

## **Borehole radar for delineation of unapproachable underground coal-mine galleries below Grand Chord railway lines**

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**There are chances of railway lines being unsafe and thus directly affecting the safety of persons and goods due to the presence of old, abandoned and inaccessible mine workings below them. In the past, about 21 galleries in the leasehold of Kunstoria and Satgram areas of the Eastern Coalfields Limited (ECL), West Bengal and 33 galleries in the leasehold of Mugma area of ECL were driven below the Eastern Railway on the Grand Chord Howrah–Delhi railway line between Andal and Dhanbad. The abandoned mine plans of most of these galleries are not available and as such the exact locations of the galleries were not known. Keeping the above points in view, the present study was taken up for delineating the inaccessible and unknown mine galleries using borehole radar near Rati-bati Colliery, Satgram area. A borehole radar survey has been conducted using an antenna frequency of 100 MHz along the six proposed railway sites. Six mine galleries were delineated in a radial distance varying from 4.5 to 5.0 m from the investigation boreholes and at the depths of 24, 27.5, 36.5, 51.5, 53.5 and 54.5 m respectively, from the surface. These mine galleries have been confirmed using direct non-coring drilling. It is also suggested that all mine galleries should be filled up with sand for the safety of the Grand Chord railway tracks in future.**

**Keywords:** Abandoned mines, borehole radar, coal-mine galleries, railway lines.

SAFETY of railway lines is important for any country. Due to the presence of old, abandoned and inaccessible mine workings, the railway lines may become unsafe and thus directly affect the safety of persons and goods. It is urgently required to delineate workings below railway lines and perform subsequent stability analysis. If found unsafe, remedial measures are to be evolved, recommended and suitably implemented. In the past, about 21 galleries in the leasehold of Kunstoria and Satgram areas of Eastern Coalfields Limited (ECL), West Bengal (WB) and 33 galleries in the leasehold of Mugma area of ECL were driven below the main line of the Eastern Railway on the Howrah–Delhi route between Andal and Dhanbad. The abandoned mine plan of most of these galleries are not available and as such the exact locations of the galleries

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are not known. Now, the stability of railway lines becomes a burning problem for the Railway and ECL managements, although no incidences of subsidence/strata movement affecting these important railway lines have been reported yet. The following points have been considered as 'words of caution':

- The galleries developed are now inaccessible and abandoned. The plans and other relevant geo-mining details are not reliable.
- Some galleries might have collapsed, but this did not extend up to the surface. A question arises as to whether the collapse of roof in the galleries, assuming no support resistance available to it, will extend eventually to the surface affecting railway lines or not.

Keeping the above points in view, the present study was taken up for delineating six inaccessible and unknown galleries below the railway track near Ratibati Colliery, Satgram area. Borehole radar surveys were conducted along the six proposed railway sites.

The study area is situated about 180 km northeast of Kolkata. Kuardi Colliery near Ratibati Colliery is situated 10 km east of Asansol, WB. The Eastern Railway main line (Grand Chord line) is on the northern boundary line of the property and 5 km south of GT Road. The proposed survey sites lie in Kuardi Colliery (near Ratibati Colliery). The boundary of Kuardi Colliery is described as follows:

- Along north by Eastern Railway line between Asansol and Raniganj.
- East – fault line demarcating Nimcha Colliery.
- South – Damodar River.
- Southwest and northwest and west – Dumra colliery (waterlogged).

The Kuardi Colliery has two major NS faults, with throw ranging from 15 to 25 m. The mica-peridotite dyke present has a thickness of about 14 m, including Jhama running in the middle of the property from west to east.

The present coal-mine workings are limited to Nega and Ghussic seams (Table 1).

