Journal of Geology & Geosciences
ISSN: 2381-8719
Sultan and Ahmed, J Geol Geosci 2014, 3:6
DOI: 10.4172/2329-6755.1000182

Research Article Open Access

Composite Geophysical Study Comprising Gravity, Magnetic, and Resistivity Surveys to Delineate Basement Salt Deposits Near Jabbar Nala East of Kherwa Gorge, Pakistan

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Abstract

A composite geophysical survey has been carried out comprising gravity, magnetic, and resistivity surveys for delineation of salt deposits, thickness of overburden and basement depth over an area of 631 acres near Jabbar Nala east of Khewra Gorge, Sodi, Pakistan. The survey is carried out on the girded pattern of 100 x 100 meters; however, some variability in coverage tends to exist due to the existence of high hills topography. Present research revealed that salt deposits exist within the depth of 75~100 meters at specific locations in the extreme northeast and northwest. Most of the anomalous zones fall in this area is analogous when these three surveys are explored and comprehensive analysis performed. Existing excavated area of salt mine also exists in the northeast where the strong Bouguer gravity, magnetic, and resistivity anomalies have been superimposed, however, anomalous zone extents further in the northeast. Gravity, magnetic, modeling has been carried out along the anomalous zones comprising cross-sections of AA', BB' and CC'. However, for further confirmation of the results, a test bore of 90~120 meters depth needs to be drilled at the recommended anomalous zones (Zone B and Zone C).

Keywords: Gravity; Topography; Mountains; Electrical resistivity

Introduction

Importance of salt

In light of various substance and physical lands of salt make conceivable 14,000 known employments. From the Stone Age, people have revealed brilliant intends to utilize salt to improve the personal satisfaction. So significant is this regular mineral that wars have been pursued and insurgencies battled for access to salt. Biggest utilization is undetectable to general society: in the ballpark of 40% of salt is utilized as the crude material that substance organizations change into chlorine and pop fiery remains, the establishments of inorganic science. Salt is a transforming help in endless commercial ventures and the methods by which creature sustenance masters guarantee the health and profit of animals and poultry. We less frequently think about the salt we use to recover our water conditioners to secure the funnels and machines in our homes. What's more occasionally, the salt is utilized within request to keep our autos, trucks and school transports securely on blanketed winter ways.

Himalayan Salt is one of the healthiest and purest regular salts accessible. The salt shaped 250 million years back when the sun went away the definitive ancient sea. The point when the old ocean close to the Himalayas went away from the sun s heat, the Himalaya mountain run started to ascent. The layers of salt that were stored settled profound into the ground. For a large number of years, the layers of gathered salt experienced a gigantic measure of weight and temperatures bringing about the establishment of unadulterated and uncontaminated gem salt Ahmad [1]. The salt is mined, from the foothills of the Himalayas, Pakistan. It is hand unearthed, washed and dried.

Objective of survey

The main objective of the Survey includes:

1. Estimation of the anomalous zones with gravity survey for the identification of suitable salt deposits for the launching of solution mining.
2. Estimation of the anomalous zones with magnetic survey for the identification of suitable salt deposits for the launching of solution mining.
3. Estimation of the anomalous zones with Electrical resistivity survey for the suitable salt deposits for the launching of solution mining.
4. Form the basis from these composite geophysical studies to arrive at the effective results:

a. To obtain total effective depth for test drilling at specific location.

b. To assess the quality and quantity of salt deposits lying over crystalline basement rock

c. Possible launching of solution mining of salt deposits over the large thicknesses of deposits lying over basement rock.

Methodology and Study Flow Model

Survey planning

For the planning of gravity, magnetic ERS/ERSS survey in the project area all sorts of geological and geomorphological information were collected. Since the area was rugged with topography highs and hillocks, therefore, the profile survey in irregular grid pattern was chosen (Figure 1). Before starting the survey some initial steps were taken to know the preliminary factors involved. This study was carried out on the gridded pattern of 100×100 meters; however, some variability in coverage tends to exist due to the existence of high hills topography. Present study revealed that salt deposits exist within the depth of 75~100 meters at specific locations in the extreme northeast and

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Received August 18, 2014; **Accepted** October 10, 2014; **Published** October 13, 2014

Citation: Sultan M, Ahmed KA (2014) Composite Geophysical Study Comprising Gravity, Magnetic, and Resistivity Surveys to Delineate Basement Salt Deposits Near Jabbar Nala East of Kherwa Gorge, Pakistan. J Geol Geosci 3: 182. doi:10.4172/2329-6755.1000182

northwest. Most of the anomalous zones fall in this area is analogous when these three surveys were compared and results were matched. Existing excavated area of salt mine also exists in the northeast where the strong Bouguer gravity, magnetic, and resistivity anomalies have been superimposed, however, anomalous zone extents further in the northeast. Modeling has been carried out along the anomalous zones comprising cross-sections of AA', BB' and CC'.

Selection and location of base station

Base station lies outside the surveyed area situated about 10 meters of the jeepable road. Its position was such that it could be repeated in the beginning and end of the daily coverage. The following maps shown in Figure 2 indicate the location of the study area, and layout of the gravity and magnetic observation stations. Height above mean sea level (meters) within the investigated area of geophysical study is shown in Figure 2.

