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Geotechnical Studies using Geophysical Logs of Sravanapalli –II Dipside Block, Adilabad District, Telangana, India

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ABSTRACT

Strata control invariably depends upon precise understanding of geological and geotechnical characteristics of overburden strata of coals which helps in managing the risks associated with various forms of strata instability. Geophysical logs of exploratory boreholes, besides overcoming the inherent limitations of conventional methods address all the geotechnical characteristics of the surrounding strata so that geotechnical engineers can design mine openings, which differ according to the mine plan. The present study provides all the geological and geotechnical characteristics of Permian coals of Barakar Formation of Sravanapalli -II dipside block of North Godavari sub-basin, Telangana, India. The 200m thick coal-bearing Barakar is resolved into Lower and Upper sequences. The coals of Lower sequence have roof rocks varying from sandstones to shale in specific directions which are prone to wash out. The High strength massive sandstones having Uniaxial Compressive Strength (UCS) of 30 MPa to 50MPa constitute the overburden strata of lower set of coals. The coals of Upper sequence contain one metre to two metre thick beds of clays/shales along their roofs and medium strength sandstones of 10MPa to 20MPa. All these interburden strata of coals contain couple of one metre to two metre thick lenses of Very High to Extremely High strength sandstones of UCS of 60MPa to 200MPa. These overburden strata are also classified in terms of Geophysical Strata Rating (GSR) computed from suite of geophysical logs. Dynamic moduli of these sediments are even computed using density and sonic logs. These logs now give wider range and several options by providing petrophysical, elastic and mechanical properties of overburden strata to earth scientists involved in mine planning.

Key words: P-wave, UCS, CMRR, GSR, SS-80.

INTRODUCTION

Strata control is the most important aspect influencing both safety and productivity of coal mining. For underground mining, the most important of these geotechnical considerations are the roof support requirements and, if longwall mining is being practiced the caving behaviour of the strata. In open cast mines, wall stability and blasting/ digging requirements are major geotechnical concerns. Rock Quality Designation (RQD) and other strength parameters such as Unconfined/Uniaxial Compressive Strength (UCS), Young's Modulus (E), Coal Mines Roof Rating/Rock Mass Rating (CMRR/RMR) etc are usually determined at rock testing laboratories using the core samples obtained from exploratory boreholes.

Uday Bhaskar and Shanmukha Rao (2016a) reported that core samples subjected to core discing and poor core recoveries are not suitable to determine RQD and mechanical properties. Stress release during drilling also lowers UCS of core samples. Different laboratories produce different values of UCS of the same litho-units intersected in the same boreholes. Peng (2015) also concludes that laboratory determined rock/coal mechanical properties usually spread over a wide range and should not be averaged to avoid serious implications on overall design. Otherwise, the local falls would be considered as main fall as noticed by Uday Bhaskar and Shanmukha Rao (2016a) and Frith and Colwell (2008) recommend UCS as an index property rather than an absolute one. Hatherly et al., (2001) remarks that conventional methods of laboratory testing of cores are prone to sampling problems and misrepresentation of actual conditions insitu. The cost of coring and rock testing also makes it impractical to drill enough geotechnical holes to sample the full range of variability present within the rock mass. Hatherly, 2013; Hatherly et al., 2016 noticed that Australian coal industry therefore depends on a suite of borehole geophysical logs to acquire geological and geotechnical information (UCS) of the entire overburden strata of coals in a much reliable and accurate manner than from core samples. UCS is now routinely estimated from sonic logs. Geotechnical engineers use these two- and three-dimensional geological and geotechnical models obtained from geophysical logs to visualise and plan their mining operations. Using geophysical logs and Geophysical Strata Rating (GSR) methods, Medhurst et al., (2014) predicted caving of strata at various stages of high capacity longwall