The Kuardi Colliery has a long history. The shape of the colliery has changed with time and with change in management. At one time, the colliery was on both sides of the Eastern Railway main line. The old workings of

Ghusick seam were developed long before nationalization and partially depillared and there are six galleries under the railway line (Figure 1). The dip side has been worked through galleries. The area has been developed and partly depillared and rest of the workings have been left abandoned. There are six inaccessible mine galleries below the railway line, which cross each other and lie between pit nos 1&2 and pit nos 11&12 (Figure 1)<sup>1</sup>. The seam was developed by bord and pillar method. The dimensions of the galleries are unknown. According to the mine management, the expected width of the galleries varies from 3 to 5 m and the height varies from 3 to 3.2 m. The depth of cover varies from 24 to 55 m. In this area, the main lithology is soil, sandstone, shaly-sandstone, intercalation of shale and sandstone, shale and coal seam. Due to the presence of upper conductive layer shale above the coal-seam, surface GPR survey was unsuccessful for delineating the inaccessible coal-mine galleries below the railway line in Kuardi Colliery. Therefore, borehole radar surveys were carried out along the six proposed profiles (Figure 1) for delineating inaccessible mine galleries below the railway lines near Ratibati Colliery.

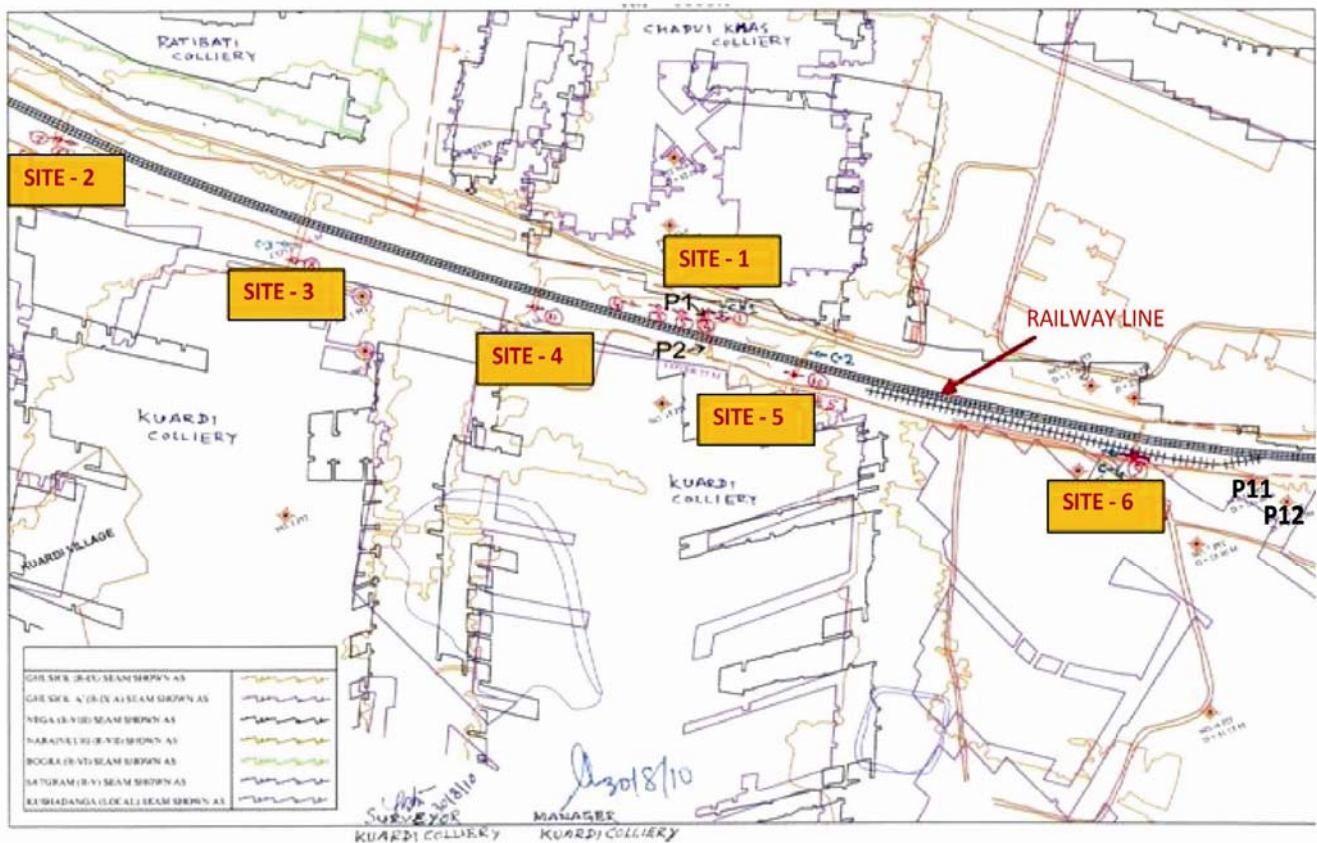
Geophysical techniques are routinely used to detect abandoned mine workings. The success of the applied geophysical methods depends on the success of detection of anomalies that are associated with the presence of a concealed mineshaft. The presence of an anomaly in the survey area depends on the physical dimensions, size and depth of the mineshaft, and the physical contrast of the shaft in relation to the surrounding material<sup>2</sup>.