Geology and structure of salt range formation

Beginning in the foothills of the Himalayas in northeastern Pakistan, the Salt Range Mountains run around the range of 150 miles in a west heading, parallel to the Jhelum River until it joins the Indus Asrarullah [2]. The Salt Range Mountains then grow some separation past the Indus. The southern edge of the eastern Salt Range Mountains drops steeply a few thousand feet to the Jhelum River plain. In this ledge and different areas, the Salt Range Mountains uncover an arrangement of creations going from the most punctual Pre-Cambrian to the latest land periods. At the lowest part of the arrangement, underneath the Cambrian Purple Sandstone, lies the Salt Range Formation, made out of thick layers of clayey material (the Salt Marl) in which are discovered layers of rock salt, gypsum, shale, and dolomite. Wynne [3] named and depicted the shaping as 'Saline arrangement'. Gee called the same unit as the 'Punjab saline arrangement' [4,5]. The present name, the Salt Range Formation, has been given by Gee [4] after the salt range.

Geology of the Al-Fajr salt mine area

With its coordinates: Lat. 32° 39' 06" N; Long. 73° 03' 59" E to Lat. 32° 40' 04" N; Long. 73° 08' 50" E, Alfajr Salt mine is located in the eastern part of the Salt Range (Figure 3). It lies on the northern part of the Jabbar Nala. Ptoterozoic, Paleozoic and Cainozoic rocks are exposed in this area. Salt Mine has been designated as type section of the Salt Range Formation.

Asrarullah [2] made a detailed study of the Salt Range Formation and divided the formation into three members based on lithology:

1.Sahwal Marl Member:

Bright red marl beds with irregularly spread gypsum, dolomite beds and Khewra Trap lithology (3-100 m thick).

Dull red marl beds with some salt 10 m thick gypsum bed on top (greater then 10 m).

2.Bhandar Kas Gypsum Member:

Massive gypsum with minor layers of dolomite and clay (greater then 80 m).

3.Billianwali Salt Member:

Ironic red marl with thick of salt (more then 650 m).

All the above mentioned members of the Salt Range Formation except Billianwali Member are present in the project area but not laterally traceable.

Structurally, the project area of the Al-Fajr Salt Mine is situated, at the southern boundary of the complex and represents elongated salt dome, which is asymmetrical in nature (Figure 4). The parallel degree of the arch is restricted, and hence the vault edges delimit the region advantageous for salt result mining. Most likely the Dome salt has streamed upward to the surface and has been broken down where it is in contact with crisp water. Centralization of the polluting influences in salt produces top shake at the top and sides of the vault. Top rock has low penetrability and armour the arch against disintegration.

Gravity survey

The variation in gravity is independent of the absolute densities of the rocks. It is only dependent on the density contrast between the ore body and the surrounding lithologies. The standard method of measuring the force of the earth's gravitational field is to measure

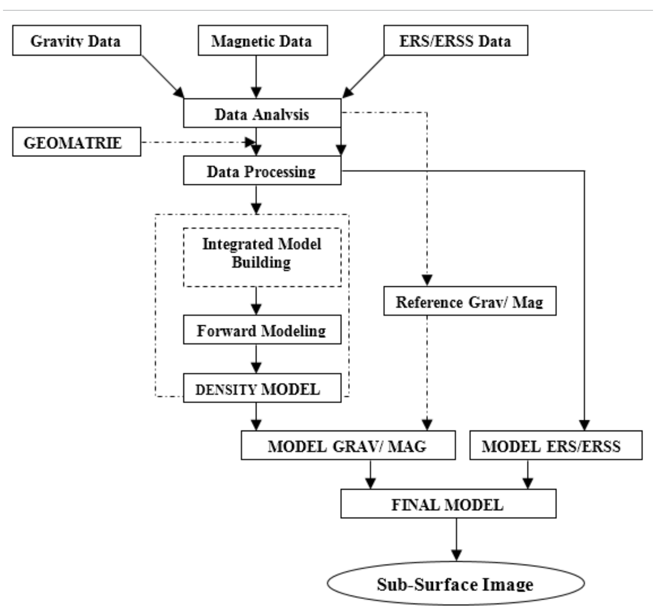

Figure 1: Flow model of study.

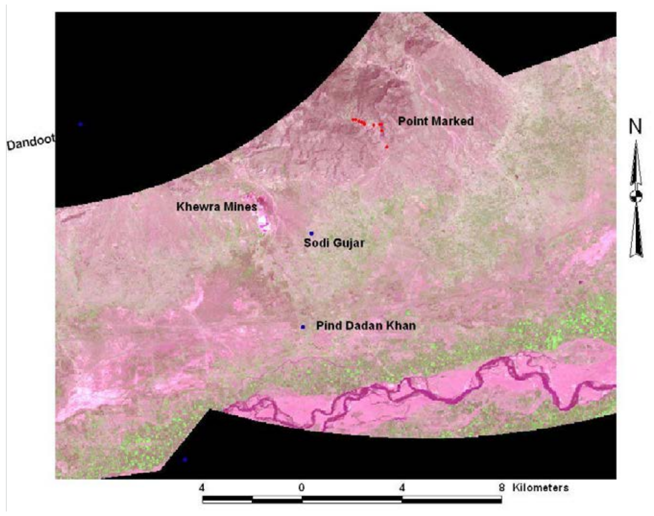

Figure 2: Landsat location map of the study area.

