# Technical Note On Ambient Stress at the Malanjkhand Copper Mine project, Madhya Pradesh, India.

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## ABSTRACT

Hydraulic fracturing stress measurements have been carried out in three boreholes (LM-2, LM-17 and LM-21) at the open-pit mine of the Malanjkhand Copper Project. The magnitude and direction of the principal horizontal stresses have been evaluated by inverting shut-in pressure data of each of the three boreholes separately. The results reveal that $S_{Hmax}$ is oriented in N70°E direction at borehole LM-21, which is situated away from the central axis of the mining zone, and is almost the same as that of the ambient stress field evaluated earlier (during 1985-86) at this mine (borehole MDN-4), implying that the ambient stresses prevail at locations about 500m away from the mining zone. The results further show that the stress field at boreholes LM-2 and LM-17, which are located on the central axis of the mining zone, has rotated anti-clockwise such that $S_{Hmax}$ is oriented in N25°E direction and N50°E direction almost parallel and sub-parallel to the central axis of the mining zone respectively. Interestingly, the rock mass at borehole LM-2 is excessively stressed (compressed) in the direction of the central axis, while it is de-stressed in the direction perpendicular to the mining axis. The mining excavation appears to be responsible for the disturbances of the horizontal stresses at these two boreholes because of their closeness to the mining zone. $S_{Hmax}$ orientation at Malanjkhand is significantly different from the mean $S_{Hmax}$ orientation of the midcontinent stress province of the Indian subcontinent. This suggests the effect of local geological factors including the nearby ENE trending tectonically active Narmada-Son mega lineament.

***Keywords***: *In situ stress, orientation, hydraulic fracturing, Malanjkhand, open-pit mine, Narmada-Son lineament, midcontinent stress province, Bengal basin.*

## 1.0 INTRODUCTION

The mining area of Malanjkhand Copper Project (MCP), Hindustan Copper Ltd. is mostly occupied by granitic rocks. The most prominent quartz reef (mineralised) in this area is arcuate in shape with convexity towards the east. The granitic rocks and quartz reef are occassionally traversed by basic dykes, and are subjected to faulting and fissuring. A detailed feasibility study was undertaken by the management of the MCP regarding expansion of the mining activity by opening underground mine workings underneath the existing open-pit mine. Srirama Rao et al.(1991) have conducted the hydraulic fracturing stress measurements in three boreholes (LM-2, LM-17 & LM-21) near the open-pit mine during January-March, 1991 and evaluated the stress field much needed for the purpose of designing new mine workings under the proposed expansion programme. Also, stress measurements were earlier carried out in this area (borehole MDN-4) in the year 1985-86 by Gowd et al.(1987). The results are presented and discussed in this paper.

## 2.0 EXPERIMENTAL TECHNIQUE

Hydraulic fracturing technique used for measuring in-situ stresses involves pressurisation of sealed segments (test sites or frac intervals) of a borehole until a tensile fracture is created and extended. One of the assumptions in the classical approach is that the fracture initiates and propagates in the direction of the least resistant path, i.e., in a plane perpendicular to the least principal horizontal stress, and that the fluid pressure to keep merely open the induced fracture is equal to the least principal horizontal stress (Hubbert & Willis, 1957). However, pre-existing planes of weakness are also reopened during the hydrofrac tests. In such situations derivation of principal stresses from the hydrofrac data using the classical method is not possible. Cornet and Valette(1984) have developed a new method for deriving the stress field from a knowledge of shut-in pressure ($P_{SI}$) data and the strike and dip of the induced as well as re-opened fractures. This method is based on the assumption that the vertical stress component is one of the principal stresses and that the ambient stress field linearly varies with depth. The following equation forms the basis of the new method suggested by Cornet and Valette (1984).

$$P_{SI} = \rho g Z_i . \text{Cos}\ \alpha_i + 0.5\ \text{Sin}\ \alpha_i\ [(S_1 + S_2) + (d_1 + d_2).\ Z_i + (S_1 - S_2)\ \text{Cos}\ 2(\theta^+ - \theta_i) - (d_1 - d_2).\ Z_i . \text{Cos}\ 2(\theta^+ - \theta_i)]$$

where $S_1$ and $S_2$ are the eigen values of S which is a depth-independent stress component, $d_1$ and $d_2$ are the eigen values of d which is a stress gradient, $\theta^+$ is the direction of $S_{Hmax}$ with respect to North (N) and $\theta_i$ and $\alpha_i$ are the strike and dip of the induced/re-opened fracture at $i^{th}$ frac interval, $Z_i$ is the depth to the $i$ th frac interval, and $\rho$ is the rock density. Using the above approach, Baumgartner et al.(1987) developed a computational procedure to evaluate the stresses by applying the least squared-residual method and random sampling technique.

