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PRELIMINARY RESULTS OF THE SABKHAH HAZAWZA GRAVITY PROJECT, WADI AS SIRHAN AREA, KINGDOM OF SAUDI ARABIA

by

Mark E. Gettings

U. S. Geological Survey
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The work on which this report is based was performed in accordance with a cooperative agreement between the U. S. Geological Survey and the Ministry of Petroleum and Mineral Resources, Kingdom of Saudi Arabia.

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PRELIMINARY RESULTS OF THE SABKHAH HAZAWZA GRAVITY PROJECT, WADI AS SIRHAN AREA, KINGDOM OF SAUDI ARABIA

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ABSTRACT

One hundred thirty seven new gravity stations at an average station density of one station per 17.5 km^2 have been established in a 40 x 60 km area centered on Sabkhah Hazawza in the northwestern part of the Kingdom of Saudi Arabia. A successful tie to existing Arabian American Oil Co. (ARAMCO) gravity data was made and a simple Bouguer gravity anomaly map was compiled during the survey. The map shows a distinct gravity low of about -8 mgal associated with the sabkhah, its minimum displaced to the northeast of the longitudinal axis of the sabkhah. However, the continuation of the gravity anomaly under the basalt field to the northeast suggests that the gravity anomaly is due to an older basin-like structure. If the sabkhah deposits are due to damming of ancient Wadi as Sirhan by basalt flows, then the deposits are probably thin. Preliminary estimates give a maximum thickness of about 270 m for the sedimentary fill causing the gravity anomaly.

INTRODUCTION

In order to facilitate the siting of proposed drill holes as much as 600 meters in depth in Sabkhah Hazawza in northwestern Saudi Arabia, a gravity survey of a 40 x 60 km area (fig. 1) centered on the sabkhah was conducted during the summer of 1977. The sabkhah is presently under investigation by a U.S. Geological Survey geologist to determine if evaporites and brine exist below the sabkhah and to give a preliminary estimate of their extent; accordingly, any information delineating the subsurface shape of the sabkhah will be useful, and a gravity survey was undertaken for this purpose.

This report presents the preliminary survey results; a final report will be prepared when photogrammetric station elevations and terrain corrections have been obtained and a more quantitative analysis completed.

This work was carried out in accordance with the work agreement between the Ministry of Petroleum and Mineral Resources and the U.S. Geological Survey (USGS). Thanks are due to D. J. Faulkender, USGS, for his efforts in surveying station locations during the fieldwork.

