skeletal intergrowths with quartz and feldspar. The pegmatites that are found near the Hadhir-Fawwarah contact have well-developed layering and commonly are intercalated with layers of aplite.

Greisenized Fawwarah granite is present in the cupolas inside the ring (pl. 1) immediately beneath the Fawwarah-pegmatite contact and contains the disseminated cassiterite and sulfide mineralization at Silsilah. The greisen varies from a quartz-topaz-fluorite assemblage at the top of the zone, through a quartz-topaz-fluorite-mica assemblage, down to a quartz-topaz-fluorite-mica-feldspar assemblage. Each zone is generally only a few meters thick. The granite is commonly albitized beneath the greisen zones. Smaller, discontinuous pods and lenses of greisen are present beneath the principal zone of greisen and albitized granite. In some places, these greisen pods are found directly beneath small pegmatite zones.

The best cassiterite mineralization discovered thus far is at or near the surface, with maximum Sn grades of 3 weight percent (Parker and others, 1985; p. 27). This strong greisen contains about 75 percent quartz, 10 percent topaz, 13 percent Fe-Ti oxides, and 1 to 2 percent cassiterite, but these rocks are highly weathered and not representative of the original mineral assemblage. Complex intergrowths of hematite, limonite, ferrimolybdite, sericite, clay minerals, and possibly traces of scorodite are common in the zone of weathering. Traces of covellite replace chalcopyrite. The weathering zone may extend down to 12-15 meters below the surface. Fresh greisen is typically a sutured intergrowth of quartz and topaz containing interstitial grains of accessory minerals. Unweathered, intensely greisenized rock has about 75 percent quartz, 10 percent topaz, 5 percent carbonate (siderite and manganosiderite), 5 percent pyrite, 2 percent sphalerite (with exsolution blebs of chalcopyrite), and less than 1 percent of each of the following minerals: cassiterite, wolframite, galena, monazite, columbite, zirkelite(?), conichalcite(?), samarskite, arseniosiderite(?), arsenopyrite, and zircon.

Zones of quartz-wolframite veins as much as 2 m wide cut Fawwarah granite (pl. 1). They commonly contain greisen envelopes as much as 1 m.

The entire igneous complex has been intruded into regionally folded, fine-grained, feldspathic sandstone of the Murdama group (ms) (fig. 2) (670-655 Ma; Cole and Hedge, unpub. data, 1985). The rocks of the Murdama group were metamorphosed to greenschist facies and consist chiefly of fine-grained, immature sandstone that contains abundant clasts of metamorphosed intermediate and felsic volcanic rock, plagioclase, and quartz in a matrix of chlorite, granular epidote, and blastic calcite. (Cole, 1981; 1985b).

RESULTS AND DISCUSSION

INTRODUCTION

Telluric-electric profiles were made along six north-south traverses (pl. 1). The resulting relative electric-field amplitudes are plotted together with the corresponding detailed geology as revealed in the trenches or otherwise exposed at the surface (pl. 1). Resistivity values obtained from induced-polarization surveys conducted by Riofinex along parts of some of these traverses are also plotted. These resistivity data were obtained using a conventional dipole-dipole configuration in which the current and receiver dipoles were 50 m in length and aligned in a colinear direction along a traverse. The data are plotted for current/receiver separations at N=2 and N=4, which correspond to separations of 100 to 200 m, respectively. In general, the equivalent depths of investigation at these two separations are approximately 30 and 60 m, respectively. They are presented for comparison with the TE results in plate 1. In detail, these two electrical techniques do not respond identically in an electrically inhomogeneous medium because of the differences in the distribution of the current flow. In the TE method, the current pattern is assumed to be planar, whereas the current pattern is more complex in the dipole-dipole method owing to the finite dipole-current source.

Two types of theoretical models demonstrate the expected responses for the TE method typical of geological features present in the study area (figs. 3 and 4). For a vertical contact at the surface between contrasting resistivities, the relative E-field amplitude ratio is proportional to the square root of the resistivity ratio. Lower frequency TE measurements sense farther both laterally and vertically than high frequencies. In the example shown (fig. 3), the undershoot and overshoot in the E-field near the contact is more pronounced at the extremely low frequency of 0.05 Hz as compared to the 8-Hz response. The other example (fig. 4) shows the response from a narrow vertical dike of high resistivity in a low-resistivity medium. It is seen that the E-field response can detect such a feature even though the width of the dike is small.

