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MODELLING OF A FAULT IN INDO-SUTURE ZONE OF LADAKH REGION

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ABSTRACT

Magnetic field is measured along the Keylong-Leh profile. This profile is approximately aligned at right angles to the main structural trend of the Himalaya and traverses across several prominent thrust zones of middle Himalaya. Apart from the strong N-S trend, this profile is characterized by a pronounced anomaly near the boundary separating Indus formation from the Ladakh plutonic belt. The anomaly is inverted in terms of a fault model. The model which best produces the observervrations has southerly dip of 75° with its top and bottom surfaces at the depths about 1 and 20 km respectively. The model also requires a large susceptibility contrast between the Indus formation and Ladakh plutonic belt. It is surmised that plutonic belt with gabbro concentration of the order of 33% will be able to provide the desired susceptibility contrast.

INTRODUCTION

Many geophysical studies have been carried out to understand the complex orogeny of the Himalaya. But a few studies have dealt with an important mega lineament viz.,the Indo-Tsangpo Suture Zone (ITSZ). As it is beleived that the collision between Indian and Eurasian plate took place along this leneament, the study of ITSZ region provides vital clues associated with the mountain building processes. Extensive magnetovariational (MV), magnetotelluric (MT) and magnetic profile studies have been carried out elsewhere in the Himalayan region in the last one and half decade and the results are summarized by Reddy (1994). But many more studies are required to provide coverage across ITSZ. As a prelude to this envisaged extensive surveys, a reconnaissance magnetic profile study was carried out in Ladakh region to get nature of contrast in magnetic susceptibility across this major litho-tectonic boundary. This region consists of a steep thrust separating a belt of clastic sediments of Indus formation from Ladakh plutonic complex. The profile cutting across this thrust zone is characterized by a pronounced anomaly and this anomaly is inverted in terms of a fault model.

The body parameters of the magnetic anomaly used to be obtained by trial and error (forward modelling) or by using standard characteristic curves (Gay, 1963 and Grant and West, 1965 and Rao and Murthy, 1978). After the emergence of computers, many schemes have been developed to compute the body parameters by automatic inversion (Murthy and Krishnamacharyulu, 1990; Marobhe, 1990). Most of the methods deploy the iterative process in which differential correction is combined with least square fitting. This is an iterative process in which the body parameters are modified in each iteration, from the process of minimizing the residual between calculated and observed values. This paper presents the results of the fault modelling along with the method used.

STUDY AREA

For the present study the observational network has been laid in N-W Himalaya extending from Chatroo to Leh. Figure 1 shows the locations of the sites where magnetic anomalies were measured. The general geology of the region is discussed in Thakur (1981), Searle (1983) and Valdiya (1984). The important surface geological formations of this region include the granitic intrusions and metamorphics exposed as Tso Morari

