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THE HYDROGEOLOGY OF THE KUTESHWAR LIMESTONE DEPOSITS, MADHYA PRADESH, INDIA

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Geological and hydrogeological studies of an aquifer in the Kuteshwar limestone deposit area, Madhya Pradesh, India show a highly cavernous and karren limestone on the left bank of the Chhoti Mahanadi River, while the right bank consists of thick porcellanite deposits in addition to the limestone. These thick porcellanites are practically impervious silts and clays that act as barriers to surface and subsurface water flow. Though the limestone deposits show easterly dips, subsurface water flow from the river into the mined areas, which are located on the eastern side of the river and the barrier, is insignificant. Thus a large number of shear zones, faults and karren structures developed in the mining region east of the porcellanite barrier became isolated. These investigations, and inferences from earlier studies, reveal that groundwater flow is controlled by intensely developed conduits in the western part of the area. In the eastern part, flow is controlled by aquifers that consist of two major formations, limestone with various degrees of karstification and fractured porcellanite. Aquifer thickness varies enormously and this variation contributes significantly to the spatial variability of aquifer parameters.

INTRODUCTION

Limestone deposits of the Kajarhat series of the Vindhyan Super Group, which occur in the Chhoti Mahanadi river basin near Kuteshwar (Lat. 24º6'7"; Long. 80º49'; Survey of India topo sheet No. 64 A/8) about 60 km NNE of Katni town, Madhya Pradesh, India, form a single large reserve of about 800 million tons of high grade material used in the steel industry. As a result of dam construction about 50 km downstream of the Chhoti Mahanadi river passing through the deposits, large areas will be submerged by back water. Efforts are being made to protect these valuable deposits from submergence by constructing a wall, or ‘bund’ in eastern parts of the river around the reserves passing through three mines, the Marwa, Joraroda and Garitalai. The ‘bund’ will also create safe open cast mining conditions restricting subsurface water flow into mines through subsurface cavernous/ karstic zones. The ‘bund’ referred to here is a wall on the surface of varying height with a 40 m grout curtain in the subsurface. A geological and hydrogeological reconnaissance was carried out to determine the subsurface flow regime in the area.

GEOLOGY OF THE AREA

The area comprising Marwa, Jararoda, Garitalai and Kuteshwar blocks of Katni tehsil, Jabalpur district consists of economically significant limestone deposits belonging to Semri and Vindhyan Super group (Table 1). These villages lie on the northern limb of an anticlinal fold with an E-W tending axis. The limestone deposits are exposed in the core portion of anticline. They are overlain by porcellanites and underlain by sandstones, schists and basement gneisses (Figure 1). These limestone series, which have a maximum thickness of about 300 m, are divided into three units (i) a lower flat-bedded unit, (ii) a conophyton type of stromatolitic unit, and a (iii) flat stratifera type unit with easterly dips of 5º-20º. They exhibit vertical jointing in the NW-SE and NE-SW directions. The biotic constitution and sedimentological characters of this rock type suggest a lagoonal deposition.

Table 1. Geological Succession of the Study Area

Age	Group	Formation	Lithological description
Recent	--	--	River alluvium, pisolitic soil and laterite
===== Unconformity =====			
Cambrian	--	Porcellanite	Chert, massive fine grained siltstone; sub-greywacke fragments; well laminated carbonaceous shale with occasional bands of argillaceous/siliceous limestone
===== Unconformity =====			
	Vindhyan Super Group	Kajarhat Limestone (KuteswarLimestone) Kudri formation (basal Stage I)	Dolomitic limestone, stromatolitic limestone and flat bedded limestone Laminated shale with chert bunds
===== Unconformity =====			
Pre-Cambrian	Bijawar Group	--	Micaceous phyllites, kaolinized, intruded by quartz veins

The Kuteshwar limestone exhibits Karren features with exo-karstic characters such as solution pinnacles, notches, flute karsts, and solution karren. The Chhoti Mahanadi river, leaving its paleo channel, presently flows across the karren fields as an allocthonous river. It is also observed that during the 6 km through Karst terrain, there is a nominal loss of 2% in discharge (Romani and Verma, 1985). Beyond the karren fields, the area east of the river is mostly covered with inorganic plastic and silty clay with permeability values ranging from 0.1 to 555.0 ft/yr (Romani and Verma, 1985). The Kuteshwar karst is a deep karst with karst baron conditions at shallow depths (Mishra 1985). Hydrologically active joints are noted to exist only at depths below about 320 m. Direct inter connection between the river and shallow dug wells in the Marwa area is not indicated (Romani and Verma, 1985).

The geological and hydrogeological conditions of the area confining the Kajarhat limestone deposits was studied by Mishra (1985), Romani and Verma (1985), Breznik (1984), and Singh (1985). A brief description of the geological and hydrogeological setting of the area follows.

HYDROLOGICAL CONDITIONS

Geomorphology

The area lying in and around Marwa exhibits an undulating terrain with isolated mounds and hillocks rising to an elevation of 355 m above mean sea level (amsl). Romani and Verma (1985) point out the existence of a N-S topographic divide. West of this divide, the slope is towards the west and northwest. To the east, the slope is towards Joraroda nala, a tributary of Chhoti Mahanadi river.

Groundwater flow

Romani and Verma (1985), on the basis of data collected from the weekly water level measurements carried out during May 1984 to Feb 1985, inferred that the elevation of the water table ranges between 325-330 m amsl, and further inferred the existence of a groundwater divide trending roughly parallel to Chhoti Mahanadi river about 1 km to the east of the river. This divide coincides with the isolated hillocks that reach an elevation of 345 m to 350 m amsl between the Marwa and Joraroda villages.