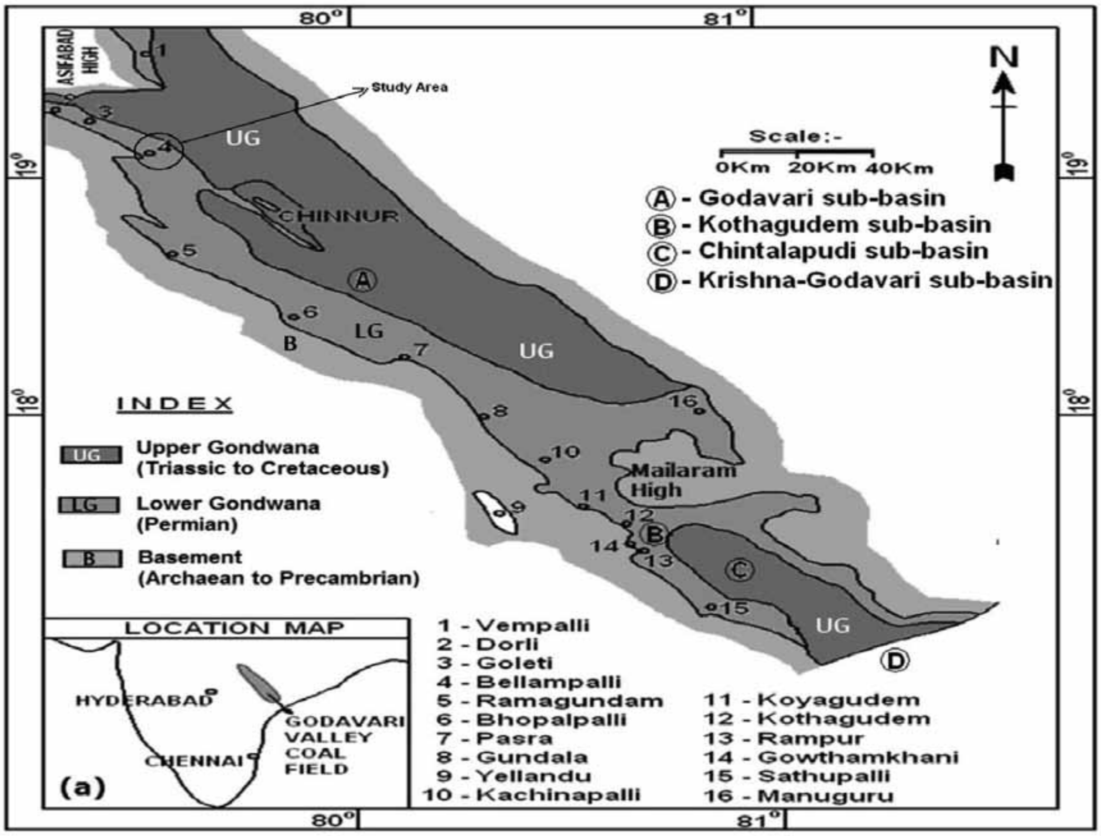

Figure 1. Outline of Pranhita-Godavari Valley.

mining in Australia. GSR introduced by Hatherly, 2013 and Hatherly et al., 2016 is considered the geophysical version of Coal Mines Roof Rating (CMRR) or Rock Mass Rating (RMR) proposed by Mark and Molinda (2003) and Bieniawski (1976) respectively.

Uday Bhaskar et al., (2015a, 2015b & 2016b); Shanmukha Rao and Uday Bhaskar (2015b); Uday Bhaskar and Shanmukha Rao (2016a); Shanmukha Rao et al., (2015a & 2015c) and Sharma et al., (2014 & 2016) of Singareni Collieries Company Limited (SCCL) situated in the state of Telangana, India carrying out detailed exploration and mining of Permian coals of Godavari Valley are the first in India to establish the usefulness of geophysical logging in coal exploration and mine planning programmes. Sharma et al., (2016); Chatterjee and Pal (2010) and Ghosh et al., (2016) computed ash and moisture contents of coal using geophysical logs from various coalfields of India. Similarly Sharma et al., (2014 & 2016); Singha and Chatterjee (2015) and Das and Chatterjee (2017) made use of geophysical logs to compute in-situ stress conditions and well bore stability. These geophysical logs now provide all the information related to geological, geochemical, geotechnical and mechanical properties of overburden of coals. The strength parameters are even empirically related to P wave velocities (Vp) obtained from sonic logs. These workers classified rock strength (UCS) proposed by (Larkin and Green, 2012) who classified rock strength by considering the Permian sediments alone but not the entire spectrum of rock types. The mechanical stratigraphy of the entire coal bearing Barakar Formation spread over a strike length of 350km is now well established from these geophysical studies. UCS and GSR maps prepared from geological and geophysical inputs provide an effective means to analyse the competency of immediate overburden strata of coals considered for underground mining and deep and large opencast mines. These maps now provide the basic inputs to construct geo-hazard maps. Uday Bhaskar and Shanmukha Rao (2016a) and Shanmukha Rao and Uday Bhaskar (2015b) demonstrated that geological and geotechnical data obtained from geophysical logs of non-cored wells allow planning and managing high capacity longwall mines of SCCL. Taking clues from these studies, an attempt is made to build up the geotechnical and geological characteristics of coal bearing Barakar Formation of Sravanapalli- II Dip side Block of North Godavari sub-basin (Figures 1 & 2).

Geological Setting

SCCL is a state owned public sector company exploring and extracting the coal deposits of Early Permian Barakar Formation along 350km long NNW-SSE trending Pranahitha Godavari Valley located in the state of

