7.1 Identification of EW trending faults and determination of sedimentary thickness in Shillong-Mawlong area by analysis of magnetic data

7.1.1 Introduction

On June 12, 1897 Shillong, the capital of Meghalaya, was violently rocked by the great Assam Earthquake of magnitude 8.1 in Richter scale. The main cause of the quake remained unknown for over a century. Most scientists previously believed that this quake was caused by a rupture on the Himalayan thrust fault that dipping to the north and propagating all along beneath Bhutan.

At the turn of the century, Captain Bond discovered an 8 ft uplift of the Shillong plateau while working for the Survey of India (Sol) to remeasure the triangular points established by the original survey of the Plateau in 1862. His superiors dismissed his results, says Prof. Bilham (Geology news, 2001).

In the early 20th century, Richard Oldham concluded that continuing movement of the Shillong Plateau following the Assam event caused errors in the original data and recommended a retriangulation in the northern portion of the plateau. He later wrote about the Assam earthquake in extraordinary detail and went on to discover the core of the earth (Bilham and England 2001).
Finally, Bilham and England (2001) analyzed Bond's data and found that the northern edge of the Shillong plateau rose violently by more than 11 m following the rupture of a buried 110 km long reverse fault, dipping steeply away from the Himalaya and penetrating 9 to 45 km beneath the surface. They dubbed it 'Oldham fault'. They also inferred that there must exist a reverse fault at the southern edge of the plateau dipping northwards that acted in concert with the Oldham fault to wedge the Shillong Plateau uniformly upward without tilting it (Geology news 2001).

The reverse fault at South of Shillong coincides with the exposed Dauki fault which is clearly visible at the southern edge of the plateau. However, the northern Oldham fault does not show any outcrops in the Nongpoh-Barapani area (Bilham and England, 2001) which is mostly covered by Proterozoic Shillong group of sediments. The Shillong plateau with a high elevation and positive Bouguer gravity (~20-40 mGal) does not have a crustal root in the mantle and the crust underneath is thinner ≈35 km, (Mitra et al., 2005). It must therefore be supported by dynamics along two reverse faults, the south bounding Dauki fault and the north bounding Oldham fault, as opined by Mitra et al. (2005). But there is no direct visual evidence of the existence of the Oldham fault. The paper addresses the question by interpreting magnetic data available for the area.

Nandy and Dasgupta (1986) used satellite images to delineate a number of buried lineaments beneath the Alluvium in northeast India. The NE-SW Tyrsad-Barapani lineament/shear is clearly discernible on the imagery, but the Oldham fault, if it exists, between Barapani and Nongpoh under the cover of Proterozoic sediments, finds no mention in Nandy (2001).
Magnetic traverses from Guwahati to Shillong along National Highways NH37 (extending from Guwahati to Jorabat) and NH40 (extending from Jorabat to Shillong via Nongpoh, Umsning and Barapani) were laid out by Jawahar and Ramaiah (1991). Without incorporating topographic and crooked-line correction to data, they considered a vertical field profile passing through Nongpoh, Barapani and Shillong as if the data were acquired on a horizontal line. A qualitative interpretation of data showed high fluctuation of magnetic anomaly over Nongpoh on the exposed granite and a negative anomaly over the Nongpoh-Shillong area, covered by sediment. In their work, no attempt was made to identify any buried feature across NH40 in Nongpoh-Shillong area.

Recently, the Geological Survey of India (GSI) carried out close-grid gravity-magnetic (GM) surveys in certain parts in Meghalaya. GM maps of Umroi-Shillong, a southern portion of the study area, were presented by Pathak et. al. (2003). The maps clearly indicate an alignment of faults in the area. No such survey however was carried out in the Barapani-Nongpoh area.