Srirama Rao and Gowd (1991) developed a similar technique for inverting $P_{SI}$ data. In this method a large number of stress models are assumed by giving different values for $S_1$ and $S_2$, $d_1$ and $d_2$, and $\theta^+$. $P_{SI}$ is theoretically computed for each frac interval ($Z$) for a given stress model, and the squared error ($X$) which is the square of the difference of the theoretical and observed shut-in pressure values, is calculated. Average squared error ($X_G$) for a given stress model is then computed. Quite a large number of stress models are initially formulated by randomly assigning values to $S_1$, $S_2$, $d_1$, $d_2$ and $\theta^+$, and $X_G$ value for each of these stress models is computed. On closely examining the values of $X_G$, tolerable limiting value of the error ($X_L$) is chosen. All the stress models whose $X_G \leq X_L$ are stored and the ambient stress field is evaluated by analysing these selected stress models. Using this method, the hydrofrac data was processed and in situ stress field was evaluated. at the Malanjkhand Copper Project. Details of the hydraulic fracturing equipment and the test procedures are described elsewhere(Srirama Rao et.al. 1991; Gowd, 1987; Srirama Rao, 1995).

## 3.0 HYDROFRAC TESTS

Location of the three boreholes in relation to the open-pit mine is shown in Figure 1. Borehole LM-2 is located on the southern side of the mining zone, and is very close to the excavated area. Borehole LM-17 is located on the northern side of the mining area, and is right on the projected central axis of the mining zone. Borehole LM-21 is located fairly away to the west of the mining area.

The cores recovered from the boreholes were critically examined and prepared lithologs and fracture logs with a view to determine the distribution of various lithological units, zones of intact and fractured rock, and discing. In borehole LM-2, a dyke is encountered extending from 147 m to 207 m depth. Further, mineralised quartz veins occur abundantly in various sections between 207-260 m, 320-335 m, and below 375 m. Borehole LM-17 is drilled through a zone of intense fracturing and abundant mineralisation associated with quartz, whereas a dyke is encountered at shallow depths in borehole LM-21 and profound discing is observed intermittantly at various depths.

Based on the fracture logs frac intervals were selected in each borehole to conduct the hydrofrac tests. Normally hydrofrac tests were attempted in the zones of intact host-rock (granite). Efforts were also made to conduct the tests in other intact lithological units excepting quartz and dyke rock so as to avoid damage of the packer elements. A few of the natural planes of weakness were also selected for this purpose. Impressions of the induced fresh fractures and reopened pre-existing planes of weakness were obtained using an impression tool for determining their strike and dip.

## 4.0 RESULTS AND DISCUSSION

The values of Shut-in pressure ($P_{SI}$) were determined from the pressure-time records of the frac tests conducted at different depths in the three boreholes (LM-2, LM-17 and LM-21). The strike and dip of the frac planes were determined from the fracture impressions. The data have been presented in Tables 1-3. The data obtained in each of the three boreholes were analyzed separately using the $P_{SI}$ -inversion method (Srirama Rao and Gowd, 1991) described above. In respect of each of the boreholes, more than half million stress models were considered by assigning values for $S_1$, $S_2$, $d_1$, $d_2$ and $\theta^+$ over a wide range. The best possible and most consistent stress models have been selected with least squared residual errors. Based on these models, equations governing variation of principal horizontal stresses with depth have been worked out as shown below:

**Borehole LM-2:**

$$S_{Hmax} \text{ (bars)} = 80.0 + 0.51 \text{ Z (meters)}$$

$$S_{hmin} \text{ (bars)} = 5.0 + 0.29 \text{ Z (meters)}$$

$$\theta = \text{N}25^{\circ}\text{E}$$

**Borehole LM-17:**

$$S_{Hmax} \text{ (bars)} = 51.0 + 0.27 \text{ Z (meters)}$$

$$S_{hmin} \text{ (bars)} = 45.0 + 0.18 \text{ Z (meters)}$$

$$\theta = \text{N}50^{\circ}\text{E}$$

**Borehole LM-21:**

$$S_{Hmax} \text{ (bars)} = 63.0 + 0.33 \text{ Z (meters)}$$

$$S_{hmin} \text{ (bars)} = 57.0 + 0.16 \text{ Z (meters)}$$

$$\theta = \text{N}70^{\circ}\text{E}$$

Borehole MDN-4 was located quite far away from the mining zone when stress measurements were conducted earlier in the year 1985, and hence $S_{Hmax}$ and $S_{hmin}$ values evaluated for this site were considered by us as representing the ambient stress field of the area[1]. It is interesting to note that the gradients of $S_{Hmax}$ and $S_{hmin}$ at borehole LM-21 are almost the same as those at borehole MDN-4 (Figure 2), and also the orientation of $S_{Hmax}$ at LM-21 agrees well with that observed at MDN-4 (N73°E). The results, thus, indicate that the stress field evaluated at LM-21 are representative of ambient stress field at Malanjkhand area. This could be due to the fact that LM-21 is located away from the central axis of the open-pit mine so that the ambient stress field is not disturbed due to the mining excavation.

$S_{Hmax}$ values at LM-2 are found to be much higher than those of LM-21. $S_{hmin}$ has nominal magnitude at the surface (5 bars) while its gradient is high as shown in Figure 4. Further, the stress field has rotated anti-clockwise by 45° such that $S_{Hmax}$ is oriented almost parallel to the central axis of the open-pit mine. It appears that the horizontal compressive stress has been amplified in the direction of the central axis, while it has been relieved in the direction at right angles to the central axis, resulting in the anti-clockwise rotation of the stress field.

Borehole LM-17 is drilled through an intensively fractured and abundantly mineralised zone. Hnece, the mineralised zone is expected to be less stiffer than the rocks hosting the other two boreholes. This might have resulted in inducing relatively low stresses at this site, as compared to the ambient stresses. Thus the low stresses observed at LM-17 could be attributed to the local geological factors.

The stress field at LM-17 has rotated anti-clockwise by about 20° suggesting that $S_{Hmax}$ is tending to be oriented in the direction of the central axis of the open-pit mine. Location of LM-17, almost on the central axis of the mining might have resulted in the perturbation of the stress field leading to its anticlockwise rotation, similar to what has been observed at LM-2.

$S_{Hmax}$ orientation of N70°E at Malanjkhand is significantly different from the mean $S_{Hmax}$ orientation (N23° $\pm$ 20°E) in the midcontinent stress province of the Indian subcontinent[9]. The clockwise rotation of the stress field at Malanjkhand might be due to the effect of local geological factors including the ENE trending Narmada-Son mega lineament.

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Table 1. FRAC DATA OBTAINED IN THE BOREHOLE NO. LM - 2

| Test | Depth(*) m | $P_{SI}$ bars | Frac Orientation $\theta$ | $\alpha$ |
|---|---|---|---|---|
| 2.1 | 113.0 | 83.7 | N62°E | 86 |
| 2.2 | 140.5 | 46.7 | N48°E | 78 |
| 2.3 | 269.0 | 65.0 | - | - |
| 2.4 | 296.5 | 70.0 | - | - |
| 2.5 | 337.0 | 105.4 | N28°E | 86 |
| 2.6 | 374.5 | 132.1 | N 6°E | 86 |