GEOPHYSICAL AND GEOLOGICAL PROFILES

The relative E-field amplitude profiles show close correlation with mapped geological features at both 27 and 270 Hz. All discussion of profiles in the following sections will be from south to north. Coordinates are from the grid system established by Riofinex (Parker and others, 1984). A one-integer difference equals a distance of 1000 m. See plate 1 for the location of the traverses.

7.0 East, 4.55-5.7 North

Correlation of E-field amplitudes with geological features in this traverse is excellent (pl. 1). The traverse begins near the mountain front in an area where alluvium and talus cover the bedrock. The first rock unit exposed in the trench is Fawwarah granite, which is texturally identical to the granite of the mountain front. The relative E-field amplitude in this traverse is lowest at the southern end. This is due to a zone of intensely clay-altered Fawwarah granite (low resistivity) that strikes approximately parallel to the mountain front and is well exposed in a trench along the 7.6 East traverse. A sharp E-field peak is present

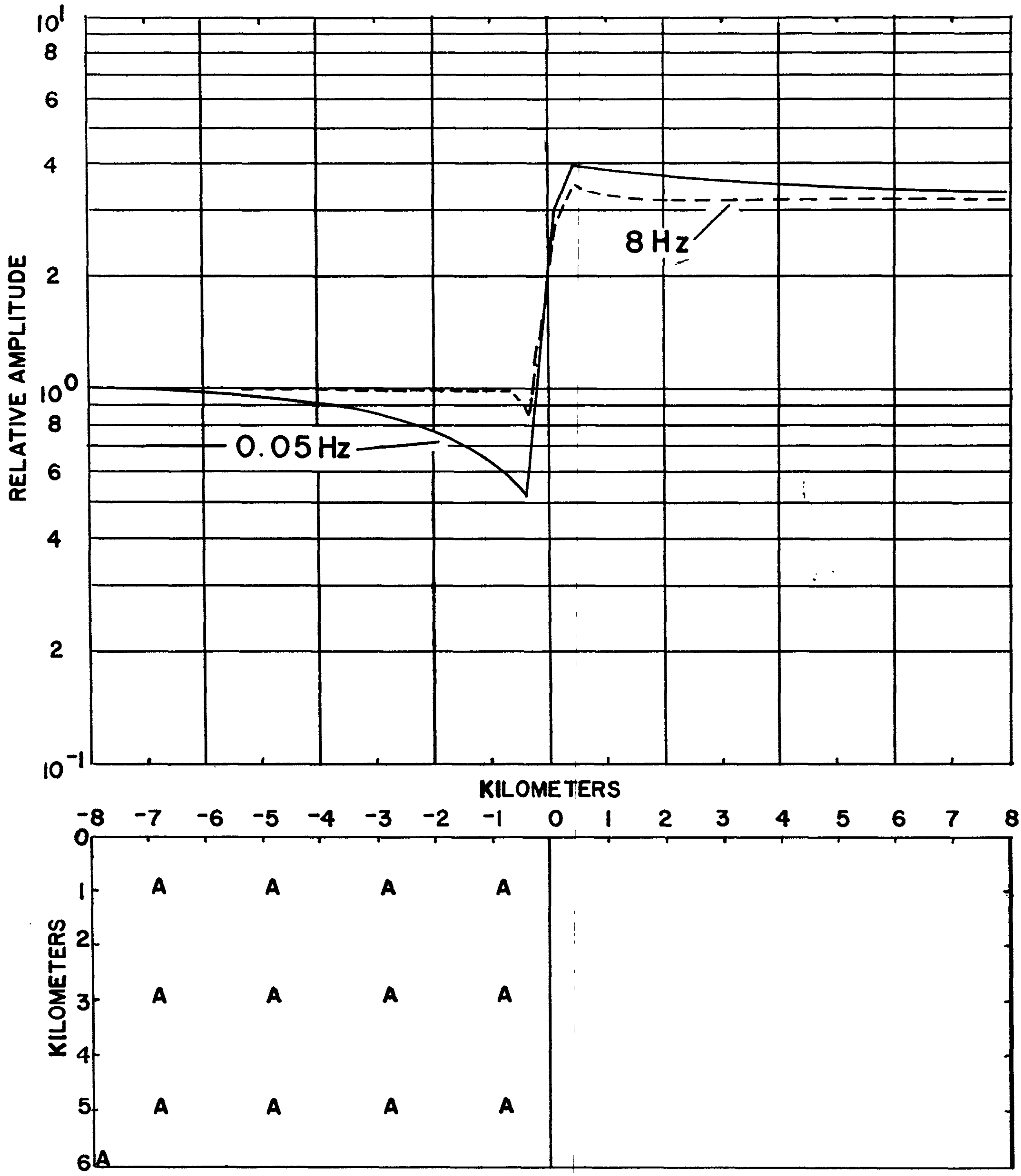

Figure 3.--Two-dimensional model of vertical geological contact, as shown by E-field ratio tellurics at 0.05 Hz and 8 Hz. Profile line is perpendicular to strike of contact. Area designated with the symbol A has a resistivity of 10 ohm-meters; blank area has a resistivity of 100 ohm-meters.