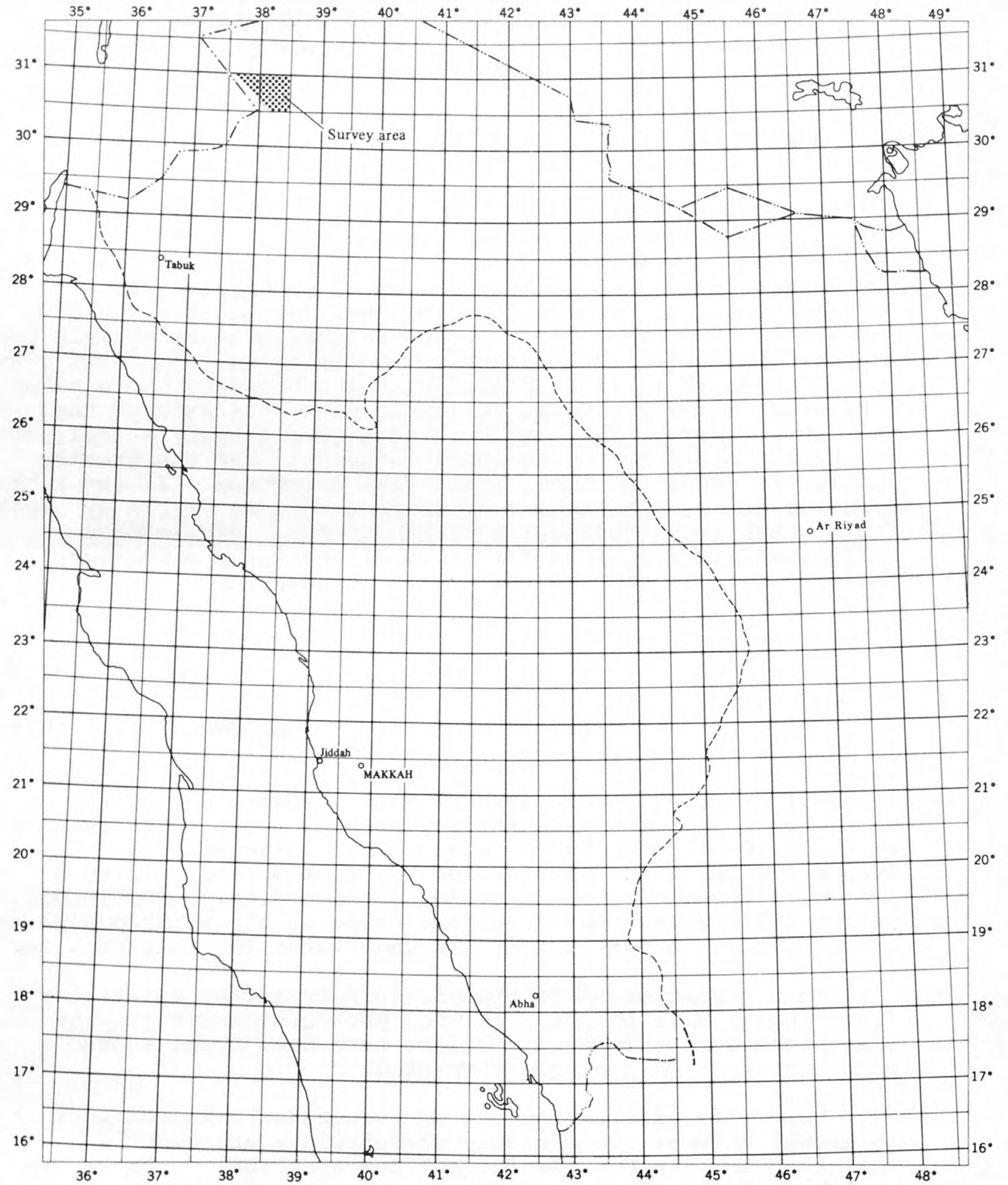

Figure 1. Map showing the location of the Sabkha Hazawa gravity survey.

GRAVITY DATA ACQUISITION AND REDUCTION

The gravity survey was carried out between 25 July and 2 August 1977 by M. E. Gettings (geophysicist) and D. J. Faulkender (surveyor). Stations were established using both a helicopter and a four-wheel-drive field vehicle for transport. In general, the sabkhah surface was too wet to support a wheeled vehicle and all stations on the sabkhah and in the volcanic field to the northeast were obtained by helicopter. In the afternoons, after the 6-hour maximum time for helicopter operation was exceeded, work was carried on by field vehicle in the southwest part of the survey area. Twenty-four hours of helicopter time were used in 4 days.

In all, 137 gravity stations were established at an average rate of 23 per day, 11 of which were at or near stations of the ARAMCO gravity surveys (Arabian American Oil Co., 1952). The survey area is approximately 60 km northwest-southeast by 40 km in the perpendicular direction, so that the average station density is one per 17.5 km^2 and the nominal spacing between stations is 4 km. Five traverses of the sabkhah (one longitudinal and four transverse) were made first and then remaining areas were filled in to produce a contourable distribution of stations.

LaCoste and Romberg gravimeter G-328 was used for all gravity measurements. The readings used in construction of the drift curve (fig. 2) are all the readings of station SH001,