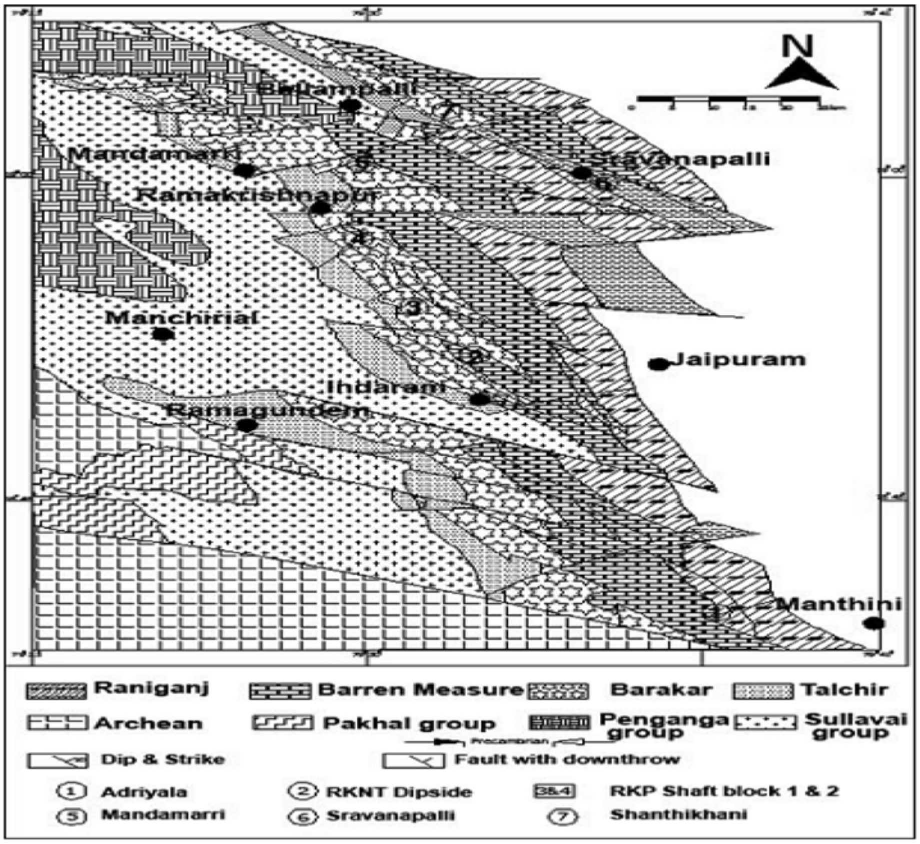

Figure 2. Geological Map of Sravanapalli-II Dipside Block and its Surrounding Areas.

Telangana, India (Figure 1). Based on geological and geophysical data, the valley is divided into four sub-basins by Ramana Murty and Parthasarathy (1988) from north to south as Godavari, Kothagudem, Chintalpudi and Krishna-Godavari sub-basins. The Early Permian Barakar Formation contains seven to ten correlatable coals of 1m to 22m thickness. The Late Permian Raniganj Formation contains intercalated carbonaceous horizons which are yet to be extracted. The Sravanapalli–II Dip side Block is located in the Northern part of the Godavari sub-basin (Figure 2). The block is bounded by Latitude: N18^0 58′ 58″ to 19^0 01′ 44″ and Longitude: E79^0 32′ 55″ to 79^0 35′ 03″of Survey of India Toposheet No: 56M/12 & 56N/09. The Sravanapalli–II Dip side Block covering an area of 7.13Sq. km (with strike length of about 5.1km and dip length of about 1.4km) is located on the almost extreme south eastern part of Dorli – Bellampalli coal belt. A few exposures of Barren Measure and Lower Kamthi (Raniganj) formations are present in the block. The area is mostly covered by soil followed by Late Permian Raniganj and Middle Permian Barren Measure formations. Figure 3 shows the location of boreholes drilled in the block.

The stratigraphic succession of the block worked out mostly from the subsurface data is furnished in Table 1. Coals are located between 300m and 700m depths below the surface. Figure 5 shows the core samples of Barakar Formation. In Sravanapalli Block –II Dip side, nine regionally persistent coal seams viz. IA, I, II, LB1, IIIB, IIIA, SJ (Top), SJ(Bot) and LB2 occur within the Early Permian Barakar Formation of 300m thickness, comprising white to greyish white, coarse to medium grained feldspathic sandstones interbedded with shale and coal horizons. The interburden strata of these coals are named SS-90, SS-80T, SS-80, SS-70, SS-65, SS-60, SS-50, SS-40, SS-40B and SS-30 in descending order (Figures 4, 5, 6a & 6b). The thickness of these coals ranges from one metre to six metres with Seam-II having maximum thickness of 6m. The 200m thick coal bearing Barakar Formation is overlain by 350m thick Barren Measure sediments comprising green to greenish grey, medium to very coarse grained feldspathic sandstones intercalated with shales and variegated clays. The Raniganj Formation of about 200m thickness in this block is made up of medium to coarse grained white to greenish grey white calcareous sandstone and buff to greenish grey clays. The Raniganj contains couple of uneconomic 0.60m to 2m thick correlatable coals, which are considered marker beds. Sondilla Seam is one such carbonaceous bed.

TABLE 1. Generalised Stratigraphic Succession Of Sravanapalli_II Dipside Block.

Age	Group	Formation	General Lithology	Thickness (m)
Recent			Soil cover/Alluvium	3.00
PERMIAN	LOWER GONDWANA	*Middle Kamthi*	Shale/clays with subordinate sandstone .	20.00+
		Raniganj (Lower Kamthi)	Sandstone with subordinate shale and coal seams	200
		Barren Measures	Coarse to pebbly feldspathic sand stones with variegated shales & clays	330.26+
		Barakar	Upper-Member: The sandstones are medium to coarse grained grey to greyish white in color with 10 correlatable coal seams.	200
			Lower Member : Predominantly fine to medium grained white sandstone with thin coal bands.	107.83+
		Talchir	Fine to medium grained greyish white to green colored sandstone and shale.	-