Several experimental results demonstrate the applicability of radar methods to mine-related subsidence problems, and show that a more complete characterization can be achieved by employing both borehole and surface radar methods<sup>3,4</sup>. For detection of voids or cavities, borehole GPR is more suitable method. Single-borehole method (dipole arrangement) can be used for this purpose. However, if the cavity is far away from the borehole, then it will not come into the picture and also using this arrangement, it is difficult to estimate the size of the cavity<sup>5</sup>. So cross-hole tomography is suitable for detection and size estimation of voids or cavities. In the granite quarry, the freshness of rock and distribution of fractures are useful in evaluating the quality of rock and making future plans of quarrying. In coal mines, it is also required to detect fractures ahead of the mine for safety purposes. In this regard, an investigation/evaluation of the quarry mines is required. But there are two inherent problems in these applications. Due to omni-directional characteristic of borehole radar, we do not know the azimuth of reflectors in the reflection images. To obtain this information, direction-finding antenna can be utilized, but its use is limited because of very weak signal level<sup>6</sup>.

Borehole radar is based on the same principles as ground penetrating radar (GPR) system for surface use, i.e. it consists of a radar transmitter and receiver built

**Table 1.** Mining details of Kuardi Colliery

Seam	Thickness (m)	Depth of cover (m)	Depth of coal seam (m)
Ghusick IX	3.0	25	25–60
Ghusick IX A	2.7	45	45–120
Nega VIII	4.27	100	120–180



**Figure 1.** Combined plan showing the outline of six sites of underground workings around Grand Chord railway line near Ratibati Colliery, Satgram area, Eastern Coalfields Limited, West Bengal.

into separate probes. These probes are connected via a cable (optical or coaxial) to a control unit used for time-signal generation and data acquisition. The data storage and display unit is normally a laptop computer, which is either an integral component or is built into the circuitry of the control unit. Borehole radar instruments can be used in different modes: reflection, cross-hole, surface-to-borehole and directional mode. The systems available now use centre frequencies from 20 to 250 MHz. Radar waves are affected by soil and rock conductivity. If the conductivity of the surrounding medium is more than a certain value, reflection radar surveys are impossible. In high-conductivity medium, the radar equation is not satisfied and no reflections will appear. In crosshole and surface-to-borehole, radar mode measurements can be carried out in much higher conductivity areas, because no reflections are needed. Important information concerning the local geologic conditions is evaluated from the amplitude of the first arrival and the arrival time of the transmitted wave only, not a reflected wave. In the present study, dipole reflection mode of borehole radar has been used.

In reflection mode, the radar transmitter and receiver probes are lowered in the same borehole with a fixed distance between them and displaced stepwise along the

measured interval. For each position, an electromagnetic (EM) impulse is generated by the transmitter antenna. Discontinuities in the rock or soil around the borehole, like contacts between the layers, voids and fractures reflect part of the incident energy back to the receiver. The resulting signals are displayed in a way similar to reflection seismics, giving an image of surrounding rock mass.