In the year 1977, an Aeromagnetic survey of the area had been conducted by National Geophysical Research Institute (NGRI) for the North East Council (NEC) at two different altitudes; the eastern and western blocks at 4600ft and the central block at 7000ft aMSL with a flight line spacing of 2km. A contour map of the magnetic anomaly was prepared for each individual block and these were composited to present an aeromagnetic map of the Plateau. A qualitative analysis of the map was carried out by Rama Rao (1999) showing EW lineaments generally in the central part of the plateau, but none through the Nongpoh-Barapani EW sector.
In this work, we attempt to examine the existence of the Oldham fault by quantitative analysis of aeromagnetic data. An attempt has also been made to reexamine the ground magnetic data of Jawahar and Ramaiah (1991).

7.1.2. Geology and topography of the study area

The Shillong plateau is a granite massif with a prominent NE-SW trending wide patch of Proterozoic Shillong group of sediments with a few exposed intrusives at its eastern edge. The study area, namely the Shillong-Nongpoh-Mawlong, bounded by latitudes 25°30' and 26°N and longitudes 91°50' and 92°7'30" E (Toposheets Nos. 78O/13, 78O/14, 83C/1, 83C/2), lies mainly in the Proterozoics. Nongpoh, north of Shillong, lies at the western edge of the Proterozoic patch, Umsning and Barapani lie at its central part (Fig. 7.1.1) and Mawlong sits on exposed granites, north of the patch.

The topographic height gradually increases towards the south as we move from Nongpoh (500m approx.) to Shillong and attains a maximum of 1964 m (Shillong peak) ~ 6km south of Shillong. The height generally varies from 500 to 1300m aMSL in the E-W sector, bounded by the latitudes of Nongpoh and Barapani. The National Highway NH40 with a zigzag course passes through Nongpoh, between Guwahati and Shillong and apparently traverses the predicted Oldham fault somewhere between Nongpoh and Barapani (Bilham and England 2001).
7.1.3. Analysis of Aeromagnetic Data

(a) Qualitative Analysis

The area under study is covered by aeromagnetic survey with flight-line spacing of 2km at flight level 7000ft (21336km) aMSL. A copy of the magnetic map on 1 250,000 scale in 10nT contour interval and its parts in 1 50,000 scale are now available at NEC, Shillong, were obtained for a quantitative analysis. However, in the absence of the associated report, it is assumed that the data had a probable of error of 1nT. A magnetic map of the study area read from 1 50,000 maps is reproduced in Fig 7.1.2.
Fig. 7.1.2: Aeromagnetic Map of Nongpoh-Shillong area showing lines of 2-D magnetic profiles under consideration.

(Flight level 2.1336Km aMSL, contour interval 20nT)
Fig. 7.1.2 clearly reflects the response of the exposed granite of Nongpoh-Mawlong corridor at its north, that of the intrusives at the southeast corner and the response of NE-SW trending Barapani lineament/shear in its central part. It further shows E-W magnetic lineaments immediately north of Shillong and NEW trending lineament immediately south of the Nongpoh-Mawlong corridor. No EW lineament could be traced in the area bounded by the latitudes of Nongpoh and Barapani.

(b) Quantitative Analysis

To carry out a quantitative analysis of the aeromagnetic data, six NS lines were drawn between latitudes 26°N and 25.5°N so that the magnetic field anomaly along each of them could be approximately regarded as a two-dimensional one. The lines are identified as A1-B1, A2-B2, A3-B3, A4-B4, A5-B5, A6-B6 in Fig. 7.1.1. The line A1-B1 extends along longitude 91°50'/E and A6-B6 extends along longitude 92°7.5'E. The line A2-B2, shown in Fig. 7.1.1, passes near Nongpoh, Umsning, Barapani and Shillong and A6-B6 defines the eastern boundary of the area under study. Topographic height along A2-B2, read from the contour map of Toposheets, is shown in Fig. 7.1.7 and that along A6-B6, in Fig. 7.1.8. It is evident from Fig. 7.1.7 that the topographic height along A2-B2 varies from 500 to 1100m over the EW Nongpoh-Barapani sector and rises sharply in the Barapani-Shillong sector beyond Barapani attaining 1964m over a distance of about 9km. The height along A6-B6 varies from 750 to 1100m over the EW sector and rises to approx.1500m south of Barapani.