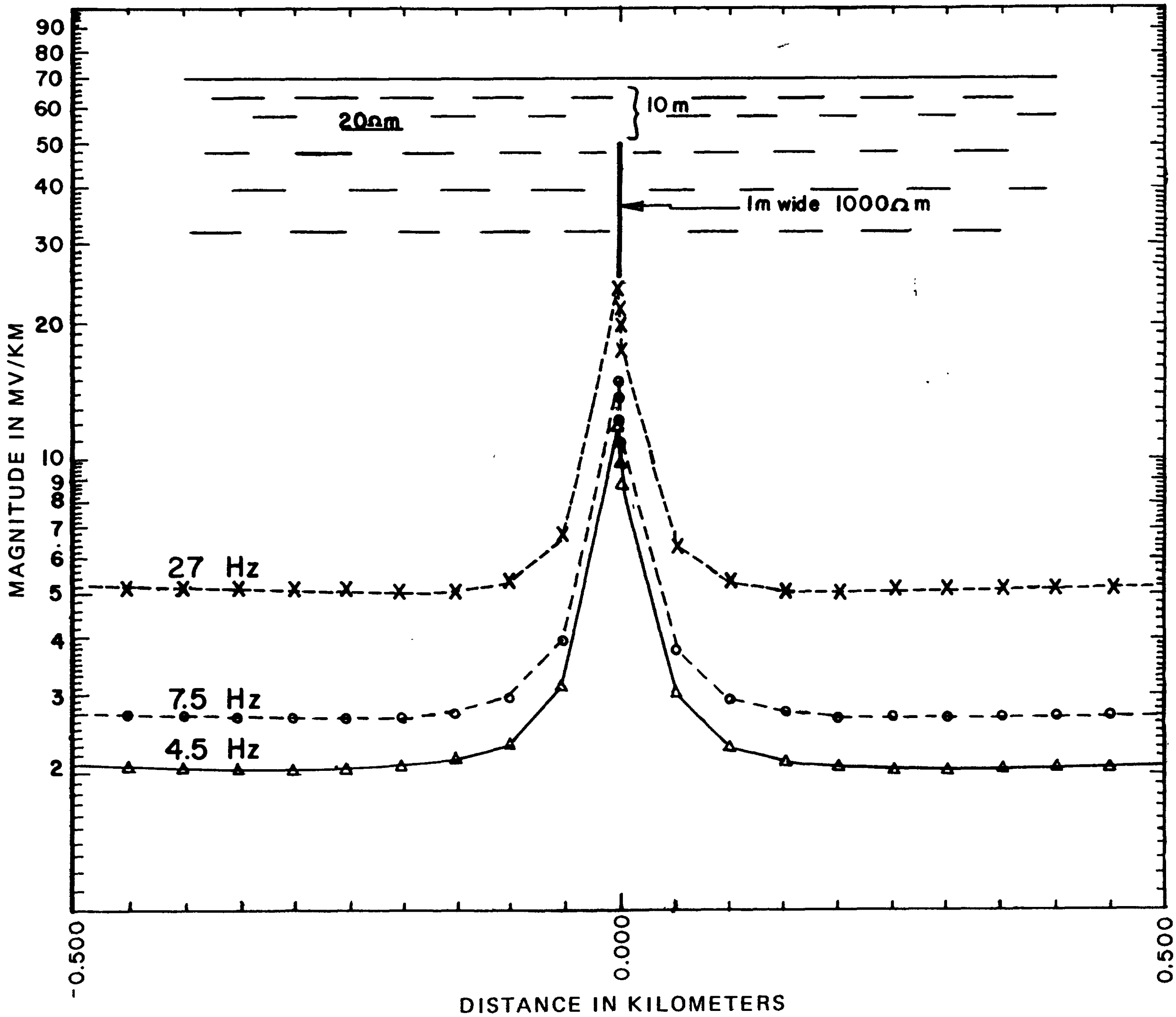

Figure 4.--Two-dimensional model of vertical, 1-m-wide dike buried at a depth of 10 meters, as shown by E-field ratio tellurics at 4.5 Hz, 7.5 Hz, and 27 Hz. Dike has a resistivity of 10^4 ohm-meters; country rock has a resistivity of 20 ohm-meters.

near a zone of moderate greisenization (very high resistivity). The E-field amplitude remains relatively high in the granite up to the pegmatitic and aplitic border and then drops off sharply at the contact with the Murdama sandstone.

A well-defined E-field peak corresponds exactly with a Silsilah comendite dike that crosses the traverse at about a 45^{o} angle. A second sharp E-field peak corresponds with another Silsilah comendite dike less than 10 m wide. Comparison of the E-field peaks associated with these two dikes demonstrates that vertical, planar features can yield E-field peaks of similar amplitude even when their exposed cross sections are as different as 10 m and 100 m, as is the case with the aplite and comendite dikes, respectively. Finer resolution of these and other small features could be achieved using more closely spaced electrodes.

Another, somewhat broader E-field peak in the Murdama sandstone corresponds to a prominent layer that contains only lithic fragments, quartz, and metamorphic biotite, unlike most of the other Murdama in the area, which contains considerable amounts of clay minerals in the matrix. The E-field peak amplitude caused by this layer is as large as those produced by the dikes, which suggests that its resistivity is similar to that of the dikes. These observations also emphasize the strong influence that clay minerals have in controlling rock resistivity.

A cursory inspection of the resistivity data reveals little correlation with the geology, E-field amplitudes, or even between the two resistivity plots. Closer inspection of the data, however, reveals that the N=2 and N=4 plots appear to be shifted about 100 m and 50 m to the north, respectively. The reason for this apparent shift is unknown.

7.35 East, 4.7-5.9 North

