HYDROGEOLOGICAL CONDITIONS AROUND AN OPENCAST MINE

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खनिजों के दोहन तथा इससे संबंधित गतिविधियाँ प्रत्यक्ष और/या परोक्ष रूप से पर्यावरण पर प्रभाव डालती हैं। खुली मुख खदानों के मामले में स्थानीय स्तर पर भूमिगत जल का नीचा हो जाना तथा इसके कारण भूमिगत जल की कमी हो जाना सामान्य घटना है।

यह अध्ययन भारत के गोवा में स्थित बिचोलिम लौह अयस्क खान में आधुनिक एवं परिष्कृत संयंत्रों, जैसे - भूमिगत राडार एवं प्रतिरोधक मापक की सहायता से, यह जाँच करने के लिए किया गया है कि यहाँ की खनन गतिविधियाँ आस-पास के जल स्रोतों पर क्या प्रभाव डालती हैं।

खदान की परिधि के चारों ओर तथा आस-पास के गाँवों एवं मायेम झील, एक पर्यटन स्थल, के जल-भूवैज्ञानिक अध्ययन के लिए किए गए प्रतिरोधक सर्वेक्षण से यह पता चलता है कि संदर्भित क्षेत्र अपारगम्य एवं अभेद्य प्रकृति का है।

जल-भूवैज्ञानिक दृष्टि से लौह अयस्क समूह एक सीमित जलीय क्षेत्र के रूप में महत्वपूर्ण भूजल वहन करने वाले संस्तर से संबंधित है। यह जलीय क्षेत्र स्थानीय पहाड़ी के शीर्ष के अगल-बगल औसतन 20 से 45 मीटर की गहराई पर पाया जाता है। इसके चारों ओर अपेक्षाकृत अपारगम्य संस्तर पाया जाता है।

कार्यरत खदानों में एक क्ले (**Clay**) डाइक मिलती है जो स्थानीय स्तर पर एक टिकान जलीय कलेवर उपलब्ध कराती है।

प्रतिरोधक सर्वेक्षण भूमिगत राडार द्वारा भी प्रमाणित पाया गया। दोनों अध्ययन के परिणामों और संबंधित अन्य आँकड़ों से यह पुष्टि होती है कि इस खुली मुख खदान एवं आस-पास के गाँवों तथा मायेम झील के बीच जलीय संस्तर की कोई स्पष्ट निरन्तरता नहीं है। अतः खनन और खनन के क्रम में जल निकासी का आस-पास के जल स्रोतों पर कोई खास असर नहीं होता है।

INTRODUCTION

Goa, a union territory of India, has a total surface area of 3,70,002 ha out of which 65,400 ha area (almost 17.6 per cent of the total area) has been leased out for mining and only 18,300 ha (5 per cent of the total area) has been under actual mining operations. A total of 70 mines covering an area of about 6,082 ha are active and they yield more than 80 per cent of the total iron ore production from Goa. Most of the iron ore deposits are located in the central and northern parts of Goa. Mining of iron ore in a small way has been going on in Goa since 1910 but significant mining can be traced only from 1947. So far over 350 Mt of iron ore has been exported during the past 47 years and in the process more than 600 Mt of waste consisting of overburden, low grade ore and tailings has been accumulated around the mining areas. The overburden to ore ratio has gone up to 3.5 : 1 at present from 2 : 1 in the past. The present annual production being 15 Mt, an additional accumulation of 40 to 50 Mt of waste needs to be tackled every year. The estimated reserve is 1400 Mt and mining is expected to continue in the area far another 30 to 40 years. The amount of waste material generated by this mining will be about 5000 Mt excluding the already existing overburden over 600 Mt at present. Open pits at some places have extended below the surrounding water table level.

Exploitation of such enormous amount of iron ore in the region may disturb the local groundwater and thereby a problem of ground water depletion may occur (Brawner, 1986; Kilmartin, 1989). However, these effects are mainly depending on geological formations of the respective area and mining methods (Chow, 1964; Viessman et al., 1972; Todd, 1980; Karanth, 1990; Kresic, 1997; Soliman et al., 1997). Therefore, to find out the effect of Bicholim mining on the surrounding ground water resources this hydrogeological study has been undertaken.

STUDY SITE

Location and Physiography

Bicholim iron ore mines are located in Bicholim Taluka of North Goa and geographically extends between 15° 35' to 15° 36' 22" N latitude and 73° 54' 43" to 73° 55' 42" E longitude (Fig. 1). The mining area comprises of five continuous leases covering an area of 498.70 ha. These leases are situated on a hill range running in SE-NW direction. The highest and lowest elevations of the area from reduced mean sea level (R.L.) are 156.98 and 15 m, respectively. The hill is gently sloping on the SE and SW sides.

