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Full Length Research Paper

3-Dimensional Analysis and Reserve Estimation of Barapukuria Coal Basin, Dinajpur, Bangladesh

Ahmed Abul Fazal* and A.T.M. Shahidul Huqe Muzemder

Department of Petroleum and Mining Engineering, Shahjalal University of Science and Technology, Sylhet-3114, Bangladesh

***Corresponding author`s e-mail**: sohel_pge@yahoo.com; Phone: +8801717502185

ABSTRACT

Barapukuria Gondwana coal deposit is one of the largest coal basin situated in the Dinajpur and Saidpur with an area of 5.16 km^{2}s in the north-eastern part of Bangladesh. Using a 3-D model it is possible to evaluate the distribution of sedimentary rocks, both through space and time. This study has aiming a better understanding of the Barapukuria coal basin through 3-D geological analysis and re-estimation of coal-reserve which has done by the means of continuous (top & base) surface modeling for the target coal seam. The continuous trends of coal seam is conceder for the volume calculation of coal seam which is not consider previously for volume calculation like of Barapukuria basin in Bangladesh. The coal deposit is bounded with a large normal fault to the east with an N-S striking axis structure of coal basin. The sub-crop of coal seam VI limits the deposit in the western part. The analysis shows seven correlated coal layer interbeded with shale. The upper seam sequences I, III, VI are in shallow depth, has less thickness and also discontinuous in nature. II, IV and VI are those only having noticeable continuity and the later one is an ultra-thick seam plan to mine out but not the other. The model did not plot coal sequence II as it rarely count in the boreholes though it has significant thickness at some location. The interbeded coal and shale layer is merging to related sandstone sequence instead of to coal seam VI as this may be misled the volume counted for seam VI. The calculated volume of coal for the seam VI is 273.33 Mt. The volume calculated only for coal seam VI as it occupies the 90% of the total reserve of coalfield and hold priority. As the seam VI only to mine out, the current analysis considers its reserve as total actual reserve. About 22.04 Mt of coal has been estimated as recoverable reserve, using multi-slice long wall mining of 9% recovery, within the structural limit of the basin.

Keywords: Bangladesh, Coal, 3-D geological modeling, Surface contour, Barapukuria coal Basin.

INTRODUCTION

The existence of the Barapukuria basin was initially indicated by a negative gravity anomaly in oil and gas exploration by the Geological Survey of Bangladesh (GSB), with seven surface boreholes. The Waddell Armstrong Company of United Kingdom drilled a further 12 deep surface boreholes and 11 shallow hydrogeological investigation borehole and 18 high resolution surface seismic survey lines by the period of year 1988 to 1990. In 1994, the China National Machinery Import and Export (CMC) completed a further 13 borehole within the known limits of the deposit. Within the structural limits of the basin approximately 273.33Mt (mega-ton) of coal in-situ has been quantified in the six coal seams that range in depth from 118 to 518 m below surface. The principal seam of interest is the lowermost Seam VI, with a variable thickness across the deposit from 22 m in the northern part of the deposit to more than 42 m in the southern and eastern areas of the basin. The Borehole data were not much to execute a true three dimensional model of the coal basin. For example

Table1. Stratigraphic succession of Stable platform in Bangladesh (after Khan and Mominullah 1980; Khan 1991; Riemann 1993)

Age	Group	Formation	Thickness (meter)	Rock Types
		Barind Clay	40	Reddish clay
Pliocene		Dupi Tila	270	Compact. Loosely sandstone
Miocene		Jamalganj (Undifferentiated Surma eqv)	400	Alternating sandstone and shale
		Bogra	160	Sandstone & shale
Eocene	Jaintia	Kopili Shale	170	Mostly shale
		Sylhet Limestone	240	Nummulitic Limestone
		Tura Sandstone	370	Mostly sandstone
Cretaceous		Shibganj Trapwash	130	
Jurassic	upper Gondwana	Rajmahal Trap	540	Basaltic volcanic rock in layer
Permian	Lower Gondwana	Paharpur Kuchma	1000	Mostly hard sandstone with some coal layers, Few shale and congl.
Precambrian Crystalline Basement				Igneous and metamorphic rocks

Grodner (2002) used 1190 borehole logs collected from three mining companies to do 3-D analysis of the Permian Witbank coalfield, South Africa. Literatures on the three dimensional modeling of coal basin in Bangladesh are rare though some work has been done on hydrogeological and aquifer modeling in 3-D (Haque, 2006, Mostafa, 2005, Rahman, 2005).

In a review paper by Islam and Hayashi (2008) describes the stratigraphy of the basin comprehensively and emphasize on coal bed methane potential of the Barapukuria coal basin. In the review paper they collated available bore-hole data. During the last 10 years number of commercial and open source computing programs made available to manipulate geospatial data in 3-D based on statistical interpolation techniques. With the evolutionary step of this progression, understanding of the complex nature of the georesources has increased. Using the 3-D model it is possible to evaluate the distribution of rocks, both through space and time. Employing these computing facilities would enable a better understanding of the Barapukuria coalfield in Bangladesh (Figure1 below, Table1).

Barapukuria Basin

The Barapukuria coal field was discovered by the Geological Survey of Bangladesh (GSB) in 1985 in the drill hole GDH-38 which encountered coal-seams at depth of 159 meter. Subsequent drillings in the field found coal at depth as shallow as 118 m. After the discovery, the GSB conducted detail gravity survey and drilled another 6 well in the coalfield.

In 1987, Wardell Armstrong Mining Consultant of U.K. was engaged in conducting mining feasibility study of the Barapukuria field and they carried out high resolution seismic survey and drilled 12 drill holes to assess coal mining feasibility during the period from 1988 to 1990.

On the basis of the above, the government decided to establish an underground coal mine at Barapukuria. In 1993, the government entered into a contract with Chinese Government for technical and financial assistances for establishing the mine. The mine construction by the Chinese contractor started in 1996 and was originally scheduled to be completed by 2001. But this was delayed and is completed in 2005 (figure2 below).

DATA AND METHODOLOGY

Data and Software

The dataset used for the geological model and coal volume estimation of the coal seams are 18 borehole logs among them 7 logs (GDHs) drilled and recorded by Geological Survey of Bangladesh in 1985 and the rest of the logs (DOBs) conducted by the China National Machinery Import and Export (CMC) in 1994 (figure3).

