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# Geomining Conditions of Seam-I of Godavari Sub-Basin-A Geophysical Study

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**ABSTRACT**
Mechanised mining is preferred to extract coals having weak clay roof at Ramagundam and Belampalli regions of Godavari sub-basin located in the state of Telangana, India. The present study has therefore focused on establishing the developmental pattern of one such coal called Seam-I and its overburden strata known as SS-80 using geophysical logs. Development of Seam-I of 4m to 7m thickness took place in a coal swamp spread over the entire Godavari sub-basin. Inundation of coal swamps by the flood basin produced higher amounts of ash of 25% to 40%. The top section of Seam-I contains lesser amounts of ash of 25% to 30%. Dynamism of sub-environments of the fluvial system produced distinct pattern of clay (1.20m thick) and sandstone as the immediate roof of Seam-I in various parts of Godavari sub-basin. Roof rock maps now constructed provide spatial distribution of clay and sandstone, that are useful to plan roof support systems. Very thick to thick (2m to 3m) massive/ graded sandstones make up the 17m to 33m thick overburden of Seam-I. These are low to medium strength and fair to good rocks classified on the basis of uniaxial compressive strength (UCS) of 6MPa to 15MPa and Geophysical Strata Rating (GSR) of 30% to 60% respectively. 1m to 2m thick beds of very low to very high strengths separate very thick beds. UCS and GSR maps provide the spatial distribution of all these beds to predict zones of separation, delamination and periodic weighting. It is also observed that intact strengths of these sandstones are lower than those of Australian and American sandstones for a given range of Vp values.

**Key words**: Seam-I, SS-80, Vp, UCS, GSR.

## INTRODUCTION

Singareni Collieries Company Limited (SCCL) carries out exploration and extraction of Early Permian coal deposits of Barakar Formation from the 350km long NNW-SSE trending Pranhita Godavari Valley, Telangana, India Figure 1a. It is a 'Crevice' type of platform rift zone containing 4,000 to 5,000 m fluviatile sediments of Early Permian to Early Cretaceous, and considered the largest single Gondwana basin belt. Geophysical studies supported with geological data subdivided the valley into four sub-basins from north to south as Godavari, Kothagudem, Chintalpudi and Krishna-Godavari (Ramana Murthy and Parthasarathy, 1988). The Early Permian Barakar Formation contains seven to ten coal seams of 1m to 22m in thickness Figure 1b whereas the Late Permian Raniganj Formation encloses few intercalated carbonaceous horizons which are yet to be extracted. Uday Bhaskar (2006) and Uday Bhaskar et al. (2002, 2011), using geophysical logs, established that the Early Permian coals of Godavari Valley are regionally extensive and can be traced and correlated in all the sub-basins Figure 1b.

These coal beds are commonly resolved into top and bottom sets separated by intervening channel sandstone and therefore given local names in different mining blocks. For example the top set of coals (Seam-II to Seam-IB) of Ramagundam continue towards NNW into Belampalli; where Seam-I of Ramagundam is called Seam-IA at RKNT dipside block, Ramakrishnapur shaft blocks 1 and 2 and Mandamarri respectively; and Seam-II at Sravanapalli and Shantikhani longwall blocks respectively of Belampalli region Figure 2.

Extraction of top set of coals is considered difficult by conventional board and pillar method because of 1m to 2m thick clay forming the immediate roof in major portions of mining blocks. SCCL is therefore extracting Seam-I by longwall mining at GDK 10A incline of Ramagundam for the last two decades. These rich experiences of longwall mining at GDK 10A incline can be extended to those areas where Seam-I prevails with a favourable structural fabric.

Keeping this in view, the geophysical logs and core data of Adriyala, RKNT dipside, shaft blocks of Ramakrishnapur, Mandamarri, Sravanapalli and Shantikhani are studied in detail to assess the Seam-I and its overburden strata locally known as SS-80 in these blocks. These studies are very crucial and important because an understanding of geomining conditions can be of help in selecting appropriate roof support systems towards successful longwall mining (Ramesh Kumar et al., 2011). Advanced digital geophysical logs including sonic and acoustic imaging logs are extensively

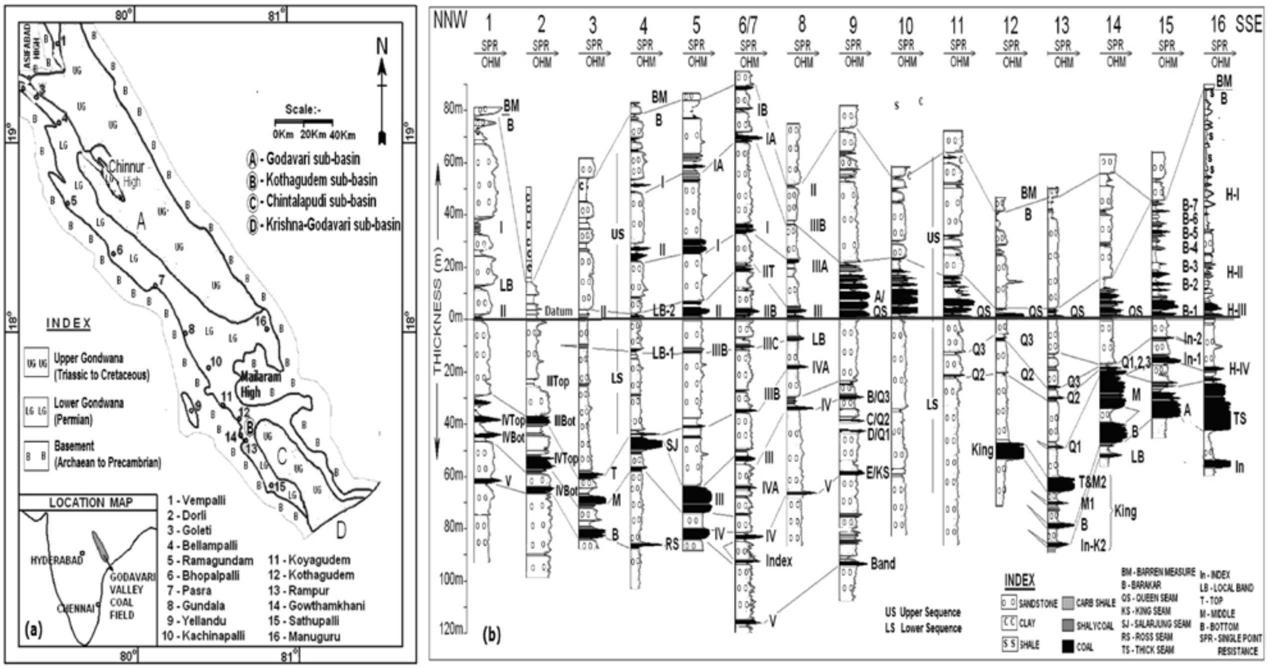


**Figure 1.** (a) Outline of Pranhita-Godavari Valley, (b) Nomenclature and Correlation of Coals using Single Point Resistance logs. Queen Seam (QS) is the datum of section (locations in figure 1a, modified after Uday Bhaskar et al., 2002 and 2011).