METHODOLOGY

Around 80 boreholes are drilled in the block to establish the lay out and disposition of coal seams (Figure 3). These boreholes were mostly non-cored and coring was limited to the coal seams and their roof and floor rocks. The Barren Measure and Raniganj formations are completely non-cored but for couple of boreholes. Similarly, the complete sequence of Barakar Formation was cored in a few boreholes. The core samples of sandstones are broken into pieces of different lengths (Figure 5). Most of these sandstone core lengths are between 10cm and 20cm while the core samples of coal are around 5cm to 10cm and clay samples are less than 5cm and often powdered. The soft and pliable nature of finer clastics and coals do not favour generating intact core samples. These core samples are broken along the same direction due to core discing and produce lower values of strength parameters as discussed by Uday Bhaskar and Shanmukha Rao (2016a). These core samples are therefore not suitable to determine RQD and mechanical properties since they mislead one to conclude massive sandstones as highly fractured/jointed rocks having low RQD. The geotechnical information of entire Barakar Formation might not possible from core samples and making it necessary to think of alternative methods to get these data. The geophysical logs of these boreholes therefore form the primary source of geological and geotechnical information. Figure 4 shows the geophysical logs along with interpreted lithologies, mechanical and elastic properties. The complete information of Barakar is possible and an easy affair from geophysical logs.

The geophysical logging was carried out using logging equipment of M/s. Robertson Geologging, Deganby, UK using SPRN, FDGS, HRAT and TRSS probes. SPRN probe contains single point resistance (SPR), short normal resistivity (SNR), self potential (SP), single detector of neutron and 241Am-Be radioactive source of 37GBq strength. FDGS probe contains far and near density detectors to compute bulk density (DENS), natural gamma (NGAM) and caliper (CALP) and 137Cs of 3.70GBq strength is the radioactivity source. HRAT is the high resolution acoustic televiewer imaging probe and TRSS is the tri-receiver monopole full waveform sonic probe. The interpretation of geophysical logs was carried out using the standard procedures and the various modules of WellCad software. The geophysical logs of nine boreholes located along the NNW-SSE strike direction are considered in the present study (locations in Figure 3). The interpretation of geophysical logs was also reviewed and correlated with the available core data.

Coals are identified by high resistance/resistivity, low density of 1.40 to 1.80g/cc, low neutron and natural gamma values of about 50cps and 30cps to 50 cps respectively (Figure 4) and Vp of coals are around 2300m/s. Coals and clays are characterised by the absence of propagation of shear waves (Vs) in the monopole sonic probe. Vp and Vs of very coarse to medium grained grey-white sandstones of Barakar are around 3000m/s to 3750m/s and 1500m/s to 2000m/s respectively and bulk density of 2.30g/cc to 2.50g/cc. Fine grained sandstones hard and compact and often silicified record high to very high resistance/resistivity, neutron (400cps to 700cps), density of 2.65g/cc to 2.80g/cc and Vp of 4500m/s to 6000m/s. Fine grained sandstones, sandy shales, shales and clays show low neutron (50cps to 125cps) and high gamma (200cps to 300cps) values and densities of 2.20g/cc to 2.50g/cc. Some of the clays and shales are prone to caving as observed from the increase in borehole diameter on caliper logs and are considered very weak beds. The neutron and Vp logs being easy to quantify give a basis to classify various lithounits on the basis of count rates and Vp values. The density and natural gamma values of coal increase with the increasing ash

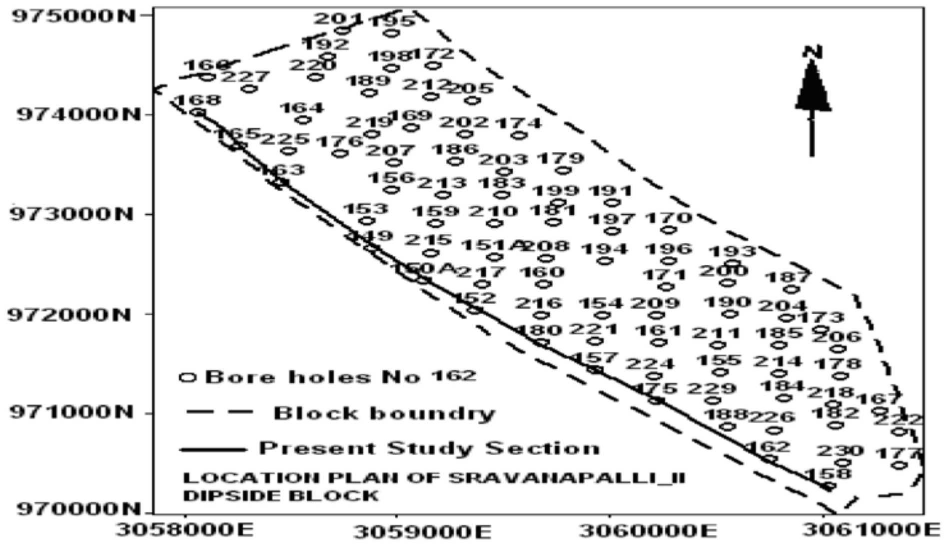

Figure 3. Location Plan of Sravanapalli –II Dipside Block.

content, while resistance and resistivity of coals decrease with ash contents.

The density and arrival times of P and S waves are used to calculate the dynamic modulus such as Bulk Modulus, Shear Modulus, Young's Modulus and Poisson's Ratio along with Vp/Vs to analyse the competency of various lithounits. The acoustic amplitude images indicate fine grained sandstones, shales and coals as high amplitude bright colour features and the medium to coarse grained sandstones as medium amplitude light brown colour features. The clay beds which are prone to easy caving appear as low amplitude dark shade features (Figure 4).