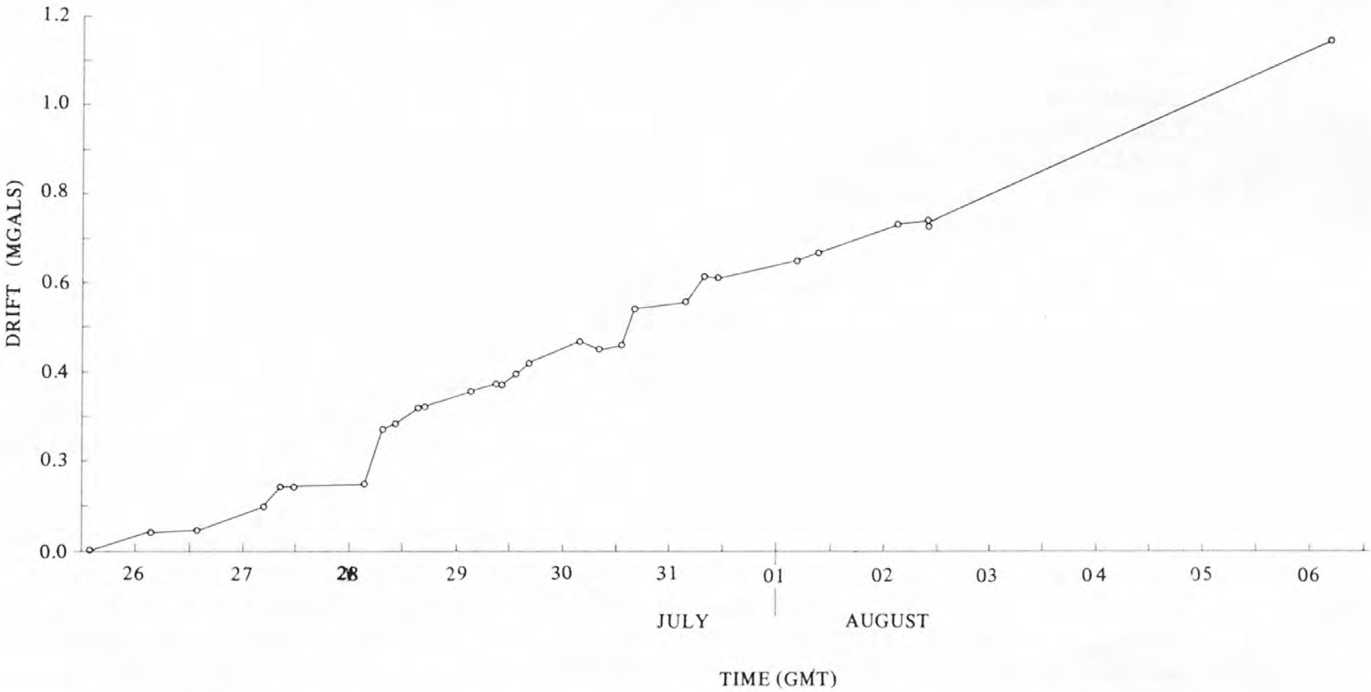

Figure 2. Drift curve for LaCoste and Romberg gravimeter G-328 for the period 25 July to 6 August 1977. Drift values have been corrected for earth tidal gravity variations and are relative to U.S. Geological Survey Jiddah gravity base at 1342 GMT, 25 July 1977.

used as a base station, and have been corrected for earth tidal variations according to the formulae of Longman (1959). The portions of the drift curve with the steepest slope correlate with periods of helicopter operation. Increased drift rates are due to the sensitivity of the gravimeter to vibrations in the 30-70 Hz range (Hamilton and Brule, 1967) and are common in helicopter operations. Total drift during the survey period was about 0.74 ± 0.02 mgal, so the maximum uncertainty in the observed gravity after drift and earth tidal corrections of any station is ± 0.74 mgal. The drift curve, however, shows the classical shape for a LaCoste and Romberg meter (Hamilton and Brule, 1967) and the uncertainty in the observed gravities is more likely about ± 0.05 mgal.

Gravity station SH001, the base station for the survey, is tied to Jiddah International Airport base station via two ties using Ministry aircraft for transportation, each of 6 hour duration, with an estimated uncertainty of ± 0.04 mgal. The probable error for all absolute gravities in the survey is then about ± 0.05 mgal.

Horizontal control was acquired by using the three-point method with an alidade and by pin-pricked locations on 1:60,000-scale aerial photographs ("9 x 9's") or the photo index wherever possible. Complete 9 x 9 photographic coverage was not available. Station elevations will eventually be obtained photogrammetrically by leveling the stereo-photographic models to the 1:100,000-scale topographic sheets NH-37-I1 and NH-37-H2, edition 3-AMS, used as bases. Thus, although absolute elevations may be incorrect because of an unknown datum shift, relative differences will be correct and therefore adequate for the reduction of gravity data. Relative uncertainties in horizontal location are about 100 m for three-point locations and 50 m for photographic locations. Relative elevation uncertainties from photogrammetric elevations are about ± 1.5 m.

