Geol. Bull. Univ. Peshawar, Vol.30, pp. 83-89, 1997.

Interpretation of Magnetic Anomalies of Salt Range of Pakistan

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ABSTRACT: *The analysis of the magnetic maps shows that study area is divided into positive and negative strips/belts extending northeast-southwest. These strips/belts seem to be defining the fault pattren. The distribution of magnetic anomalies in these features points out an extensive diapiric activity in the area. This activity coupled with the thrusting of the sedimentary wedge towards south on the ductile Salt Range formation developed several anticlinal and synclinal features which are marked respectively by the positive and negative anomalies in the study area. The proven anticlinal features of Lilla, Khewra, Warnali, and Vasnal are associated with positive residual magnetic anomalies and Dhariala, Kallar Kahar, Bhadrar, Chakri and area southwest of Pail are associated with negative magnetic anomalies. The differentiation in this case,lies within the proportional thickness of paramagnetic and diamagnetic lithologies. It is one of the conclusion that negative anomalies are representing the anticlinal/domal structures having the greater proportional thickness of Salt Range formation and Nilawahan group which are behaving as diamagnetic lithologies. The anticlinal/domal structures with positive magnetic anomalies would be associated with relatively greater thickness of Siwalik and Jhelum groups behaving as paramagnetic lithologies. Residual anomaly map has also shown clearly the Salt Range frontal fault, continiation of Diljaba thrust to Nilawahan fault and the character of Kallar Kahar fault. The two anomalous zones in the south western half, north of Khushab and around Katha Sughral, apparently seems to be local features, however, the depths of these features categorize them the basement fealures, as the suprabasement and intrabasement anomalies respectively.*

INTRODUCTION

The Salt Range of Pakistan, a part of the Himalayan foreland fold-and-thrust belt is a product of ongoing collision between the Eurasian and Indian plate. The structural style is represented by south-verging thrusting along the Salt Range thrust in the central and western Salt Range. This style contrasts with the eastern Salt Range, where deformation is distributed along a broader zone of northeast-southwest-trending, tight to overturned anticlines separated by broader synclines. Structurally, the Salt Range is bounded on the west by the Kalabagh right-lateral tear fault, on the east by left-lateral Jehlum Fault (Khan and Ali, 1994), and on the south by the underformed Jhelum Plain.

In 1960's the Geological Survey of Pakistan(GSP) and the Oil and Gas Development Corporation(OGDC) prepared Bouguer gravity maps of the Punjab plains, Salt Range, and Potwar-Kohat Plateaus (Farah et al.,1977; Khan et al.,1986), and Later on, the aeromagnetic regional survey was carried out in 1961. More recently the seismic reflection lines run by national and multinational Oil and Gas companies have been interpreted in conjunction with surface geology, drill holes and the gravity data, and the results indicate that the crystalline basement reflector extends northward beneath the Salt Range and northern Potwar plateau (Lillie et al.,1987; Baker and Baker et al.,1987,1988; Pennock et al.,1989). Crawford (1974), using paleomagnetic data of Khewra and Baghanwala formations hypothesized the rotation of Salt Range.

Gee (1980) suggests that the low strength evaporates were squeezed southward in response to the overthrusting in the Potwar Plateau, resulting in the great thickness of the salt observed in the Salt Range. Baker (1987) and Baker et al. (1988) modelled the overall geometry of the central Salt Range as a fault bend fold, although with some flowage within the ductile flow as the advancing thrust sheet encountered the upthrown block of the basement normal fault. The deformation front advanced towards south through the platform strata along with this ductile flow of the salt, resulting in the present anticlinal form of the Salt Range (Baker, 1987 and Baker et al., 1988).

The present work is based on the re-interpretation of a semi-detailed magnetic data that was collected in 1977 along with gravity survey of the eastern Salt Range, Central Salt Range (fig.1) and its adjoining areas (latitudes 32^0 20' N to 32^0 50' N and longitudes 72^0 25' E to 73^0 35' E), by the Department of Earth Sciences, Quaid-i-Azam University Islamabad in collaboration with Punjab Mineral Development Corporation (PUNJMIN) for the evaluation of the potential of evaporites (Brine) in this area.