The sonic log being a function of rock elasticity can be empirically related to various rock strength parameters. Uday Bhaskar et al., (2015a, 2015b & 2016b), Shanmukha Rao and Uday Bhaskar (2015b), Uday Bhaskar and Shanmukha Rao (2016a), Shanmukha Rao et al., (2015a & 2015c) and Sharma et al., (2014 & 2016) estimated strength parameters of Permian sandstones of Godavari Valley from sonic logs. These studies also provide a clue to identify the uncertainties in the laboratory determinations of strength parameters of Permian sediments of Godavari Valley. Hanson et al., (2005) classified the sediments on the basis of Vp values rather than UCS values. Sonic logs provide reliable and accurate arrival times and wave velocities and are therefore considered to classify the rock strengths and even to compute UCS.

Empirical equation (1) developed by Uday Bhaskar and Shanmukha Rao (2016a) being comparable to the world-wide studies is considered to estimate UCS from Vp obtained from sonic logs.

$$UCS=10^{-5}\text{-}5Vp^2-0.0269Vp-122.73 \quad (R^2=0.94) \qquad (1)$$

UCS and Vp are in MPa and m/s respectively.

CMRR/RMR are usually preferred over UCS because the rocks of contrasting geological make up can still have similar and identical UCS values due to which the UCS on its own cannot ascertain the overall competency of the rock. CMRR/RMR though has the ability to define the overall competency of a rock is never determined during exploration stage in India. Mine plans are prepared only on the basis of much debated RQD and UCS values but not on the basis of CMRR/RMR in India. One has to wait for the opening to determine CMRR/RMR. GSR, the geophysical version of CMRR/RMR allows having first-hand information on competency of overburden strata of coals at the exploration stage itself. Medhurst et al., (2014) suggested a rating system based on GSR, wherein a range of approximately 15% for very poor quality rock to 100% for very good quality rock. The classification is in line with CMRR/RMR rating schemes which are based on core samples. GSR of the coal bearing Barakar Formation of Sravanapalli –II Dipside block has also been calculated by following the procedures of Hatherly et al., (2016).

A strike section along the NNW to SSE direction of about 5km length is constructed to analyse latero-vertical variations, UCS and GSR of the overburden strata of coals (Figure 4, 6a & 6b). The section extends from borehole SBS-168 in the NNW to borehole SBS-158 in SSE as shown in Figure 3

Discussion of Results

The coal bearing Barakar Formation can be resolved into Lower (70m) and Upper (80m) Sequences with the base of Seam-LB1 as the interface. The Lower Sequence comprises