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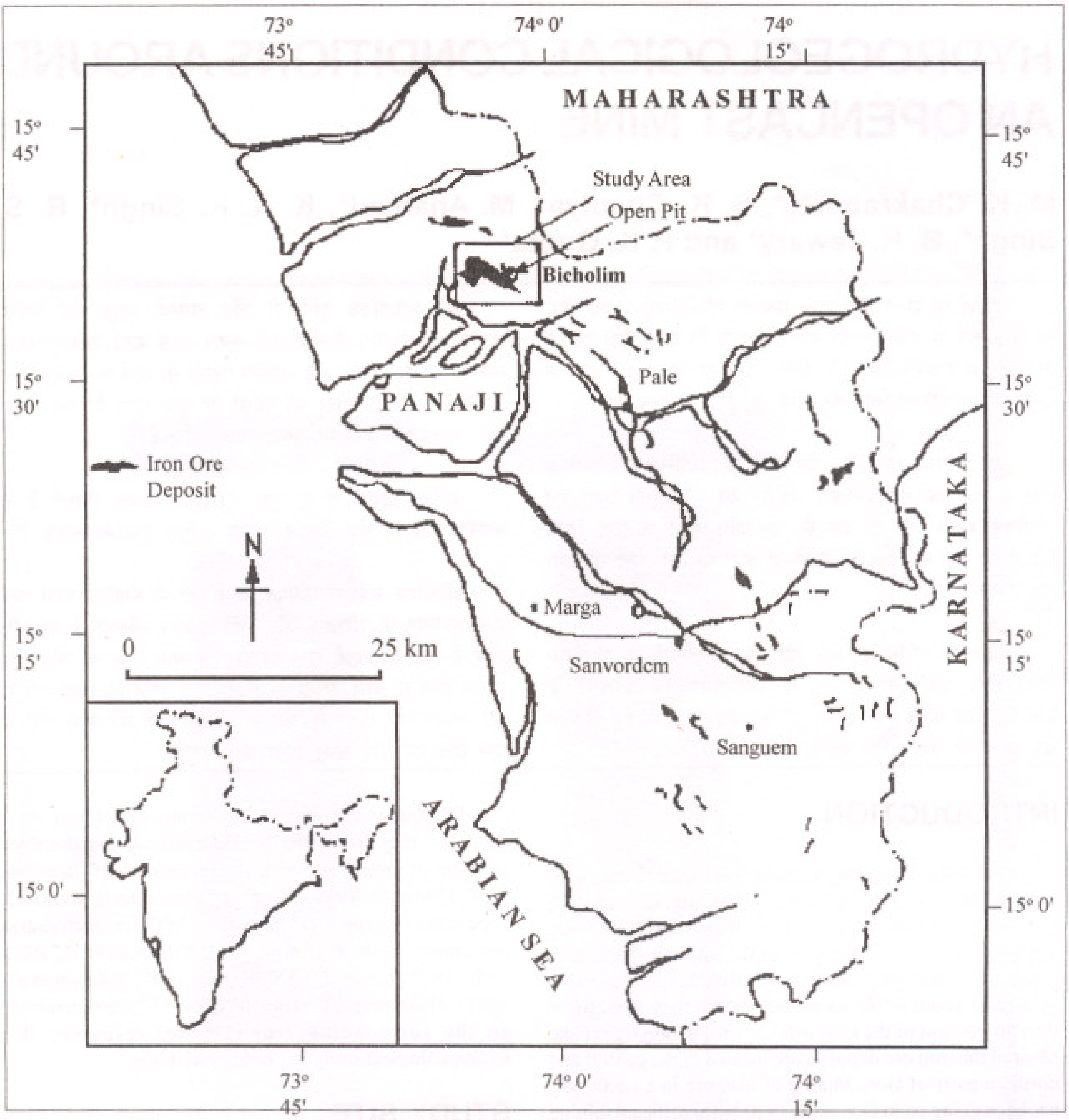

Fig. 1 : Location map of Bicholim iron ore mine, Goa, India.

The core zone comprises parts of three villages, namely Mulgaon, Lamgaon and Bordem at the foot of the hill to the north. There are no rivers or surface water bodies (perennial or seasonal) within the lease boundary.

The buffer zone consists of eight villages, namely Bicholim, Lamgaon, Mulgaon, Asnode, Shrigaon, Mayem, Piligaon and Sarvon. Mandovi river flows through the buffer zone from east to west at a distance of 4 km at the south of the lease area. Bicholim River, a tributary of Mandovi, flows from NE and meets Mandovi at Sarmanas. Asnode River, another tributary of Mandovi flows from NW. It meets Mandovi at south of Corjuvem. There is also a water body called Mayem Lake, a tourist spot, located at distance of 1 km from the mine lease boundary which is surrounded by lush green vegetation.

Mining Details

Exploitation of iron ore in this mine is being carried out by shovel and dumper combination. Drilling and blasting are not practised in this mine. Drilling is only practised for geological exploration of the area. Screening and beneficiation are practised to wash and upgrade iron ore quality. The average annual production of the mine is 2 Mt and waste generation rate is about 4 Mt per annum.