used in the present study to generate geological and geotechnical models of interburden strata which in turn can form the basic inputs to plan mechanised mining. These logs have the unique advantage of acquiring continuous spectrum of rock strength parameters and establish the spatial distribution of weak and strong beds so important to manage coal mines (Hatherly, 2013). Within coal, the acoustic images establish the trends of joints/fractures, coal cleats and stress directions (Green and Ward, 2002 and MacGregor, 2003). It is also observed that Geophysical Strata Rating (GSR) obtained from geophysical logs provides an easy means to predict caving during longwall mining (Hatherly et al., 2009). Medhurst et al. (2014) classified the rocks on the basis of GSR and established the inter-relationship between GSR characterisation, longwall monitoring analysis and caving behaviour. Hatherly (2013) concluded that logging techniques are improving the productivity and safety in mining at Australia. In Godavari Valley, Shanmukha Rao et al. (2015) used P wave velocities (Vp) obtained from sonic logs to empirically estimate uniaxial compressive strength (UCS) of sandstones of Barren Measure and Barakar formations. Shanmukha Rao et al. (2014) and Uday Bhaskar et al. (2015) applied geophysical logs to plan and manage deep and large opencast mines. Shanmukha Rao and Uday Bhaskar (2015) developed methodology to provide suitable inputs to model overburden strata of coals to predict inter-relationship between strata characteristics and longwall caving behaviour and various support loading related parameters; Sharma et al. (2014) made similar conclusions.

## Geological Setting

Ramagundam and Belampalli coalbelts of Godavari sub-basin forming the study areas are located along the western margin of Godavari Valley along its northwestern parts Figure 3. These areas are mostly covered by soil and followed by Middle Permian Barren Measure and Late Permian Raniganj formations. Extensive drilling followed by geophysical logging established geological and geotechnical characters of the interburden strata of Early Permian coals of Barakar Formation of Adriyala, RKNT dipside block, Shaft blocks of Ramakrishnapur, Mandamarri, Sravanapalli dipside blocks and Shantikhani longwall block.

The stratigraphic succession of the block, worked out mostly from the subsurface data, is furnished in Table-1. In Ramagundam ten regionally persistent coal seams viz. IA1, IA2, IA3, I, IIT, IIB, IIIB, IIIA, III and IV occur within upper part of the Early Permian Barakar Formation of 160 m thickness, comprising white to greyish white, coarse to medium grained feldspathic sandstones interbedded with shale and coal horizons. These coals are called by different local names in various blocks of Belampalli region. The coal bearing Barakar Formation is overlain by 430m of 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 these blocks is made up of medium to coarse grained white to greenish grey white calcareous sandstone and buff to greenish grey

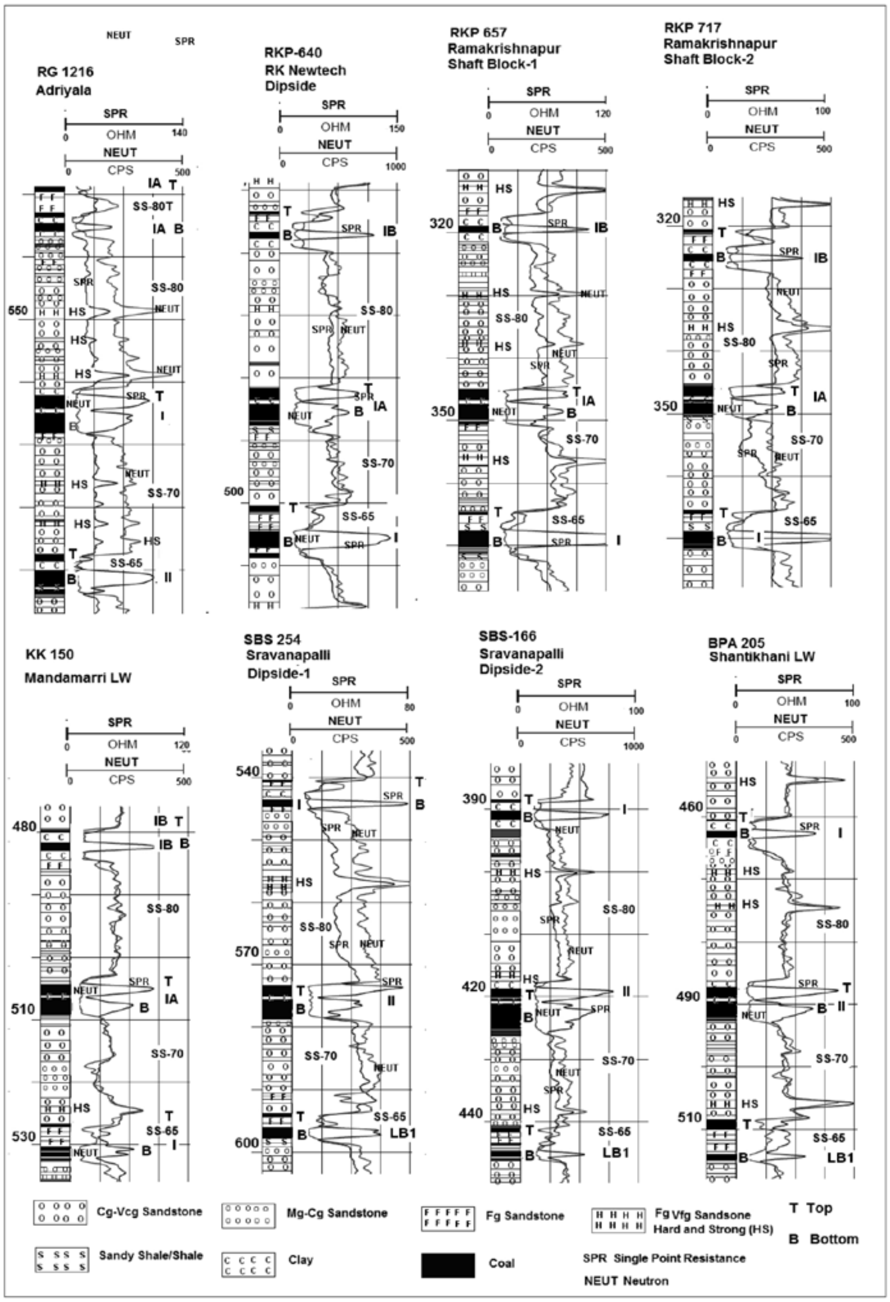


**Figure 2.** Nomenclature and Correlation of Top Set of Coals using Geophysical Logs, Ramagundam and Belampalli areas. These coals are given local names in different blocks.

clays and a few carbonaceous horizons (Sondilla Seam) is intersected in the dip side boreholes.