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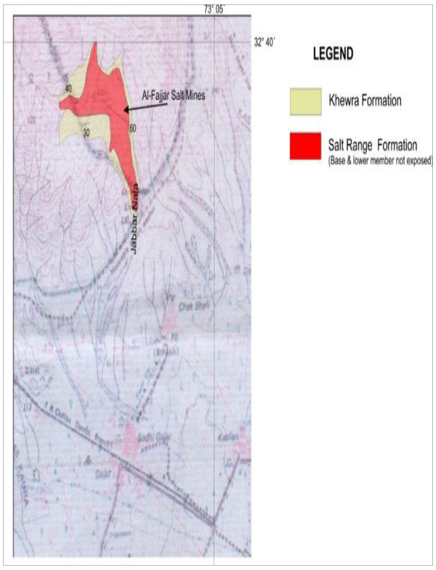

Figure 3: Location map of the Salt Range area.

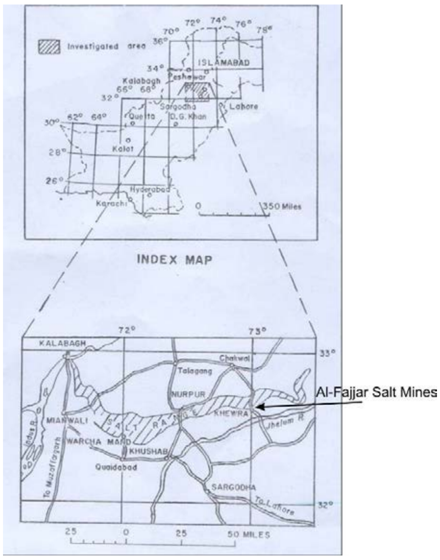

Figure 4: Geological map of the Al-Fajar Salt Mines area.(Scale=1:50,000).

the acceleration due to gravity, which was defined by Isaac Newton: $g=(G)(m1)/r^2$ (where g is the acceleration due to gravity), and $F=(m^2)(g)$. The gravitational force, or gravity field, can be calculated at any specific location on the earth using the same principle. The value of the gravity field (acceleration) is directly related to the mass (density) of the earth beneath the station where the measurement is made. A gravimeter measures the acceleration by sensing the pull by the earth's gravitational field on a mass suspended from a very sensitive spring. Gravity surveys use the "milligal" or "mgal" (=0.0001 gal.) as the standard unit of measure (named after Galileo). The acceleration for one "gal" is equal to 1 cm per second per second.

The gravimeter measures very tiny increases in acceleration, which suggest the presence dense rocks or minerals. Anomalous gravity highs may indicate where basement rocks are closer to the surface, or where fold structures is located in the subsurface.

Density and specific gravity

It is useful to develop a system of comparing densities of different minerals or rocks. This is done by measuring the "specific gravity", which is essentially a comparison of the density of the substance to an equal volume of water. Salt specific gravity is 2.1-2.4. The density contrast of 0.55~0.6 gm/cm^3 has been used for Bouguer correction.

Setting the measuring options of Cg-5 autograv

CG-5 Autograv (Scintrix, Canada) was used for gravity measurements in the area. CG-5 Autograv has better advantage over other gravimeters as it is capable to apply drift correction with respect to the time and elastic expansion in its internal components due to heat index and temperature. Free air correction can also be applied automatically as CG-5 Autograv measures the elliptical ground elevation with its built-in Garmin global positioning system (GPS). The instrument showed a steady and regular drift. The drift rate was generally of the order of 0.001 to 0.002 mgal per minute during the coverage. At this stage it was expected that the gravity meter would show the same behavior during the fieldwork.

Error evaluation and accuracy of gravity data

The gravity maps prepared from the gravity data also depend upon the accuracy of the observed data. Minute errors in the gravity observations may lead to larger errors in the geological interpretation of gravity anomalies. Thus it was important to know about the accuracy of the survey in advance. The accuracy of the gravity data was established from the errors involved in different phases of observations, computation and reduction of gravity survey. Thus the following errors were taken into account for calculating accuracy of the data.

a)Observational error.

b)Inaccurate heights.

c)Inaccurate position.

d)Inaccurate density.

Magnetic survey

Magnetic Strength of a mineral or rock is based on two things (a) the amount of iron or cobalt (b) the amount of alignment which take place. Every mineral has at least some very minor amount of magnetic susceptibility. The degree to which a substance can be magnetized is determined by its magnetic susceptibility. It is the fundamental parameter in magnetic prospecting since the response of rocks and minerals depend on the amount of magnetic minerals present in them. Ahmed [1] has given the susceptibilities of magnetic minerals from core samples of different areas. These analyses show that generally salt is the main deposit present at different depth and quantity. The susceptibility of salt in massive/disseminated form generally varies from 1×10^{-4} to 1.75×10^{-4} nano Tesla (nT).

Electrical resistivity sounding survey (erss)

The electrical resistivity sounding surveys were carried out at eight locations distributed randomly within the leased area (Figure 4). This survey was carried out to firm up and authenticate the results obtained from the gravity and magnetic studies.

The main objective of the ERSS study was to evaluate the resistivity low area over the salt deposits in the undulating crystalline basement rock, which may be associated with the presence of salt deposits at deeper horizon. Overall the resistivity low pertaining to 8 to 12 ohm meter could be associated with the presence of salt deposits.

Electrical resistivity survey

Electrical methods are generally referred to as “resistivity surveys”. Metallic minerals are relatively good conductors of electricity. In contrast, common rock forming minerals are generally poor conductors. The electrical properties of rocks can be measured at much greater.

Rocks containing abundant pore waters are also excellent conductors, in fact without these pore waters, resistivity methods would not be possible. In general, the abundance and chemical composition of pore waters have a greater influence on conductivity than do metallic mineral grains. For example, pore waters containing salts (sodium chloride) are the best conductors of all.