The groundwater level fluctuations during June to September 1984 recorded in the areas on either side of the water divide reveal that the water level fluctuation in the area west of divide varied between 2.80 and 3.25 m, whereas it generally exceeds 5 m in the area east of the divide with a range of 3.65 and 7.23 m. This variation is attributed to the variation in porosity of the aquifers. The pumping tests carried out in some of boreholes located on either side of the divide reveal that the permeability is high in areas west of groundwater divide (up to 925 ft/yr), while it is very low, generally less than 4 ft/yr, in areas located east of the divide.

Hydraulic characteristics of Kajarhat limestone aquifer

Continuous pumping for 25 hours with constant discharge of 461 m^3 /day (about 5 lps) in OW-3 resulted in a drawdown of only 0.244 m in the pumped well and insignificant drawdown in the observation wells OW-1 (47 m away) and PZ-3 (38 m away). The computed transmissivity value is 1590 m^2/day. The drawdown after pumping for 1000 minutes with 10 lps discharge in wells of group 6 located on the southern portion of the bund at Marwa resulted in only 0.556 m of drawdown. The computed transmissivity is 3860 m^2/day and the hydraulic conductivity of the first cavernous zone is 337 m/day (Romani and Verma, 1985). Wells of group 12, northeast of the bund have shown a drawdowns of 0.89 m in the pumped well after 1000 minutes of pumping with a discharge of 10 lps. On the basis of these data it is inferred that the shallow and deeper aquifers are interconnected through fissures and solution channels in areas lying adjacent to the river and west of the groundwater divide. In addition to these pumping tests, Table 2 shows values of permeability from percolation tests conducted in most of the shallow wells.

Hydrochemistry

The groundwater in the study area is colorless, odorless and exhibits a slight alkaline pH values ranging from 7 to 8.1. Chemical analysis of groundwater collected from a large number of bores reveals that it belongs to the bicarbonate type.

Table 2. Permeability Values obtained from the Percolation Test

Bore hole No.	Depth of the well in m	Permeability in m/day	
		Minimum	Maximum
R-6	47.0	0.28	0.34
R-7	57.0	0.32	0.43
R-8	50.6	0.34	0.41
R-9	46.0	0.06	0.25
R-10	40.5	0.14	0.39
R-11	47.5	0.04	0.12
R-12	58.0	0.37	0.44
R-13	52.0	0.30	0.46
R-16	47.5	0.34	0.77
R-17	46.0	0.18	0.28
R-18	66.1	-	0.29
4-A	40.0	0.002	0.003
4-B	40.0	0.008	0.12
4-C	40.0	0.001	0.004
4-D	40.0	0.00008	0.003
10-A	40.0	0.042	0.217
10-B	40.0	0.083	0.208
12-A	50.0	0.058	0.240
12-B	50.0	0.100	0.250
15-A	50.0	0.041	0.280
16-A	80.0	0.008	0.075

STUDY RESULTS

Geological and hydrogeological conditions

The area lying to the west of Chhoti Mahanadi river (left bank) consists of scattered siliceous and ferruginous rounded pebbles up to a distance of about 300 m from the river. This suggests that the Chhoti Mahanadi river has changed its course towards the east and the level of erosion has decreased from 340 m to the present 313 m. Huge limestone outcrops with karstic structures are also observed on either bank of the river. The remaining area encompassing the Marwa, Joraroda and Garitalai mine pits is mostly covered with thick pisolitic soil, yellow plastic clays, and alluvium with reworked porcellanites. Limestone outcrops are scarcely observed (Figure 1).

Thick porcellanite formations comprising mostly shales and silty shales are observed north of the Garitalai mine, in an area extending more or less up to the eastern boundary of Marwa mine and extending to the north up to a small nala flowing east of Joraroda mine. This northwest flowing stream joins with another Southwest flowing stream, and together they flow in a western direction for some distance and take a sudden turn due north. These porcellanites show a N70^{o}E trend and dip 15-20^o NW. Jointing is prominently observed of N70^{o}E, N40^{o}E and east-west directions. Joints which are developed at N70^{o}E are very widely spaced, while those developed in N40^{o}E are closely spaced.