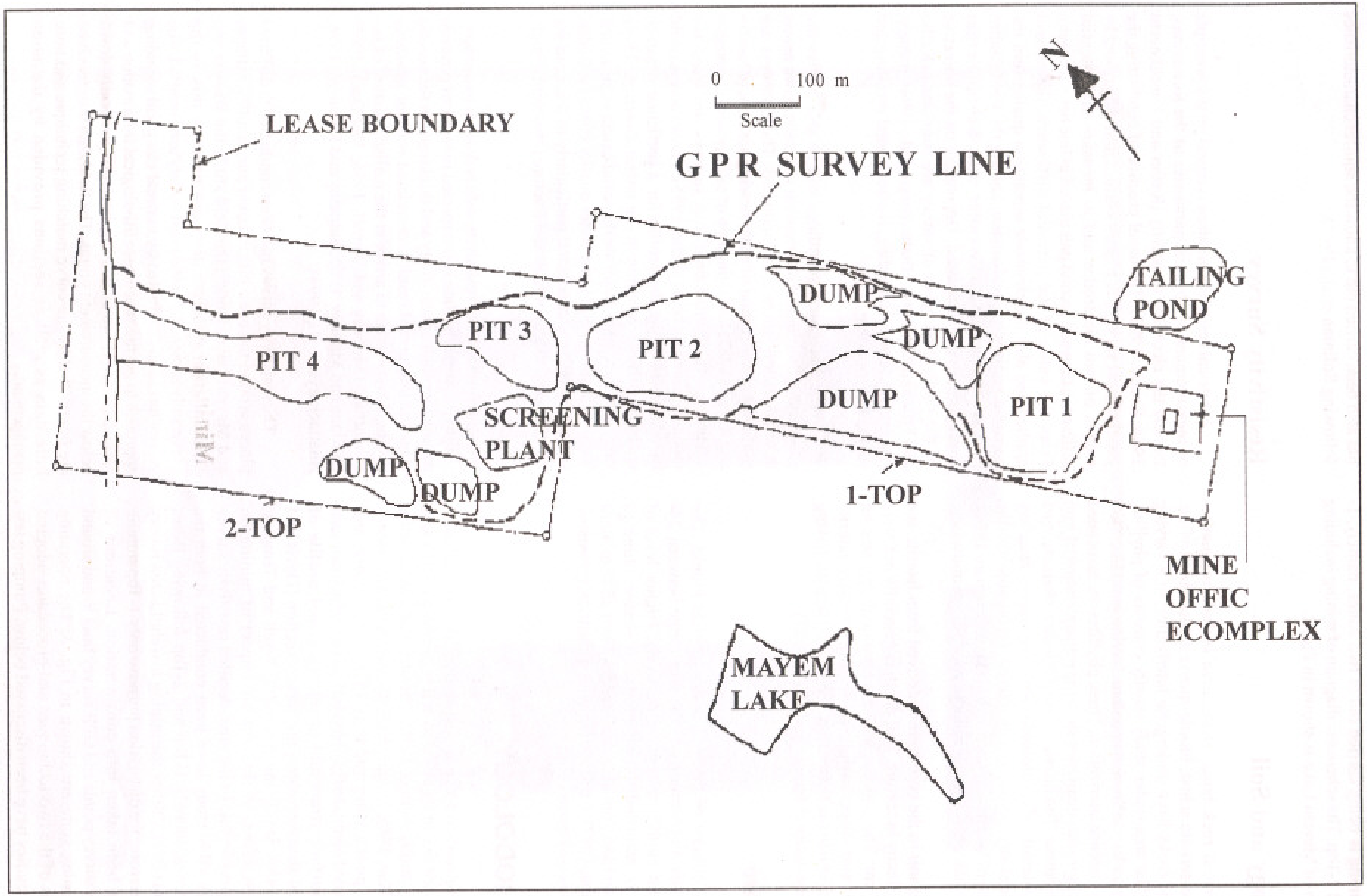

Fig. 2 : Schematic p1an of the mining area including Mayem Lake.

Mining is being carried out at two zones, namely, 1-Top and 2-Top. The schematic diagram of mining including position of Mayem Lake is shown in Fig. 2.

Geology and Soil

General rock types of the area include magnetite-hematite-sericite schist, biotite-quartz schist and phyllite. All these rocks have undergone laterization to a varying extent. The area under study mostly consists of phyllite, which is pink to yellowish in colour, having good lineation and show intense laterization. These phyllites are associated with ferrugineous quartzites showing mineralization of iron and manganese. The humid tropical climate, characterized by high intensity of precipitation and temperature, resulting in wet and dry period is considered favourable for the formation of laterite and lateritic soil (Venkataraman, 1984). This lateritic zone acts as recharge zone for groundwater.

The soil in the core zone is derived from laterite and is sandy loamy in texture. Soil depth is generally not more than 20 cm. The soil cover is predominantly present on hillsides and slopes, while hilltops are mostly laterite outcrops. Soil in the buffer zone is generally lateritic having low permeability (Marathe and Shah, 1987).

Climate

The climate of the area is dry tropical humid. The temperature and humidity in the area range between 24-38^{o} C and 58-89 per cent, respectively. Higher level of rainfall is recorded during monsoon season (June to September) and annual rainfall ranges from 2500 to 4000 mm (Ratha, 1997). Land use includes industries, grassland, mangroves and barren land.

METHODOLOGY

The electrical method (resistivity survey) is still most widely used due to its low cost and better diagnostic value (Satpathy and Kanungo, 1976; Chandra and Kumar, 1982; Rao and Rao, 1985; Singh. 1985; Bhattacharya et al., 1994). Ground penetrating radar (GPR) is a modern and sophisticated method of geophysical survey, which can scan the subsurface strata and generates visual profile of geological structure along the survey section (Davis and Annan, 1989; Smith and Jol, 1992; Wyatt and Temples, 1996). Therefore, to find out the impact of mining on hydrological regime of the area, detailed resistivity survey as well as GPR study have been conducted in both the mining zones, namely 1-Top and 2-Top following Beres and Haeni (1991). Since the mining leasehold area is very large, therefore, for discussion purpose only 1-Top mining zone has been taken into consideration. Locations of resistivity survey points and GPR survey lines in and around 1-Top mining zone are shown in Fig. 3. The operating principles of the two techniques and procedures adopted for field studies have been discussed below. Pumping test has also been carried out to know the aquifer characteristics following Soliman et al. (1997).

Resistivity Survey

Electrical resistivity method is based on the principle of measurement of physical parameter of the formations, namely the electrical resistivity (Keller and Frischknecht 1966; Kresic, 1997). The usual practice of conducting the geoelectrical surveys is to pass current into the ground by means of two electrodes and to measure the potential difference between second pair placed in line between them. From the value of the potential difference, the current applied and also the electrode separation quality turn the apparent resistivity is calculated. During the field studies universally accepted Wenner and Schlumberger configuration could be used. Depending on the objective of the study, three types of survey are conducted (Keller and Frischknecht, 1966; Bhattacharya et al., 1994), namely, (i) vertical electrical sounding, (ii) horizontal profiling and (iii) radial sounding.

Vertical electrical soundings will be able to give the sub-surface lithological information vertically down below at one location where it is conducted. These surveys are useful for identification of water bearing horizons (Chandra and Kumar, 1982) and estimation of salinity with reasonable accuracy. Horizontal profiling surveys are used for reconnaissance surveys (Flathe, 1955). These surveys could be conducted along the profile for a particular depth to enable resistivity variation in the lateral direction. These surveys are useful to delineate the aerial extent of structural features (Ghose, 1971) and water quality changes. Radial surveys have been conducted particularly to trace out the direction and extent of fault and fracture lineament (Singh, 1985).

Interpretation of resistivity data is done in two stages. In the first stage the data is interpreted in terms of physical parameters such as resistivity and thickness. In the second stage the interpreted result is correlated with the available geologic knowledge to arrive at the realistic picture of the subsurface (Mooney and Wetzel, 1956; Van Dam, 1965; Orellana and Mooney. 1966; Satpathy and Kanungo, 1976; Bhattacharya et al., 1994).

The resistivity survey has been conducted at different places around the open pits to cover surrounding villages and Mayem Lake. During the field study the Wenner and Schlumberger configuration are used as this is the universally accepted and the most widely used method. The survey has been conducted by vertical electrical sounding approach to get the subsurface lithological information and identification of water bearing horizons vertically down below the measurement points. The field data thus received are interpreted by the curve matching technique and bore hole data as well as sections provided by the mine management.