## METHOD OF STUDY

### Interpretation of Basic Lithologies using Geophysical Logs

The geophysical logging was carried out by deploying the equipment of Ms Robertson Geologging, Deganby, UK whose probes are called SPRN, FGDS, HRAT and TRSS. The SPRN probe contains single point resistance (SPR), short normal resistivity (SNR), self potential (SP), single detector of neutron and $^{241}$Am-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 $^{137}$Cs 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

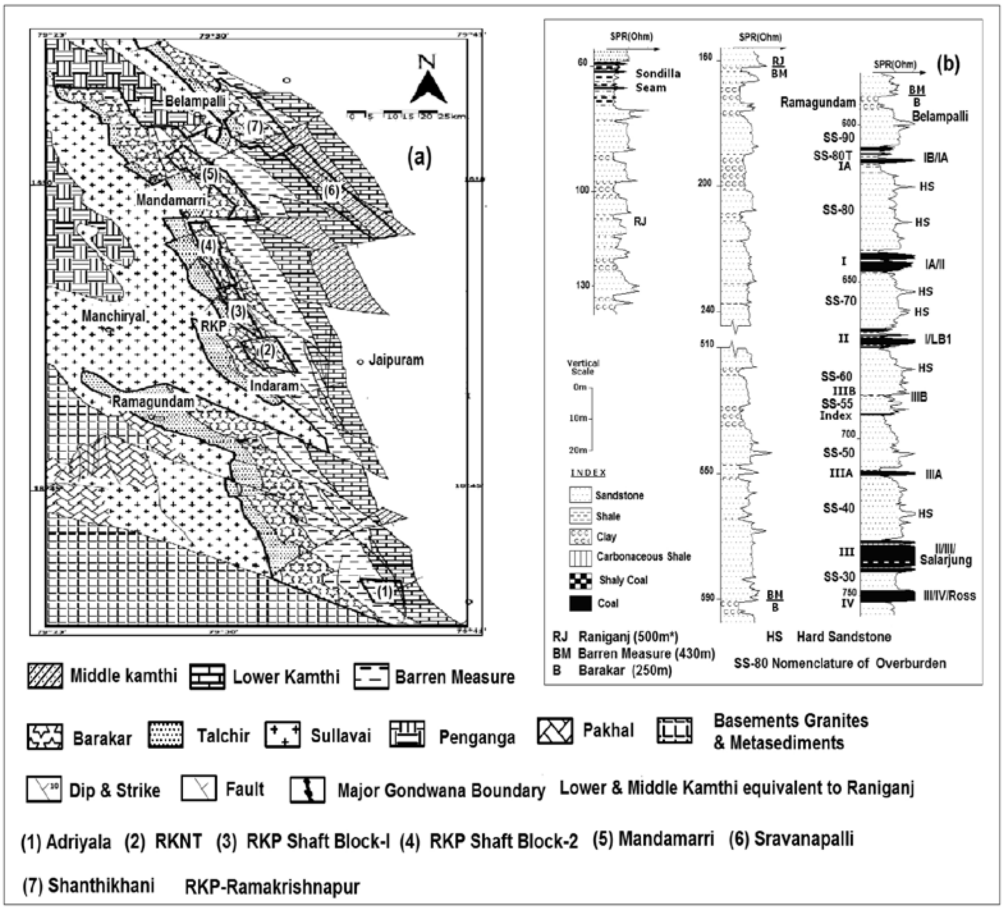


**Figure 3.** (a) Geological map of Ramagundam and Belampalli. (b) Lithostratigraphy of Ramagundam and Belampalli using single point resistance logs.

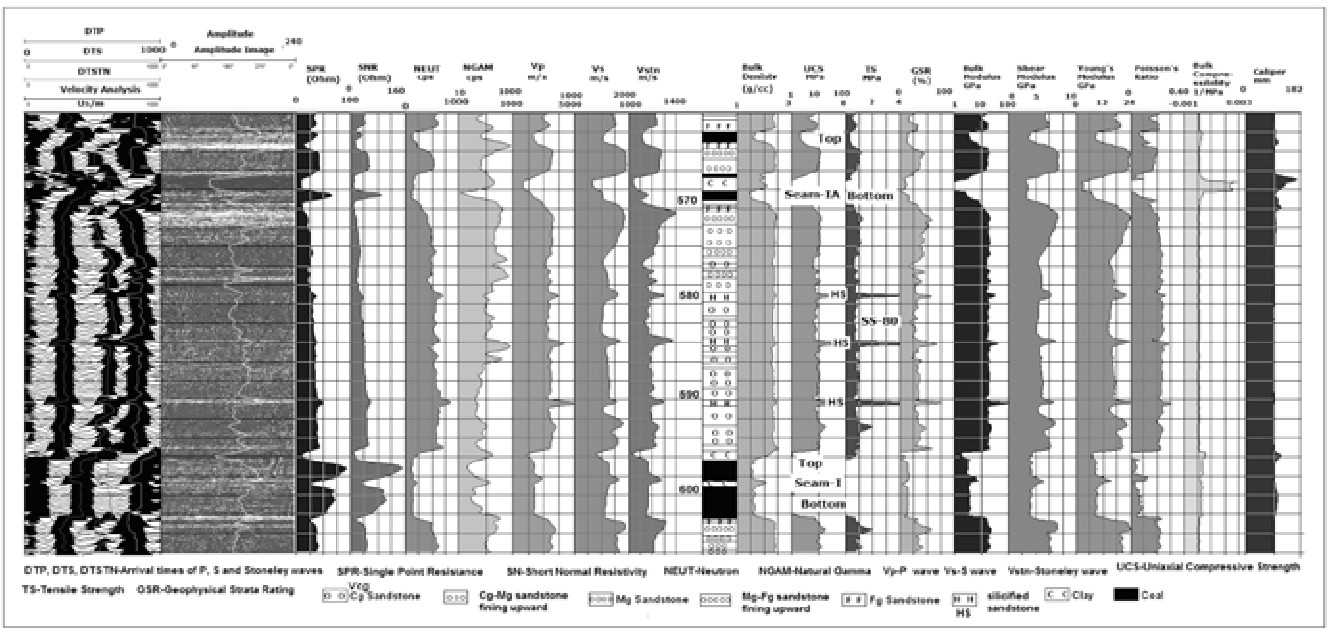


**Figure 4.** Interpretation of basic lithologies, geotechnical and elastic properties using geophysical logs. Borehole No RG-1330, Adriyala dipside block, Ramagundam.