These borehole logs are converted to a common data format and spatial information are converted to planner earth projection UTM (Universal Transverse Mercator) for

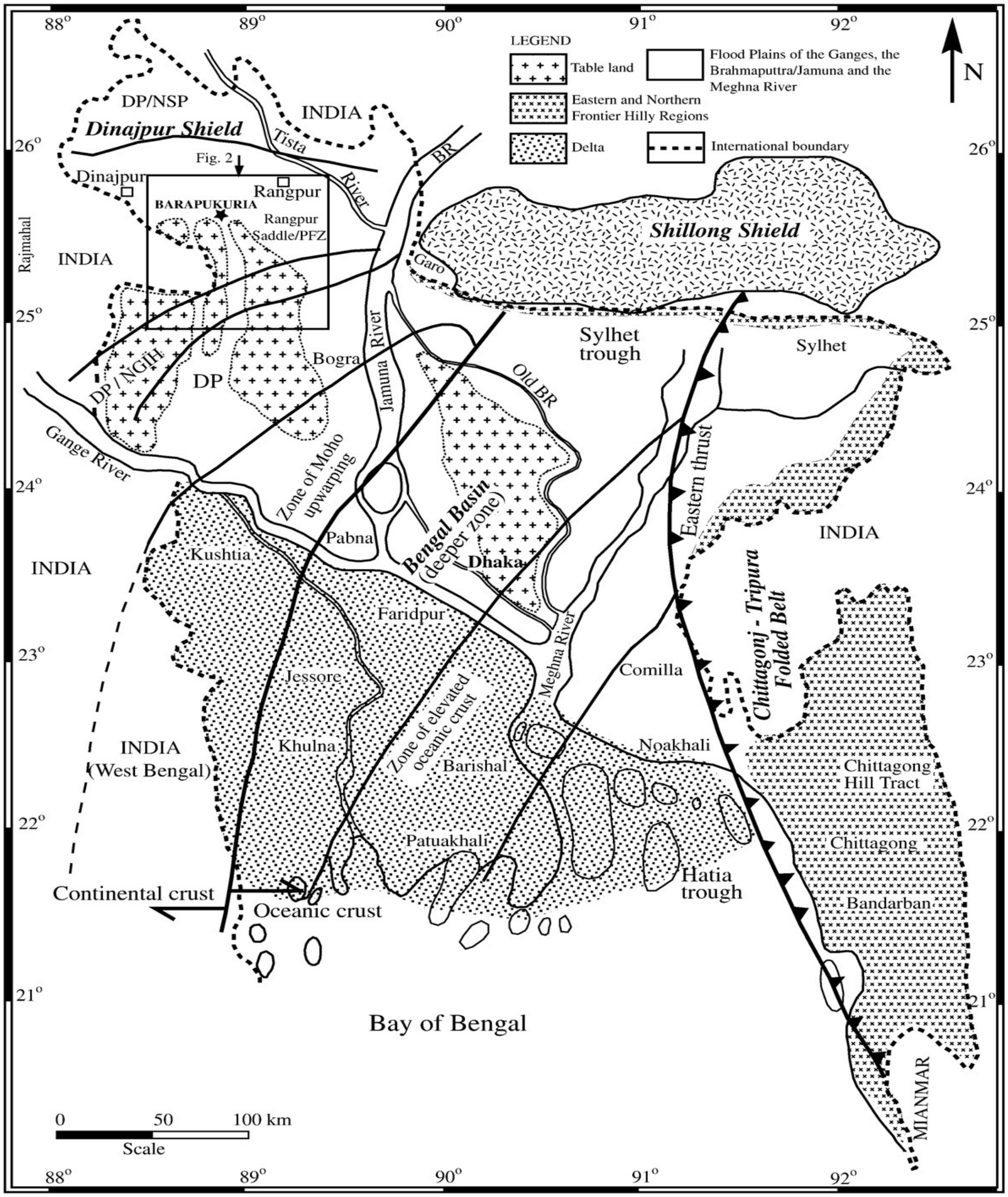

Figure1. Location of the Barapukuria coal deposits within the physiographic divisions and in the major geotectonic features of Bangladesh. Bold lines indicate boundary of the tectonic divisions. BR, Brahmaputtra River; DP, Dinajpur Platform; NGIH, Nawabganj-Gaibandha Intracratonic High; NSP, North Slope of the Platform (part of Sud-Himalayan Foredeep) (after Khan, 1991; Khan and Chouhan, 1996; Islam and Hayashi, 2008a; Islam et al., 2009)

better area and volume calculation and 3-D analysis (Figure 4).

The study conducted by Surfer 8.4 (surface mapping and computing software) (Golden Software, Golden, Colorado, USA) for the continuous trends coal seam volume calculation, and Rockworks version 14 (RockWare Inc. Golden, CO, USA) for the 3-D analyses.

3-D project build up and modelling

The borehole logs are recoded to a common data format and spatial information are converted to planner earth projection UTM in a Rockwork project. In case of 3-D analysis both Lithology and Stratigraphy were considered. The lithologic analysis is conducted by the 15

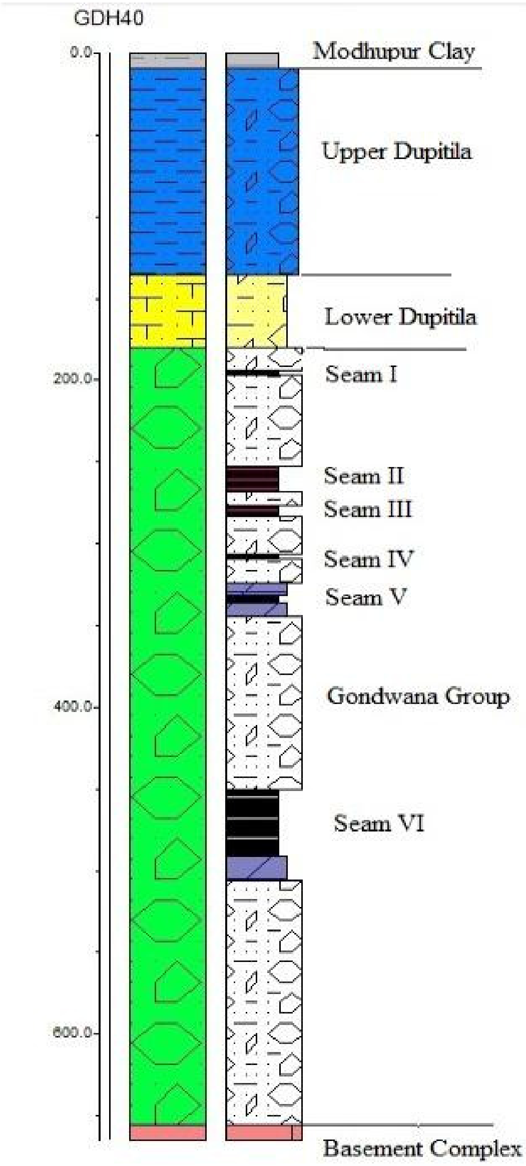

Figure2. Stratigraphic occurrence in Log GDH-40 of Barapukuria Basin (coal seams are included in Gondwana group)