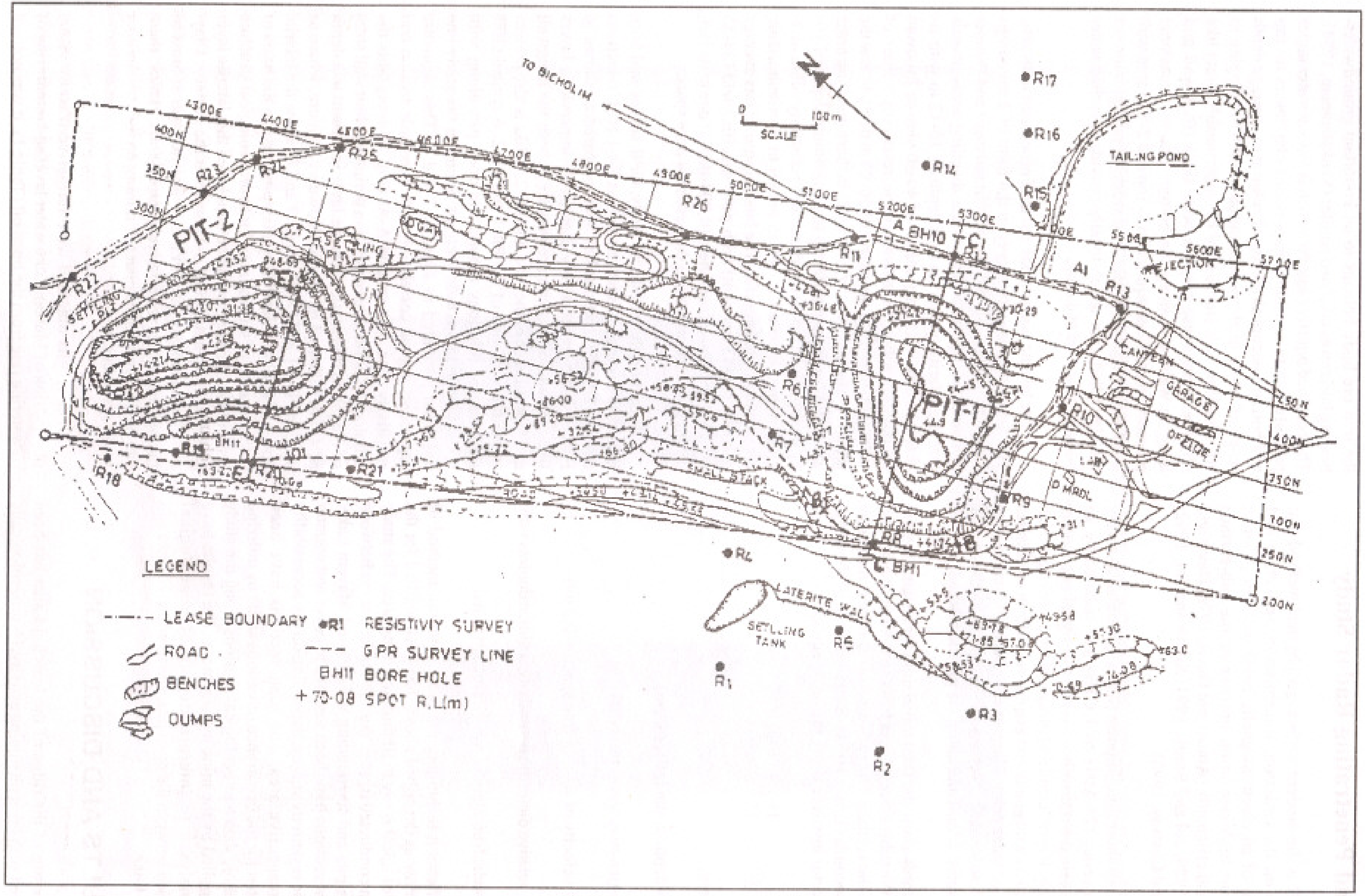

Fig. 3 : Surface plan of the mine showing the resistivity and GPR survey locations.

Ground Penetrating Radar Study

GPR is the modern surface-geophysical method that depends on the emission, transmission, reflection and reception of an electromagnetic pulse and can produce continuous high-resolution profiles of the sub-surface rapidly and efficiently (Annan and Davis, 1976; Davis and Annan, 1989; Jol and Smith, 1991; Smith and Jol, 1992; Annan and Cosway, 1992).

A very short time impulse (ns) is generated at a very high frequency (25 MHz to 1 GHz) and radiated by an antenna, called a transmitter. When the signal encounters an anomaly, it is reflected and picked up by a receiver, which transmits it to a magnetic and graphic recorder. It constitutes a "scan" or radar echo. The waves reflected by anomalies in the subsurface are observed successively with the regular displacement of antenna along the profile studied.

Records show the total travel time for a signal to pass through the subsurface, reflect from an inhomogeneity and return to the surface. The two-way travel-time is measured in nanoseconds (1 ns = 10^{-9} s). Determination of the depth to a reflector involves using the basic equations :

$$D = T\,(V/2)$$

& $$V = C/\,\varepsilon^{0.5}$$

where,

D = depth to the reflector (m)

T = two-way travel time (ns)

C = velocity of light in free space = 0.3 m/s

ε = relative dielectric permitivity, a dimensionless ratio

V = electromagnetic wave velocity (m/ns)

Reflection technique, the most common method of GPR survey as described above, has been applied for the hydrogeological study in Bicholim mining area. The study has been conducted to scan the sub-surface areas between the open pits and surrounding villages and Mayem Lake. Different sections have been scanned to cover and counter check the resistivity survey, depending on the accessibility in the respective area. The scan sections have been interpreted for the occurrence of various strata by utilizing the borehole data and geological sections along the study lines supplied by the mine management. The results have been analysed to interpretate any hydrogeological connection between the open pits, surrounding villages and Mayem Lake.