**Table 1.** Generalised Lithostratigraphy of Ramagundam and Belampalli Blocks

| Age | Group | Formation | General Lithology | Thickness (m) |
|---|---|---|---|---|
| Upper Permian | LOWER GONDWANA | Raniganj (Lower and Middle Kamthi) | Alternating sequence of medium to coarse grained white to greenish grey white calcareous sandstone and buff to greenish grey clays and a few coal seams | 200 |
| Middle Permian | | Barren Measure | Medium to coarse-grained greyish white feldspathic sandstone with subordinate variegated clays and micaceous siltstone. | 450 |
| Upper part of Lower Permian | | Barakar | Upper Member: Coarse-grained white sandstone with subordinate shales & coal seams.<br>Lower Member: Coarse-grained sandstone with lenses of conglomerates, subordinate shales/clays and few thin bands of coal. | 300 |
| Lower Permian | | Talchir | Fine grained, sandstones splintery green clays / shales chocolate coloured clays, pebbles beds and tillite.<br>………………Unconformity…………… | 350 |
| Upper Pre-Cambrian | | Sullavai | Medium to coarse-grained white to brick red sandstones, at places quartzitic and mottled shale. | 545 |
| Lower Pre-Cambrian | | Pakhal | Greyish white to buff coloured shale and phyillite.<br>……………………Unconformity……… | 3335 |
| Archaean | | | Granite, banded gneiss hornblende gneiss, quartz magnetite, schist, biotite schist, quartz and pegmatite veins. | |

interpretation of geophysical logs was carried out using the conventional procedures and the various modules of WellCad software. Interpreted results are also reviewed and correlated with core data. Figure 4 shows the basis of geophysical log interpretation. Hatherly et al. (2008) provides guidelines to compute GSR from geophysical logs.

Coals are identified by high resistance/resistivity, low density of 1.40g/cc to 1.70g/cc, low neutron and natural gamma values of about 50 cps and 30 to 50 cps respectively Figure 4. P (Vp) wave velocity of coals are around 2300m/s. Coals and clays are characterised by the absence of propagation of shear wave (Vs). The Vp and Vs of very coarse to medium grained grey-white sandstones are around 3000m/s to 3500m/s, 1500m/s to 1750m/s and 1200m/s to 1600m/s respectively and bulk density of 2.30g/cc to 2.50g/cc. Hard and strong sandstones marked 'HS' are characterised by high resistance/resistivity, neutron (400cps to 500cps), density of 2.65g/cc to 2.80g/cc and Vp of 4500m/s to 5500m/s. Fine grained sandstones, sandy shales, shales and clays show low neutron (50cps to 125 cps) and high gamma (200 cps to 300 cps) 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 weak planes.

Vp, Vs and density obtained from geophysical logs are also used to compute dynamic elastic properties such as Bulk Modulus, Young's Modulus, Shear Modulus, Poisson's ratio and Bulk compressibility and are shown in Figure 4. The dynamic modulus values obtained from geophysical logs are about twice the static values, obtained on core samples at laboratory. These variations are presumably because rocks appear stiffer when the strains are very small. These elastic properties along with density, Vp, GSR and UCS of SS-80 of various blocks are shown in table-3 and are discussed in the section on geotechnical properties in the following pages. These elastic wave velocities and dynamic modulus are one of the most used index properties of rock and can been correlated with other index and mechanical properties of rock (Karzulovic and Read, 2010).

## Estimation of Rock Strength from Sonic Logs

Sonic logging being a function of rock elasticity enables empirically estimating strength parameters by correlating P wave velocities (Vp) with laboratory determined uniaxial compressive (UCS) and tensile (TS) strengths of sandstones. McNally (1987 and 1990) was the first to estimate coal measures rock strength using sonic and neutron logs of Australian coalfields. Hatherly (2013) reviewed that site specific empirical estimates of Vp-UCS are established all over Australian coalfields now. Mark and Molinda (2003) and Oyler et al. (2008) use sonic logs to estimate UCS in USA. Shanmukha Rao et al. (2015) made similar studies in the exploratory blocks of SCCL and derived following equations. Present studies estimated UCS using equation (2) derived from core samples of exploratory blocks under consideration.