The data from this traverse also correlate well with the exposed geological features (pl. 1) and allows one to confidently hypothesize that the sharp E-field peak at the south end of the traverse correlates with a dike buried beneath the alluvium and talus. Twin E-field peaks about 250 m to the north imply that the comendite dike seen in the 7.0 East traverse bifurcates. Although only Murdama sandstone is exposed at the large E-field peak at 5.3 North, the peak correlates well with the subsurface projection of one of the principal cassiterite-bearing, greisenized Fawwarah cupolas that crops out about 25 m to the east. A steady increase in E-field amplitude to the north, culminating in a broad, domal peak indicates that the cupola exposed in the trench is larger than the portion exposed. This interpretation is supported by the presence of many small aplite dikes in the Murdama sandstone, as well as the outcrops of Hadhir aplite to the north-northeast and west.

7.6 East, 4.3-7.0 North

This traverse (pl. 1), the longest of the six, shows most of the different types of geological features in the area and how they correlate with the TE data. The high relative E-field amplitude and sharp decrease at the southern end of the traverse is a reflection of the change from essentially unaltered Fawwarah granite at the mountain front to strongly altered Fawwarah at 4.45 North, where the rock has been completely altered to kaolinite, montmorillonite, sepiolite(?), and trace 2M1 illite. The possible presence of sepiolite is unusual and the identification may be incorrect, but the mineral is certainly from the palygorskite group (I. M. Naqvi, oral commun., 1986). Sepiolite ($2MgO \cdot 3SiO_2 \cdot 4H_2O$) usually occurs as a weathering product of serpentinite (Hurlbut and Klein, 1977). But it is also reported from quartz and sulfide mineralization in magnesium-carbonate beds near acidic intrusive rocks and is believed to be formed by low-temperature hydrothermal solutions during the last stages of sulfide mineralization (Ehlmann and others, 1962). The source of magnesium, however, is enigmatic. The MgO content of Silsilah granite and comendite, Fawwarah granite, and Hadhir aplite are generally less than 0.1 weight percent (du Bray, 1984; Kamilli, 1987). Murdama sandstone at Silsilah contains a maximum of only 2.95 weight percent MgO (du Bray, 1984).