RESULTS AND DISCUSSION

The top of the ridge of the leasehold area has been associated with open pit mining activity. Hydrogeologically the iron ore body belongs to an important groundwater-bearing horizon as confined aquifer (Venkataraman, 1984). The confined aquifer (aquifer which is having water under pressure due to confining impervious clay layers on top and bottom) occurs along top of ridge at an average depth range of 20-45 m along inclination of 60°-70° dipping in NE direction. It is surrounded by impermeable strata like phyllite, manganese clay on both sides (foot wall and hanging wall) and along the bottom side by occasional presence in confined aquifer on 1-Top and 2-Top area with good yield of groundwater. The working pits do intersect the clay filled dike which locally provides perched water body as observed at 1-Top.

The laterite horizon has 3 sets of prominent joint sets. The detailed resistivity survey in the form of 2 soundings and 10 profilings with the use of Schlumberger and Wenner electrode configuration over these dwelling areas reveals that the laterite occurs up to a depth of 10-12 m with its characteristic resistivity values of 40-50 ohm-m followed by phyllite within its characteristic resistivity values of 100—300 ohm-m to the extent of 50-60 m depth below the ground surface. However, dug wells in these dwelling areas are in the confined aquifer up to a maximum depth of 10-11 m as deciphered by characteristic resistivity value of 7-20 ohm-m. These wells, which are all in laterite horizon, act as unconfined aquifer. The laterite aquifer has average porosity (34-43 per cent) with poor specific yield (24-35 m^3 /day) or storage coefficient (0.004-0.006) due to its lack of interconnection among the available pore spaces.

Based on the resistivity study, GPR survey and bore hole data geological sections across Pit-1 (C-C1 section) and Pit-2 (E-E1 section) has been prepared as shown in Figs. 4 and 5, respectively. Relatively impervious layers like clay and/or phyllite are present in both the hangwall and footwall side of the Pit-1 and Pit-2. A dike is also present in the footwall side of the Pit-1 and Pit-2. A typical GPR signature of lithology around the open pits along with resistivity and bore hole sections falling in the study line has been presented in Figs. 6, 7 and 8. This signature represents a good correlation with bore hole section and resistivity data. The section A-Al (Fig. 6) represents the lithology of north side correlation periphery (foot wall side) of the pit. In this section laterite layer is present to a depth of 4-5 m followed by phyllite/powdery iron ore, where as sections B-B1 and D-D1 (Figs. 7 and 8) show the laterite cover of 8-12 m followed by clay/phyllite. On the basis of interpretation of GPR survey for hydrogeological structure around the open pit, it may be concluded that laterite layer presents up to a depth of 4-12 m from the surface. Clay/ phyllites layers are present below laterite layer at most of the places, which are relatively impervious. Hence, there can be no significant impact of mining on the surrounding water resources.

The results obtained were further verified by visual observation of Mayem Lake water level and monitoring of dewatering rate from the open pit (Table 1). It was noticed

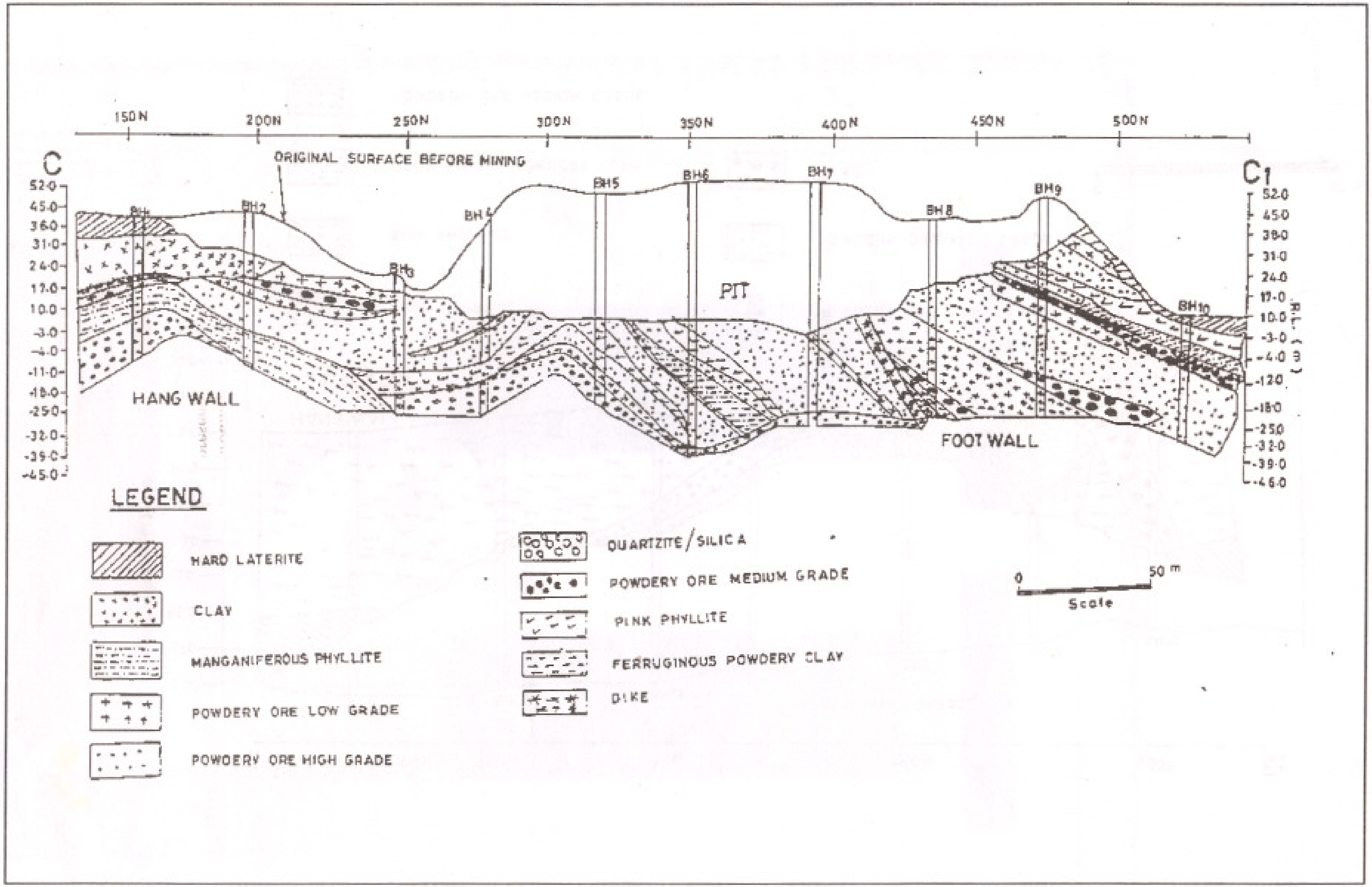

Fig. 4 : Geological cross-section along C-C1 including boreholes.