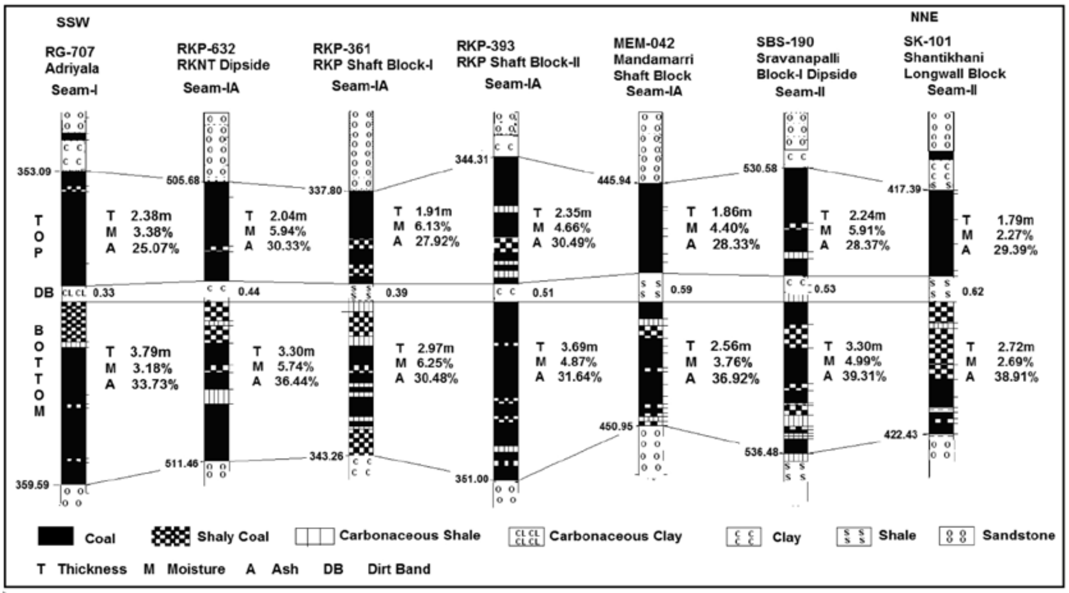


**Figure 5**. Lithotype profiles of Seam-I, (ash and moisture are over-all values)

$UCS\_adr = 0.0429e^{0.0016Vp}$ ------------ (1) $R^2 = 0.82$

$UCS\_adrktk = 0.0798e^{0.0014Vp}$ ------------ (2) $R^2 = 0.72$

$UCS\_all = 0.1401e^{0.0012Vp}$ ----------------- (3) $R^2 = 0.73$

$UCS = 9.5729 * TS$ ------------- (4) $R^2 = 0.95$

Where UCS is uniaxial compressive strength in MPa,
TS is Tensile Strength in MPa
Vp is P wave velocity in m/s

These studies also indicate that Vp of Permian sandstones of Godavari Valley are similar to those of Permian sandstones of Australia and Cretaceous sandstones of USA (Oyler et al., 2008). However UCS values of Godavari Valley are considerably lower than those of Australia and USA for a given range of Vp. The reasonably higher velocities could indicate that sandstones are strong at insitu conditions while the intact strength of core samples could be reduced because of core discing. Xing et al. (2013) reviewed that the drilling phenomenon called core discing breaks core samples into pieces of different lengths along the major horizontal stress direction due to the release of locked-in stresses. Core breaks perpendicular to the core axis are therefore considered as drilling induced artificial breaks due to release of stress. Poor core recovery is yet another good example of core discing. Release of stresses also breaks kaolinite in sandstone and results in lower UCS values being obtained on core samples. Degradation of clay in dry rock samples is another possibility of lowering UCS values. Karzulovic and Read (2010) reviewed that core samples from zones of poor recovery produce lesser strengths than those selected from zones of higher core recoveries. Best core samples exaggerate intact strength values. These studies conclude that nature of core samples influence UCS values. Laboratory determination of Vp of core samples and comparing them with Vp obtained from sonic logs could ascertain the accuracy of Vp values, as is being done by SCCL (Sliwa et al., 2008). UCS can be determined in couple of laboratories to improve the certainty of data by following the standard procedures. GSR is an additional advantage towards effective mine planning (Hatherly et al., 2009 and Medhurst et. al., 2014).

## DISCUSSION OF RESULTS

### Lithotype Profiles of Seam-I

Seam-I having a thickness of around 4m to 7m contains 0.40 to 0.63m dirt band of carbonaceous clay, clay or shale along the middle parts Figure 5. The dirt band splits Seam-I into bottom and top sections. The bottom section is around 3 to 4m thick is close to shaly coals with a weighted average of sum of moisture of 37% to 42%. The top section is also close to shaly coals with relatively lesser moisture and ash of 30% and a lesser thickness of 1.71 to 2.31m than the bottom section. All these blocks have similar minimum and maximum thickness of 4 to 7m, respectively indicating prevalence of similar amount of vegetal matter and uniform bio-chemical depositional conditions.

Development of Seam-I took place in the depositional sites transforming into one big coal swamp on a valley-wide scale, which is possible by a major reorganisation in basin's tectonics and climatic conditions (Uday Bhaskar et al., 2002 and Uday Bhaskar, 2006). Prevalence of very stable and tranquil conditions favoured the development of

**Table 2.** Thickness of Seam-I and SS-80

| Block | Thickness of Seam-I (m) | | Thickness of SS-80 | |
|---|---|---|---|---|
| | Min | Max | Min | Max |
| Adriyala (Seam-I) | 5.35 | 7.43 | 20.23 | 29.74 |
| Ramakrishnapur (Seam-IA) | 3.84 | 6.33 | 17.87 | 26.87 |
| Mandamarri LW (Seam-IA) | 4.50 | 6.50 | 16.50 | 26.36 |
| Sravanapalli (Seam-II) | 4.37 | 7.02 | 25.00 | 33.00 |
| Shantikhani LW (Seam-II) | 4.00 | 6.00 | 20.60 | 25.30 |

*Seam names in brackets are local names of Seam-I in various blocks.

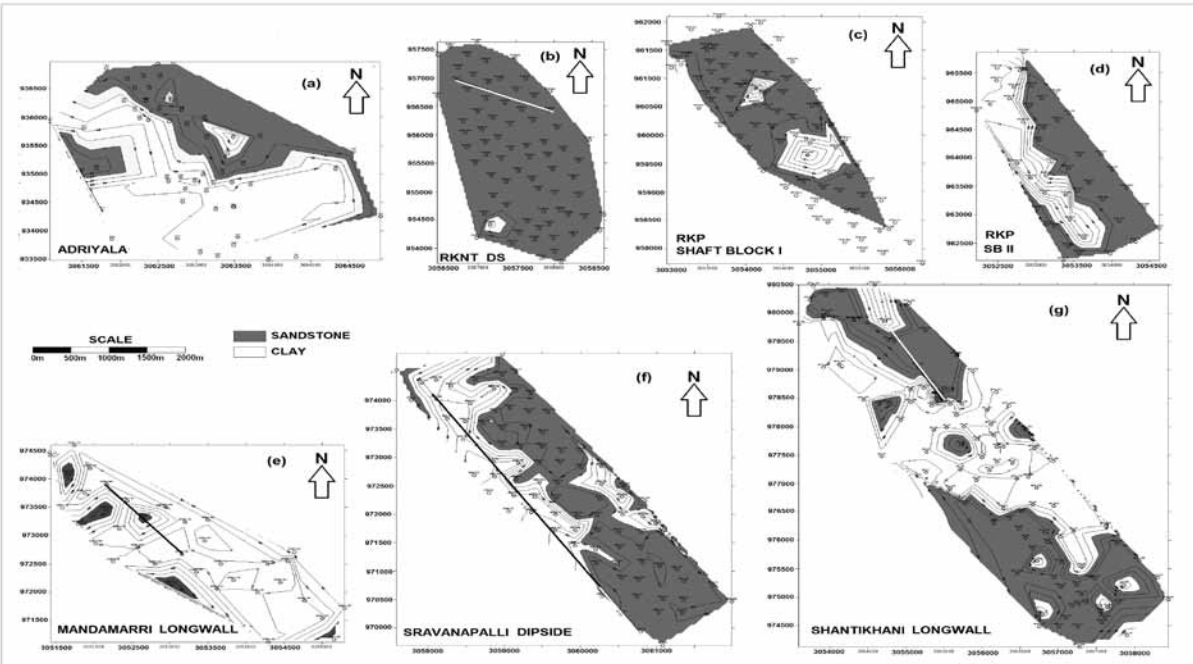


**Figure 6.** Roof Rock Maps of Seam-I.

two coal beds with gentler variations in their thicknesses. These coals also indicate aggradation of swamps with high water table and low energy more likely in a high accommodation condition. The 0.40m to 0.60m dirt band of clay/carbonaceous clay resolving the Seam-I into two sections is yet an another manifestation of coal swamp being periodically invaded by flood basin producing shale incursions due to which these coals contain higher amounts of shale.