Electrical Resistivity Survey is a practical application of Ohm’s law i.e. R=K x (□V/l) to study the subsurface hydrological set up of the earth. The objective of electrical resistivity survey is to map the subsurface changes in earth resistivity and correlate them with the hidden geological formations. The resistivity of any formation is mainly dependent on two factors, viz. the porosity of the formation and the salinity of the solution held in the pores. In water bearing formations the current is carried, entirely, by the dissociated ions of the salt held in solution. Thus the resistivity of the formation is not characteristic of the formation itself and any one formation may have a wide range of overlapping values, depending upon its nature and the quality of water, which is influenced by such factors as porosity and the amount of salts, held in solution. Bearing in mind these factors, it is possible to classify the resistivity of the formation in terms of its textural and lithological character. For example, a particular formation with constant porosity will have different resistivity values depending on (a) its moisture, and (b) its salt content.

Data Acquisition

For gravity, magnetic and ERSS/ERS data acquisition we adopted the procedure as flow

Field procedure

Since the area was flat in the middle with some rugged features therefore, it was accessible on foot only. A grid pattern with a grid interval of 100x100 meters was used for data acquisition. In all 166 stations were established in the area but at places the similar grid spacing could not be maintained due to hills and rugged topography. Gravity, magnetic, ERSS/ERS Base station was established close to the area that was accessible in the start and end of the survey. This gravity base was then connected and values referred to gravity base station at Jhelum Wynne [5].

Gravity survey

Measurements were made on the grid nodes where gravity observations were made (Figures 5 and 6). A Proton Precession Magnetometer Model G-856 Memory-Mag of the Geometrics, was used for the data collection. Its accuracy is of the order of 1 gamma. Two types of variations affect the magnetometer readings. First is the diurnal variation, which is caused by solar radiations, and the second is due to variation in the magnetic field over poles and magnetic equator called the normal variation.

Magnetic survey

As the area was small, the normal correction was not applied. The diurnal variation was taken care of and the data was corrected. The calculated total magnetic anomaly is presented in map shape in processed Data

Electrical Resistivity Sounding Survey (ERSS)

The electrical resistivity sounding survey (ERSS) is numbered as ERSS-1, ERSS-2, ERSS-3, and so on. Table 1 is provided that gives information of the location of sites with corresponding latitude and longitude, which is shown in Figure 5. These geographical locations are evaluated using global positioning system with reference to the Allai Khwar Indian base station, geodetic data, and satellite tracking

The Schlumberger electrode configuration was employed extending the electrodes separation to a maximum distance of 240 meters for all the electrical resistivity survey. This has enabled to obtain subsurface soil and geological conditions condition in terms of resistivity lows and highs values.

Electrical resistivity survey

Syscal Junior resistivity meter (France), a highly sensitive and wide measuring range instrument was used for the purpose of data acquisition. Although there are number of electrode configurations used to lay out the electrodes, Schlumberger configuration is the best when used for probing deeper into the ground. Four electrodes were used in the Schlumberger configuration. The current was passed to the ground through two outer electrodes A & B while two inner electrodes M & N were used to measure the potential drop at different points.

The distance between the current electrodes was always kept greater than equal to 5 times the distance between the potential electrodes. The distance of current electrodes was gradually increased to the maximum of 240 meters from the center point while the position of MN was only changed when required.

At each position of A & B the resistance R (Ohm Law) was calculated by dividing the potential drop with the current supplied. The geometric constant K that is evaluated from current electrode spacing AB/2 is then multiplied it. At each position a new geometric constant is calculated to get the apparent resistivity of the subsurface material.

Resistivity sites	Latitude	Longitude
ERS1	32° 39'49' N	73° 03'06' E
ERS2	32° 39'48' N	73° 02'54' E
ERS3	32° 39'46' N	73° 03'02' E
ERS4	32° 39'43' N	73° 03'12' E
ERS5	32° 39'41' N	73° 03'10' E
ERS6	32° 39'39' N	73° 03'20' E
ERS7	32° 39'31' N	73° 03'37' E
ERS8	32° 39'32' N	73° 03'34' E

Table 1: Locations of ERSS Sites And their Latitude/ Longitude, Al Fajir salt mine.

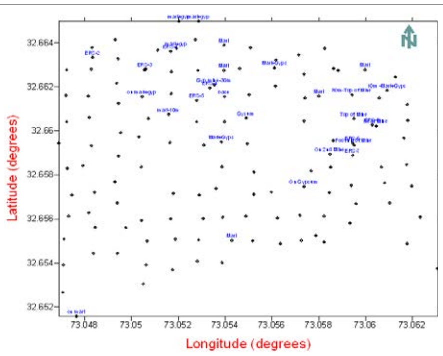

Figure 5: Location map showing the Gravity-Magnetic-Resistivity Stations.

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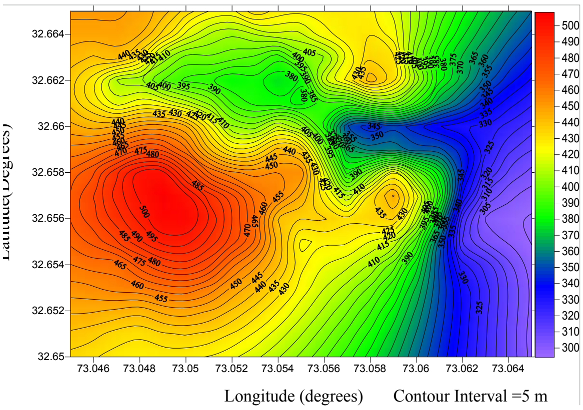

Figure 6: Height above mean sea level (meters).