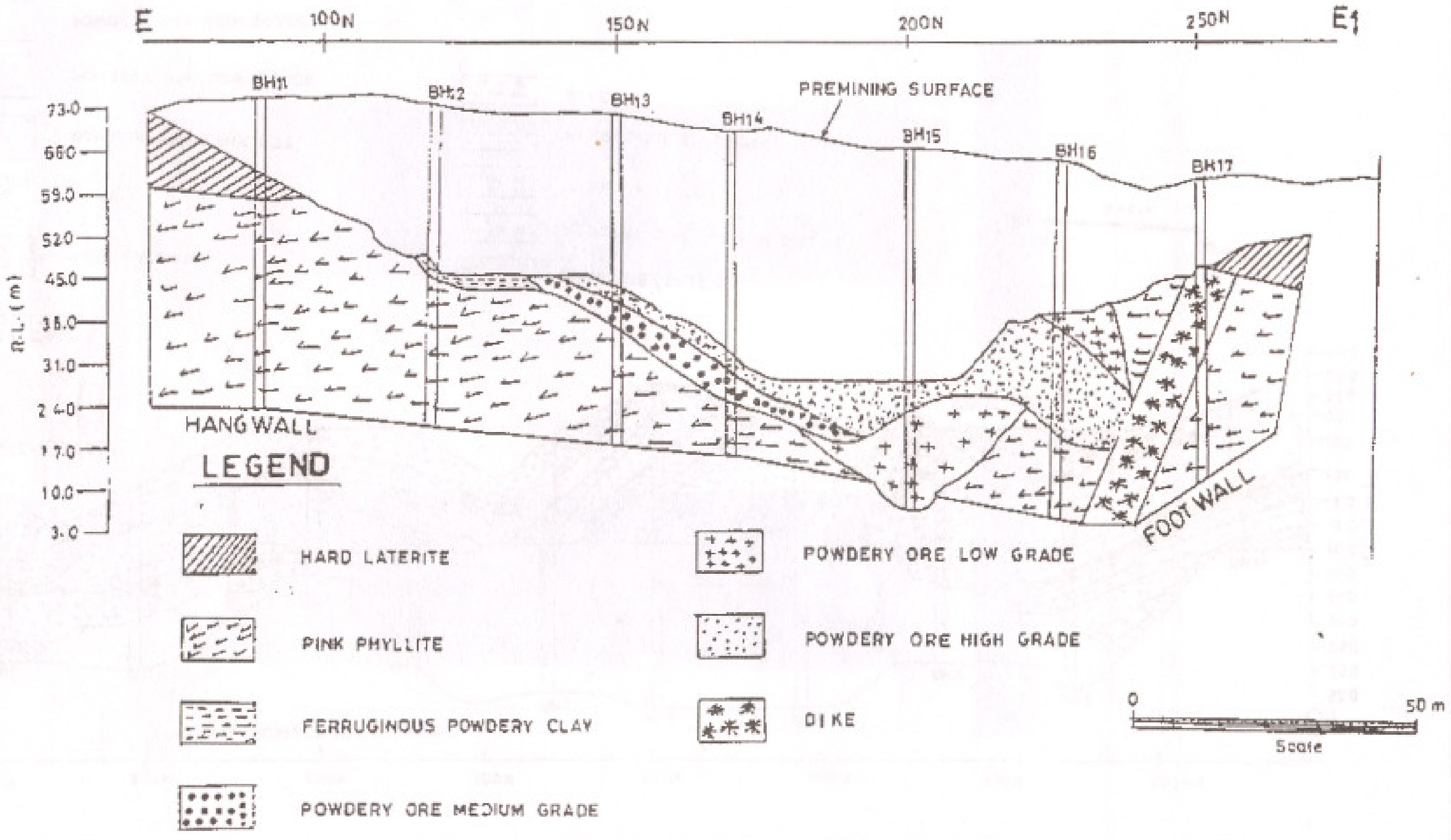

Fig. 5 : Geological cross-section along E-El including borehole data.