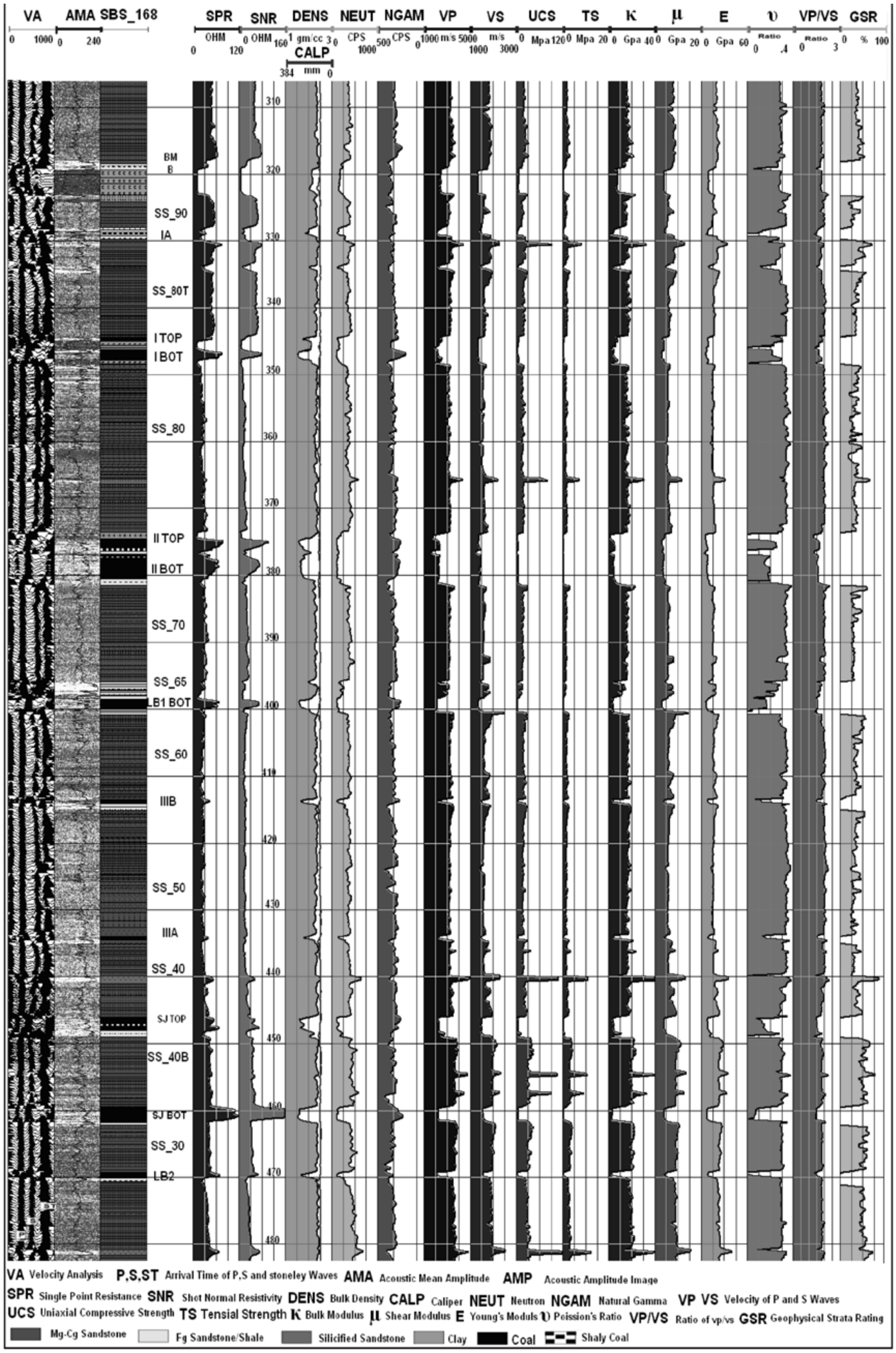

Figure 4. Borehole Geophysical Logs along with Interpretation of Lithology, Mechanical and Elastic Properties, Borehole SBS-168.

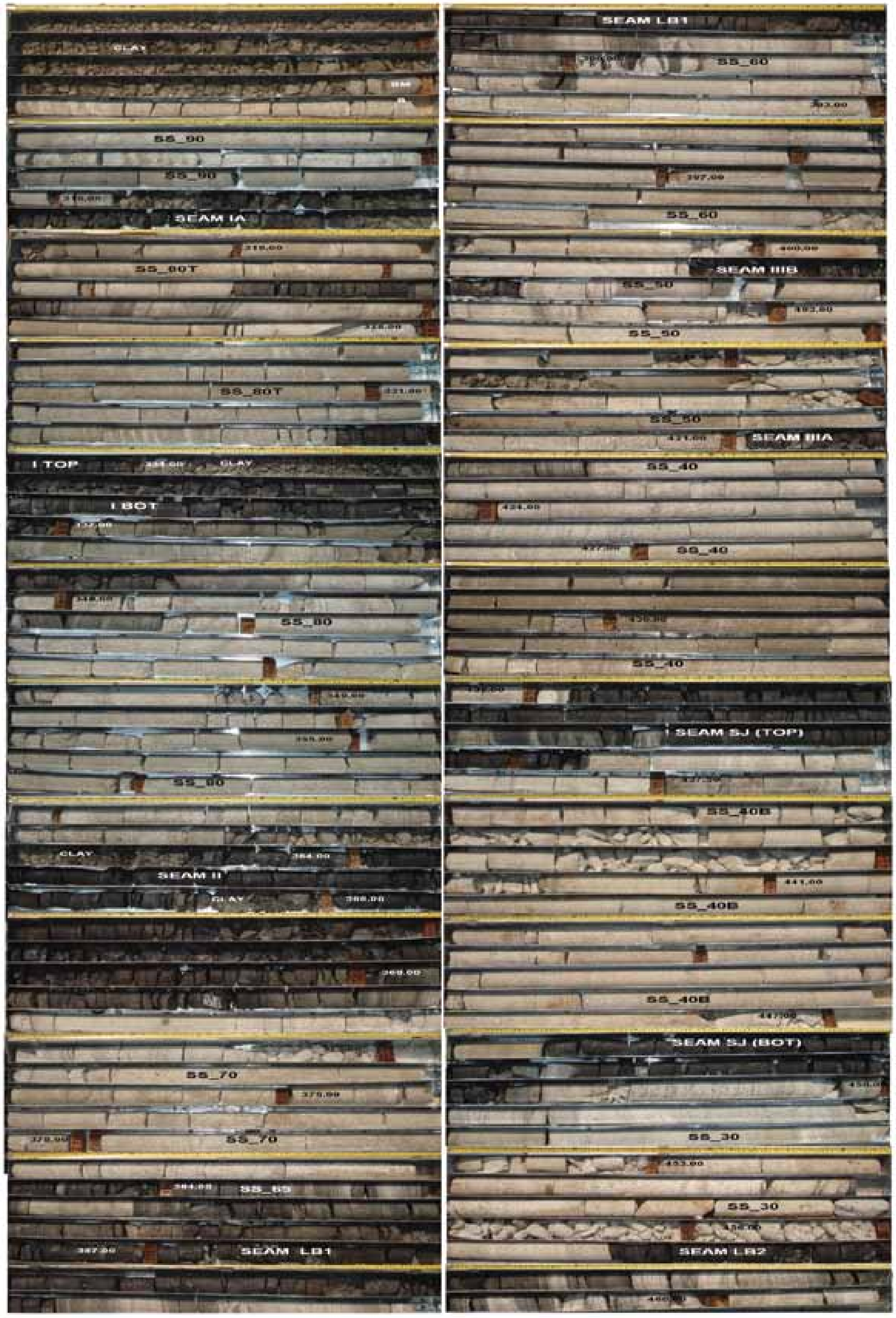

Figure 5. Core Samples of Barakar Formation, Borehole SBS-165. Core Samples are arranged in descending order. (Clay, Coal, Sandstone).