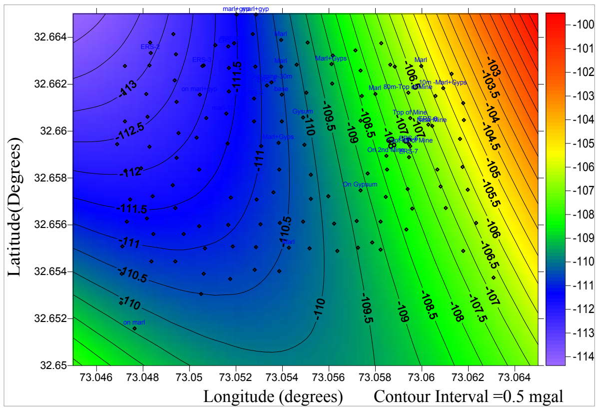

Figure 8: Regional Gravity anomaly map.

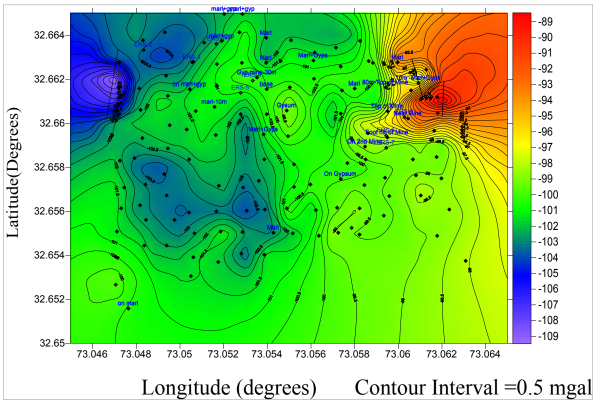

Figure 7: Bouguer Gravity anomaly map.

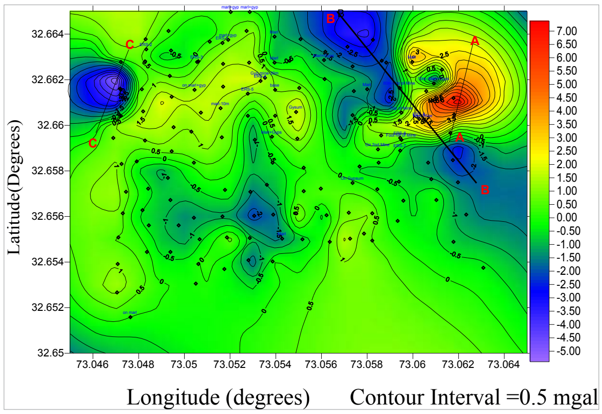

Figure 9: Residual Gravity anomaly map.

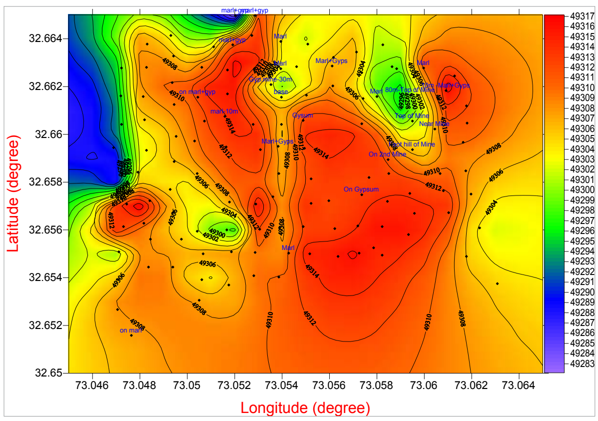

Figure 10: Total Intensity Magnetic anomaly map.

Data processing

The field data contains noise due to instrumental drift, latitude, free air, bouguer and terrain effects. These were removed by applying corrections for the respective errors. After applying the necessary corrections on the raw gravity data, the final corrected gravity was obtained and then used to calculate the Bouguer anomaly and presented in the shape of a Bouguer Anomaly Map (Figure 7).

Regional-residual separation

In this work regional and residual anomalies were separated by Polynomial fitting technique. The resulting data is presented in the shape of Regional Gravity Anomaly Map and Residual Gravity Anomaly Map (Figures 8 and 9), while regional magnetic anomaly map and residual magnetic anomaly map are shown in Figures 10-13.

Results and Conclusions

Data interpretation

Three dimension surface maps of residual gravity and residual magnetic anomaly: Three dimensional surface maps of residual gravity and residual magnetic are shown in Figures 14 and 15. It is interesting to note that anomalous zones AA', BB' and CC' for both the gravity and magnetic maps are compatible and conform to the same location, orientation and shape. As gravity lows over the anomalous bodies (also marked by vertical lines at places) existence of salt dome is delineated. Similarly, in three dimension surface of magnetic map (Figure 15), magnetic lows represent the anomalous zones where the existence of probable salt dome has been identified.