DATA ANALYSIS AND INTERPRETATION OF MAGNETIC ANOMALY MAPS

Normal and diurnal effects-free total intensity magnetic data reduced to the main base Katha Sughral was acquired at an interval of half a mile (0.8 km) along several profiles in the eastern Salt Range and presently was digitised at a grid interval of one kilometer using linear interpolation. The isolation of regional and residual effects was performed using a linear polynomial model. Based upon regression analysis of all profiles, best possible correlative model with goodness of fit (96%) was selected for the regional trend. Using data files of total intensity and those of calculated regional effects, the residual magnetic effects were determined and corresponding maps were produced at suitable contour intervals which are shown in figs. 2, 3 and 4 respectively.

The examination of the composite map of total intensity magnetic anomaly given in fig. 2 shows magnetic values decreasing northward from 300 gammas (around Lilla) to -500 gammas (North of Kallar Kahar and Dhariala) with an average gradient of -7 gammas/km. At Lilla, the magnetic values (relative to Katha Sughral) are positive and the contour trend is NE-SW, and the gradient is 65 gamma/km. North of Lilla, the magnetic values decrease consistently and the contour trend is changed to WNW-ESE. At Katha Sughral a sharp circular positive anomaly is emerged, whereas towards Khushab, in the southwestern corners of the map, the magnetic values decrease rapidly to -400 gammas giving contour trend NW-SE. High negative anomalies over the portions of high relief area ranging from 0 to -550 gammas have, however, a lesser gradient of -8 gamma/km. The contour trend of the magnetic anomaly describes reasonably the structural patterns of the area which strike generally east-west and dip towards north. The smaller undulations of the contours define the local lithostructural features. The positive magnetic anomalies are indicative of relatively more susceptible shallow features related to the structure or lithology. The negative susceptibility of the evaporates and sediments of the salt range formation is playing a major role in the development of the regional contour pattern.

The regional magnetic anomaly map (fig.3), demonstrates the regional tectonic setting of the crystalline basement under the thick pile of sedimentary cover. The regional magnetic contours which show a systematic decrease in magnetic field from +100 gammas in the south to -600 gammas in the north describes the basement deepening towards north and correspondingly increasing thickness of the sedimentary cover/Eocambrian evaporate

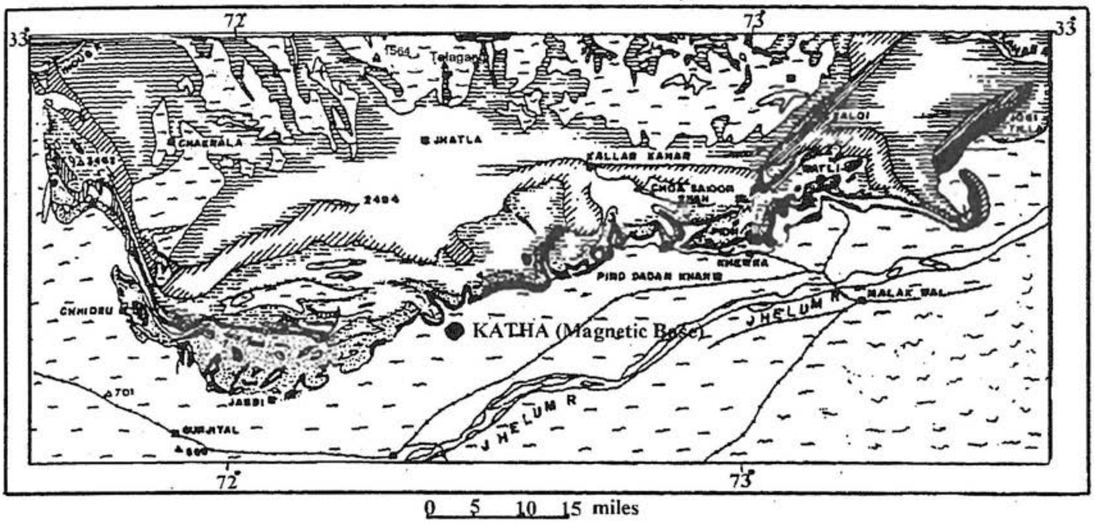

Fig. 1. Geological map of Punjab salt range (After Gee, 1980).