Floor rocks of Seam-I also demonstrate lateral variations in lithofacies changing from sandstone to shale/clay within a block and also from one block to another. These variations correspond to dynamism of sub-environments of fluvial system and differential subsidence of depositional area during their deposition. The channel (sandstone bodies), overbank levee (fine sandstone-clay) and flood plain/basin (clay) facies of fluvial system represent discrete/independent events and their accumulation reflects differential subsidence of depositional basin (Maejima et al., 2008). The coarse to medium grained sandstone show slow accommodation (subsidence rate) as compared to clay and coal swamps (Potter at al., 2005).

## Roof Rock Maps of Seam-I

The immediate roof rocks of Seam-I show distinct patterns of development of clays and sandstones within the block and from one block to another Figure 6. In Adriyala block, clays and sandstones constitute the immediate roof rocks along the western and eastern parts respectively Figure 6a. The alignment of these sandstones and clays in a specific and orderly manner indicate that channel (sandstones) and flood plain (clay) of the fluvial system occupied the eastern and western portions of the block The trend of the contours indicates that the channel was flowing towards NNW corroborating field studies of Gondwana

**Table 3.** Bulk Density, Elastic Properties, GSR and UCS of SS-80

| PAR | TYPE OF BED | BPA-194 | SBS-160 | SBS-243 | KK-192 | RKP-725 | RKP-648 | RKP-733 | RG-1330 |
|---|---|---|---|---|---|---|---|---|---|
| DEN | WB | 2.06 - 2.14 | 2.00 | 1.57 | 1.66-2.38 | 1.94 | 2.02 - 2.09 | 2.21 - 2.26 | 2.17 - 2.22 |
| | NB | 2.42 - 2.58 | 2.25 - 2.38 | 2.12 -2.45 | 2.38-2.49 | 2.28 - 2.44 | 2.33 - 2.50 | 2.28 - 2.43 | 2.24 - 2.44 |
| | SB | 2.59 - 2.72 | 2.44 - 2.58 | 2.54 | 2.54 | 2.55 | 2.56 | 2.43 - 2.48 | 2.45 - 2.54 |
| VP | WB | 2420-2588 | 2240 | 2271 | 1859-2961 | 2301 | 2241-3185 | 2361-2716 | 1919-2960 |
| | NB | 2837-3785 | 3071-3571 | 3155-3571 | 3280-3750 | 3137-3731 | 3376-3870 | 3161-3945 | 3139-3651 |
| | SB | 4646- 5320 | 4629-4897 | 5000 | 5044 | 5494 | 4735 | 4529-4846 | 6472 |
| BM | WB | 2.33 - 4.93 | 3.04 | 3.34 | 2.24 - 14.89 | 3.58 | 4.06 - 9.70 | 4.30 - 7.14 | 6.27 - 9.85 |
| | NB | 6.81 - 3.65 | 15.04 - 21.67 | 13.79 - 20.46 | 16.87 - 23.70 | 14.03 - 22.5 | 15.88 - 28.06 | 13.85 - 23.39 | 11.93 - 21.33 |
| | SB | 41.99 - 51.29 | 40.50 - 47.74 | 41.20 | 44.87 | 48.54 | 35.99 | 32.46 - 39.08 | 25.18 - 94.23 |
| SM | WB | 5.78 - 6.58 | 4.82 | 4.27 | 3.34 - 5.78 | 5.37 | 4.78 - 6.29 | 5.44 - 5.49 | 4.55 - 5.37 |
| | NB | 6.72 - 11.94 | 5.94 - 7.43 | 5.85 - 7.76 | 6.03 - 8.69 | 6.45 - 9.77 | 8.00 - 9.52 | 5.55 - 10.56 | 5.46 - 8.26 |
| | SB | 12.45 - 20.14 | 8.92 - 10.31 | 14.92 | 17.30 | 22.05 | 15.54 | 10.69 - 13.93 | 8.30 - 9.12 |
| YM | WB | 9.67 - 10.93 | 8.78 | 9.11 | 6.63 - 15.22 | 10.06 | 7.63 - 15.51 | 12.69 - 15.10 | 8.17 - 14.71 |
| | NB | 15.67 - 30.44 | 15.85 - 20.17 | 15.52 - 20.34 | 16.12 - 23.39 | 17.25 - 25.09 | 19.16 - 24.77 | 15.21 - 26.95 | 15.09 - 22.04 |
| | SB | 34.56 - 54.32 | 25.40 -29.39 | 39.93 | 45.54 | 57.21 | 40.67 | 19.67 - 36.44 | 22.34 - 24.41 |

WB-Weak Bed; NB-Normal Bed, SB-Strong Bed

rocks of Peninsular India (Tewari, 1998). Clays of very limited extension enclosed within the channels (sandstone) represent suspension over channel bar top within multi-storey sandstone bodies. Occurrence of sandstone along the northwestern parts within the flood plain (clay) could be due to the lateral migration of palaeochannel/levee eroding the previously deposited clay following Walther's law of succession of facies (Middleton, 1973). Similar fining upward coal cyclothems are reported and interpreted elsewhere in Permian Gondwana Formation of eastern-central India (Casshyap, 1970; Maejima et al., 2008). Hanson et al. (2005) concluded that intertonguing of rocks of contrasting strengths leads to differential compaction and fractures/joints along the contact planes which might pose geotechnical risks.

In RKNT dipside block, sandstones constitute the immediate roof rocks of coal suggesting crevasse flooding of sand in the coal forming swamps (Casshyap and Tewari, 1984) in the entire block except for clay at the southwestern parts Figure 6b.