In this mode an optical cable for triggering of the probes and data acquisition is necessary to avoid parasitic antenna effects of the cable. The most commonly used antennas are dipole antennas, which radiate and receive reflected signals from a 360° space (omni-directional). Borehole radar interpretation is similar to that of surface GPR data, with the exception of space interpretation. In surface GPR surveys, all the reflections originate from one half space, while the borehole radars receive reflections from 360° radius. It is impossible to determine the azimuth to the reflector using data from only one borehole if dipole antennas are used. What can be determined is the distance to the reflector and in the case where the reflector is a plane, the angle between the plane and the borehole. As an example, let us consider a fracture plane crossing a borehole and a point reflector next to the same borehole. When the probes are above the plane, the

fracture reflections from the upper part of the planes are imaged, in this case from the left side of the borehole. When the probes are below the plane, reflections from the bottom of the plane are imaged, in this case the right side of the borehole. Figure 2 shows the two sides of the plane. A point reflector shows up as a hyperbola, in the same way as a point reflector appears in surface GPR data. Interpreting dipole radar data from a single borehole, an interpreter cannot give the direction to the point reflector, but can interpret only the distance to the source. In order to estimate the direction to the reflection, data from more than one borehole need to be interpreted.

High soil resistivity value (low conductivity) is the most important factor for successful borehole radar measurements. Above 100 Ohm m, borehole radar is usually a good method. Between 50 and 100 Ohm m, conductivity needs to be accounted for, especially if it is close to the lower limit. Below 50 Ohm m, severe limitations on penetration capabilities will occur and at 30 Ohm m and less, borehole radar is not a good technique. Figure 3 displays a typical radar response from Kuardi Colliery, where we have very limited penetration in the sandstone above and below the coal seam. Note that the resistivity values in the figure are only estimated from the empirical experience we have from the use of borehole radar antenna (100 MHz). It is only in limited parts in the sandstone that the receiver can detect the direct wave from the transmitter.

Depth of target is another important factor to be considered for calculation. Even if this depends on the resistivity of the soil, the depths to the target have a large impact due to the antenna frequency (wavelength). In practice, the result can be that a low-frequency antenna can penetrate to the target depth, but the resolution is not good enough to obtain reflections from the target. On the other hand, a high frequency antenna that has the capacity to detect and resolve the target will fail due to lack of penetration.

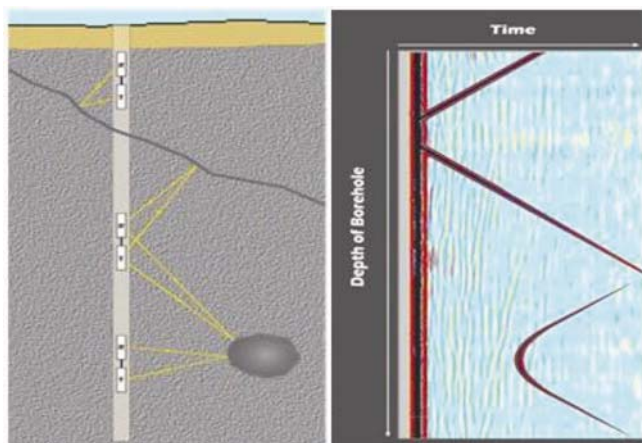


Figure 2. Operating principle of dipole-reflection mode of borehole radar system.

The complexity of the studied site is most often an underestimated factor for successful results from GPR measurements. At sites containing too many obstacles and if they are arranged in a way which makes it impossible to resolve the individual targets, this may be a severe limitation. For this trial with the borehole radar, several tunnels close by the investigation borehole will make the interpretation difficult. Radar dipole antennas (100 MHz) can only determine the radial distance up to 10.0 m on either side to the closest tunnel from the investigation borehole, depending on the surroundings geological environment as shown in Figure 3.

The result from radar measurements is often presented in the form of a radargram in which the position of the probes is shown along one axis and propagation is shown along the other axis. The amplitude of the received signal is shown in the radargram with a grey scale, wherein black colour corresponds to the large positive signal, white colour to the large negative signal and grey colour to no reflected signals. The data presented here are adjusted for the measurement point of the borehole antenna. The measurement point is considered to be the central point between the transmitter and the receiving antenna.

Two basic patterns to interpret in borehole measurements are, point and plane reflectors. In reflection mode, borehole radar essentially gives a high-resolution image of the rock mass, showing the geometry of planar structures, which may or may not intersect the borehole (contact between layers, thin marker beds, fractures, etc.), or the presence of local features around the borehole (cavities, lenses, etc.). The distance to a reflecting object or plane is determined by measuring the difference in arrival time between the direct and reflected pulses. The basic assumption is that the speed of propagation is the same everywhere.