Although the elevation factor used in reduction of the ARAMCO Wadi as Sirhan gravity map B-1575-G (Arabian American Oil Co., 1952) is not given on the map, it was deduced by comparison with stations of the present survey at or near ARAMCO stations. The resulting value is 0.210 mgal/m for the elevation factor, which implies that a Bouguer reduction density of 2.4 gm/cm^3 was probably used by ARAMCO. Simple Bouguer gravity anomaly values given on the ARAMCO map were recalculated using 2.67 gm/cm^3 for the reduction density, and a datum shift of about +0.6 mgal for ARAMCO relative to the present survey resulted for all stations in ARAMCO line R. ARAMCO stations in line G show erratic behavior compared to the present survey after recalculation to 2.67 gm/cm^3 reduction density. By applying an arbitrary correction of +2.0 mgals to the ARAMCO stations of line G, all stations but one were made to fit satisfactorily in areas of overlap. After recalculation to

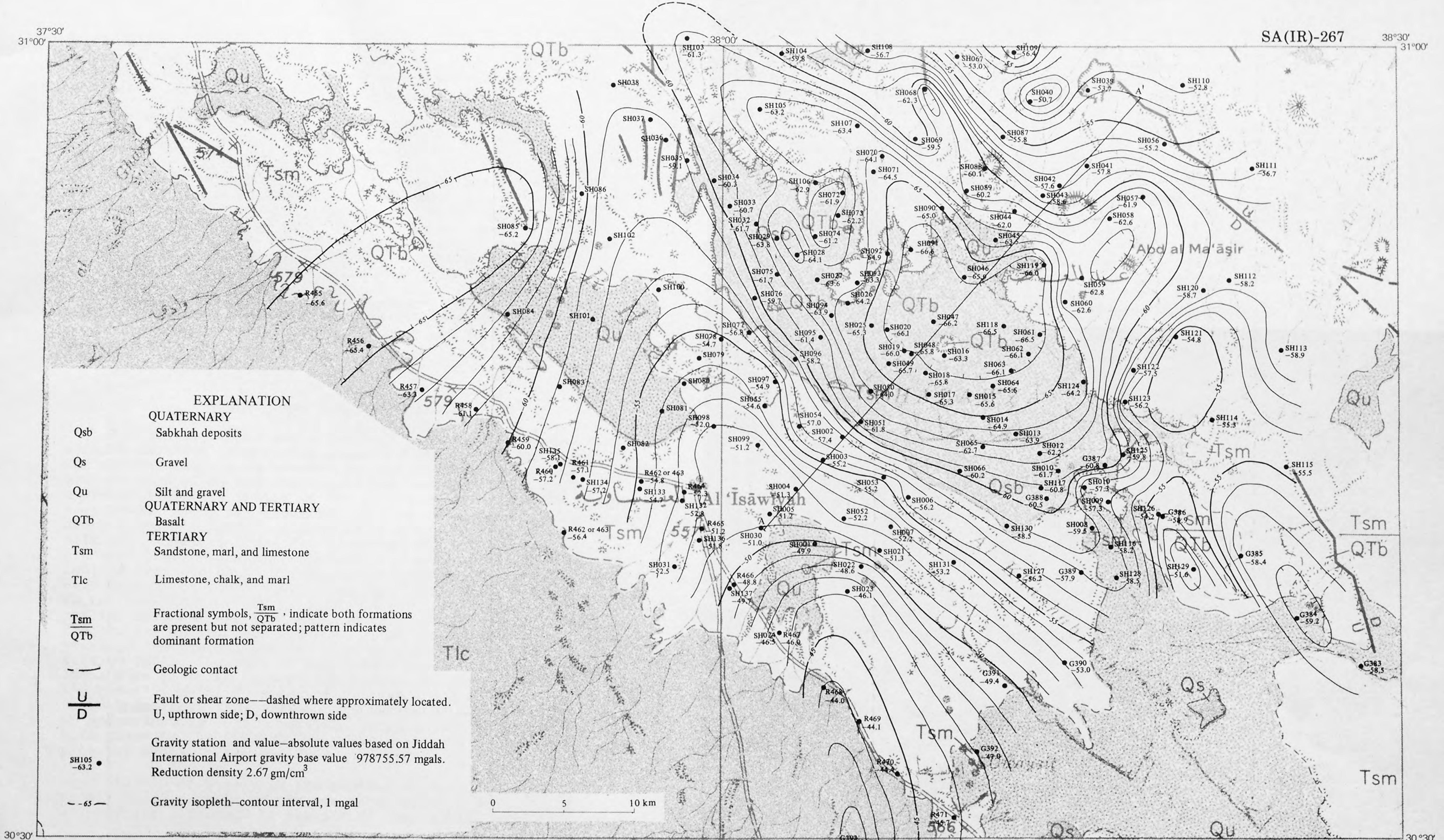

Figure 3. Simple Bouguer gravity anomaly map of the Sabkha Hazawza area.

Field work by M.E. Gettings and D.J. Faulkender, July 1977

2.67 gm/cm^3 and subtraction of 0.6 mgal from the line R stations and 2.0 mgal from the line G stations, the ARAMCO data were then used in the survey area to extend the coverage and define better the regional gravity field.