The altered granite is well exposed in a trench and clearly retains its original igneous texture, thus having the appearance of a saprolite. It is highly unlikely that a saprolite would form in such an arid climate. The most probable explanation is that this pervasive clay alteration is due to a late hydrothermal event, perhaps analogous to the widespread kaolinite deposits associated with the greisenized granites of southwest England. The exposures in this trench also provide the best evidence that neither the mountain front nor the clay alteration are due to the presence of a post-intrusion boundary fault.

At about 4.55 North, a distinct E-field peak in the 270-Hz plot that is absent in the 27-Hz data. It is the only significant difference between the two data sets in the traverses. There is no trench in this area and the cause of this difference is unknown, but may be due to the presence of a shallow, isolated zone of greisen that is better resolved at the higher frequency. The seemingly random distribution of greisen pods is fairly common throughout the Fawwarah granite. Early, strong greisenization would have converted most of the rock to quartz, leaving no feldspar to be altered to clay minerals.

The sharp E-field peak at 4.9 North coincides with the projection of the comendite dike seen on the surface and detected in the 7.0 and 7.35 East traverses.

The data from 4.95 to 5.35 North are instructive because they correlate well with the mineralogy of the rocks in a greisenized cupola at Silsilah and in the Murdama sandstone immediately surrounding it. The Murdama sandstone at the contact with the cupolas at Silsilah and extending for several hundred meters laterally is extremely friable, with high clay (montmorillonite, kaolinite, sepiolite?, and trace 2M1 illite), calcite, and gypsum content. This is reflected in the low E-field amplitudes immediately on either side of the cupola. Any TE evidence for the presence of the fault that lies at the northern contact of this cupola may be obscured by the large contrast in resistivity between the Fawwarah and the clay-rich Murdama sandstone. The borders of the cupola, especially the pegmatite-aplite zone, have distinct E-field peaks associated with them that probably reflect the relative lack of hydrothermal alteration and subsequent weathering in these areas. This effect is offset slightly in the zones of strongest greisen alteration where so much of the rock has been converted to quartz that little is left to alter or weather to clay minerals (topaz excepted).

Two sharp E-field peaks at 5.4 and 5.65 North correspond with Silsilah comendite dikes.

The sharp E-field peak at 6.3 North, corresponding to a dike of relatively unaltered Fawwarah granite is higher than the lower, broader peak that corresponds with the weakly greisenized, and therefore clay-weathered, Fawwarah mass immediately to the north. The lack of an aplite-pegmatite contact zone and the presence of uniformly weak alteration gives this cupola a simpler E-field pattern compared to the cassiterite-rich and more strongly altered cupola to the south. This marked difference could be important in interpreting any further TE geophysical exploration at Silsilah. It should be mentioned that the cupola at the northern end of the 7.35 East traverse does not produce the characteristic TE profile seen between 4.95 and 5.35 North of the 7.6 East traverse because the pegmatitic cap has not been breached by weathering. Therefore, the pattern of the cupola at the southern end of the 7.6 East traverse could only be useful in locating cupolas that have been unroofed and subsequently buried by alluvium.

As in the the 7.0 East traverse, the resistivity data do not reflect the geology as well as that obtained with the telluric-electric method. The N=2 and N=4 plots from the resistivity data are shifted with respect to the TE data and with each other, which demonstrates the more complex nature of the current and potential distribution of dipole-dipole techniques, such as the Induced-Polarization method.

7.8 East, 4.35-6.2 North

This traverse (pl. 1) is similar to that of 7.6 East in that a relatively high E-field amplitude decreases immediately north of the mountain front due to the presence of the strongly clay-altered zone in the area. An E-field peak in the middle of this zone is possibly due to the presence of a buried dike. The peak at about 4.75 north corresponds well to the projection of the comendite dike seen in the other traverses.