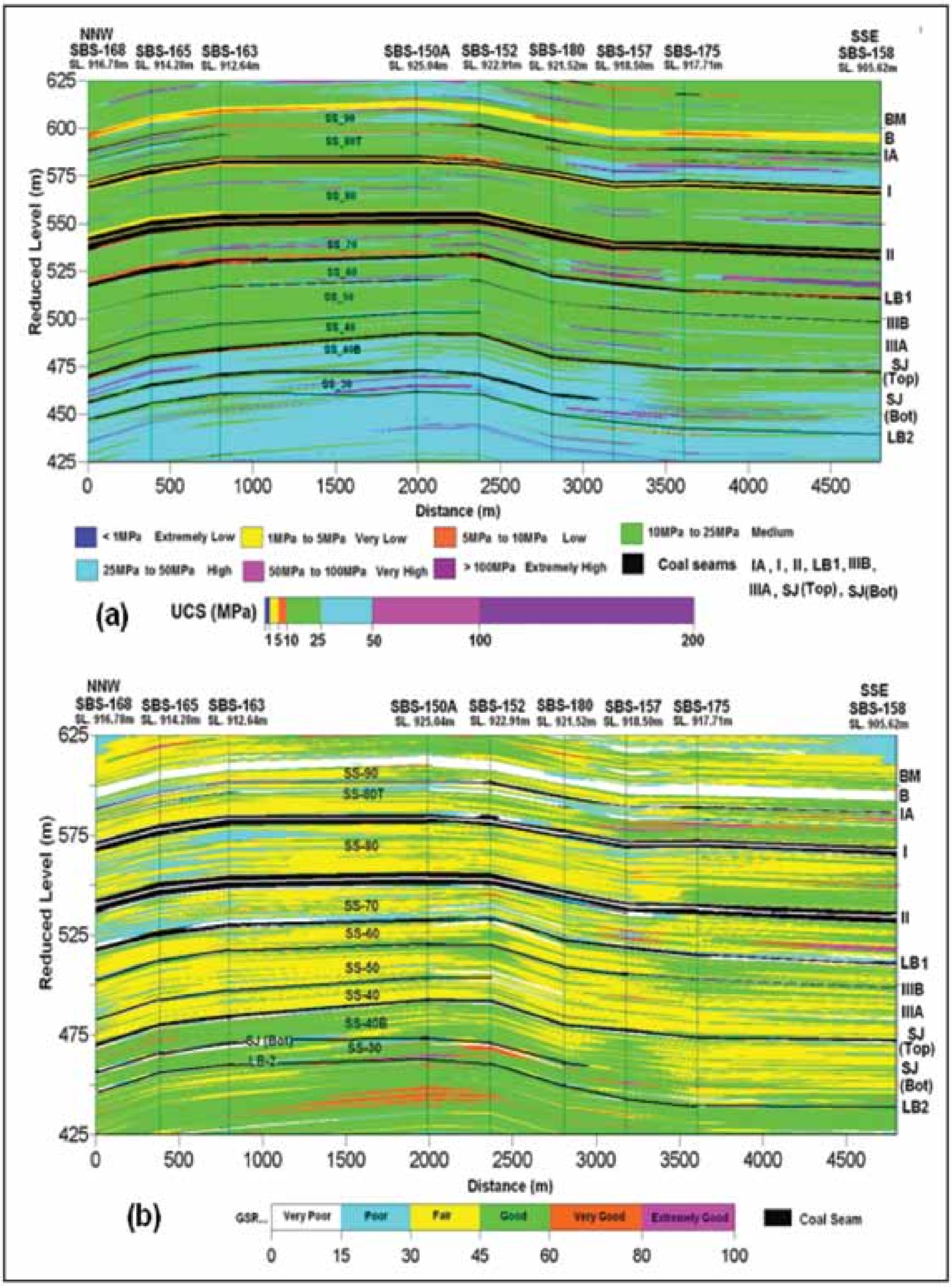

Figure 6. (a) UCS and (b) GSR Maps of Barakar Formation of Sravanapalli-II Dipside Block along Strike Section.

relatively compact and massive sandstones having Vp of 3500m/s to 4000m/s, UCS of 30MPa to 40MPa and GSR of 50% to 60% corresponding to a clasification as High Strength and Good rocks respectively. SS-30 and SS-40B show increasing trends towards SSE indicating that the channel was active along these portions of depositional sites. The wash out of coals LB2 and SJ (Bot) and their replacement by surrounding sandstones is a common phenomenon. Thus, these coals go through facies change from coals to sandstone through finer clastics. The net increase in the thickness of Barakar from 146m in the NNW to 165m in the SSE is mostly due to the increase in the thickness of SS-30 and SS-40B. The sedimentation during the other various episodes is almost uniform indicating stable conditions of syn-sedimentary tectonic conditions. The thickness of Seam SJ (Bot) also displays decreasing thickness followed by washout along the SSE. The wash out of SJ (Bot) and LB2 at different parts indicates encroachment of coal swamps by active channels. The Seam SJ (Top) though having a better persistency shows variation in its thickness from 1.18m to 1.97m with a decreasing trend towards SSE. Similar to Seam LB2, the coals IIIA and IIIB are around 0.48m to 0.88m and 0.43 to 0.81m respectively. Seam IIIA is mostly washed out along the SSE direction. High Strength sandstones of about 30MPa to 40MPa (UCS) and GSR of 50% to 60% constituting the immediate roof rocks of these coals however grade to much weaker shale beds towards the zones of washout. Part of these coals could be replaced by shales and other finer clastics classified as poor to fair rocks by GSR. The floor rocks of these coals being deposited during in-active stages of channel are made up of one metre to two metres thick finer clastics of fine grained sandstones, sandy shales and shales. Thus, these coals have weak rocks as their immediate floor. The inter-tonguing and wedging of weak and strong rocks produces differential compaction and fracturing and jointing of rocks. These zones can be considered as geotechnical risks and appropriate measures should be taken to handle them.