Indian Journal of Earth Sciences, Vol. 22, No. 3, p. 83 - 89, 1995

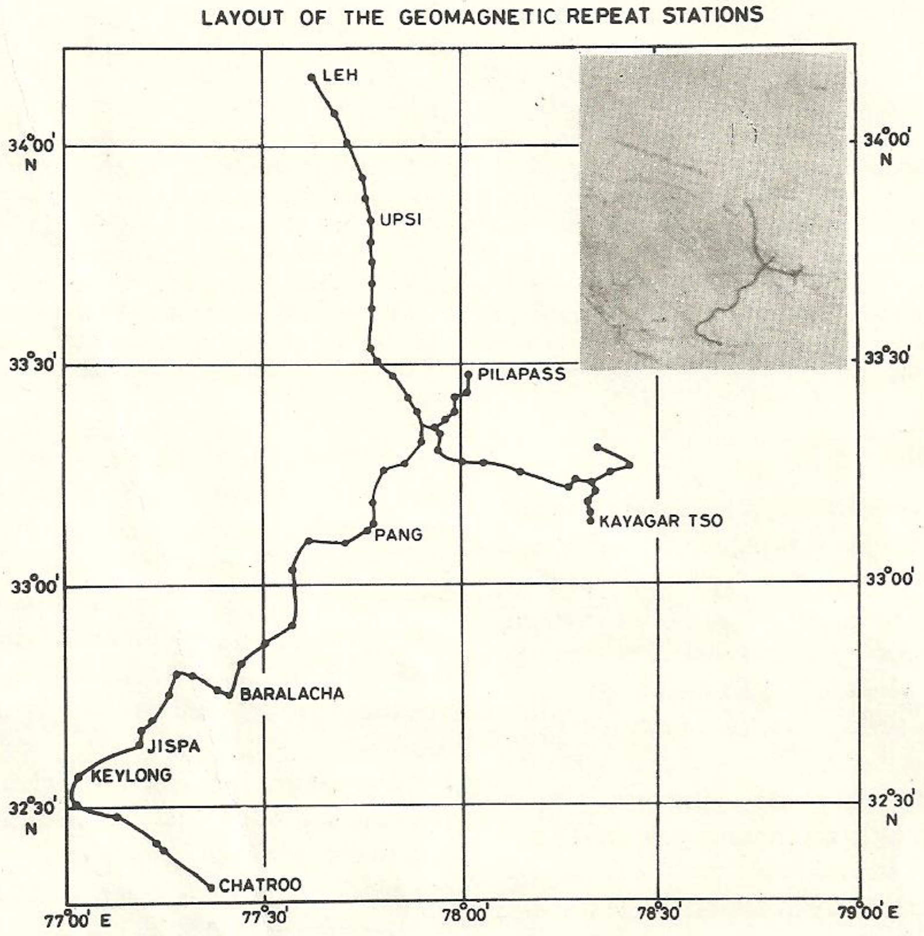


Fig. 1 : Map showing the location of measurment sites. The inset shows the layout of the profile superposed on geological setting.

crystallines, Sarchu plains intrusives, Jispa granite and Rohtang gneiss complex etc. In the south eastern region, the profiles covers Puga and Sumdo formations. The northern part of the profile runs across many important geological and lithotectonic zones like Zanskar and Indo-suture zones with formations like Tethyan Mesozoics, Thanglang-La, Indus, Kargil, Ladakh Granitoid formations which give rise to several thrusts and counter thrusts (see inset Fig. 1). In this region a steep thrust separates a belt of clastic sediments (conglomerates, sandstone, siltstone and shale) of Indus formation from the Kargil formation and Ladakh plutonic complex which is batholithic body cropping out in Ladakh range as a NW-SE trending belt.

DATA AND REDUCTION

For observational purpose, sixty five stations with an average spacing of about 5 km have been selected. Total (F) and vertical (Z) fields are measured using proton precision (to the accuracy of 0.1nT) and vertical field (Scintrex) (to the accuracy of 1 nT) magnetometers respectively. The measured values are projected along the two profiles (Fig. 2), Kar Tso-Leh (profile 1) and Keylong - Pila Pass (profile 2) of the observational network (Fig. 2). At each observation site ten spot measurements were taken and their average corrected for diurnal variation with respect to the continuous data recorded at Jispa, Pang and Upsi. The corrections were worked out as detailed below:

$$F_{i,q} = F_{i,t} - (F_{b,t} - F_{b,m}) - (F_{b,m} - F_{b,q})\text{..........}(1)$$

where i - measurement site reference

b - base station,

t - time of observation,

m - reference time with which diurnal corrections are made and

q - time of qqietest magnetic interval of each survey period. While the second term on R.H.S. of equation (1), corrects data for diurnal variation, the third term accounts for day to day variability. The variation in total field (F) and vertical component (Z) along profile 1 and profile 2 are shown in Fig. 2. A strong linear trend is apparent in both the profiles. This regional trend is primarily due to the variation of the main geomagnetic field with latitude. This trend is removed by approximating it as a linear trend between northern and southern most points. The validity of this approximation is checked by reducing the data with IGRF coefficients of 1985. A prominent anomaly of the order of 700 nT is seen in total field along the northern part of the profile 1. It is interesting to note that this large magnitude anomaly falls over the thrust zone which separates the Indus formation from Ladakh plutonic complex. The material below the plutonic belt is considered to be magnetically homogeneous all along the profile and considering only induced magnetization case, the magnetic variations along the profile were inverted assuming a fault model.