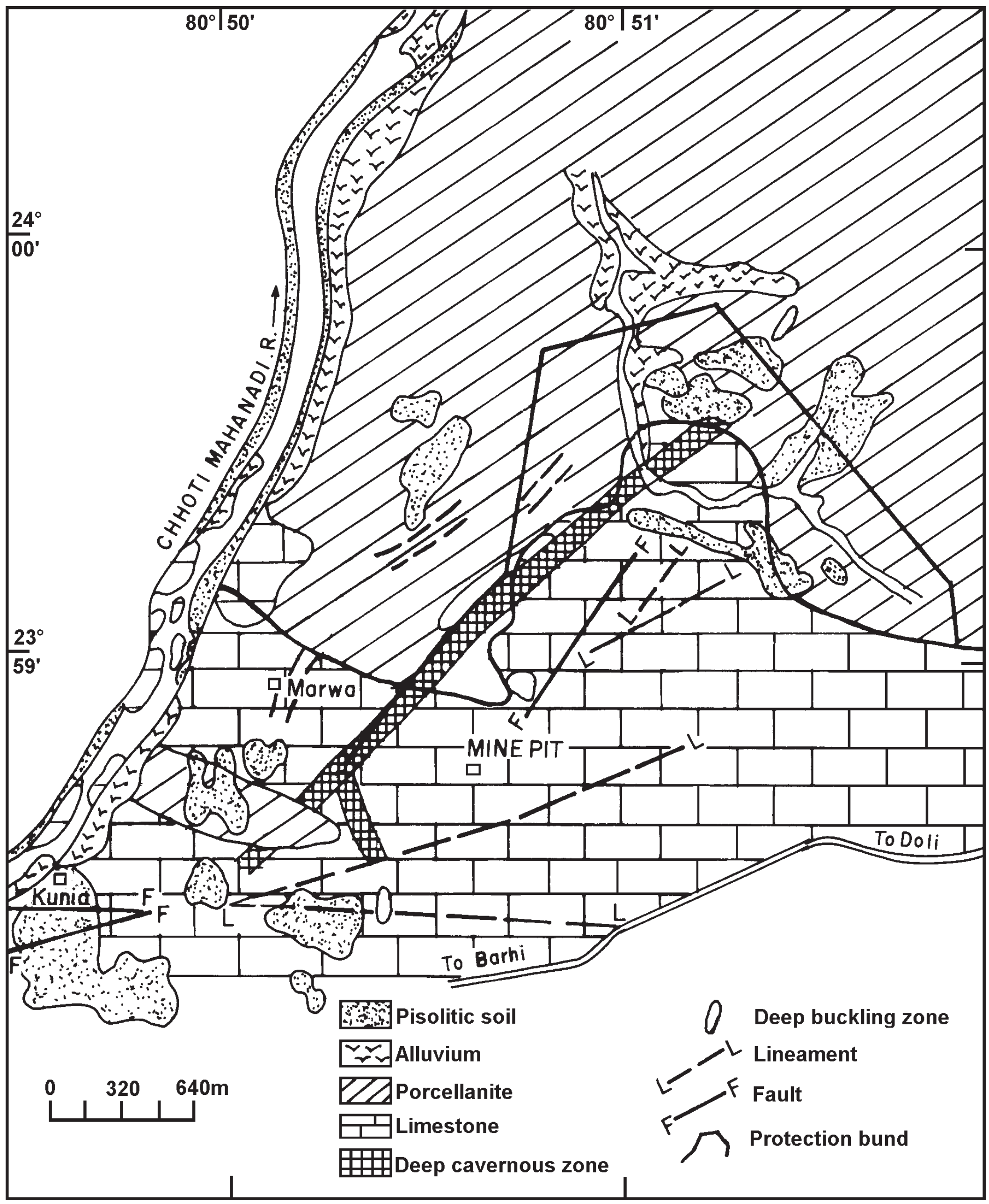

Figure 1. Geology of the area.

Older limestone formations occupying the central portions of the fold are found all along the fold axis due to erosion. Jointing observed in limestone formations are more or less identical with those developed in porcellanites, suggesting that the disturbance occurred only after the emplacement of limestone sequences. A number of collapsed circular holes of 10 to 20 ft diameter and 8-10 ft depth are observed on the western side of the above small nala lying NW of Garitalai mine. A few collapsed linear holes about 40'-50' long are also observed. A couple of meters south of the nala, huge outcrops of highly karstified limestone about 10 m high are observed. The paleo karst is of the pinnacle type, standing as huge pillar-like structures, through which a person can easily pass. Not only surface karstic structures, but also subsurface karstic structures, are seen in Marwa and Joraroda mine pits.

The Marwa mining pit, the biggest and deepest among the three open cast mines located in the area, shows a 4 m long cavernous zone at about 20 m deep. This zone is filled with yellowish clayey material. Many such cavernous zones are observed all along the tectonically disturbed zones. Weaker zones of limestone are inundated by water solution activity along fractures, converting them into softer yellowish limestone, and ultimately into a yellow ochre/clayey material. At places hollow cavernous zones are also noticed, in addition to the yellow clay filled karstic zones. Overburden thickness in the mine pits varies from 0 to 10 m. Thicker overburden comprising mostly soil and porcellanitic material is observed around the Marwa mine extending to the Garitalai mine to the east, and the Joraroda mine to the north.

Open anticlinal folds and drag folds are abundant. Some show plunging to the NW. An open fold with axis trending N75^{o}E is observed near the A-9 borehole located on the proposed 'bund', where a shear zone is also observed and the presence of a subsurface cavernous zone is suspected. Engineers working on the construction of the protection bund at this location report a cavernous zone exists starting from a depth of 20 m, which is corroborated by the quantity of cement consumed in the process of pressure grouting.

Subsurface geology

The subsurface geology of the area is inferred from the study of borehole logs located as shown in Figure 2.

Boreholes of the R series are drilled along the eastern bank of Chhoti Mahanadi river, but a few of them are also drilled north of Marwa village (Figure 2). Lithologic logs show three layers, namely pisolitic soil on the top and limestone at deeper levels. Limestones are overlain either by porcellanites or soil of varying thickness. Porcellanite of varying thickness encountered in some of the boreholes listed in Table 3. Very thick porcellanite of about 95 m is encountered in D-4 boreholes located at the protection bund. Cavernous zones of varying sizes are well developed both in limestone and porcellanite formations. These are found at different horizons in many boreholes (Figures 3 A - E). Since the area encompassing the R series is highly cavernous, it is unsuitable for construction of a protection bund. Alternatively, a second bund axis, which is tentatively selected passing through boreholes of the A series, is located a few hundred meters east of the R series. It also shows a cavernous zone, even at a depth of 30 m bgl at A-1. The entire length of the core column shows only angular clasts of porcellanite and limestone, which are quite permeable. Borehole A-3, drilled to a depth of 100 m, shows about half a dozen cavernous zones extending from a depth of 52.5 m to 90 m with intermittent thin layers of hard and massive limestone. Both shallow and deep cavernous zones are observed in A-4 (at 14 and 77 m), and in A-5 (at 12, 20, 85-89 and 95-100 m). Four levels of cavernous zones are observed in A-6 extending from 48 to 77 m with thin intermittent layers of massive limestone. At least 14 levels of cavernous zone are inferred in A-7 drilled to a depth