Salt domes: Figures 14 and 15 show the three dimensional projection of the surface based on the residual gravity and residual magnetic maps mapped over a topographic mound of the area of Al Fajr salt mine. The origin of the topographic feature was not established until the gravity survey indicated a large closed minimum coincident with the contours of the elevated mound that could be accounted for only by assuming a piercement-type salt dome (Figure 16). The survey was

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not extensive enough to define the gravity closure on all sides, but judicious extrapolation indicated the maximum negative anomaly to be about 5 mGals. Figures 17 and 18 along profiles BB' and CC' show interpretation of the salt structure giving rise to the anomaly. This is not strictly a "known" source for the anomaly, but the near-surface geology of the area is well established from extensive salt mining operation up to 45 meters depth excavated to level 3 that no identification for such a gravity feature other than a salt dome would be geologically plausible. Because the top of the dome is so shallow, it is probable that the uppermost part of the salt (crosshatched in the figure) has a higher density than that of the surrounding sediments at the same level and hence gives rise to a positive anomaly above the center of the dome. This feature is referred to as the salt dome.

Figures 9 and 12 represent the residual gravity and residual magnetic maps that have been derived after subtracting the regional anomaly maps from the bouguer anomaly map and total intensity magnetic maps. Interpretations are made in a better way on these residual anomaly maps.

Polynomial fitting: In this study a polynomial of 7th order has been applied to have the better correlation as shown in Figure 11, the regional magnetic anomaly map with 7th order polynomial surface. The resemblance of the polynomial surface and the total intensity magnetic / Bouguer maps increase with the order of the polynomial.

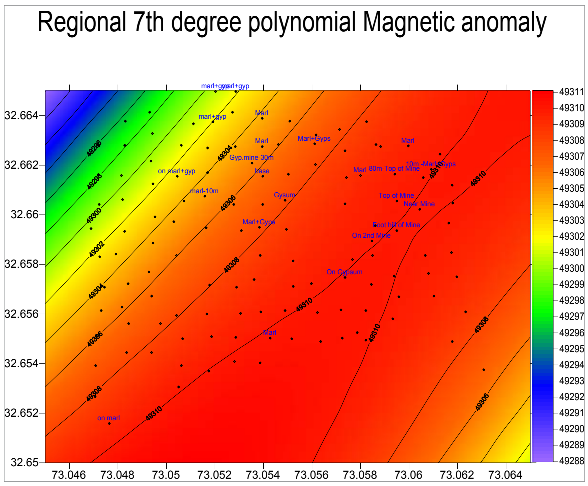

Figure 11: Regional Total Intensity Magnetic anomaly map.

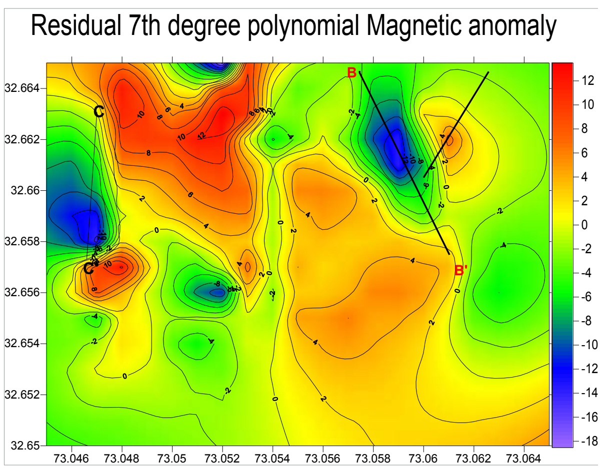

Figure 12: Residual Magnetic anomaly map.

Ers/erss interpretation: Raw resistivity data collected from sites were entered in the computer and interpretation done by computer modeling using 1D1X 3-D software and results are rechecked manually. The lithologies with their respective thicknesses for the subsurface layers are shown in Annexure 1. The interpretative results of the electrical resistivity measurements obtained from modeling are shown in Annexure 2.

Field data is interpreted by using the software packages that gives the model interpretation of individual curves stating/reflecting the number of layers, their true resistivity values, thickness and depth from the surface. These true resistivity values are interpreted /converted into lithologic units by adjusting these values in different resistivity zones indicating the presence of salt deposits and host rocks composed of marl, gypsum and dolomite.

Apparent resistivity values are not true representation of the subsurface lithology until they are matched with the theoretical master curves manually or with the computer modeling. Resistivity data was interpreted manually and also by using the Computer Softwares on a microcomputer. Results were compared and adjusted, wherever needed, through an iterative procedure that finally provided a layer model based on true resistivity values. These subsurface layers have been assigned lithological units in terms of their true resistivity values, as shown in Annexure 2.

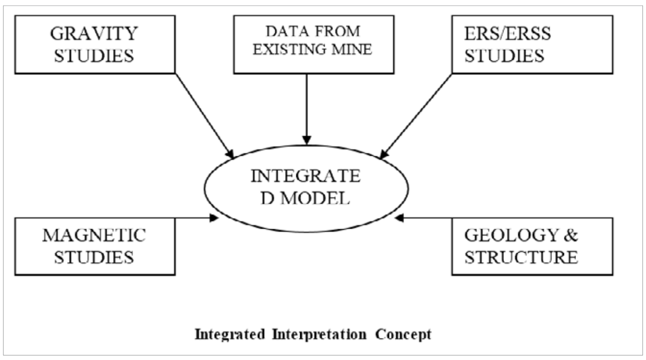

Figure 13: Integrated modeling.