In the evenings, during the course of the fieldwork, a simple Bouguer gravity map was constructed using standard formulae, map elevations, and a density of 2.67 gm/cm^3 for the data reduction. This map, which has a contour interval of 1.0 mgal, enabled planning the next day's work so as to establish stations in the best locations for definition of the gravity field. The Bouguer gravity anomaly values in the field map have been corrected for gravimeter drift but not for earth tidal or terrain effects, and certainly some elevations used in the data reduction are incorrect; furthermore, several stations for which no elevations are available are omitted. Nevertheless, the map presented here (fig. 3) shows a well defined negative gravity anomaly of about -8 mgals associated with the sabkhah. Although the final gravity map will differ in detail when the above corrections are made, its overall features will be the same.

PRELIMINARY INTERPRETATION

The gravity map shows a distinct low associated with the sabkhah embedded in a rather complex regional gravity field. The sabkhah anomaly is bounded by the nose of a ridge-like gravity high along the southwest side and by northeasterly-increasing gravity values in the basalt fields along the north-east side. Along the southwest edge of the sabkhah, a distinct steep gravity gradient is associated with the edge of the sabkhah. However, along the northeast edge, the corresponding gradient lies well within the basalt field, which relationship implies that the basin structure reflected in the gravity field extends beneath the basalt. Further, the gravity minimum occurs to the northeast of the axis of the sabkhah itself. Whether or not the sabkhah materials and the implied basin fill outlined by the gravity anomaly are the same (that is, whether the sabkhah predates the basalt) has not been determined. At gravity station SH055, the base of the basalt lies on material that looks much like the present day sabkhah surface. The base of the basalt flow at this locality is about 10 m above the present sabkhah surface. Small-scale, northwest-trending normal faults of approximately 5-15 m vertical displacement in the basalt on both sides of the sabkhah are visible in aerial photographs and probably explain this uplift.

Islands of basalt in the sabkhah distant from the main basalt field contain no obvious vent-facies materials. These islands are difficult to explain if the sabkhah predates the basalt. It seems more likely that the gravity anomaly delineates some sort of basin- or trough-like structure that is associated with Wadi as Sirhan and that predates the basalt. Damming of the wadi by basalt flows resulted in formation of the present sabkhah. Subsequent deposition in the sabkhah and faulting along the edges have resulted in the above noted features. If the suggested sequence is correct, then the sabkhah deposits are probably thin, of the order of a few tens of meters. The possibility of the sabkhah predating the basalt is not entirely ruled out, however, and to obtain an estimate of maximum thickness for the sabkhah deposits, the entire anomaly was attributed to the sabkhah. Figure 4 displays a northeast-trending profile across the center of the gravity anomaly, the assumed regional gravity field, and the resulting residual anomaly, assumed to be due to the sabkhah.

The simplest thickness estimate is to treat the sabkhah as an infinite horizontal sheet whose gravity effect is the maximum gravity anomaly given by the residual anomaly curve of figure 4. Such treatment yields a thickness of 266 m for the sheet, if it is assumed that the sedimentary fill is less dense than the host rock by 0.7 gm/cm^3.