The Upper Sequence extending from the base of LB1 to the BM/B contact of about 80m thickness shows near uniform thickness of overburden strata of various coals indicating uniform and stable conditions of deposition. The sandstones which are mostly medium to coarse grained are relatively less compact and less hard than those of sandstones of Lower Sequence. Vp and UCS of these sandstones are around 3000-3500m/s and 10MPa to 20MPa and can be classified as Medium strength rocks. GSR of these sandstones is around 30% to 45% and classified as Fair rocks. The coals LB1 (Bot), Seam-II, Seam-I and Seam-IA show uniform thickness while the thickness of Seam LB1 reduces to 0.80m at SSE. This is because of the replacement of coals by shales. LB1 (Top) is developed only in borehole SBS-152 located on this section. Clays, shales and other such weak beds form the immediate roof rocks of these coals of Upper Sequence thereby making it difficult to mine them. The less thickness (1.10m to 1.50m) of Seam-I and presence of 1.00m to 1.50m thick clay along the roof can make it difficult for mining of Seam-I. The Seam-LB1 (Bot) presents similar picture. The Seam-II of 6m thickness is one of the important coals which can be considered for mining by leaving coal along the roof. Uday Bhaskar et al., (2016b) indicated that the development of Seam-II of 6m thickness took place in coal swamp spread over the entire Godavari sub-basin. Inundation of coal swamps by flood basin produced higher amounts of ash of 25% to 40%. The 0.30m to 0.60m dirt band in the form clay, shale and carbonaceous shale resolves the Seam-II into Top and Bottom sections. Top section of Seam-II contains lesser amounts of ash of 25% to 30%. The bulk density as obtained from the density logs indicates that the Top and Bottom sections have a density of 1.50g/cc to 1.55g/cc and 1.55g/cc to 1.60g/cc respectively. The Seam-II can be mined by considering the experiences of Adriyala block as noticed by Uday Bhaskar and Shanmukha Rao (2016a).

The overburden strata of all these coals contain one metre to two metres thick fine grained to very fine sandstones, hard and compact and often silicified with their UCS varying from 60MPa to 200MPa and classified as Very High to Extremely High strength rocks. GSR of these beds range from 60% to 90%. Some of these beds persist over considerable extensions of hundreds of metres to one to two kilometers. The impact of these beds in terms of periodic weighing or differential compaction needs analysis using appropriate techniques.

The seam-wise overburden maps in terms of various mechanical, elastic and petrophysical properties gives further scope of taking up bed-wise analysis.

CONCLUSION

Geological investigations for coal mining should not be just about determining the thickness and quality of the seams to be mined. They should also address the geotechnical characteristics of the surrounding strata so that geotechnical engineers can design mine openings which differ according to the mine plan. The conventional methods often fall short of providing all these data. Geotechnical studies conducted in Sravanapalli-II dip side block using geophysical logs concludes that Geophysical logging of exploration boreholes provides a means for acquiring both geological and geotechnical information. The non-core drilling followed by geophysical logging should be considered as an additional advantage to bring down the exploration costs. To obtain these benefits, the main requirement is that the geophysical logging tools should be well calibrated. Mine companies should therefore properly supervise geophysical logging activities and ensure that logging contracts encourage delivery of high quality results. However, the human nature still continues to consider the bird in the hand in the form of a piece of core regarded much more highly than elusive birds in the bush in the form of 'esoteric' geophysical measurements. (Hatherly et al., 2016).

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Compliance with Ethical Standards

The authors declare that they have no conflict of interest and adhere to copyright norms.

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‘Super-deep’ diamonds- new information about Earth’s interior

Researchers at Tohoku University believe that it is possible for natural diamonds to form at the base of Earth’s mantle. The formation of such “super-deep” diamonds was simulated using high-pressure and high-temperature experiments by the Japanese research team, led by Fumiya Maeda.

Results of their experiment show that super-deep diamonds can form through the reaction of Mg-carbonate and silica minerals. The reaction may occur in cold plates which descend all the way to the base of the mantle.

Details of actual diamond formation in such a deep part of Earth has so far, never been reported. But researchers plan to combine their recent experimental model with observation and analysis, in the hopes of getting information from natural diamonds that would provide further knowledge about our planet.

Source: Fumiya Maeda et al., 2017. Diamond formation in the deep lower mantle: a high-pressure reaction of MgCO3 and SiO2. *Scientific Reports*, 2017; 7: 40602 DOI: 10.1038/srep40602