The broad, high E-field peak that extends from 4.9 to 5.35 North almost certainly represents a concealed cupola of Fawwarah granite that has not been unroofed. This hypothesis is supported by the presence of numerous, subvertical aplite dikes in the Murdama exposed in the trench that extends across this anomaly. It is probably an intrusive mass distinct from the strongly mineralized cupola exposed immediately to the west, because the fault observed in the 7.6 East traverse turns southeast and projects between the two high amplitude zones. The fact that the northeast side of the fault is downthrown could explain why this cupola is not exposed here, in contrast to the one immediately to the west. The peak between (approximately) 5.6 and 5.9 North probably also reflects a buried Fawwarah granite cupola. These anomalies are the most significant observed in these studies and, as such, should be considered as the initial targets of any additional drilling of this prospect.

The well-defined E-field peak at 6.0 North corresponds with an exposed Silsilah comendite dike. No evidence of the dike that is exposed at 5.4 North in traverse 7.6 East is seen in this traverse, implying that it was faulted out of place.

Resistivities calculated from the induced-polarization traverse between 4.75 and 5.85 North are informative. The N=2 plot corresponds nicely with the TE data, whereas the deeper-looking N=4 data shows distinctly higher resistivities at the edges of the hypothesized cupola and lower resistivities in the core. This could be due to the presence of relatively unaltered pegmatite-aplite at the contacts and clay-altered Fawwarah granite beneath the zone of strong greisen in the center of the cupola. Since the equivalent depths of investigation at N=2 and N=4 are approximately 30 and 60 m, respectively, a lower limit of 60 m can be placed on the hypothesized zone of strong greisen.

8.2 East, 4.8-7.3 North

The E-field low at the southern end of this traverse (pl. 1) may correspond to an extension of a small, highly altered (weathered?) cupola of mixed Fawwarah granite and Hadhir aplite 200 m to the west. Likewise, the broad, low-amplitude E-field peak at about 5.1 North may correspond to a less-altered cupola of Fawwarah granite. The Silsilah comendite dike near 6.0 North shows up well in the TE profile.

The transition at about 6.0 North from the broad, more or less homegeneous mass of Murdama sandstone in the southern portion of the traverse to the broad, relatively unaltered mass of Fawwarah granite in the north is reflected quite well in the TE data. The less abrupt change in E-field amplitude at the northern boundary of the large Fawwarah granite mass, as compared to the southern boundary, may be due to a relatively shallower dip in the contact there. Parker and others (1984; pl. 1) show the southern contact of the large Fawwarah mass as a fault. Although the principal author of this study saw no evidence of this fault in trenches, its existence is consistent with the observed geophysical profiles.

While the broad pattern of resistivities derived from Induced-Polarization data is the same as the TE profiles, they are different in detail. A prominent low in the N=4 resistivity profile at 6.0 north may correspond to the hypothesized boundary fault at the southern end of the large Fawwarah granite mass. The absence of the peak seen in the N=2 profile and the TE profiles implies that the older Silsilah comendite dike may be faulted out of place at depth.

8.8 East, 4.9 - 5.65 North

The E-field profile along this short traverse shows a remarkable correlation with an unroofed greisenized cupola. The E-field amplitude rises sharply from the Murdama sandstone to the aplite-pegmatite contact zone and then decreases slightly in the more clay-altered core of the cupola. The amplitude rises again at the northern contact and sharply decreases upon entry into the Murdama sandstone. A subtle peak near the core of the cupola (near 5.2 North) probably reflects the small greisen zone visible in the trench.

The resistivity profiles also reflect the geology, but not as well as the TE profile. As seen in previously discussed traverses, the resistivity data seem compressed and would need to be stretched somewhat to fit the observed contacts more accurately. Again, these observed variations may be caused by the more complex pattern of response from dipole-dipole-derived data.

POTENTIAL FOR USE OF TELLURIC-ELECTRIC TECHNIQUES IN MINERAL EXPLORATION ELSEWHERE IN THE ARABIAN SHIELD

The telluric-electric technique, as demonstrated in this report, is not only informative about the nature and location of unexposed geological features, but also is fast and inexpensive. Such attributes clearly make this the geophysical method of choice during prospect evaluation when unexposed igneous masses, veins, and altered zones, such as exist at the Silsilah prospect, are being sought. In light of its utility, this method would have immediate practical application at a number of prospects in the northeast Arabian Shield. Some specific areas located in the Aban al Ahmar quadrangle (sheet 25F) -- immediately to the south of the quadrangle (26F) which contains the Silsilah tin prospect -- are discussed below.