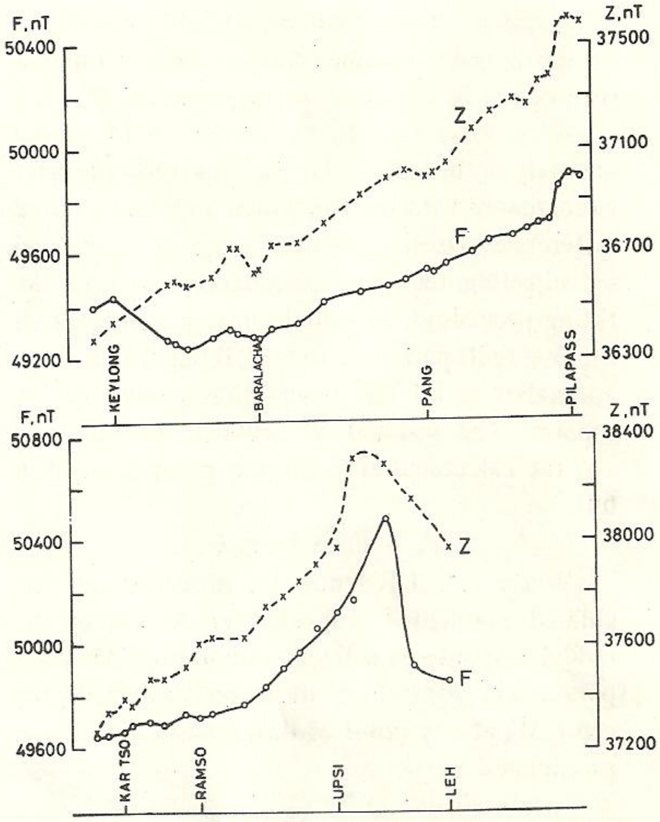


Fig. 2 : Spatial variations in total (F) and vritical (Z) components of geomagnetic field along (a) Keylong-Pila Pass and (b) Kar Tso-Leh Profiles.

MATHEMATICAL ANALYSIS

Following the Gulatee's rules, the total magnetic field anomaly due to a fault at any point x_i (see Table 1) is given by Rao and Murthy (1978) as

$$F(X_i) = 2I_F\,\mathrm{Sin}\theta[\mathrm{Cos}(\theta + \vartheta_F)(\Phi_2 - \Phi_1) + \mathrm{Sin}(\Phi + \Phi_F)\,\mathrm{In}\,({}^{r_2}\!/_{r_1})]$$

Nomenclature used are given in the Table 1. Magnetization characteristics (I, Φ) and the fault parameters (0, Z_1, Z_2) are obtained by direct inversion of the observed total field variation along the profile. Gauss iterative method which combines the differential correction and least square process (Won, 1981) to improve the initially assumed parameters of the fault is followed. Unlike the method given by Marquardt (1963), this method rapidly converges to the absolute minimum rms error and final values will not depend on the initially assumed values. In this method parameters of the fault are approximated in the sense of least squares by making a fit to the anomaly in the total field. The observed anomaly is compared with the calculated anomaly and the difference between the two curves is minimized by adjusting the body parameters. To start the fitting procedure, an initial guess is made for all the five fault parameters ($I, \Phi, \theta, Z_1, Z_2$) and the anomalies at all the observation points are estimated. The residual Y_i between the observed and the calculated anomalies at point x_i is given by

$$Y_i = F_o(x_i) - F_c(x_i)$$

Where $F_o$and $F_c$denote the observed and calculated anomalies respectively. Assuming the model response is a linear function of the body parameters (P_j) (which are to be optimized), the error ΔF_i at any point of observation can be approximated as

$$\Delta F_i = \sum_{j=1}^{N} \frac{\delta F_c(x_j)}{\delta P_j} \Delta P_j$$

where the $\Delta P_j = P'_j - P_j$ is difference between the true and guessed value of the J^{th} parameter. Now we attempt to minimize the quantity S where

$$S = \sum_{i=1}^{N} (\Delta F_i - Y_i)^2$$

with respect to ΔP_j and obtain five simultaneous equations (called normal equations) and ΔP_j are obtained by solving these equations. The improved values of the parameters are obtained as

$$P'_j = P_j + \Delta P_j$$

The iterative process is then repeated with improved values of the parameters until a reasonable fit is obtained for observed variations i.e. rms deviation between observed and calculated values are sufficiently low.

Goodness of the fit

To see how well the inversion fits the data, total variability can be calculated using variance and residual variance as given below.

$$\text{Total Variance TV} = \frac{1}{N}\sum (F_o(x_i) - \bar{F}_o)^2$$

where, $\bar{F}_o$ is the average of the observed variations.

$$\text{Residual VarianceRV} = \frac{1}{N}\sum \left[(F_o(x_i) - F_c(x_i) \right]^2$$

$$\%\ \text{variability} = \left[1 - \frac{RV}{TV} \right] \times 100$$

100% variability means that the fitten line lie on the observation.