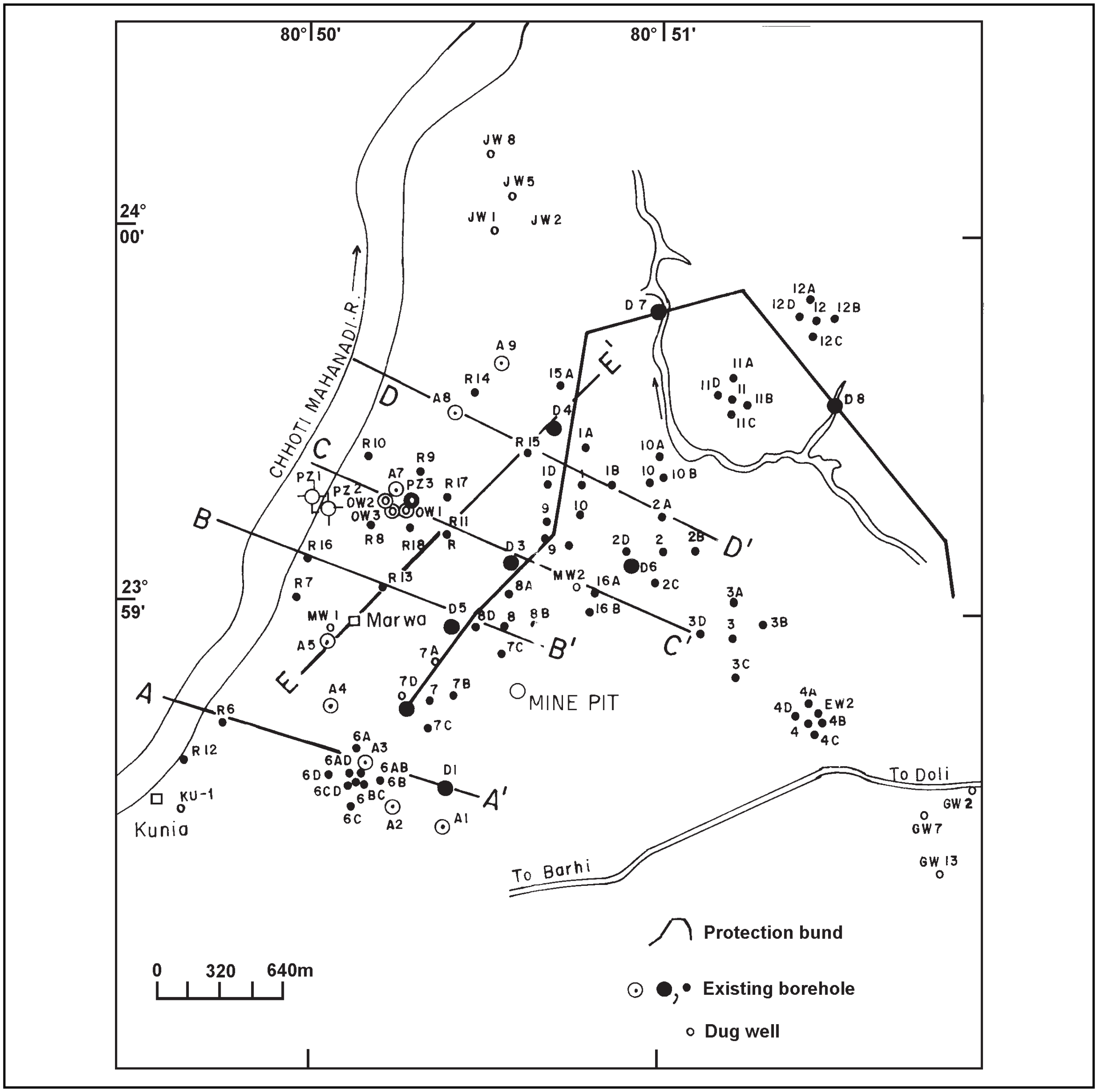

Figure 2. Borehole locations and cross sections.

of 78 m. A large number of cavernous zones to a depth of 50 m are also observed in A-8 and A-9. The general aspect of these bores suggests that the southern portion of the bund axis is more cavernous at levels greater than 50 m, while the northern portion shows cavernous zones only at shallow depths i.e. less than 50 m.

Lithologic logs of open wells OW-1, OW-2 and OW-3 located north of Marwa village show a cavernous zone at about 20 m. Wells OW-1 and OW-2 exhibit 2 to 3 horizons of cavernous zones with intermittent hard limestone layers. Further east, a few of the D series boreholes fall on the proposed bund axis. Borehole D-3 shows a large number of cavernous zones separated by thin layers of limestone from 335 to 318 m amsl. This site is highly permeable.

A large number of boreholes (1-18) drilled in an area encompassed by Marwa, Joraroda and Garitalai mines show deep multilayered cavernous zones at 1-A, 2-B, 6-A, 7-C, 8-A, 8-C, 9-D, 10-

Table 3. Thickness of Porcellanite Formation

Borehole No.	Thickness in m
R-8	60
R-3	24
R-5	55
A-9	45
D-3	50
D-4	90
3-D	40
6-A	15
9-B	45
15-B	45

A, 11-B, 12-A, 16-A and 16-B boreholes. These zones show more or less a NE-SW trend, coinciding with the lower portion of bund axis.