In shaft block-1 of Ramakrishnapur, sandstones constitute the immediate roof rocks of coal in major portions of the block, with clays of considerable extent occupying the southcentral parts of the block Figure 6c. Clay of limited extension can also be observed at northcentral parts of the block. In shaft block-2 of Ramakrishnapur, sandstone and clay constitute the immediate roof rocks along the eastern and western parts of the block Figure 6d. The orderly alignment of these contrasting lithounits indicates that channel (sandstone) and flood plain sediments, respectively occupied the eastern and western parts of the block. Channel was flowing towards NNW as inferred from the trend of contours. In the Mandamarri longwall block, clays constitute the immediate roof rocks in the block but for sandstones of limited extension along the western parts and in the northcentral parts Figure 6e. These relatively fine grained sandstones and associated clay correspond to the levee and flood plain respectively of the fluvial system. Figures 6f and 6g show the roof rock maps of Sravanapalli and Shantikhani longwall blocks, respectively. The eastern and western parts are occupied by sandstones and clays at Sravanapalli dipside block; clay body is also observed along the southeastern parts of the block Figure 6f. Clays occupy the immediate roof of coals along the central and northwestern parts of Shantikhani longwall block Figure 6g. Clays of very limited extension can be observed within the regions dominated by sandstones along the roof of coals at southern parts of the block. Sandstones of limited extension can also be observed along the regions dominated by clays along the central parts of the block.

The geometry of sandstones and clay forming the roof rock in different mining blocks, their mutual relationships

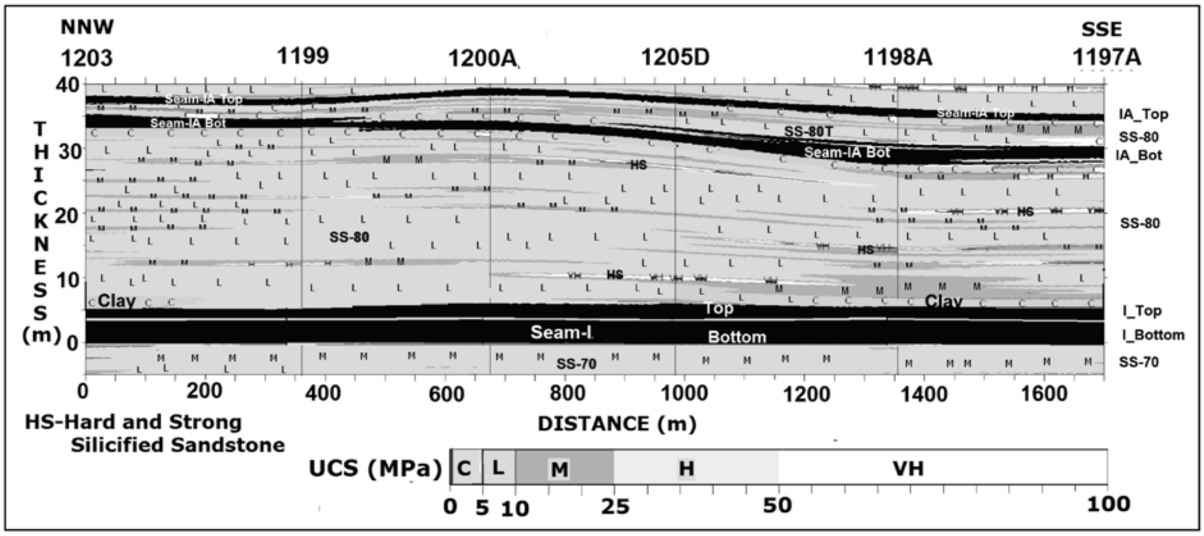


**Figure 7.** UCS Sections of SS-80 the overburden strata of Seam-I, Adriyala Block, (after Shanmukha Rao and Uday Bhaskar, 2015). 0MPa to 1MPa-Extremely Low, 1MPa to 5MPa-Very Low, 5MPa to 10MPa-Low, 10MPa to 25MPa-Medium, 25MPa to 50MPa-High and 50MPa to 100MPa-Very High (Larkin and Green, 2012)

and variable occurrence are suggestive of lateral migration of palaeochannel and levee within the parts of fluvial system. Therefore the roof rock maps prepared here in different mining blocks are not only providing interpretations of fluvial architecture, but may also be useful for geomining of the seam I.

## Geological and Geotechnical Nature of SS-80

The SS-80 forming the overburden strata of Seam-I is around 17m to 33m thick in these blocks (table 2). SS-80 has maximum thickness range of 25m to 33m at Sravanapalli blocks followed by Adriyala (20m to 30m), Shantikhani (21m to 25m), Ramakrishnapur (18m to 27m) and Mandamarri (17m to 26m). These variations could indicate the prevalence of differential subsidence during the deposition of SS-80 along these blocks. The bulk density, elastic properties, GSR and UCS of SS-80 are given in Table 3. UCS and GSR sections shown in Figures 7 to 10 and Figure 11 respectively bring out the stratigraphic placement of various beds which help predicting zones of separation, delamination and periodic weighting. These maps also indicate rolling nature of the beds at Adriyala and Mandamarri blocks.

SS-80 comprises very thick to thick bedded massive sandstones made up of medium to coarse grained feldspathic and micaceous sandstones Figure 2. The upper portions of these sandstones are sometimes graded/fining upward often ending up with fine grained sandstones, sandy shales and shales, a characteristic feature of fluvial deposits. These very thickly to thickly bedded massive sandstones are also resolved into sub-sequences terminating with finer argillaceous clastics of fine grained shales, sandy shales, fine grained sandstones etc. These argillaceous beds are weak beds and can form potential planes of separation and delamination.

Very thickly to thickly bedded massive sandstones of SS-80 have UCS of 5MPa to 15MPa and are classified as Low strength (5MPa to 10 MPa) and Medium strength (10MPa to 25MPa) rocks (Larkin and Green, 2012). GSR of these sandstones range from 30% to 60% and are classified as Fair (30% to 45%) to Good (45% to 60%) rocks (Medhurst et al., 2014). Dynamic elastic modulus such as Bulk Modulus (6.81GPa to 21.67 GPa), Shear Modulus (5.46GPa to 11.94GPa) and Young's Modulus (15GPa to 30GPa) of massive sandstones of SS-80 show similar ranges in the various exploratory blocks and few exceptional values (Table 3). Bulk density and Vp of these sandstones range from 2.22g/cc to 2.58g/cc and 3100m/s to 3800m/s respectively. Very thick massive beds can create conditions of heavy periodic weighting during longwall extraction while the thin beds contained by it can act as separation planes and reduce the effective thickness of sandstone that could otherwise contribute to periodic weighting (Venkataramaiah, 2008).