Assuming that the effect of remanent magnetic elements, if present, is negligibly small, the downward vertical component magnetic field $T_z$ is computed along each line using the formula $T_z = T \sin i$, where $T_z$ is the vertical field, $T$ the total field and $i$
the inclination of the Earth’s magnetic field at the point under consideration. (Murthy, 1998). The inclination angle $i$ varies from $37.33^\circ$ to $36^\circ$N as we move from latitudes $26^\circ$N (north of Nongpoh) to $25.5^\circ$N (south of Shillong). The normalised versions of $T_z$ obtained along the line A2-B2 and A6-B6 are shown in Figs. 7.1.3 and 7.1.4 respectively.

(i) Gradients of Vertical magnetic profile and Identification of Approximate Fault-trace Points

Thin plates represent the simplest model of step faults in two-dimensions. For a $35^\circ$ angle of polarisation, all the points, maximum of $T_z$, inflexion of its horizontal gradient $T_{zx}$ and the minimum of its vertical gradient $T_{zz}$, form a cluster in the vicinity of the fault-trace point. (Fig. 1, Appendix III)

To model the approximate location of a basement fault from observed magnetic data; we computed the gradients of $T_z$ numerically. It has been pointed out by Hammer (1979) that computed gradients of an observed potential field are highly sensitive to errors in the input data. However, stable and reliable horizontal and vertical gradients of a gravity or magnetic profile can be computed from field data at $z=2h$ level above the datum line $z=0$ by the source technique of Laskar (1999), where $h$ defines the uniform spacing of data over the datum line. In this case the error in the computed horizontal gradient $T_{zx}$ appears almost within the uncertainty of input data, whilst the error in the vertical gradient $T_{zz}$ is slightly enhanced, without any shift in the locations of the extrema of $T_{zz}$ (Laskar et.al 1996). Hence, horizontal and vertical gradients of the vertical field were computed following Laskar (1999). Computed gradients $T_{zx}$ and $T_{zz}$ of the vertical field $T_z$ at up-continued level along A2-B2 and A6-B6 are shown in Figs. 7.1.3 and 7.1.4 respectively.
Fig. 7.1.3: Vertical Component field and its horizontal and vertical gradients defining approx. location of basement faults along A2-B2.

Fig. 7.1.4: Vertical Component field and its horizontal and vertical gradients defining approx. location of basement faults along A6-B6.
Following the criteria for identifying the approximate location of a fault from gradient analysis of the vertical field discussed earlier, possible locations of the faults across the NS lines have been noted. The \( T_z \) profile and its gradients along A2-B2 and A6-B6 are shown in Figs. 7.1.3 and 7.1.4 respectively. Four possible faults lying across A2-B2 over the EW sector are identified and designated as \( F_1 \), \( F_2 \), \( F_3 \) and \( F_4 \) (Fig. 7.1.3). Fault \( F_1 \) lies south of the Umsaw reserve forest (RF), at a distance of about 7km north of Umsning, \( F_2 \) lies at around Umsning at the southern margin of the Proterozoic basin bounded to the south by an intruding patch of exposed granite (Fig.7.1.1), \( F_3 \) lies about 3km north of Barapani and \( F_4 \) lies about 6km south of Barapani. On examining the \( T_z \), \( T_\gamma \), and \( T_\alpha \) profiles of A6-B6, we find that the northern half of the \( T_z \) profile is almost flat and two possible faults \( F_1 \) and \( F_2 \) lie across the southern part of A6-B6. Fault \( F_1 \) lies about 4km north of Umsning and \( F_2 \) about 4km south of Barapani.