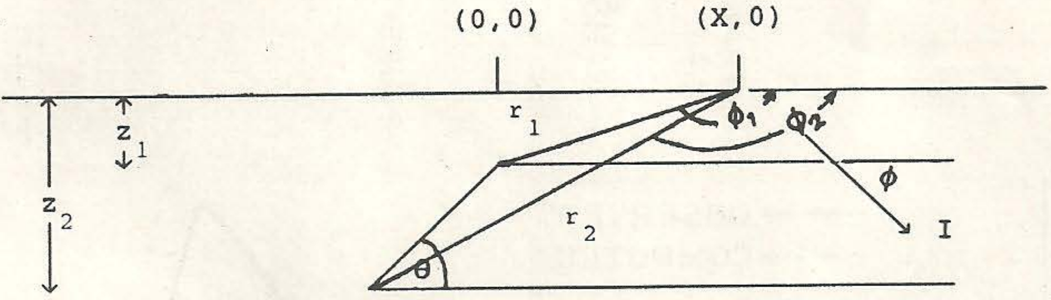
RESULTS

Here the model examined is simple fault model (Fig. 3) where in left side represents Indus formation and right side represents Ladakh plutonic structure. The Kargil formation which mainly consists of conglomerates is considered to be the part of Indus formation. Indus formations are basically composed of clastic sediments, such as sandstone, silt stone, shale and conglomerates and can be considered to be primarily non-magnetic formations. On the other hand, Ladakh plutonic zone represents a batholithic body (which crops out in Ladakh range as a NW-SE trending belt). Plutonic belt essentially consists of bodies of an igneous mafic complex ranging in composition from gabbro, gabbro-norite, gabbroic anorthosite to diorite (Thakur, 1981). In other words plutonic belt is rich in magnetic minerals known from their high susceptibility.

Magnetic anomaly pattern calculated using the final inverted parameters for fault is shown in Fig. 3 together with the observed data. Convergence to minimum rms error is reached at fourth iteration. Table-2 shows the values of fault parameters and rms errors for first four iterations. To see the goodness of the fit, variability is calculated and found to be acceptable at significant level of 90%. This means that the parameters ex-

TABLE 1

NOMENCLATURE



$I_F = I\sqrt{1 - \mathrm{Cos}^2\alpha \cos^2 i}$

$\Phi = \Phi - \tan^{-1}(\mathrm{sing}\ \alpha\ \cot i)$

$\Phi_1 = \tan^{-1}(x/z_1)$

$\Phi_2 = \tan^{-1}(x + (z_2 - z_1)\cot 0)/z_2)$

$r_1 = \sqrt{x^2 + z_1{}^2}$

$r_2 = \sqrt{[x + (z_2 - z_1)\cot 0]^2 + z_2^2}$

0 = dip of the fault face

Φ = dip effective magnetization vector

z_1 = depth to the surface of the body

z_2 = depth to the bottom of the body

α = strike of the body (mesured westwards from magnetic north)

i = inclination or magnetic dip (in degrees)

I = intensity of magnetization

dip of 57° and its top and bottom surface lie at the depths of 1.1 km and 18.5 km respectively. In addition, a moderate susceptibility contrast of 2×10^{-3} e.m.u is suggested to exist across the fault. Considering that the gabbro has an average susceptibility of 6000×10^{-6} e.m.u. as against the susceptibility of the order of $10\text{-}50 \times 10^{-6}$ e.m.u. of Indus sediments, it can be surmised that plutonic belt with gabbro concentrations of the order of 33% will be able to provide the desired susceptibility contrast.

CONCLUSIONS

To examine whether any subsurface intrusions along or at the base of Kargil formation could produce observed signature on magnetic anomaly, rigorous structure, taking into account the effect of Kargil formation in the form of intrusion is being worked out to get better picture on the geometry and susceptibility contrast. However, the fair agreement between observed and preliminary model calculation suggest the presence of large susceptibility contrast between Indus and Ladakh plutonic belts. The future investigation planned for the region will help in the better understanding of the region.

ACKNOWLEDGEMENTS

This study is made as a part of All India Co-ordinated project on 'Seismicity and seismotectonics of Himalayan Region' sponsored by the Department of Science and Technology (DST), Government of India. Authors are grateful to Prof. B.R. Arora for his guidance at all stages. Authors also wish to thank Prof. B.P. Singh and Prof. I.V.R. Murthy for their suggestions and many useful discussions. The help provided by Dr. Surendra Kumar of Wadia Institute of Himalayan Geology, Dehradun in the hostile terrains of Ladakh and Lahul-Spiti regions is gratefully acknowledged.

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Manuscript Received March 26, 1992
Revised Manuscript October 19, 1994