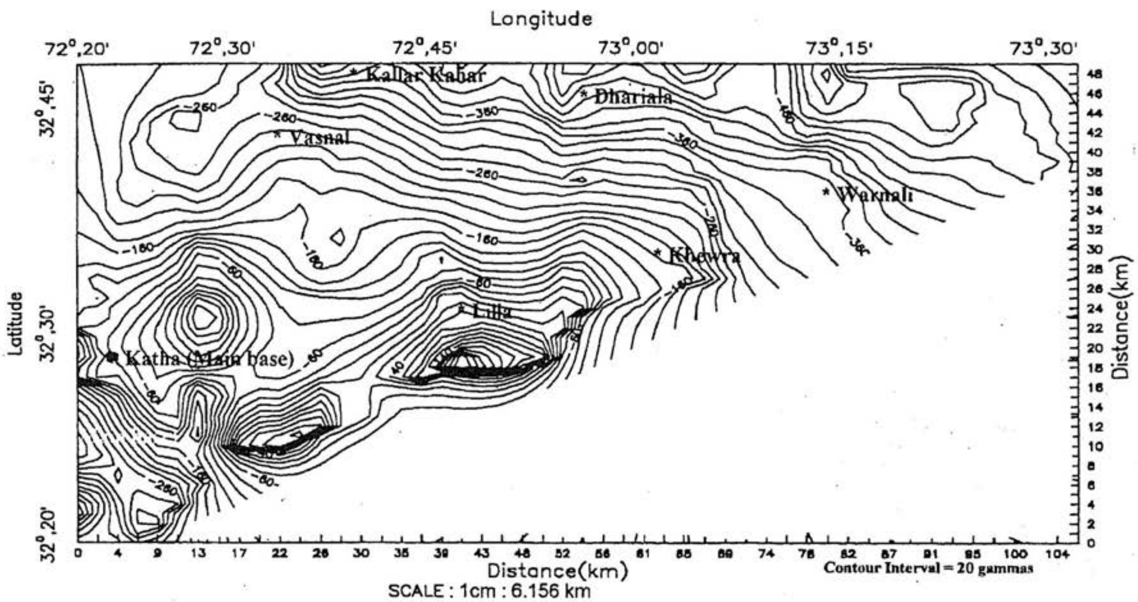

Fig. 2. Total intensity magnetic anomaly map of the area.

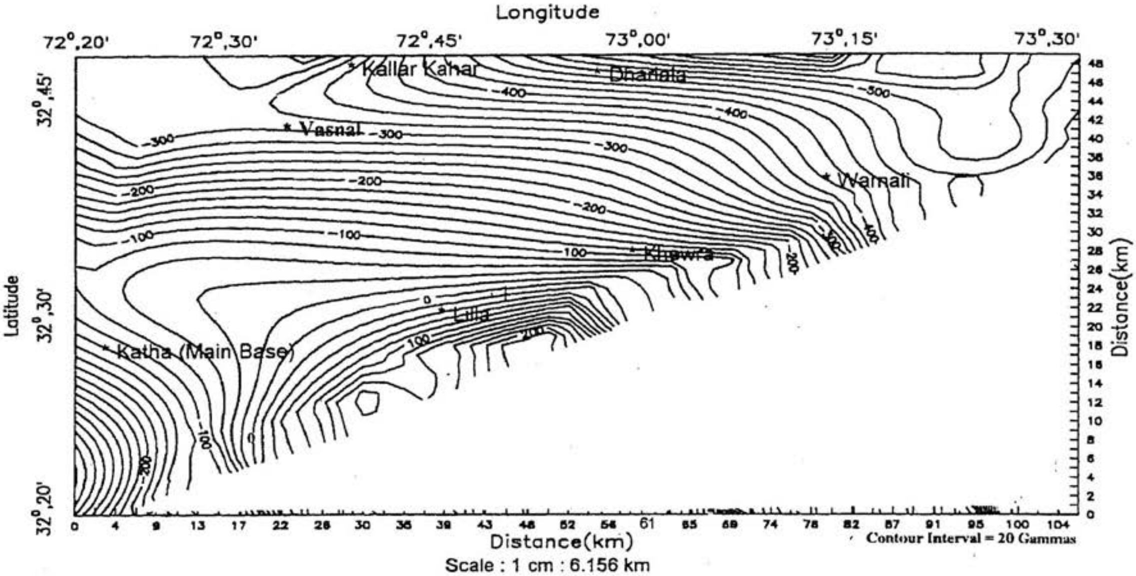

Fig. 3. Total intensity regional magnetic anomaly map of the area.