Baid al Jiamalah West (MODS 2661), about 105 km south of Silsilah, is a sheeted, greisen-vein, wolframite deposit that outcrops in some low hills surrounded by extensive, but relatively thin, alluvium. Gravity data (Kamilli and others, 1987) indicate that the granite bodies that host much of the deposit are apophyses of a larger, buried pluton. It is possibile that other mineralized, but concealed, cupolas exist in the area. The country rock at Baid al Jimalah is Murdama sandstone, but in contrast to Silsilah, the granite cupola is surrounded by a hornfels aureole. This could make the resistivity contrast between the country rock and the intrusion less pronounced than at Silsilah. On the other hand, based on the presence of late clay alteration of the granite at Baid al Jimalah West, a geophysical traverse across a buried cupola might show a high amplitude E-field surrounding a lower amplitude center or core, similar to the TE profile shown in plate 1. Several test traverses across the exposed cupola at Baid al Jimalah West would establish a geoelectric model profile.

The Sukhaybarat gold prospect (MODS 405 and 406) straddles the boundary between quadrangles 25E and 25F. Disseminated and fracture-controlled native gold is associated with the apexes of small intrusions of intermediate composition (Kamilli and others, 1987). As at Baid al Jimalah West, the surrounding Murdama sandstone has been converted to hornfels, whereas the intrusions are altered to varying degrees. The area is flat and a thin veneer of alluvium may conceal other mineralized intrusions.

The Al Khaymah gold prospect (MODS 3941) contains five areas of ancient workings in quartz veins and lenses that cut volcaniclastic sedimentary rocks of the Jurdhawiyah group (Kamilli and others, 1987). No associated intrusion is exposed, but the presence of a small buried stock is suggested by aeromagnetic anomalies, diorite dikes, and weak recrystallization of the Jurdhawiyah group rocks near the ancient workings. Telluric-electric traverses could more accurately delineate the hypothesized stock and detect any altered zone that might contain disseminated-gold ore similar to the occurrence at Sukhaybarat.

Jabal Minyah (MODS 3945) is a tin prospect in the southeast corner of sheet 25F (Kamilli and others, 1987). The most promising area is to the north of an exposed, relatively barren, highly differentiated granite pluton, where aplite dikes contain 70 to 500 ppm Sn. These dikes may indicate the presence of another pluton at depth, but J. Cole (oral commun., 1986) has suggested that the dikes may be only offshoots of the pluton to the south. Some TE profiles over the area might be able to resolve this question.

SUMMARY AND CONCLUSIONS

1. The telluric-electric method for qualitatively measuring resistivities is a rapid, inexpensive, highly sensitive, and accurate way in which shallow, buried plutons, alteration zones, and other geological features may be located and evaluated on the scale of an individual prospect.

2. At the Silsilah prospect, the method can identify and differentiate among unroofed granite cupolas, cupolas with their aplite-pegmatite carapaces intact, strong (quartz-rich) greisen, weak (quartz-poor) greisen, dikes, faults, and pervasively clay-altered rock.

3. At least for the conditions existing in the present study, telluric-electric profiles are more accurate than the more expensive and time-consuming Induced Polarization method for obtaining resistivity data. It is realized that the primary Induced-Polarization data, however, can detect the presence of metallic minerals, such as sulfides.

4. Little difference was seen between the 27 Hz and 270 Hz TE profiles, suggesting that only one frequency may be needed in future studies.

5. Two anomalies revealed by this study probably represent buried cupolas that should be considered as primary targets for any additional drilling of the prospect. They are located at 7.8 East, 4.8 to 5.35 North, and 7.8 East, 5.6 to 5.9 North.

DATA STORAGE

DATA FILE

All original data used in the preparation and writing of this report, as well as some data that were not used, are stored in Data File USGS-DF-06-9 at the Jeddah office of the U. S. Geological Survey Mission. The contents of this file are listed below.

(1) Geophysical profiles
(2) Geological profiles
(3) X-ray diffraction data

The original trench maps and geological map used in this report may be found in USGS-DF-06-5.

MINERAL OCCURRENCE DOCUMENTATION SYSTEM (MODS)

Data on mineral occurrences recorded in this report have been entered or updated as follows:

MODS No.	Occurrence	Comments
3262	Jabal as Silsilah	Existing MODS file updated January, 1987

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