The vertical disposition of cavernous zones and their relationship in the study area are inferred from geological cross sections (Figure 3). The south profile, A-A´ shows cavernous zones both at

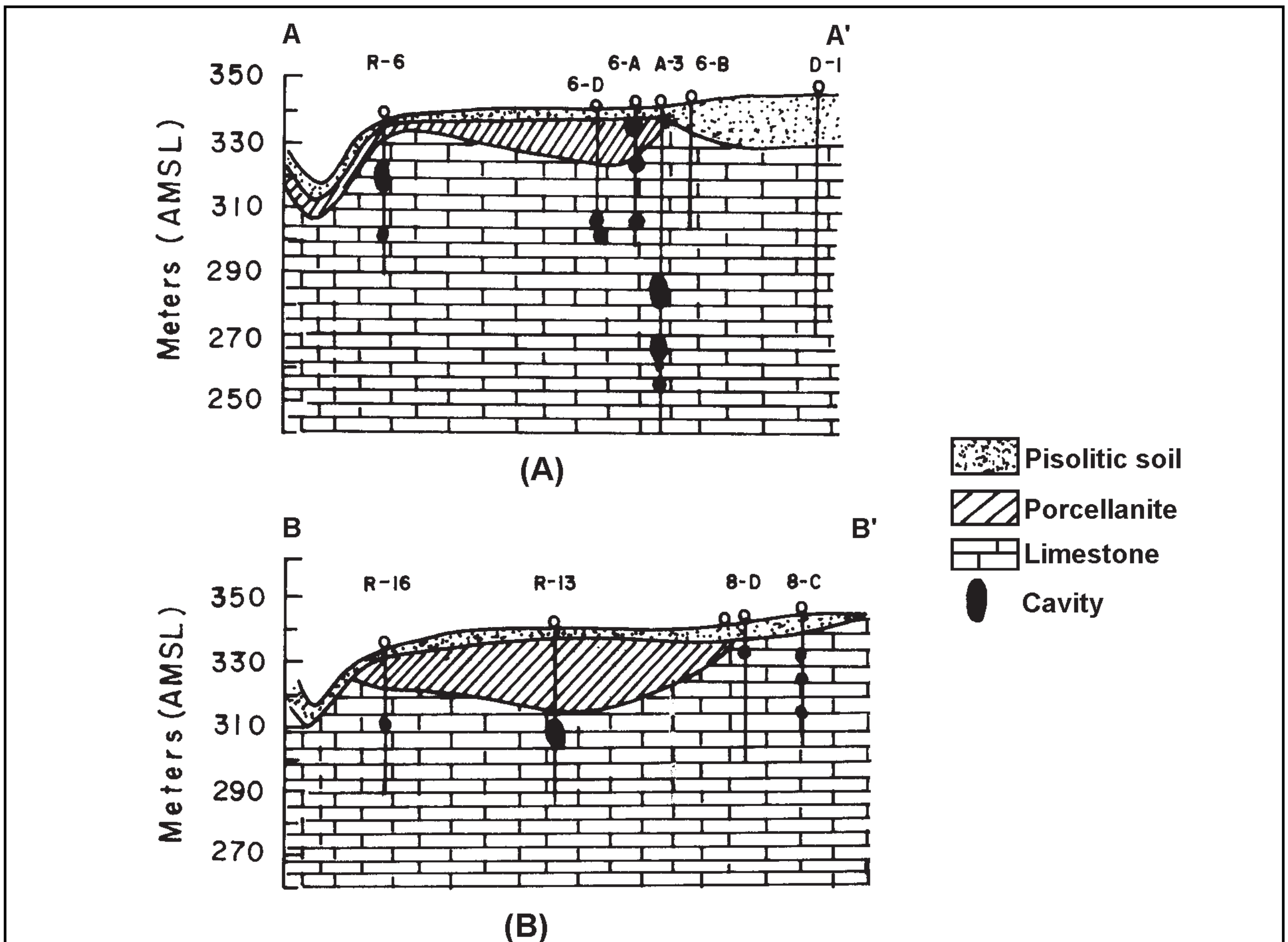

Figure 3. Geological sections AA´ and BB´.