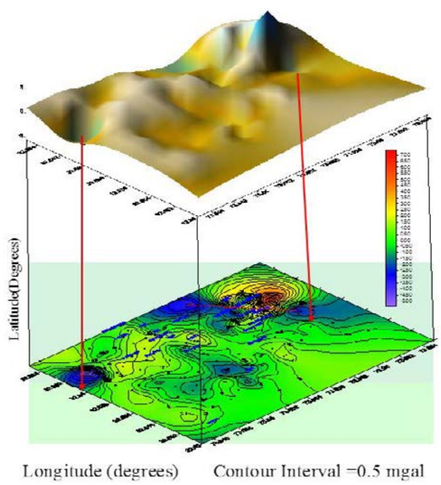

Figure 14: Surface projection of Gravity anomaly map.

Earth resistivity models and field photographs are shown in Annexure 2.

Two-dimensional models (geosoft software): Geosoft Software has been used to perform the two dimension gravity and magnetic modeling with the selected profiles AA', BB' & CC' over the well-defined anomalous bodies. Results of these gravity and magnetic modeling are shown in the following Figures 16-21.

Results

Results of the gravity, magnetic, and resistivity studies have revealed the probable salt dome near surface structures over the anomalous zones BB' and CC'. In profile BB', presence of salt is expected at a 27 meters depth that is likely to be continued to an average depth of 120 meters interpreted by gravity modeling. Likewise in Profile CC', presence of salt is expected at a 35 meters depth that is likely to be continued to an average depth of 100 meters interpreted by gravity modeling.

Results of the magnetic study also supports the existence of salt dome, however, its further continuity has been delineated up to an average of 80 meters depth.

Both the anomalous zones BB' in the extreme northeast and CC' in the northwest are of prime importance as they demarcate the existence of salt dome that extends laterally 380 meters (over extreme northeast anomalous zone 1, BB') and 200 meters (over northeast anomalous zone 2, BB') with a separation of 400 meters; an area that is composed of high density material comprising marl, dolomite and gypsum. Anomalous zone CC' in the northwest shows a lateral extension of salt dome of 240 meters.

Three dimensional surface maps of residual gravity and residual magnetic as shown in Figures 14 and 15 exhibit compatibility and confirm to the same location, orientation and shape. At gravity lows over the anomalous bodies (also marked by vertical lines at places) existence of salt dome is delineated. Similarly, in three dimension surface of magnetic map (Figure 15), magnetic lows represent the anomalous zones where the existence of probable salt dome has been identified.

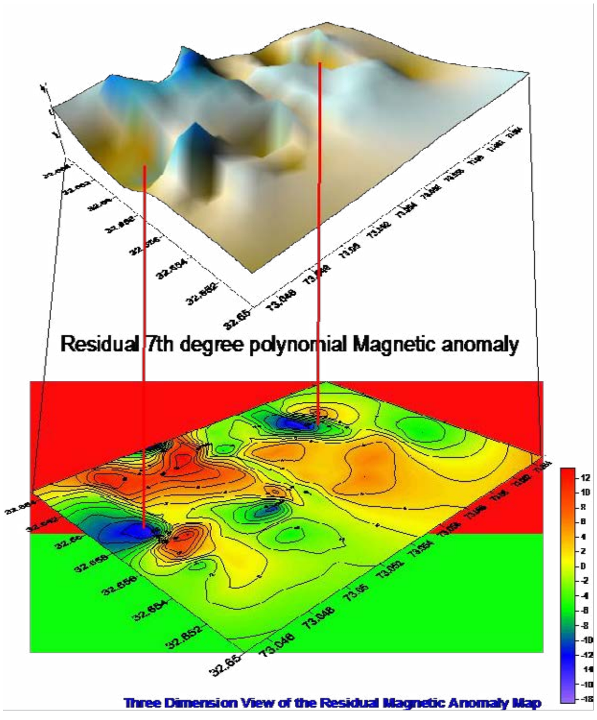

Figure 15: Surface projection of Magnetic Anomaly.

The high and low value zones alternate giving an undulated configuration most probably due to the complexities in the basement of crystalline rock. The depth of basement is approximated around 120 and 80 meters exactly below where the salt dome extent is terminated. This shows the influence of shallow lying basement. The basement is coming up towards northwest and it becomes deepens in northeast. The Regional gravity map shows an east-west trend of the contours with values increasing northwest and northeast indicating the presence of a high-density basement that is shallowing in these directions.

The magnetic and gravity anomalies show a closing trend northeast and also in northwest. Same pattern exists in the residual gravity and magnetic anomaly maps, that is, on low gravity and low magnetic anomaly zone. Therefore, a test drill hole is recommended in the northeastern & northwest extremes for verification and future control (depth about 90~120 meters).

Conclusions

Results of this composite study facilitates and supports the salt dispositional environment, confirm to the same location, orientation

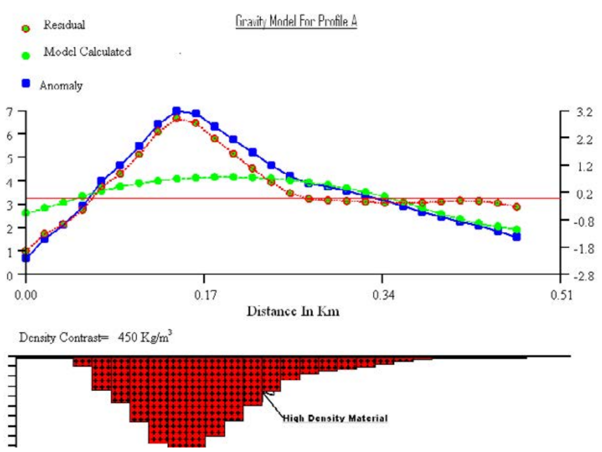

Figure 16: Gravity modeling of profile AA' over extreme northeast anomalous zone.