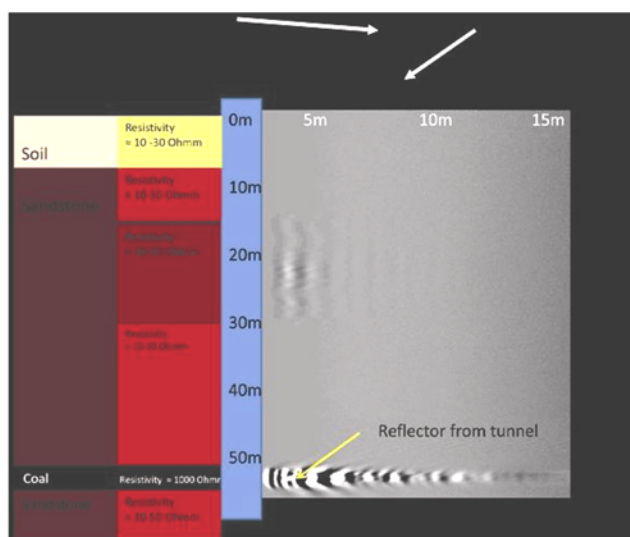


Figure 3. BHR profile of Kuardi Colliery.

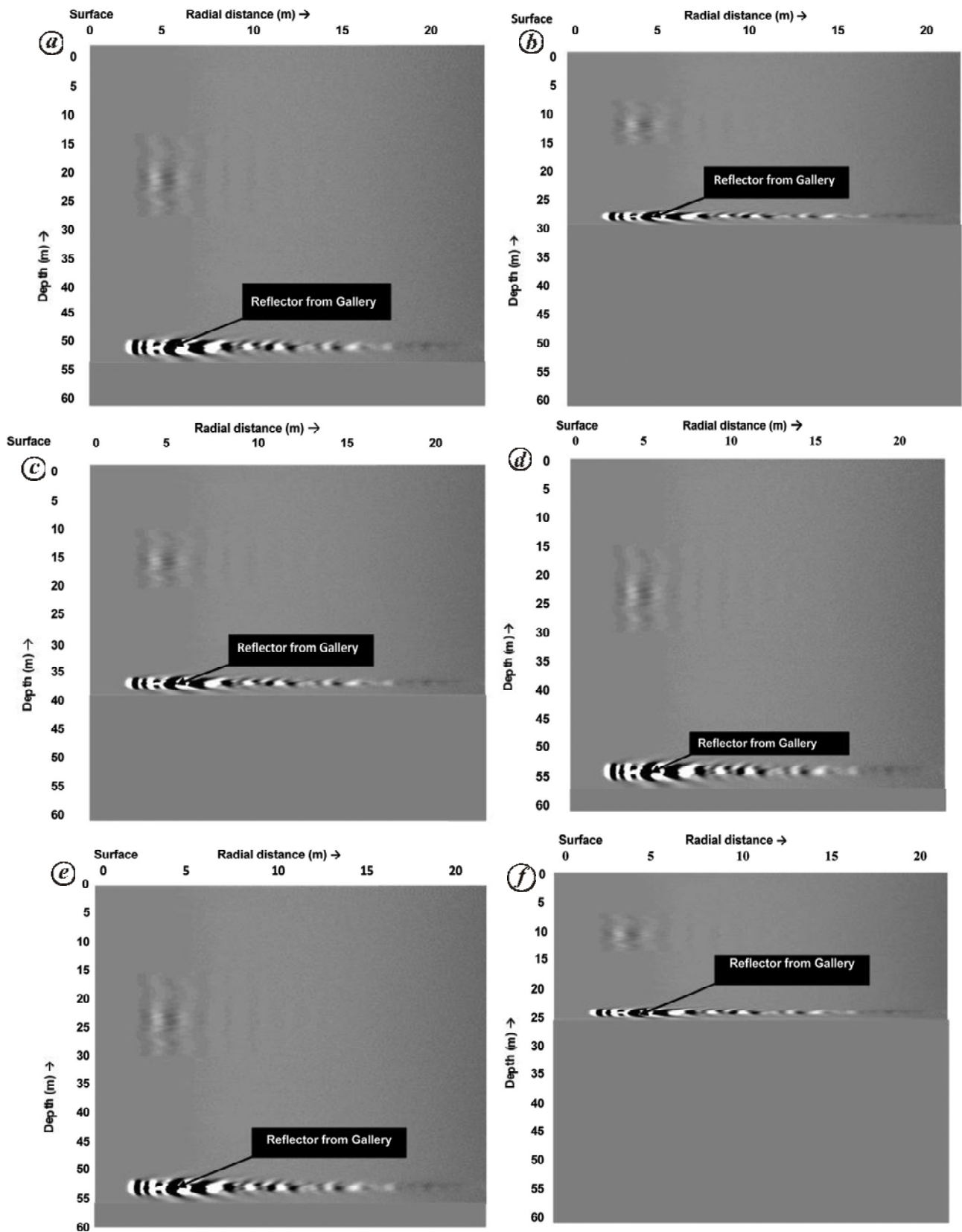


Figure 4 a-f. Vertical radar profile from mine gallery at a, site no. 1; b, at site no. 2; c, at site no. 3; d, at site no. 4; e, at site no. 5; f, at site no. 6.



**Table 2.** Borehole radar survey results showing coal-mine galleries at different depths and the non-coring boreholes that confirmed their presence

Site no.	Depth (m) of galleries using borehole radar	Non-coring boreholes no. used to confirm the mine galleries	Depth (m) of different drilled boreholes	Dimension (m) of the galleries according to mine management (estimated)
1	51.5	BH-1	55	3.0 × 3.5 × 5.0
2	27.5	BH-7	30	3.0 × 3.5 × 5.0
3	36.5	BH-8	40	3.0 × 3.5 × 5.0
4	54.5	BH-11	55	3.0 × 3.5 × 5.0
5	53.5	BH-10	55	3.0 × 3.5 × 5.0
6	24.0	BH-9	25	3.0 × 3.5 × 5.0

In this study, velocity determination was not possible because the coal seam was very thin. For radial distance assumption, we have used a velocity of 130 m/μs based on empirical knowledge from other coal projects. For the processing and interpretation of radial distances to the mine gallery, the Mala software Radinter has been used. Figure 4a–f shows the borehole radar survey results along six different railway sites. Only in the coal seam, the radar penetrates and can obtain reflections from the surroundings. An electrically conductive environment like shale/sandstone at the site causes attenuation of the radar wave, which in turn decreases the penetration. In this case, we hardly get any penetration in the shale/sandstone, which results in decreased possibility to distinguish structures in the sandstone that otherwise could give reflections.