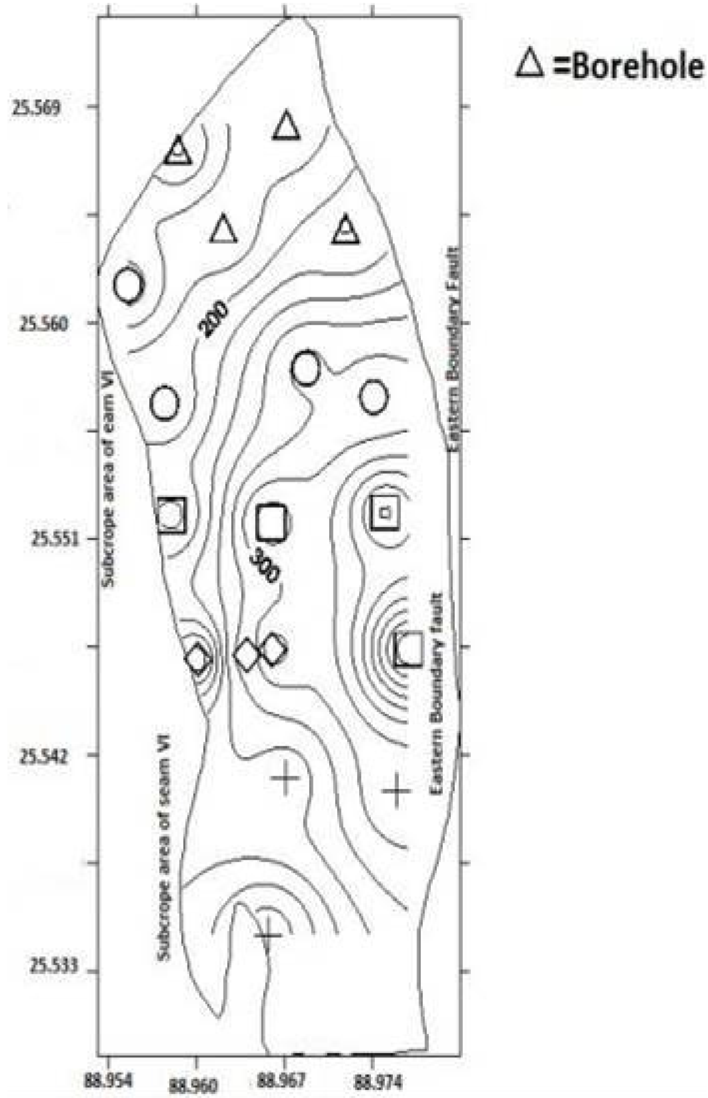

Figure3. Location of the borehole, major faults and structural pattern of the Barapukuria coal basin, Dinajpur, Bangladesh

layer for convenient (Figure 5). All these lithological layers are not encountered in every hole. Total area was considered to be made of >85000 voxels, i.e., rectangular grids.

Creation of coal bed surface and calculation of coal volume

From the drilling record log i.e., lithologs it is apparent that seam number six is the main reserve for coal. In this project 're-estimation of coal reserve' indicates the estimation of coal reserve for the seam number six only. Previously, Islam and Hayashi (2008) estimated a reserve for the coal seam six using 'polygon method'. Here continuous surface for the top and base of the coal seam has been modeled using known data points extracted from the logs employing Surfer program.

It is to mention that same grid size has been used during the (top and base) surfaces creation, with inverse distance to power algorithm, which enabled the facility of using volume calculation in Surfer program. Later the volume of coal is converted from cubic meter to acre-ft for coal reserve estimation.

In the current project the 'net volume' calculation is considered. Mathematically, the volume under a function f(x, y) is defined by a double integral -

$$\text{Volume} = \int_{Xmin}^{Xmax} \int_{Ymin}^{Ymax} f(x,y)\,dx\,dy \quad \text{.......... (1)}$$

In Surfer, this is computed by first integrating over X (the

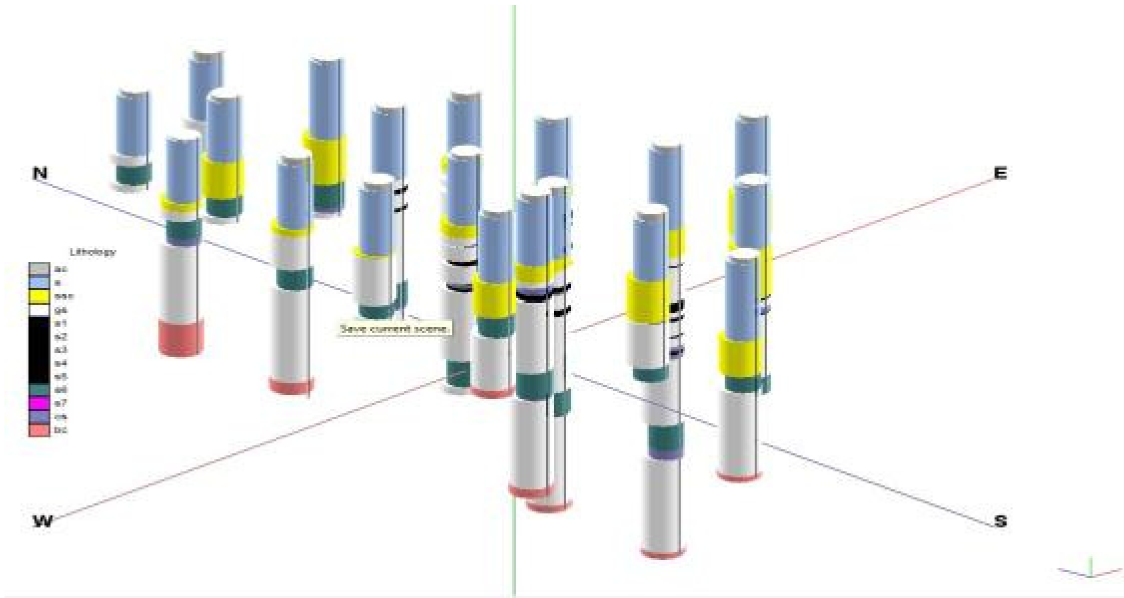

Figure4. All 18 logs are shown in a 3-D orientation. Here Lithologies are, ac=Alubium clay, S=Upper Dupitila sandstone formation, SSC=Lower Dupitila sandstone, silt, white clay formation, gs= Gondowana sand formation, s1=s2=s3......=all are Coal seams, bc=Basement Complex.