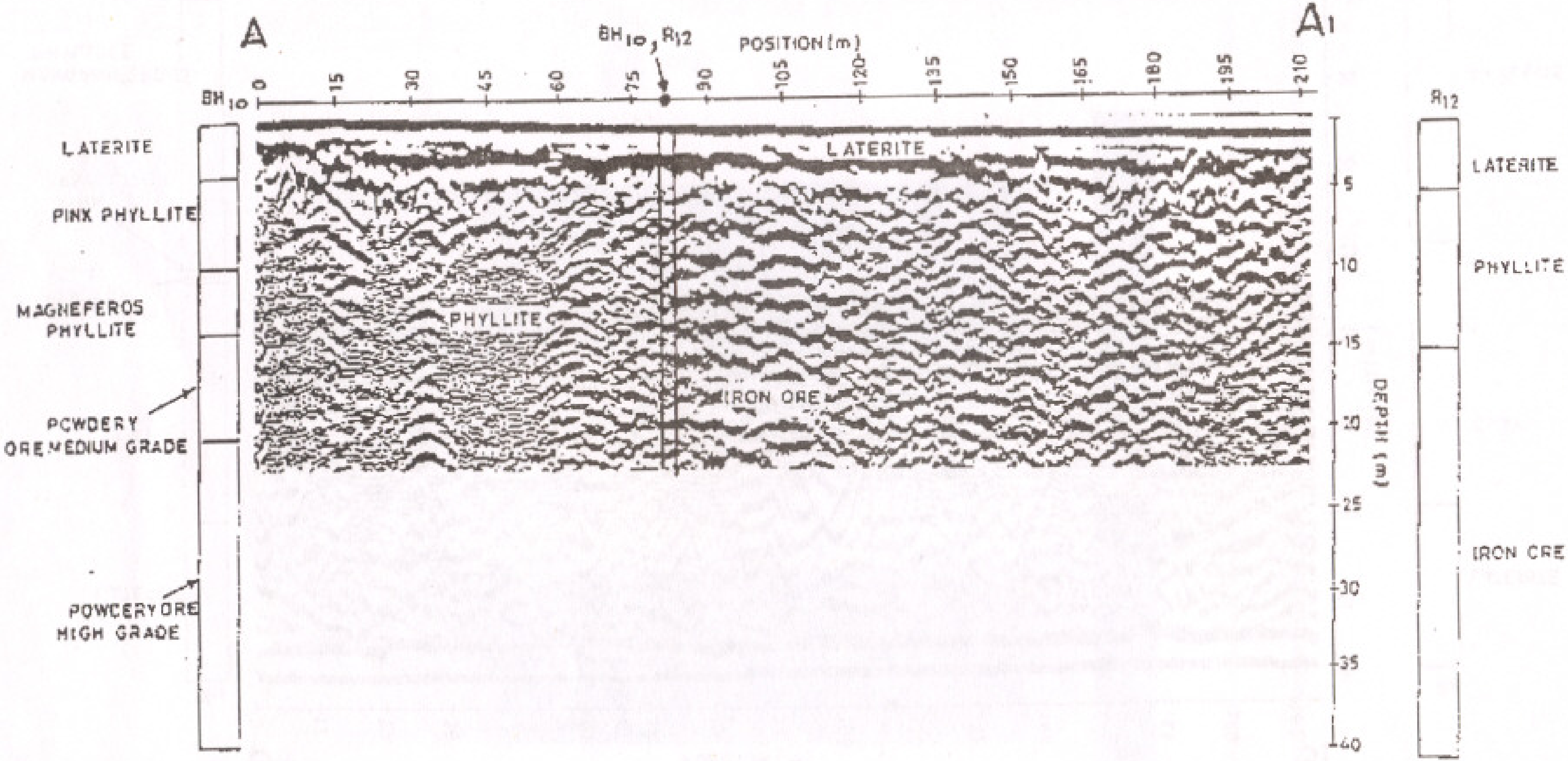

Fig. 6 : GPR signature along A-Al section including resistivity and borehole data.

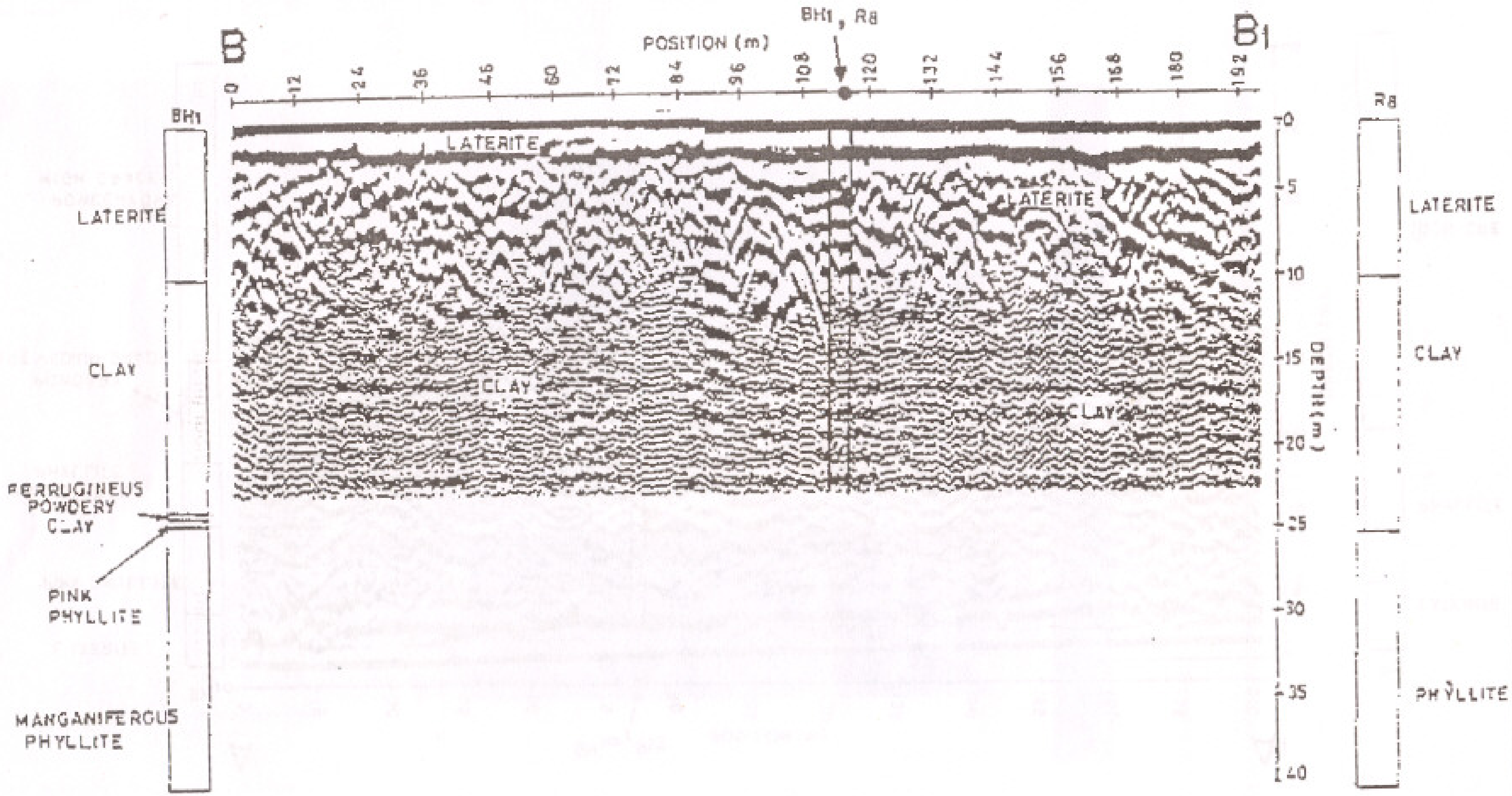

Fig. 7 : GPR signature along B-B1 section including resistivity and borehole data.