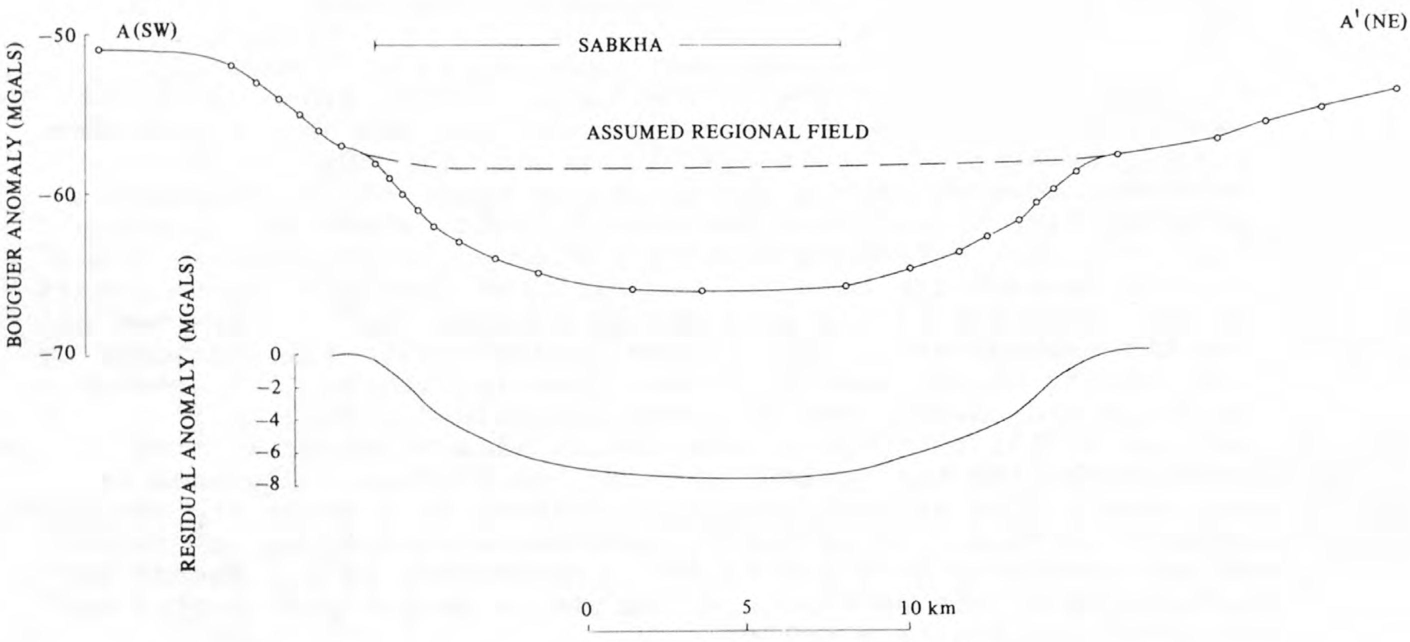

Figure 4. Profile across Sabkha Hazawza (A–A' of figure 3) showing the assumed regional gravity field and the resulting residual gravity anomaly profile. Under assumptions explained in the text, the residual anomaly profile gives a thickness estimate of about 270 m for the causative body.

The slope of the bottom of the fill at the edges may be crudely estimated by analysis of the gravity gradient defined by the residual gravity field along the southwest side of the sabkhah. If one assumes this gradient is due to half of an inverted, two dimensional, horizontal isosceles triangular prism (Grant and West, 1965, p. 290) with a density contrast of -0.7 gm/cm^3, a slope of 7° down from horizontal is estimated.

As a final depth estimate, a simple three dimensional model was calculated. It was assumed that the gravity anomaly was due to a frustum of an inverted circular cone with a basal diameter of 22 km, an apical angle of 83° (edges dipping inward at 7°), and a density contrast of -0.7 gm/cm^3. The expression for the maximum gravity effect of a frustum of an inverted circular cone (Duska, 1958) is not easily solved explicitly for the thickness of the frustum. The thickness can be found, however, by treating it as the independent variable and using a root-finding algorithm, such as the secant method, to solve the equation for a particular set of parameters. This procedure was carried out on a programmable calculator and yielded a thickness estimate of 272 m. The maximum predicted depth under the assumed conditions is thus about 270 m.

SUMMARY

One hundred thirty seven new gravity stations were established at an average station density of one station per 17.5 km^2 during a gravity survey of the Sabkhah Hazawza area. During the course of the survey a successful tie to pre-existing gravity data of ARAMCO was completed that allowed the use of the ARAMCO data to help define the regional gravity field. A simple Bouguer gravity map was prepared in the field as survey work progressed; this procedure proved very useful in insuring adequate station coverage.

The resulting Bouguer gravity anomaly map shows a gravity minimum of about -8 mgals, which correlates well with the sabkhah along the southwest edge but extends beneath the basalt fields to the northeast. The minimum of the gravity anomaly is displaced to the northeast from the axis of the sabkhah and presumably represents the area of deepest fill. The fact that the gravity anomaly extends beneath the basalt implies that the basin structure represented by the gravity anomaly predates the basalt. A likely hypothesis is that the gravity anomaly reflects the structure of ancient Wadi as Sirhan and that the sabkhah deposits have formed only since the wadi was dammed by basalt flows. If this is so, the sabkhah deposits are likely to be thin. Conversely, if the entire gravity anomaly is attributed to the sabkhah deposits, a maximum thickness estimate of about 270 m is obtained.

In a subsequent report, the gravity data, together with the drilling results, will be used to make improved depth estimates, construct a three dimensional prismatic model of the basin, and estimate the basin volume by integration of the residual gravity anomaly field.

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