The flat, smooth behaviour of the magnetic profile indicates that either the basement is flat or, with small topographic variation, it lies at a greater depth. As such, to pick up the variation, if any, at the basement below the northern portion of A6-B6, the observed magnetic profile need to be continued downward to a level below the flight altitude.

On examination of the geological map (Fig.7.1.1) and the Sol toposheets, we find that the flight line clearance varies approximately from 834m to 1634m over the EW sector bounded by the Nongpoh and Barapani latitudes. The topography rises sharply south of Barapani and it attains a maximum height of 1964m over a distance of about 9km south of Barapani. As such, for a reliable continued field along a NS line over the EW sector, the field is to be continued downward to a curved lower boundary, as
shown in Fig. 7.1.8, with its flat part lying above the EW sector at a depth 750m below the flight level.

(ii) **Downward Continuation of Profile Magnetic Data and Preparation of Magnetic Map at a lower level**

It is evident from the topographic variation of the area under study that the T7-profiles can be continued downward to a level 1.3836km aMSL (750m below the flight level) over the E-W sector mentioned above, on a curved lower boundary ABCDEF (Fig. 7.1.7) without violating the Dirichlet condition that $T_z$ remains a harmonic function in the upper half-space domain bounded below by the continuation boundary. Formulation of the problem is presented in subsection 4.2.1 and model studies is carried out in subsection 6.2. It may be mentioned here that for the input data within 1\% random error spaced at a regular interval $h (=0.5m)$ over the datum line, the field can be continued downward within 2\% error, in general, to a level which is 1 unit (=2h) below it.

To prepare a map of the magnetic field at a lower level, the vertical component profiles were continued downward taking into consideration the full-length data extending from latitudes 25°30'N to 26°N. The down-continued field obtained along A6-B6 profile is shown at the top of Fig. 7.1.8. The down-continued field so obtained along the lines at the lower level are contoured by SURFER-32 at intervals of 10nT. The map so prepared is shown in Fig.7.1.5. The approximate fault trace points identified earlier along the NS profiles by gradient analysis were transferred to the new map shown as F.
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Fig. 7.1.5: Contour map of vertical component magnetic field at level above EW central sector (Contour interval = 10nT)

[(lat 25°30'N, long 91°50'E) define the origin of the reference frame. Distance between 25.5°N and 26°N is 55.3 km. Map prepared at level 1.3638km.]

It is evident from Fig. 7.1.5 that all the faults identified earlier by the gradient analysis of profile data, visibly appear in the new map without much change in their locations. Further, a new fault location across A6-B6 distinctly appears at a latitude about 8km north of Umsning. This fault did not appear in the gradient analysis along the line at the flight level.
Fig. 7.1.6: Regional Magnetic profile along Guwahati-Shillong highway and its harmonic components

Profiles 1, 2, 3 and 4 represent superposition of first 10, 15, 20, 25 harmonic respectively. Profile 5 represents the original VF profile of Jawahar & Ramaiah (1998).
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Fig. 7.1.7: Flight level, Continuation boundary, ground and basement topographic profiles along A2-B2

[A2-B2 line extends from south of Barnihat (lat 26°N, long 91°53'E) to south of Shillong peak (lat 25°30'N, long 91°53'E). Topographic elevation varies from 260m to 1920m aMSL along the line.]
(c) Alignment of EW Trending Faults in Nongpoh- Barapani sector

The down-continued magnetic map (Fig. 7.1.5) shows a series of lows aligned in a NE-SW trending corridor at the central part of the Nongpoh-Barapani sector. This coincides with the Barapani shear identified by Nandy (2001).