(*) - Apparent depth measured along the borehole

$\theta$ - Strike of the fracture plane in degrees w.r.t. North

$\alpha$ - Dip of the fracture plane in degrees

Table 2. FRAC DATA OBTAINED IN THE BOREHOLE NO. LM - 17

| Test | Depth(*) m | $P_{SI}$ bars | Frac Orientation $\theta$ | $\alpha$ |
|---|---|---|---|---|
| 17.1 | 99.6 | 75.6 | N104 °E | 55 |
| 17.2 | 116.5 | 70.6 | N120 °E | 85 |
| 17.3 | 137.0 | 65.8 | N75 °E | 85 |
| 17.4 | 180.7 | 44.0 | - | - |
| 17.5 | 331.0 | 76.0 | - | - |
| 17.6 | 398.3 | 124. | N90 °E | 53 |

Table 3. FRAC DATA OBTAINED IN THE BOREHOLE NO. LM - 21

| Test | Depth(*) | $P_{SI}$ | Frac Orientation | |
|---|---|---|---|---|
| | m | bars | $\theta$ | $\alpha$ |
| 21.1 | 57.3 | 91.1 | N94°E | 46 |
| 21.2 | 81.5 | 65.8 | N78°E | 77 |
| 21.3 | 120.5 | 72.3 | N101°E | 75 |
| 21.4 | 153.8 | 39.0 | - | - |
| 21.5 | 175.0 | 79.0 | N20°E | 43 |
| 21.6 | 220.3 | 56.0 | - | - |
| 21.7 | 248.0 | 63.0 | - | - |
| 21.8 | 249.7 | 64.0 | - | - |
| 21.9 | 280.0 | 72.0 | - | - |
| 21.10 | 326.0 | 83.0 | - | - |