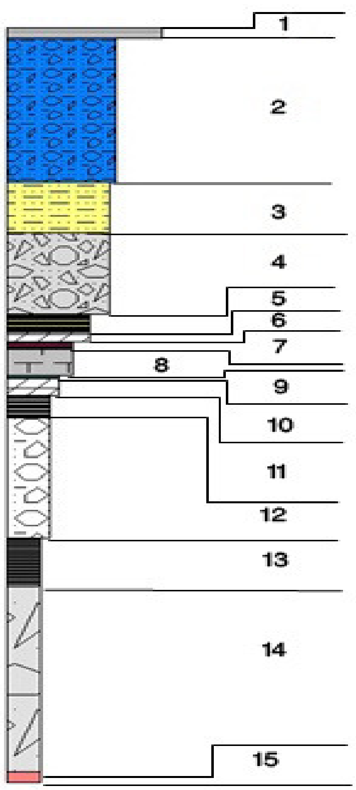

Figure 5. The 15 layers common data format for lithology analysis. The layers are, 1= Modhupur clay, 2= Upper Dupitila, 3= Lower Dupitila, 4= Sandstone, 5= Coal Seam II, 6=sandstone, 7=Coal seam III, 8= Sandstone, 9=Coal seam IV, 10=Sandstone, 11= Coal seam V, 12= Upper sandstone sequence of seam VI, 13= Coal seam VI, 14= Lower sandstone sequence of seam VI, 15= Basement complex. Seam I, coal+ shale are included in sandstone sequence for simplification.

columns) to get the areas under the individual rows, and then integrating over Y (the rows) to get the final volume (Press, et al, 1988).

Estimation of coal reserve

Tons of coal on the seam= A***b***C ....(2)

Where: A = the number of acres underlain by a coal bed, **b** = the average coal thickness in decimal feet; and 'C' is tonnage of coal, which is a conversion factor 1,770 tons/acre-foot. Value of conversion factor depends on the rank of the coal. Following paragraph tells about the estimation a value for 'C' for Barapukuria coal.

In Barapukuria an average 14,993 tons per hector per meter thickness (1,770 tons per acre per foot thickness) of coal seam is assessed (Islam and Hayashi, 2008). Coal at Barapukuria is of 'sub-bituminous' rank (Islam and Hayashi, 2008). The specific gravity was measured as 1.45 with different coal sample of coal seam with reference DOB-9 borehole (Islam and Hayashi, 2008).

Given that:

Specific gravity of Sub bituminous coal of Barapukuria coal field = 1.45

1 ft^3 of water = 62.6 lbs

1 acre = 43,560 ft2

1 ton = 2,000 lbs

Conversion factor, C for Barapukuria coal is calculated as follows:

(1.45* 62.6 lbs. * 43,560 ft2) / 2,000 lbs/ton = 1,976.97 tons/acre-foot.

Equation (2) is converted into;

Tons of coal on the seam= V*C ....(3)

Where, V= Volume in acres-ft; 'C' is conversion factor, 1,976.97 tons/acre-foot.
Finally, equation (3) has been used to estimate the coal reserve.

Three methods are used to determine volumes are Extended Trapezoidal Rule, Extended Simpson's Rule, and Extended Simpson's 3/8 Rule. The difference in the volume calculations by the three different methods measures the accuracy of the volume calculations. If the three volume calculations are reasonably close together, the true volume is close to these values. If the three values differ somewhat, a new denser grid file should be used before performing the volume calculations again. The net volume can be reported as the average of the three values.

RESULTS

3-D analysis of coal basin

The basin is progressively shallower to the west, north and south away from the depo-center near the Eastern boundary fault (Figure 6). The western area of the basin is down thrown by a 518 meter as indicated by sudden depth variation of the basement between GDH-40 and GDH-44 wells (Bakr et al 1996). The deepest part of the basin and also the thickest sedimentary succession is accumulated near the drill hole GDH-40 about 200 meters west of the Eastern boundary fault. The coal seams have gentle easterly, southerly, or northerly dip towards the depocenter depending upon the position in the basin. The subcrope of the roof of the seam VI is not well established in south. In the north, seam VI thought to be present immediately below the base of Tertiary sequence (Figure 6).

The Archean basement

The lithologic pre-cambrian base encountered relatively shallow depth in middle or south western part of the basin area at 300 m in GDH-39. In GDH-40 the base is found at a depth of 655 m . The base consists of hard rock diorite, meta-diorite, ophlitic gneiss and granite (Islam, 2008).

Cut and Fill Volumes

The Cut and Fill Volumes displays the Positive Volume (Cut) and the Negative Volume (Fill). The cut portion is the volume between the upper and lower surface when the upper surface is above the lower surface. The fill portion is the volume between the upper and lower surfaces when the upper surface is below the lower surface. The area is also shows as positive planer (Cut) area and negative planer (Fill) area.

Lithologic bed and lithostratigraphy

The lithological sequences are not same spatially and vertically as these are composed of clay, withy clay, very fine silt, sandstone-arkose, fine to corse sand with occasional conglomerate. Coal seams have the depth range 118 m to 506 m beneath the surface.

Lithological modeling shows the distribution of all lithology in 3 dimensions. The sedimentary sequence, average thickness 500 m, is dominated by sand and other is silt-clay. Some of the lithological units are also patchy. In surface the dominant material is clay and silty clay (Figure 6). The coarse grained size, sand, is increase with deep in the basin.

The Lower Dupi Tila Formation, a minor clayed bed, is absent in the northern part. The formation thickness progressively increases as it approaches to southern part. The mine water inrush accident in the northern part is May 1998 occurred due to the absence or limited thickness of Lower Dupi Tila. It appears that the clay unit in filled the depression on the uneven Gondwana rock surface before the major sandy Dupi Tila was deposited in a fluvial environment (Figure 7).

The modeling of basin with lithology shows zone of coarser or finer grained lithologic strata, and mixed lithology, in 3D fences (Figure 3-1). Fine grained Modupur clay, Dupi Tila formations are dominent in southern and middle part of the basin. Clay based Lower Dupi Tila formation is absent in north part of the basin. Coarser grimed are dominant in the whole basin especially in middle and south part at deep of the basin. The 3D fence show a north, east and southern shallow deposition of coal seam VI (Figure 6) others a deep burial of the seam.

3-D characteristics of the coal sequences

As the coal seam VI occupies the 90% of the total reserve of Barapukuria coal field and it holds priority. So, I discuss about the major coal seam VI. The seam has a topography with variable depth of occurrence range <100 m to >400 m below ground level, e. g., 80 m at DOB-12 and 420 m at the borehole GDH-40 (Figure 8). There is a depocentre in the basin at south-east corner where seam VI is thicker. The highest thickness is near about 40 m is in the adjacent area of DOB-4 and GDH-38 along with one of GDH-40.