On joining the approximate fault trace-points, shown as $F_1$ on each of the NS lines in Fig. 7.1.5, we note that a nearly E-W trending fault begins to appear north of the Umsaw reserve forest ($91^\circ 50'\ E$ longitude) continuing eastwards up to the end of the study area, taking a northward shift in between the NS lines 4 and 5 where it
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encounters a NE-SW trending fault of the Barapani shear. In the western part, it lies about 7km north of Umsning and follows the up-stream course of the west flowing tributary of the Umsaw River. In the eastern part it shows a SEW trend on crossing the Barapani shear. The analysis also reveals the existence of a second fault at Umsning, defined by the trace points F2 marked on the first 3 NS lines, that extends in the SEW direction and joins the Barapani shear about 5km east of Umsning.

7.1.4 A Comparative Study of Throw of the Faults

On acquiring vertical component magnetic data along the zigzag and undulated Guwahati-Shillong road with a spacing of 1km, Jawahar and Ramaiah (1991) presented a vertical field profile extending from Jorabat to Shillong passing through Nongpoh, Umsning and Barapani. The data were not corrected for topographic and crooked line corrections as mentioned earlier. The profile is therefore unsuitable for the study of small throw faults. However, since the basement lies at a shallow depth along the NS line (Fig. 7.1.1) that passes through Nongpoh and Shillong, the data acquired by Jawahar and Ramaiah (1991) may be expected to contain at least a weak signature of faults, if any, even though it be masked by errors.

To extract this information, the profile data were decomposed into different harmonics using the finite Fourier Series. Superposition of the first 10, 15, 20 and 25 harmonics are presented along with the original data in Fig. 7.1.6. We observe that the 3rd and 4th profiles show their maxima at around Umsning and also at a point about 6km north of Umsning indicating the possible existence of faults at these locations. On examination of trace 2, which is obtained by a combination of the first 15 harmonics, we observe that the maximum at around Umsning persists whilst the other
maximum north of Umsning, disappears. This indicates that for a shallow basement, the fault north of Umsning is of much smaller throw than that near Umsning.

7.1.5 Sedimentary thickness in the Shillong-Nongpoh-Mawlong Area

The Proterozoic Shillong group of sediments directly overlies the basement in the area (Das 1990, Karim et. al. 2003). Once the depth to the basement below the flight level is known, the sedimentary thickness can be determined from a knowledge of the topographic height of the ground surface.

To find the depth to the basement, we use the DEPTHDNC software (Laskar & Singh 1993) for computing point to point depth to the basement along a 2-D profile. The theoretical basis and working principles of DEPTHDNC are outlined in Subsection 4.2.3.

Two vertical field profiles A2-B2 and A6-B6, shown in Fig. 7.1.3 and 7.1.4 respectively, were analyzed to determine depth to the basement underneath. The profiles are given at the flight level 2134m aMSL. Flight line clearance varies approximately from 1030 to 1634m along A2-B2 and approximately from 1030 to 1384 along A6-B6 over the EW sector bounded by the latitudes of Nongpoh and Barapani.

Since the maximum flight-line clearance along A2-B2 is 1634m and that along A6-B6 is 1384 over the sector, the search-depth for the basement top can be initially taken as being 2km for the apex \( z_k \) of \( S_L \) moving downward along a vertical in \( \Delta z=0.25 \) steps (see Fig.4.2.1). Depending on the search-depth, the data spacing along the datum line \( \tilde{S} \) at flight level becomes \( h=0.5 \)km. (See Subsection 4.2.4)
Depths to the basement along A2-B2 and A6-B6 were obtained at points every 2km apart. The basement is encountered almost at every point along A2-B2 but only at a few points along A6-B6 at the northern margin of the basin. The depth profile, so obtained along A2-B2 thus shown at the bottom of Fig.7.1.7. Subsequently, the program was run for a 4km search depth along A6-B6 with h=1km and Δz=0.5km. These were then further refined by taking Δz=0.25km. The depth profile so obtained, is shown at the bottom of Fig.7.1.8 along with the normalised total field and down-continued Tz profiles on its upper part.