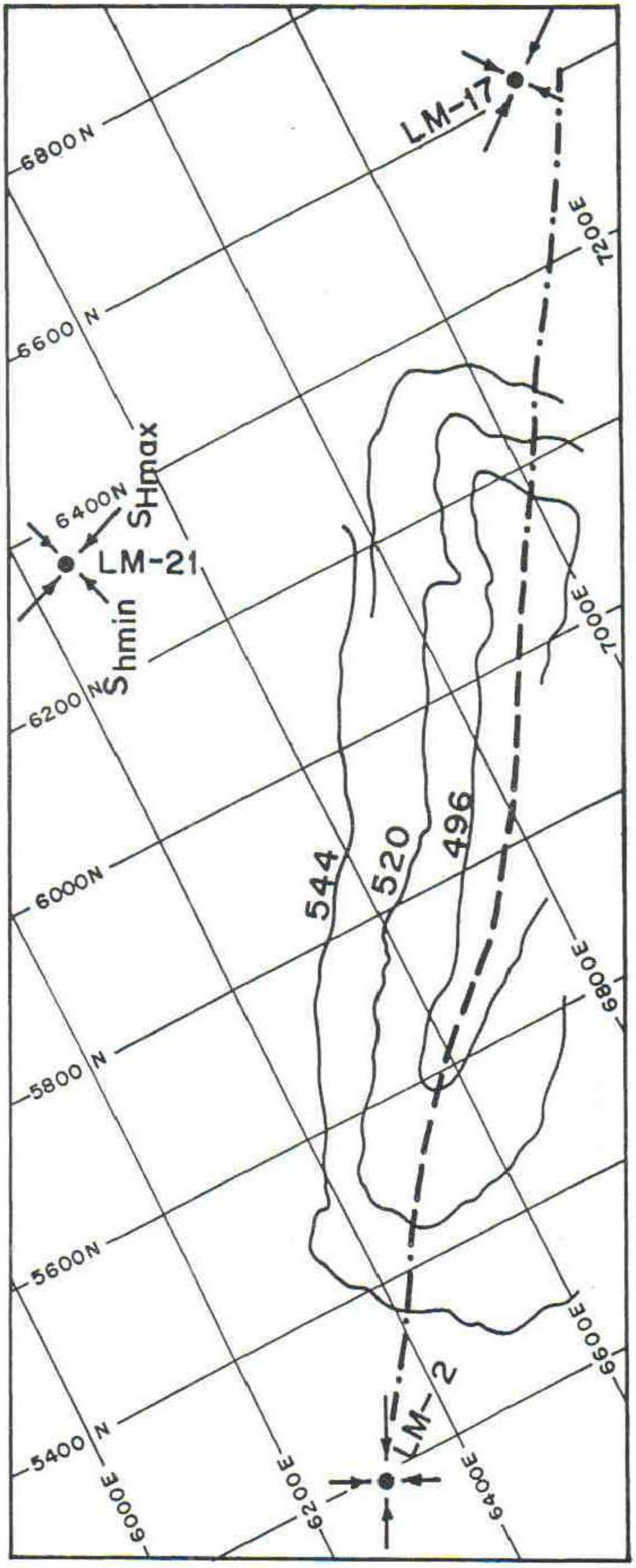


**Figure 1** Location map of the three boreholes ( LM-2, LM-17 and LM-21) in relation to the 544 m, 520m and 496 m bench marks of the present open-pit position at the Malanjkhand Copper Project site. The maximum and minimum principal stress directions are indicated by arrows.