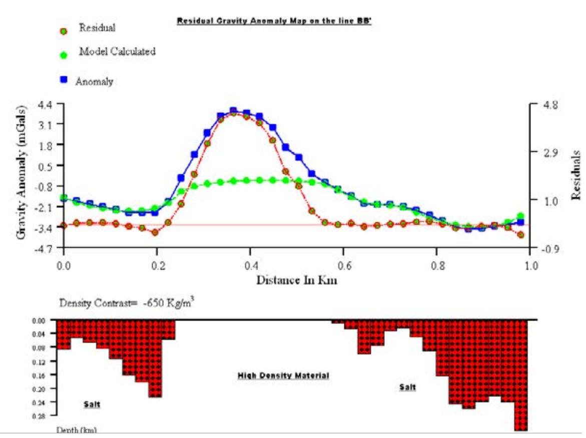

Figure 17: Gravity modeling of profile BB' over northeast anomalous zones.

Citation: Sultan M, Ahmed KA (2014) Composite Geophysical Study Comprising Gravity, Magnetic, and Resistivity Surveys to Delineate Basement Salt Deposits Near Jabbar Nala East of Kherwa Gorge, Pakistan. J Geol Geosci 3: 182. doi:10.4172/2329-6755.1000182

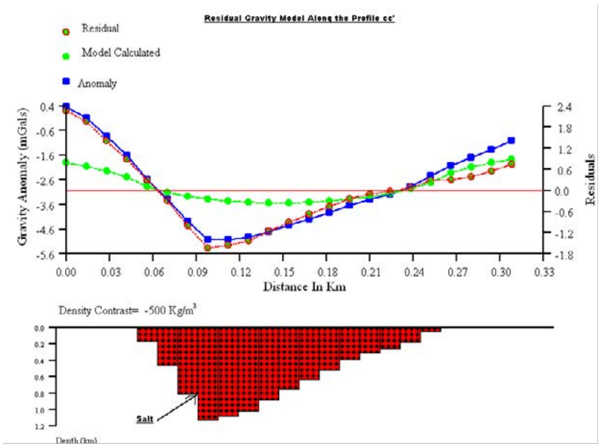

Figure 18: Gravity modeling of profile CC' over northwest anomalous zone.

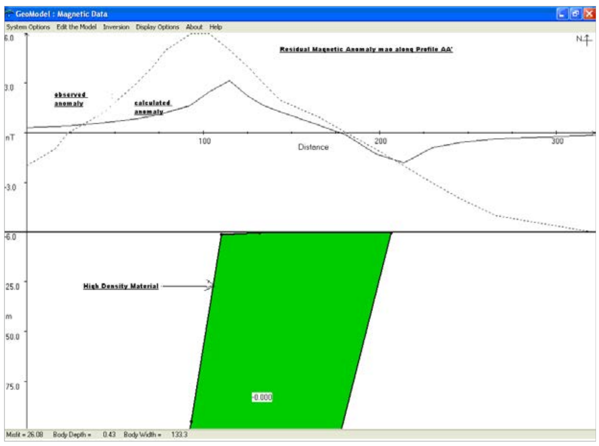

Figure 19: Magnetic modeling of profile AA' over northeast anomalous zones.

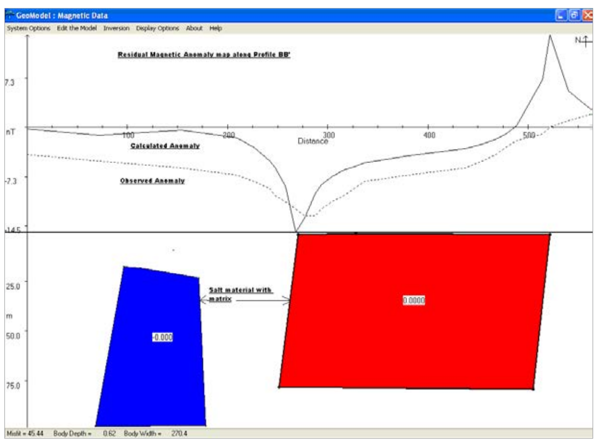

Figure 20: Magnetic modeling of profile BB' over northeast anomalous zones.

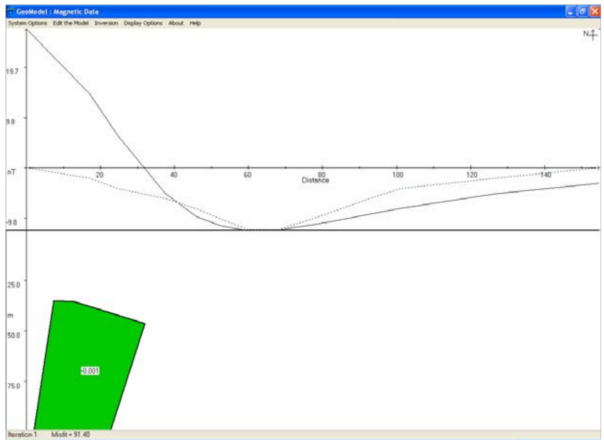

Figure 21: Magnetic modeling of profile CC' over northwest anomalous zone.

and shape and recommends probable launching of solution mining of salt in the light of commercial benefits because of shallow level presence that leads to cost effectiveness and market competitiveness, local export of raw salt solution and industrial demand.

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