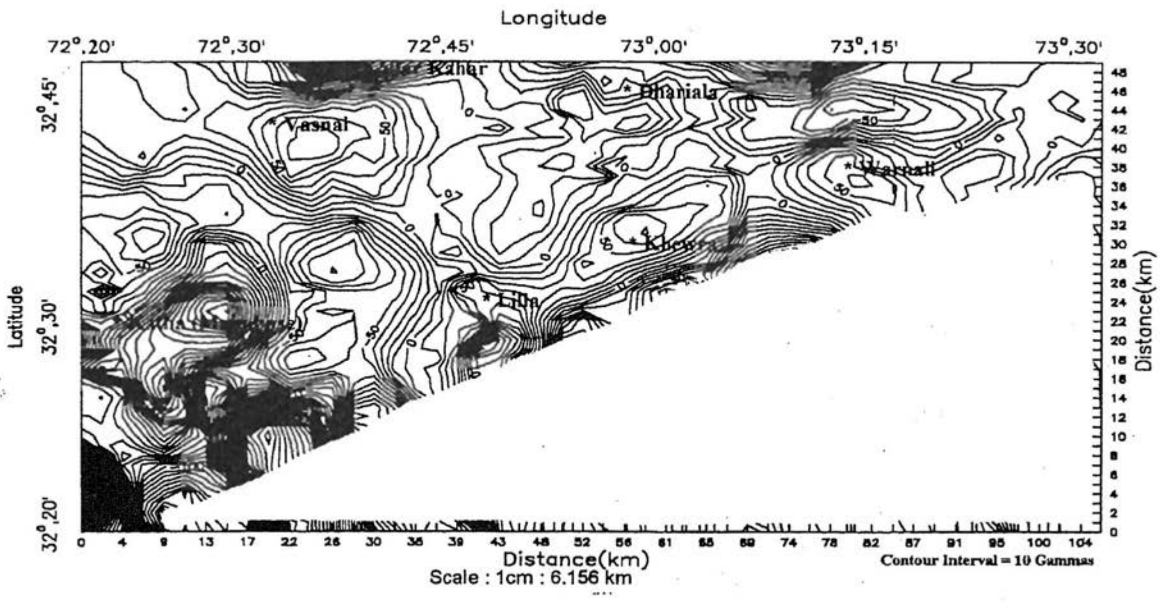

Fig. 4. Total intensity residual magnetic anomaly map of the area.

deposits of the Salt Range Formation towards north (Seeber et al., 1980; Gee, 1980; Lilli and Yousaf, 1986). On northern boundary, the magnetic contours seem to be forming two magnetic depressions, centered northeast of Dhariala and northwest of Kallar Kahar. These features may be the presentation of horst-graben structures.

The magnetic anticline in southwestern part running WNW-ESE through Lilla and Kattah Sughral is possibly the continuation of flexural bulge of basement exposed as Sargodha High. The limbs of this magnetic/tectonic structure are dipping in opposite directions (northeast and southwest) and are documented by northeast and southwest decreasing magnetic values.

The residual magnetic anomaly map (Fig-4) presents an interesting pattern of the distribution of positive and negative magnetic anomalies. The alignment of magnetic anomalies produces a sequence of five negative and positive belts or strips trending NE-SW.

1. The southern belt is a negative narrow strip lying south of Khewra and Lilla.

2. North of 1, is the positive belt/strip comprising four prominent positive anomalies over Warnali, Khewra, Lilla well and over the area southwest of Lilla.

3. North of 2, is a negative belt/strip comprising four negative anomalies over the area of Chakri, north of Khewra, Bhadrar and north west of Katha Sughral.