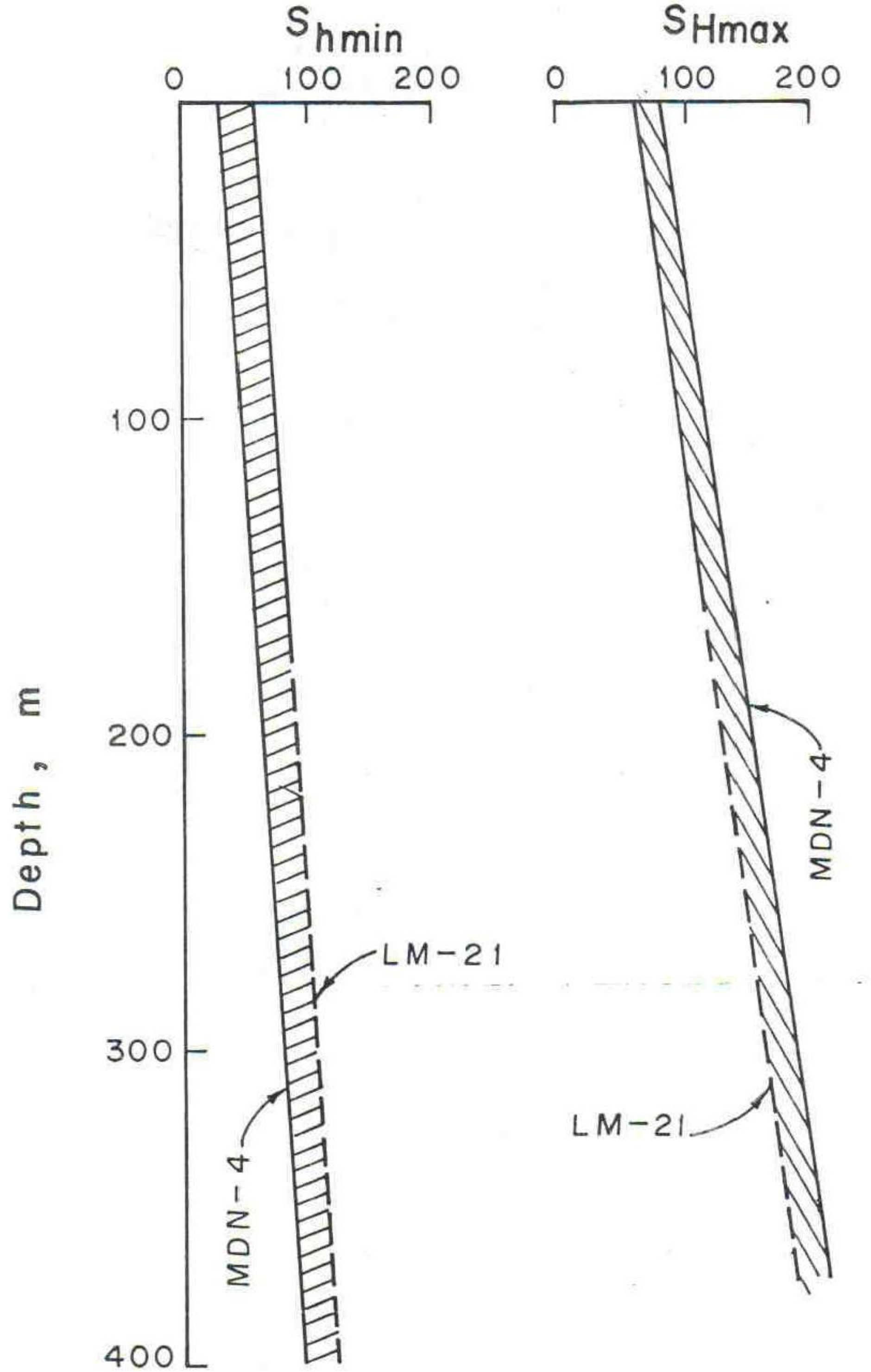


**Figure 2** Maximum and minmum principal horizontal stresses ($S_{Hmax}$, $S_{hmin}$) as a function of depth of the two Boreholes ( LM-21 and MDN-4), Malanjkhand Copper Project.

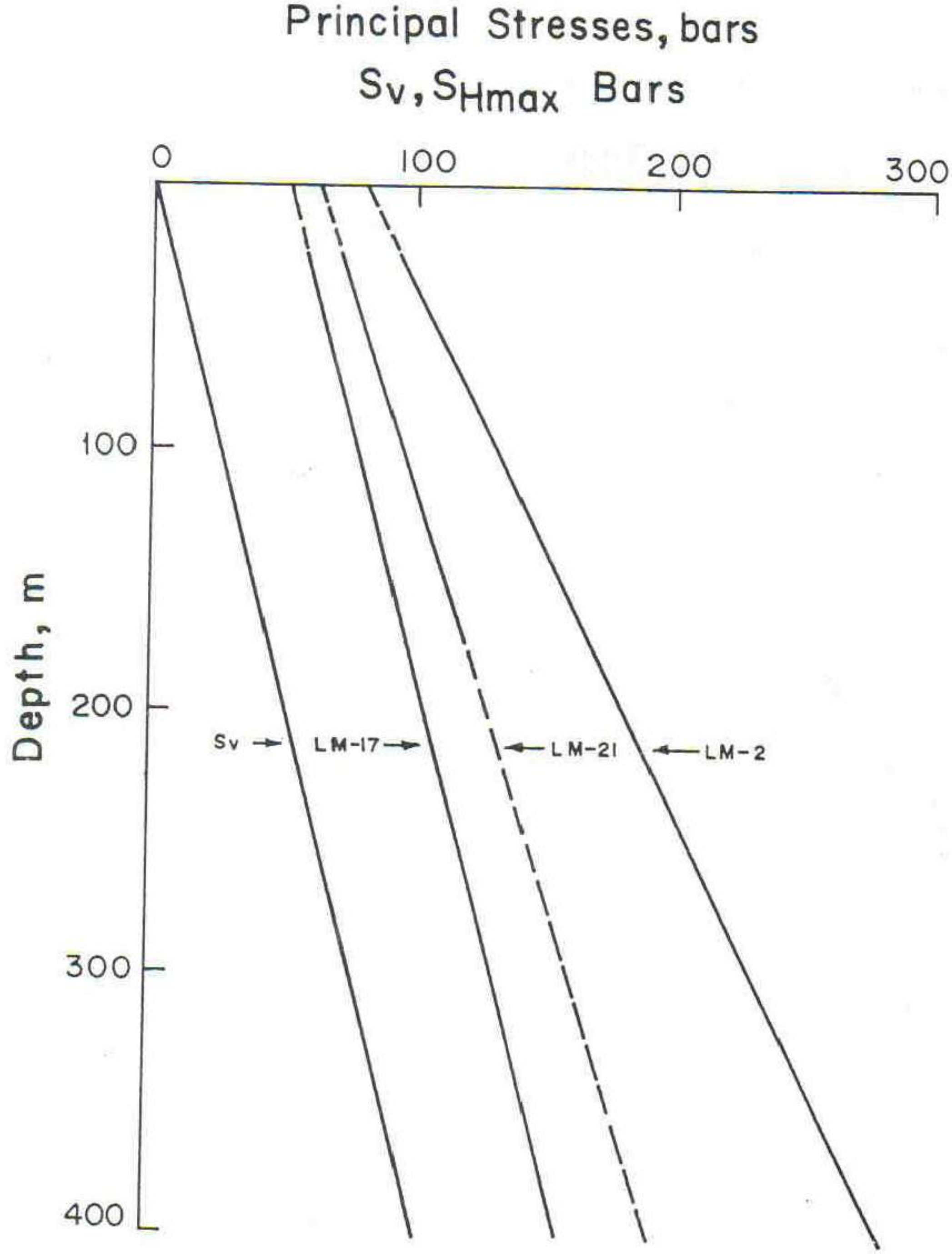


**Figure 3** Maximum principal horizontal stress ( SHmax ) and the vertical stress (Sv), as a function of depth of the three Boreholes (LM-2, LM-17 and LM-2), Malanjkhand Copper Project.