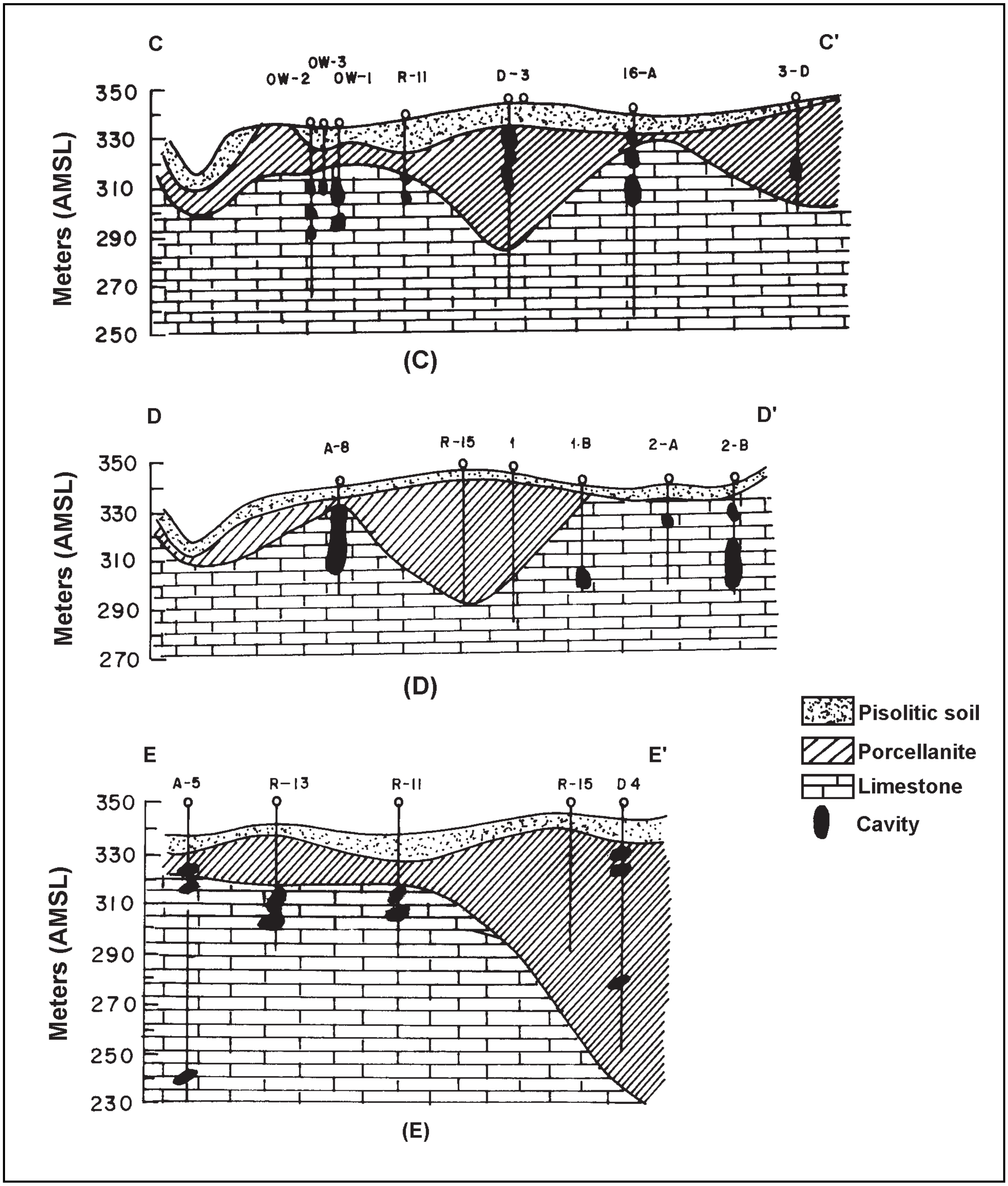

Figure 3 (continued). Geological sections CC´, DD´and EE´.

shallow and as well as at deeper levels (Figure 3A). At B-B´, the thickness of porcellanite ranges from about 25 m to 60 and 95 m at D-3 and D-4 in C-C´ and E-E´ respectively. The vertical disposition of cavernous zones in different cross sections suggest their interconnectivity if separated by only thin laminae less than 5 m thick. The regional groundwater flow is controlled by the varying and anisotropic hydraulic conductivity arising from these karstic features (Greene and Rahn, 1995; Jagannathan, 1992; Shevenell, 1996).

The thickness of porcellanite formations is generally in the range of 0 to 30 m. Near borewells D-4, R-15, and 9 thickness is 95m, 55m and 50m, respectively (Figure 3E), narrowing into a deep trough-like structure form. The trough-like structure is observed in almost all the E-W profiles, and it may represent a paleochannel of the river. A line passing through the deeper levels of these troughs shows a parallel trend to the present river course, suggesting that the river has drifted west and the channel was filled with thick deposits of soil/procellanites.

Horizontal sections at intervals of 10 m are drawn from 330 m to 310 m amsl (Figures 4, 5 and 6) to assess the horizontal disposition of cavernous zones. Figure 4 at 330 amsl shows a thick porcellanite band occurring west of the protection bund trending almost parallel to the river. In the absence of information regarding lithology between D-3 and R-11 and surrounding areas, an identical geology is assumed. The porcellanite formation is quite wide and thick near the D-3