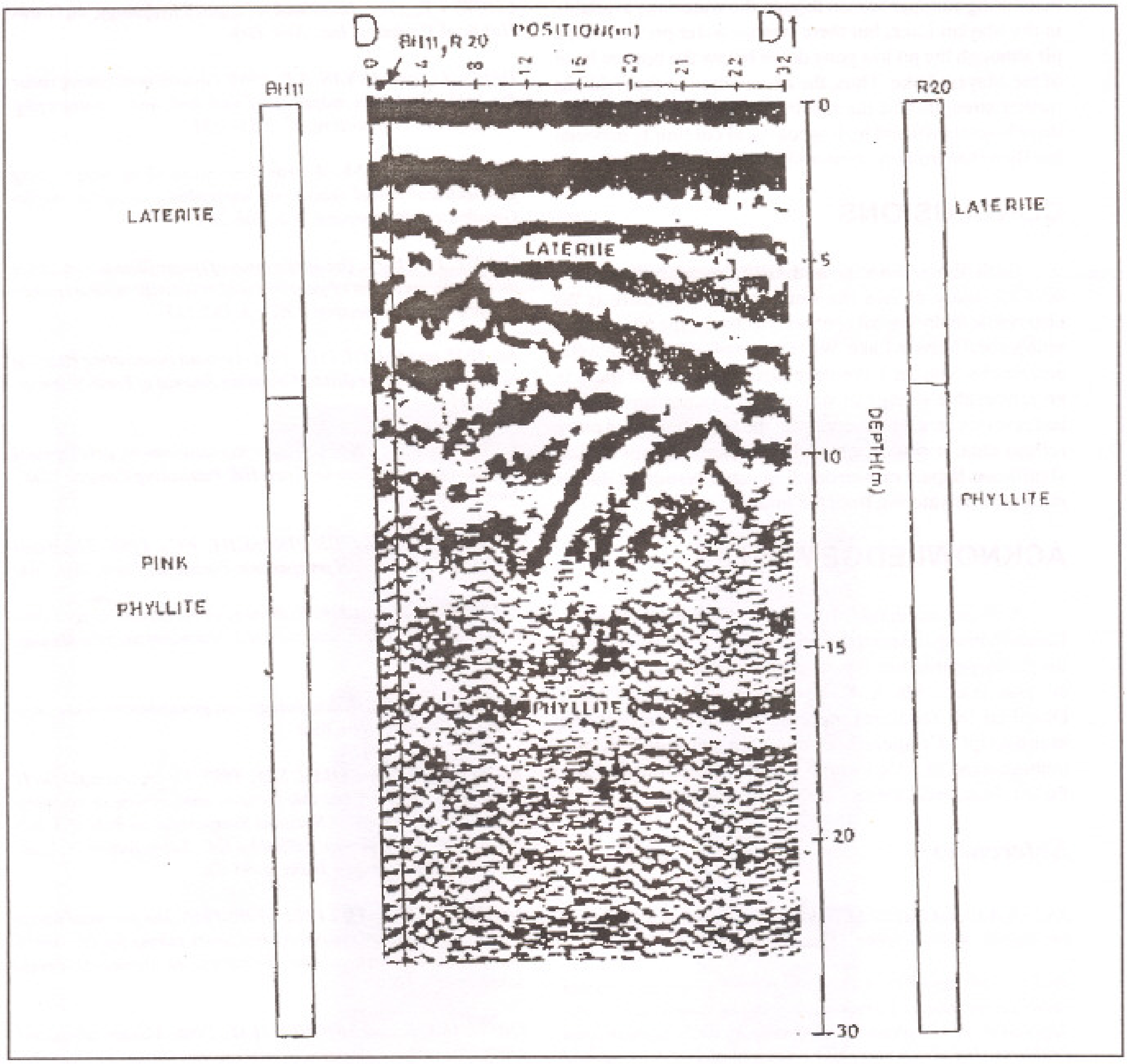

Fig. 8 : GPR signature along D-D1 section including resistivity and borehole data.

Table 1 : Details of dewatering from the Bicholim open pit

Month	Number of hours pump operated	Quantity per hour (m^3/hr)	Quantity of water pumped (m^3)	Monthly rain fall (mm)
June 1997	0	0	0	0
July 1997	472.15	180	84,987	1,180
August 1997	546.45	180	98,361	1,200
September 1997	300.00	180	54,000	1,000
October 1997	399.00	180	71,820	100
November 1997	369.50	180	66,510	0
December 1997	287.00	120	34,440	0
January 1998	227.00	120	27,240	0
February 1998	12.00	120	1,440	0
March 1998	0			
April 1998	0			
May 1998	0			
Total	**2613.1**		**4,38,798**	**3,480**

that during summer season though the water was available in the Mayem Lake, but there was no water present in the pit although the pit has gone down below the bottom level of the Mayem Lake. Thus, the observation in the field has further strengthened the result of geophysical study that there is no significant hydrogeological continuity between the Bicholim iron ore mine and Mayem Lake.

CONCLUSIONS

Both the resistivity and GPR investigation have depicted more or less the same results that there is no observable hydrological continuity between the pits, nearby villages and Mayem Lake. Water levels of surrounding wells and nearby Mayem Lake have also revealed that there is no remarkable change in water level fluctuations for the last several years. Therefore, from the two studies and other related data, it could be stated that there may not be any significant impact on surrounding water resources due to mining or dewatering from the mines.

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