The three dimensional figure can give the clear idea of shape of whole seam by two side view, one from west and others from east (Figure 10). The undulation is counted and coal seam is deeper in south eastern part. The color code shows the elevation in different part of the seam in 3-D (Figure 11).

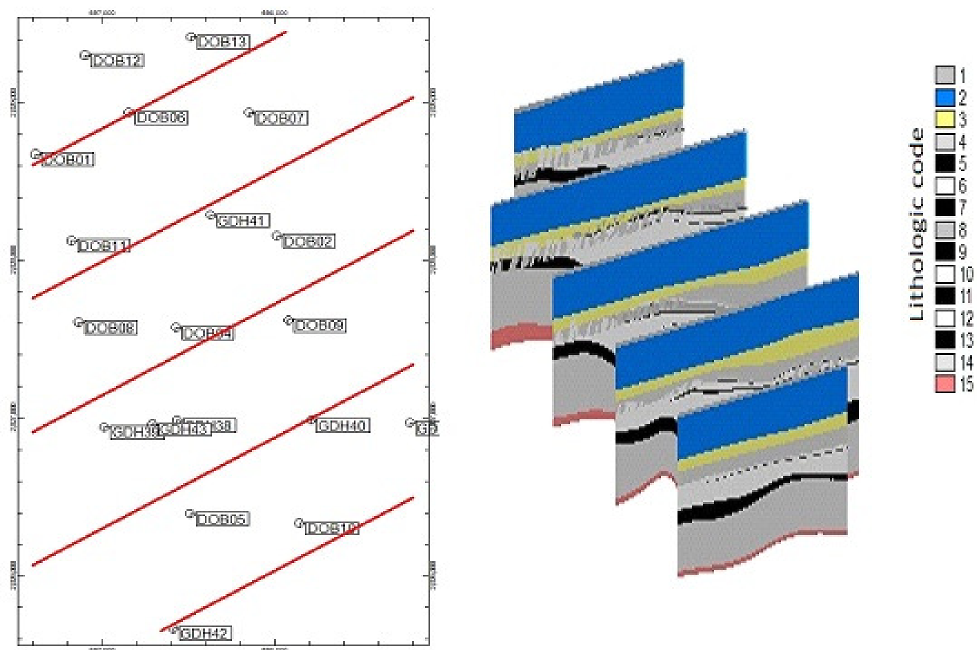

Figure 6. Fence diagram based on lithologic modelling-used Rockworks 15 with Inverse Distance (ID) algorithm for a grid size 50 m x 50 m x 20 m.

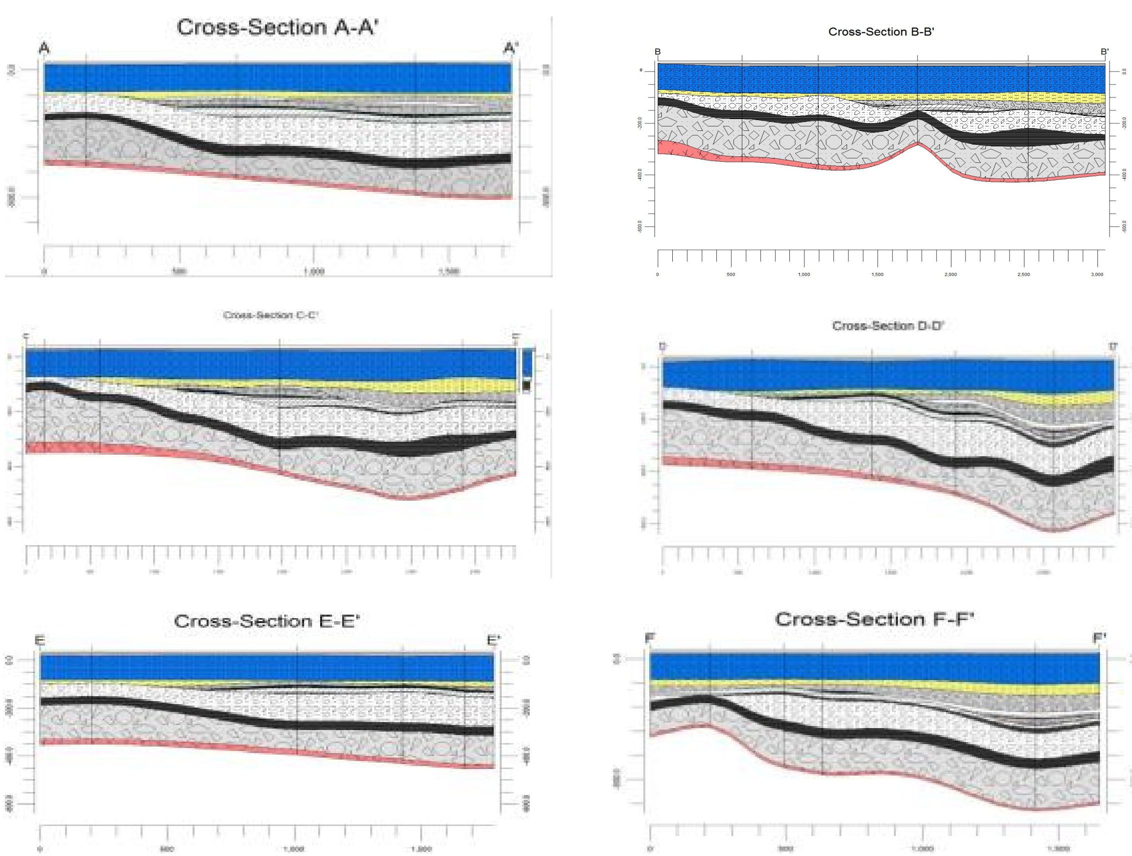

Figure7. Structure, stratigraphy, and distribution of coal seams in Barapukuria coal basin.