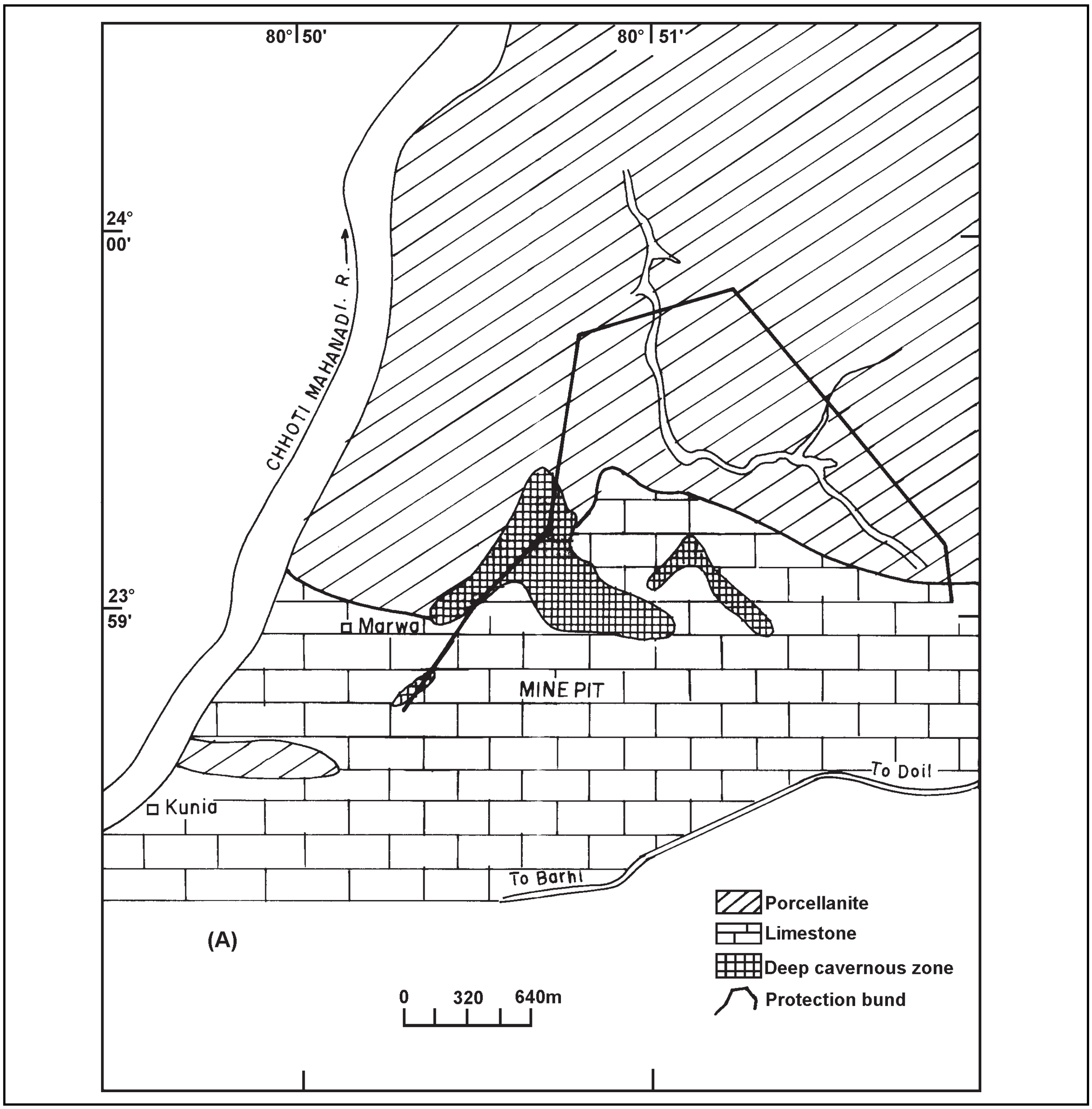

Figure 4. Horizontal section at 330 m amsl.

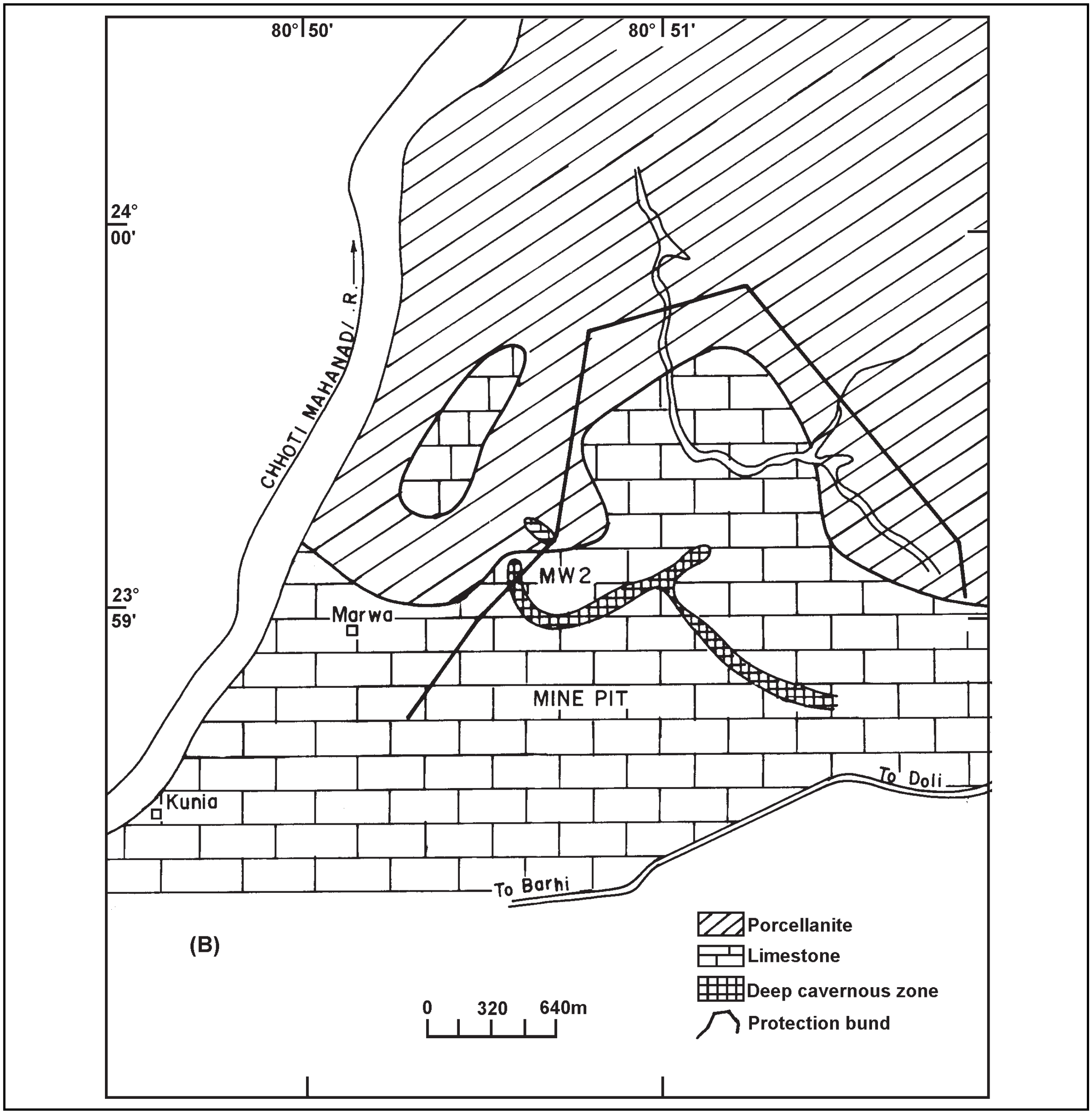

Figure 5. Horizontal section at 320 m amsl.

borehole and tapers on either side. It is interesting to note the occurrence of a deep cavernous zone running across this bund axis near D-3 (Figure 3 C), which is a highly permeable zone. This figure further shows the areal extent of the limestone formation which was overlain by about 10 m of soil/porcellanite. Deep, narrow and linear cavernous zones are inferred at (a) the southern end of the bund axis near bore holes 7-A, 8-A and 8-C, (b) near D-3 extending up to 1-C, and (c) near 2-C extending up to 3-B. An increase in the areal extent of limestone (Figures 5 and 6) and the cavernous zone is noted. The cavernous zone starts from D-3, passes through bore holes 8-B, 16-B and D-6, and branches at D-6. One branch extends to 2-B and the other to 4-A.