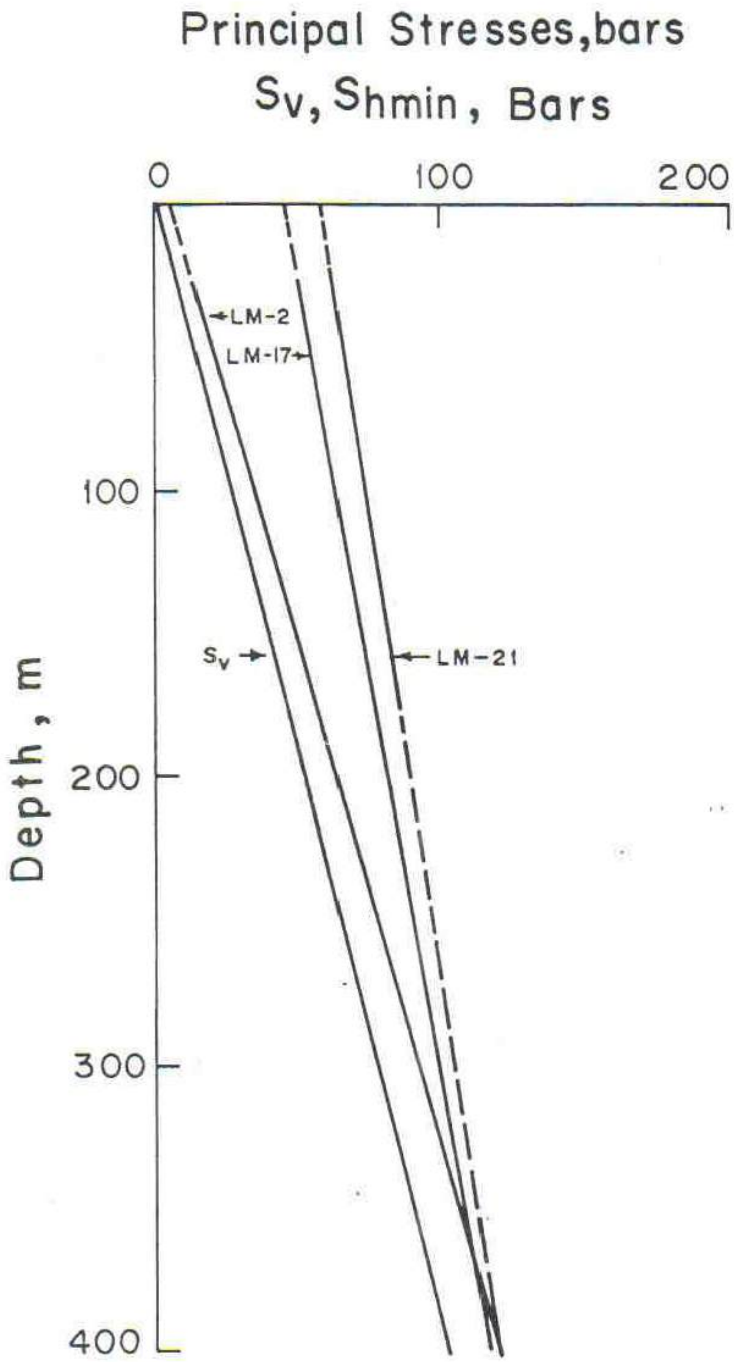


**Figure 4** Minimum principal horizontal stress ($S_{hmin}$) and the vertical stress (Sv). as a function of depath of the three boreholes ( LM-2, LM-17 and LM-21), Malanjkhand Copper Project.