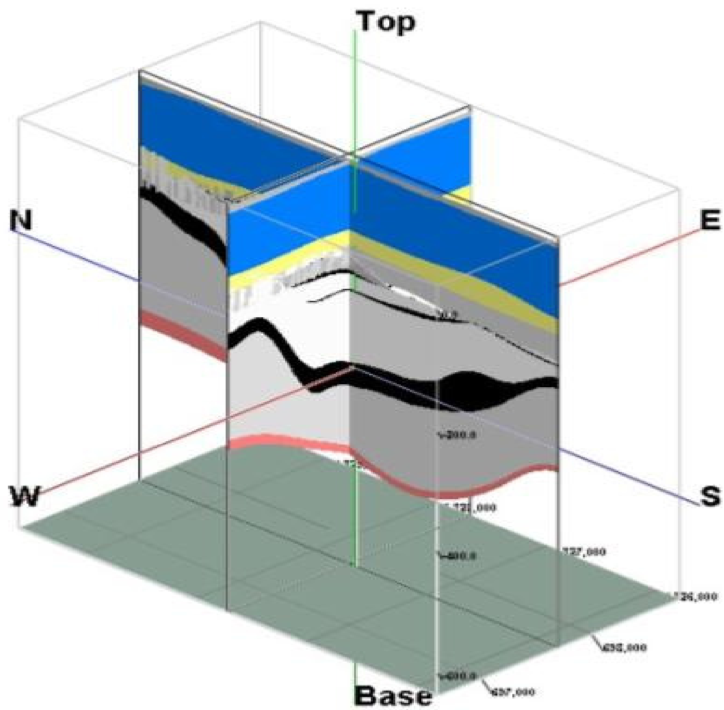

Figure8. The fence diagram, view of coal basin section as diagonally.

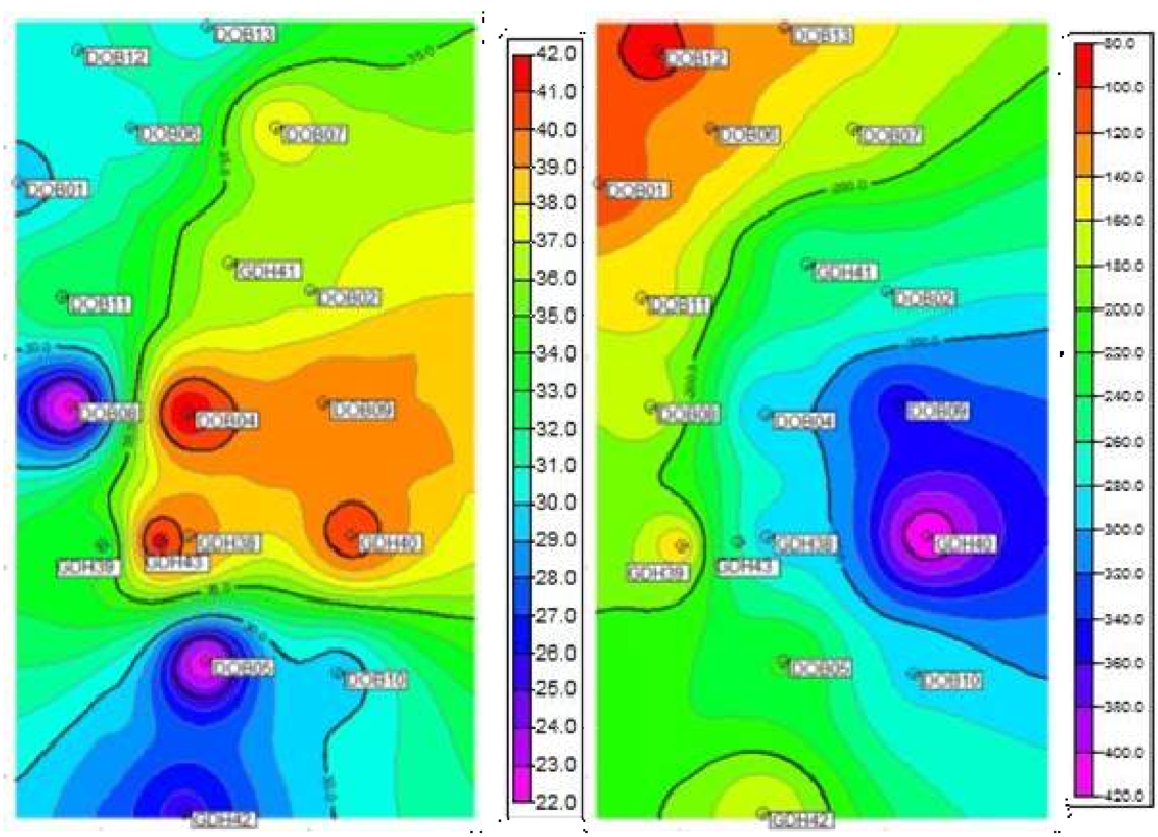

Figure9. The 2 dimensional map of coal seam VI-stratigraphic thickness (isopach map) in left side and Structural elevation in right.

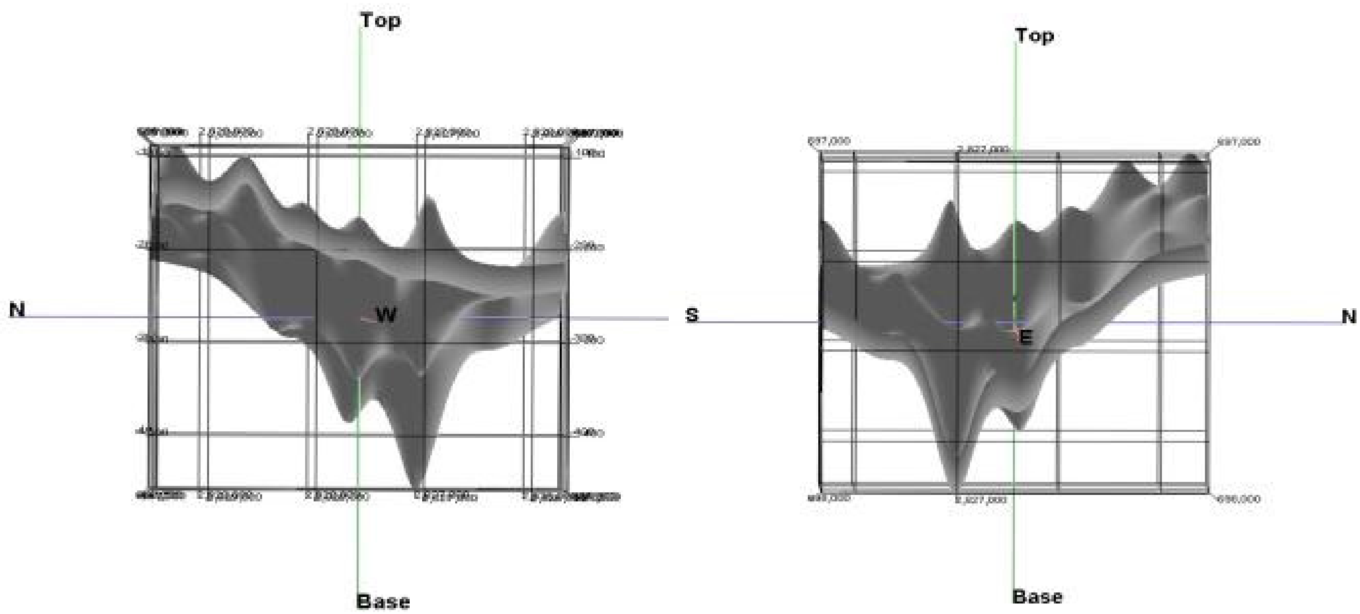

Figure10. Stratigraphic thickness of seam VI, view from west in the left and east to the right.