The cavernous zone widens, encompassing the area lying between Kunia village in the south, open wells OW-1, OW-2 and OW-3 in the north, and 3-A in the east. A cavernous zone intersects the bund axis between boreholes 8-A to 9. Here the bund axis separates the porcellanite on the west and the

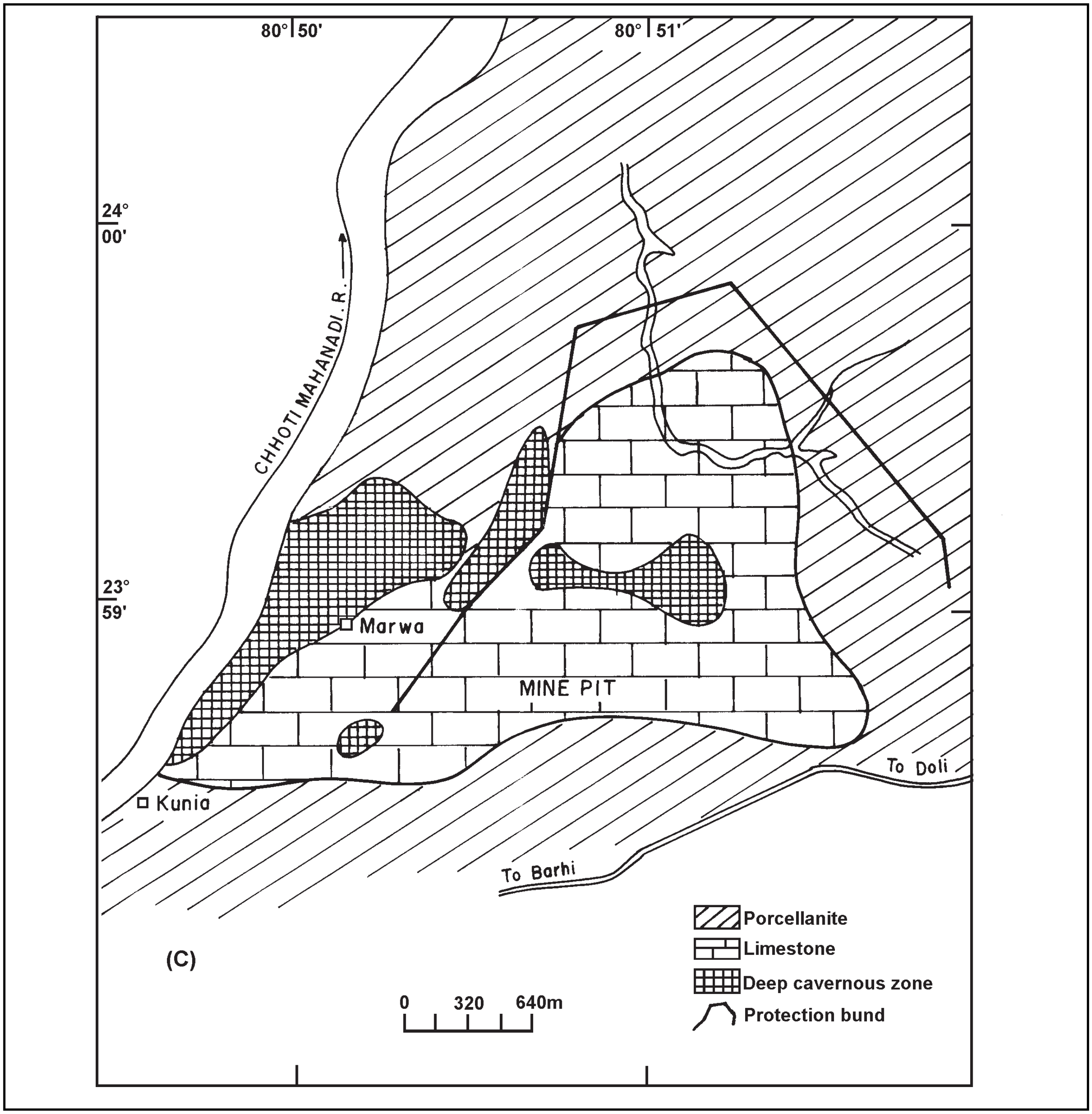

Figure 6. Horizontal section at 310 m amsl.

limestone in the east. Since the porcellanites mainly consist of clayey material about 60 m thick, the chance of water seepage into the limestone terrain is low.

CONCLUSION

The study of geological maps (both cross sections and plans) showed cavernous zones at all levels in the eastern portion of the river. Thick porcellanite formations are found in a N-S direction and a surface protection bund with a grout curtain has been proposed for protecting the mine area from seepage of the groundwater. Though both the porcellanite and limestone formations are highly cavernous, the thick porcellanite formations occurring between the mines and the river act as a barrier. The water levels at all time periods have shown a local water divide which can be explained by this barrier. All the geological information with the lithologic logs of the boreholes shows the spatial distribution of the aquifer parameters to be used for flow modeling. This geological and hydrogeological study has helped in preparing a conceptual model of the complex aquifer system.

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