4. North of 3, is a positive belt/strip comprising two positive anomalies, one at Vasnal and the other near Chakri.

5. North of 4, is a negative belt/strip covering the area of Kallar Kahar.

6. Positive magnetic anomalies in the southwestern corner (near Khushab) and at Katha Sughral are the exceptions in the negative belt/strip no.3.

It is interesting to note that the southern boundary of negative belt/strip no.3 or the Zero magnetic contour coincides reasonably with the trace of Salt Range Frontal Fault (SRFF). Disruption to this association is found at Katha Sughral where the line of SRFF passes just north of it through the sharp positive anomaly which might be related with intrabasement feature.

The northern contact of this negative strip (belt-3) with that of positive belt-4 or the Zero-magnetic contour also defines a fault that runs almost NW-SE between Vasnal and Pail and may be the Nilawahan fault. The zero-contour is found to extend northeast passing nearby Dahariala well. If this contour correctly represents the fault, then it can be envisaged that this fault is the southwestern extension of the Diljaba thrust. Similarly, towards east the contact of belt-3 with the positive anomaly north of Chakri shown by closely spaced contours is possibly the extension of Jogi Tilla fault that is shown in the fig. 1.

The southern and western contacts of Kallar Kahar negative anomaly with the positive belt-4 also are being defined by high gradients which probably represent respectively the right-lateral Kallar Kahar fault and the Karangal fault. Further, the positive and negative anomalies aligned linearly in respective belts are considered to be representing locally the anticlines and/or the domal structures.

DISCUSSION AND CONCLUSION

The interpretation based on this study suggests that the Salt Range formation giving diapirisim is migrating from Potwar and accumulating/ extending to the west and southwest(Faruqi, 1986). The coupling of diapirism and compressional movements has developed several anticlinal and synclinal features which are marked respectively by the positive and negative anomalies in the study area. This is interesting to know that the proven anticlinal/domal structures are associated with prominent negative and positive anomalies. Out of these domal/anticlinal features, Lilla, Khewra, Warnali, and Vasnal are associated with positive residual magnetic anomalies and Dhariala, Kallar Kahar, Bhdrar, Chakri and area southwest of Pail are associated with negative magnetic anomalies. This is a dilemma, however, the possible explanation for that is the proportional distribution of thickness of rocks of para and diamagnetic properties. Rocks of Siwalik and Jhelum groups show paramagnetic properties whereas Nilawahan group and Salt Range formation are of diamagnetic nature. For example, Lilla anticline is associated with positive anomaly. The stratigraphic sequence of the Lilla well indicates that the Siwalik and Jhelum groups are about 2000 m thick, whereas Nilawahan is absent and the remaining Salt Range formation (upto basement) is only 500m thick. Thus, the paramagnetic material being thicker than that of diamagnetic one, hence produces positive magnetic anomaly. At Kallar Kahar, negative anomaly is emerged due to thick sequence of diamagnetic rocks, that is, due to the presence of Nilawahan group and very thick Salt Range formation (~1.5 km, Baker et al. (1988)). From these two examples an assumption can be made that negative anomalies are related with anticlinal/domal structures having thick sequence of Nilawahan group and salt deposits in the core, and the positive anomalies indicate relatively more thickness of Siwalik and Jhelum groups. The presence of salt in the cores of anticlines is related with the process of diapirism, which appears to be a common and prominent feature of the Salt Range. The two anomalous zones in the south western half, north of Khushab and around Kattah Sughral, apparently seems to be local features, however, the depths of these features categorize them the basement features, as the suprabasement and intrabasement anomalies respectively.

From this interpretation it appears that originally there was a major basin which was divided (later) into small basins by the barriers. Regional anomaly map (Fig.3) shows northeastern and southwestern basins separated by the barrier which may be the part of northwestern extension of the raised basement such as the Sargodha high (magnetic anticline in the regional anomaly map). The northern basin includes Dhariala, Dalwal, Vasnal, Pail and the area north of Kallar Kahar. The deepest portion lies in this basin around Kallar Kahar and north of Dhariala well where maximum negative contour of -550 is encountered. This basin appears to be further subdivided into two small basins i.e. northeast of Dhariala and around Kallar Kahar by NE-SW trending ridge, and gives impression of horst-graben structuring of the basement.

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