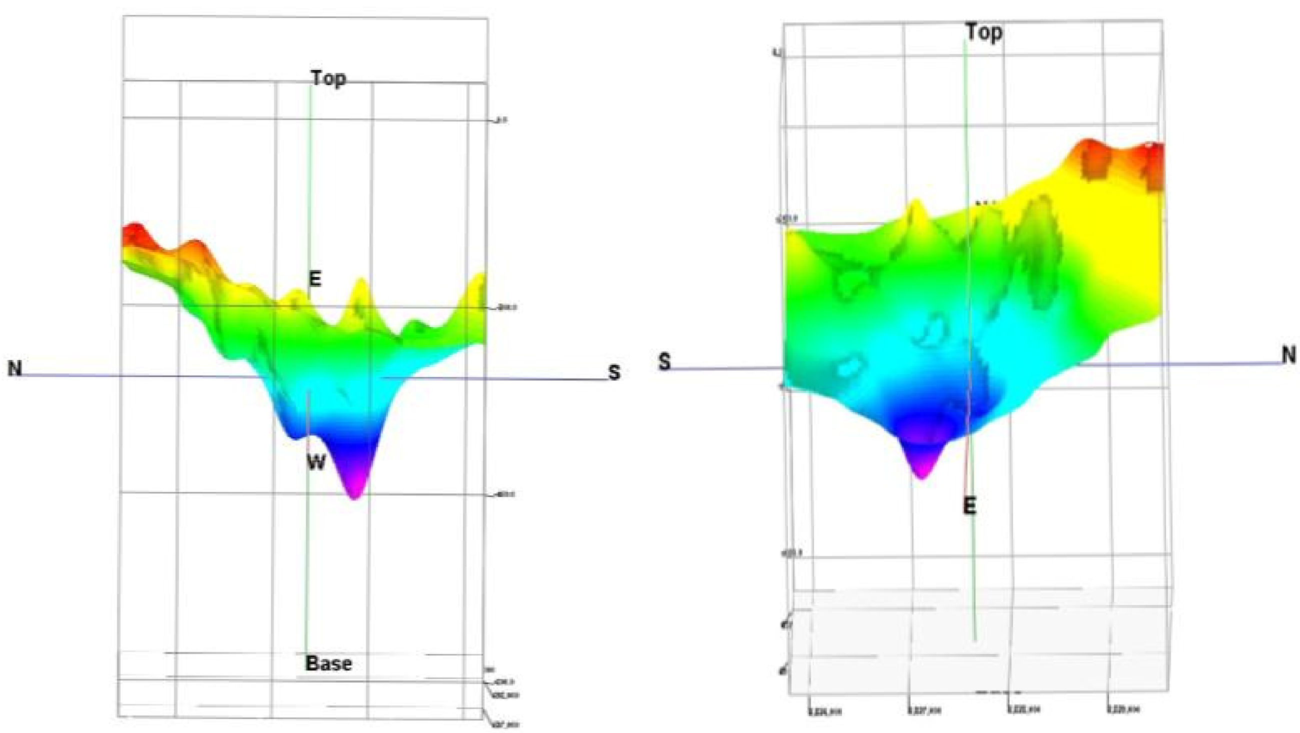

Figure11. Structural elevation of seam VI, view from east in the left and west to the right.

Coal Reserve

Coal seam VI has the vast amount of reserve and the plan to mine out seam six only as the other seams are discontinuous spatially, and has very less thickness. For the calculation of the volume of coal in seam VI continuous surfaces were produced: one of is for top of seam and other is for the bottom (figure 12). Total volume