It is evident from Fig.7.1.7 that the maximum possible thickness of sediment is about 300m between Nongpoh and Umsning and a fault of small throw clearly appears in the basement profile about 7km north of Umsning. Further, an apparently incorrect depth appears at the exposed narrow NE trending granite patch, south of Umsning showing that the computed depth to the top of the granite lies about 200m below the actual. This happens because the response at the flight level, at about 1.5km above the exposed patch, is devoid of the high frequency response of the granite patch. The software therefore yielded a smooth version of the top of the basement showing it at about 200m below the actual over the exposed patch of granite south of Umsning. Further, from Fig.7.1.8, we find that the basement is more undulated in the central part of A6-B6 with depths varying from 3.416 to 2.066 km below the flight level than that found along A2-B2. A maximum of about 2.5km thick sediment overlies the basement along A6-B6.

It can also be inferred from the above exercise that the Shillong group of sediments are probably non-magnetic in nature since the analysis did not indicate the presence of a magnetic causative at the ground surface over the EW sector.
7.1.6 Discussion

(i) Bilham and England (2001) predicted that the Oldham fault with a small throw extends east-west over a distance of about 110 km passing through the study area somewhere between Nongpoh and Barapani and it penetrates to a depth of about 9 to 45 km, dipping away from the Himalayas. The present study indicates the possible existence of two EW trending faults in the study area. The first one, an EW trending fault, extends over the entire EW sector of the study area located at 7 km north of Umsning and the second one, a SEW trending fault, extends over a distance about 10 km starting from west of Umsning and ending at around the Barapani shear. The former has a small throw as evident from the harmonic analysis of the ground magnetic profile along A2-B2 and also from the basement profiles computed along A2-B2 and A6-B6. The trend, length and throw all appear to be closely matching with the Oldham fault (Bilham and England, 2001), although its depth extent and dip angle remain to be verified by other geophysical means.

(ii) The method used here for locating an approximate fault-trace using the simplest fault model, appears to work well for field data. It is evident from Fig. 7.1.5 that the possible existence of faults identified by gradient analysis also appear in the contour map of down-continued data. Furthermore, they corroborate the basement profiles obtained along A2-B2 and A6-B6 lines in the area.

(iii) The technique of down-continuation of data from the datum line to a horizontal line below it, could have been used by limiting the data-length over the EW Nongpoh-Barapani sector at the flight level. Excluding the end values, unacceptable for any practical purpose, however would have restricted reliable field values only to the central part of the EW sector. The present approach
provides reliable field values over the entire NS-span of the EW sector taking into account the contribution of data specified over the entire data-length from north of Nongpoh to south of Shillong.

(iv) The ground gravity-magnetic (GM) survey, carried out by Pathak et al. (2003), in the southern part of the area suggests that close grid GM data with proper corrections may possibly provide sharper indications of faults in the area.

(v) The basement profile obtained from magnetic data, in a shear zone in particular, needs further verification from gravity data. The exercise could not be carried out for non-availability of gravity data.

(vi) Upward or downward continuation of a potential field from boundary data is governed by the theory of reproduction of a harmonic function from boundary data. Implementation of total field as boundary data leads to generation of an unknown harmonic function, in general, above or below the boundary. As such, in this work, vertical component magnetic field is constructed from total field for its upward or downward continuation from the boundary.
7.1.7. Conclusion

The possible existence of a long EW trending continuous fault of small throw in the northern half of the Shillong-Nongpoh-Mawlong area of Meghalaya appears to be required by the analysis of available magnetic data. Appearing somewhere west of the Umsaw reserve forest, it follows the upstream course of a west flowing tributary of the river Umsaw, crosses the Barapani shear and continues past the eastern boundary of the study area in the SEW direction. This corresponds rather well with the Oldham fault predicted by Bilham and England (2001). The shillong group of sediments appears to be non-magnetic in nature, its thickness varying from 200 to 300m in Nongpoh-Umsning area, and about 2.5km thick in the eastern part of the study area.