In coal the penetration is surprisingly good, indicating resistivity values of more than 1000 Ohm m. The limitation is related to the thin coal seam (3 m) in relation to the distance (2.75 m) between the transmitting and receiving antenna parts. Thus the reflected energy from the gallery (point source) does not show up in the radargram as clear hyperbolas. It is only possible for the radar to get reflections from the closest gallery wall during approximately 1 m logging. This makes the interpretation difficult, and mistakes may arise if the coal seam is not homogenous.

Table 2 provides a summary of the borehole radar survey carried out along the railway line at the six sites. At site 1 (Figure 4a), radar reflections are obtained at a depth of 51.5 m due to presence of a coal seam and hyperbolic structure at 51.5 m depth indicates a void, in the mine gallery. This mine gallery was confirmed by direct borehole drilling (BH1).

Similar borehole radar survey has been carried out along the railway line at sites 2–6 (Figure 4b–f). Radar reflections from coal seams and galleries in each of these sites have been confirmed by direct bore hole drilling (Table 2).

Based on the results and analyses of the data recorded during delineation of mine galleries using borehole radar system at six sites below railway lines near Ratibati Colliery, the following salient points and conclusions can be drawn:

- Six mine galleries are delineated below railway lines using borehole radar survey at depths 24, 27.5, 36.5, 51.5, 53.5 and 54.5 m respectively.
- These mine galleries have been confirmed by non-coring drilling of boreholes nos BH-9, BH-7, BH-8, BH-1, BH-10 and BH-11 respectively.
- It is suggested that all mine galleries should be filled up with sand for long-term stability and prevention of any damage to the Grand Chord railway line near Ratibati colliery.

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