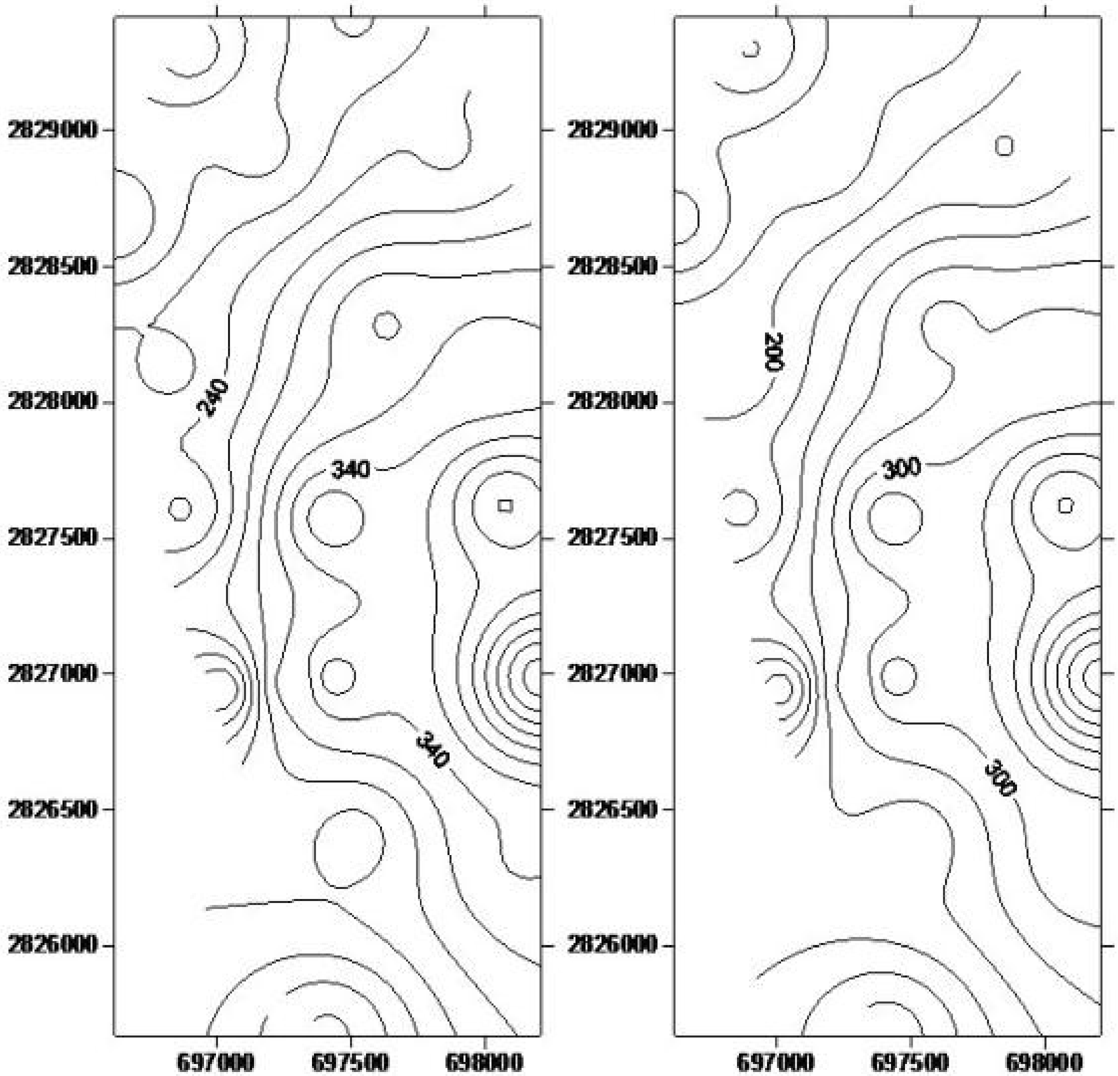

Figure12. Contour map of seam six using Surfer8 with Inverse Distance to a power (IDTP) algorithm in meter. Top surface shows in left and Base in right.

calculated below as an average of volume by above three numerical equations. Cut and fill volume and area also show in paper as there is no place found where the lower surface up crosses the upper surface.

Volumes

Total Volumes by,

Trapezoidal Rule:	170,533,194.70244 m^3
Simpson's Rule:	170,512,876.04411 m^3
Simpson's 3/8 Rule:	170,541,067.18426 m^3

Total volume by averaging above three value,
V=170,529,045.90 m^3
V=138,249.8709 acre-foot.
[Here, 1 acre= 4046.85642 m^2 and 1 m= 3.28083333 ft]

Tons of coal= (138,249.8709 acre-foot)*(1976.97 tons/acre-foot.)
=273315845 tons
=273.31 mt

The Recov**e**ry percentage in Barapukuria is 9%,
So, th**e total recoverable volume of** coal in seam VI= (273.31)*(0.09) mt = 24.60 mt

Cut and Fill Volumes,

Positive Volume [Cut]:	170536869.97773 m^3
Negative Volume [Fill]:	0 m^3
Net Volume [Cut-Fill]:	170536869.97773 m^3

Areas
Planar Areas,
Negative Planar Area [Fill]: 0 m^2

Blanked Planar Area:	992581.56132756 m^2
Total Planar Area:	5968408

Surface Areas,

Positive Surface Area [Cut]:	4976442.6528687 m^2
Negative Surface Area [Fill]:	0 m^2

DISCUSSION

The present modeling and reserve estimation

By using a 3-D model it is possible to evaluate the distribution of sedimentary rocks, both through space and time. By this modeling one can interpret the depositional environment condition at the time of sediment deposition. The depth variation where the basement occurs in between GDH-40 and GDH-44 indicate a major fault there (Figure 9).The thrust fault create asymmetry with view to the synclinal peak of the basin. The geometry of basin has a typical extensional structure. So, it's developed a half graben type basin which increases thickness in deposition towards the east and south east (Warderl Armstrong, 1991; Bakr et al., 1996). The 3D fans show an agreement with this (Figure 6, Figure 7, and Figure 8).

For lithological analysis the rocks strata within the Barapukuria basin are simplified in a 15 layers. All strata are encounter at log GDH-40 as it digs a 665 m in the basin deep. The discontinuous and also less thick coal seam I is included sandstone sequence below the Dupi Tila formation as it occur only in GDH-40. The model did not plot coal sequence II as it rarely count in the boreholes though it has significant thickness at some location. The interbeded coal and shale layer is merges to related sandstone sequence instead of to coal seam VI as this may be misled the volume counted for seam VI. A negligible amount thickness 0.45 m and 0.76 m is encounter at GDH-40 and GDH-43 respectively for the seam VII below than.

The geostatistical method 'inverse distance to a power' is used to calculate the volume, a weighted average interpolator, can be either an exact or a smoothing interpolator. 273.31mt is quantified.

Reserve estimated by wardell Armstrong 1991

The reserve calculated demonastred for coal seam VI during the mine feasibility study estimated as 271Mt by Warderl Armstrong Company. Another 64 Mt calculated as inferred reserve. The total reserve demonastred as 303 Mt for the whole basin with two relatively consistent and three discontinuous, limited coal seam (Warderl Armstrong 1991). In another calculation, approximately 300 Mt of coal in-situ has been quantified in the coal seam VI that range in depth from 118 to 518m below surface within the structural limits of the basin. The calculation was used polygon method by Islam and Hayashi (2009). The whole reserve shows for the coal field is 377 Mt.

Comparison among the estimates

As mention earlier this project done with calculation of seam VI only as it is the only seam to be mine out. The amount calculated has shown a good agreement with the initial amount calculated by Wardrel Armstong Company. The measurement method is unknown by which the calculated. In present calculation, with inverse distance to a power algorithm, data are weighted during interpolation such that the influence of one point relative to another declines with distance from the grid node. So, the any effects of distance between two data points are reduced.
However, the amount calculated is less than the previous study which conducted polygon method to calculate the volume. The coal seam bounded with boundary fault and subcrope which is applied to the surface by blanking these two surfaces, using .bln extension file in surfer program. Therefore, the two surfaces reduced in volume, which goes another way to a perfect estimate.

The polygon method is considering accurate compare to arithmetically averaged borehole data due to variation in borehole distribution data. The reserve estimated with continues gridding of upper and lower surface is counted a thickness which varies with grid to grid in more than 85000 rectangular grids in 5.16 Km^2 area of basin.

CONCLUSION

The Barapukuria coal basin analysis in 3D shows how geological surface maps and other three dimensional figure can be used to better understand how the structure and thickness of coal bed and other strata vary on a small scale. Also, applying this information across areas which have mined out will increase the understanding and accuracy of the model.
The re-estimation of the coal reserve has been done using the aforesaid method, and 273.31mt, a good agreement has been found with the previous estimates with one calculated in during the mine feasibility study estimated 271mt and there is another calculation using polygon method found 300mt for coal seam VI. So, the 3-D analysis of the coal-basin reveals better visualization of the coal reserve. This outcome of the current project would shed some lights towards better understanding of the Barapukuria coal basin.

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