SS-80 also contains 1m to 3m thick very fine to fine grained silicified sandstones hard and strong (HS) whose UCS ranges from 37 MPa to 81 MPa and are classified as high (25MPa to 50MPa) and very high (50MPa to 100 MPa) rocks and can induce periodic weighting (Venkataramaiah, 2008). GSR of these silicified sandstones range from 63% to 97% and are classified as Very Good (60% to 80%) and Extremely Good (80% to 100%) rocks respectively. Bulk Modulus (25GPa to 94GPa), Shear Modulus (8GPa to 20GPa) and Young's Modulus (20GPa to 57GPa) of silicified sandstones show similar ranges in various exploratory blocks

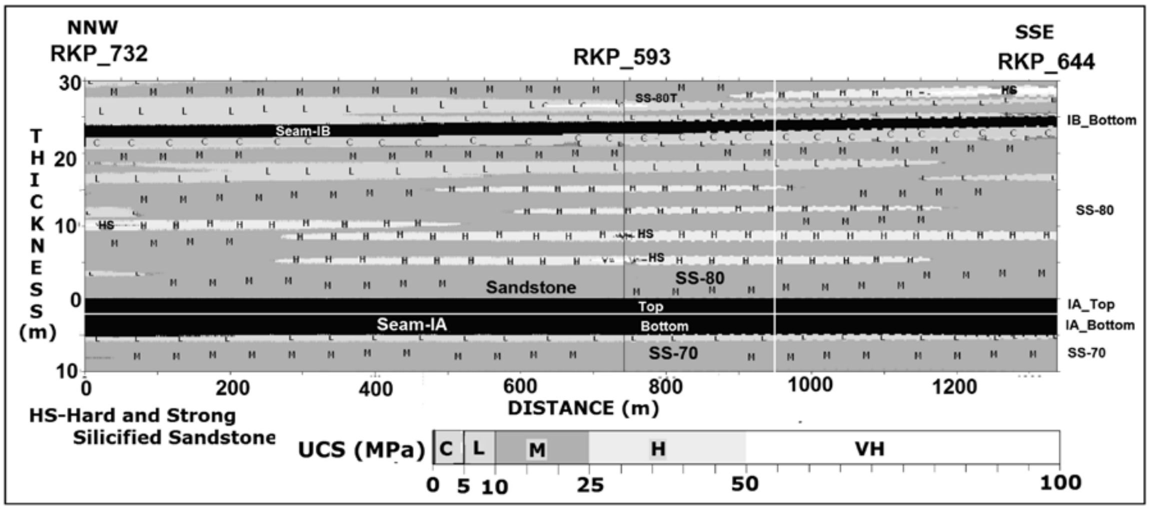


**Figure 8.** UCS Sections of SS-80 the overburden strata of Seam-IA, RKNT Dipside Block. 0MPa to 1MPa-Extremely Low, 1MPa to 5MPa-Very Low, 5MPa to 10MPa-Low, 10MPa to 25MPa-Medium, 25MPa to 50MPa-High and 50MPa to 100MPa-Very High (Larkin and Green, 2012).

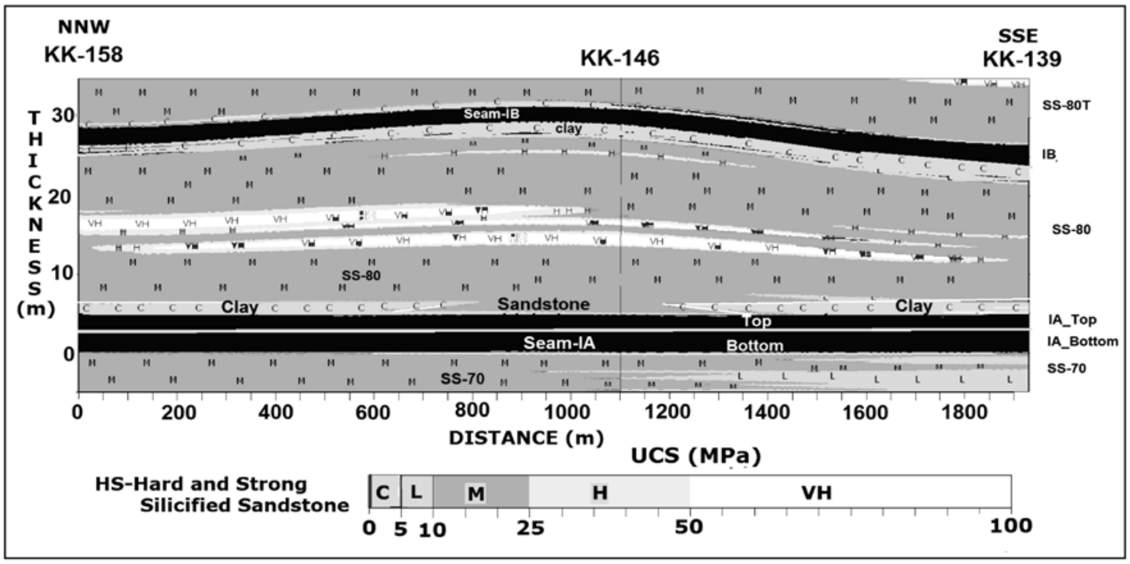


**Figure 9.** UCS Sections of SS-80 the overburden strata of Seam-IA, Mandamarri Block. 0MPa to 1MPa-Extremely Low, 1MPa to 5MPa-Very Low, 5MPa to 10MPa-Low, 10MPa to 25MPa-Medium, 25MPa to 50MPa-High and 50MPa to 100MPa-Very High (Larkin and Green, 2012).

but for few exceptional values (Table 3). Bulk density and Vp of these sandstones range from 2.44g/cc to 2.72g/cc and 3900m/s to 6500m/s respectively. These sandstones also grade to surrounding medium and coarse grained sandstones producing zones of intertonguing and differential compaction associated with geotechnical risks (Hanson et al., 2005).

## SUMMARY AND CONCLUSIONS

Geo-mining conditions should be understood well in advance to choose the appropriate roof support system. This is because majority of downtimes and failures of longwall mining in India are due to severe ground control problems and selecting inadequate capacity and type of powered roof support systems (Ramesh Kumar et al., 2011). Geophysical logs provide the important geological and geotechnical inputs which can help the uptake of numerical modelling and to establish interrelationship between strata characterisation, longwall monitoring analysis and caving behaviour as being done by Hatherly et al. (2009) and Medhurst et al. (2014) in Australia. Present study demonstrated the developmental pattern of Seam-I and its overburden strata in several mining blocks of Godavari sub-basin

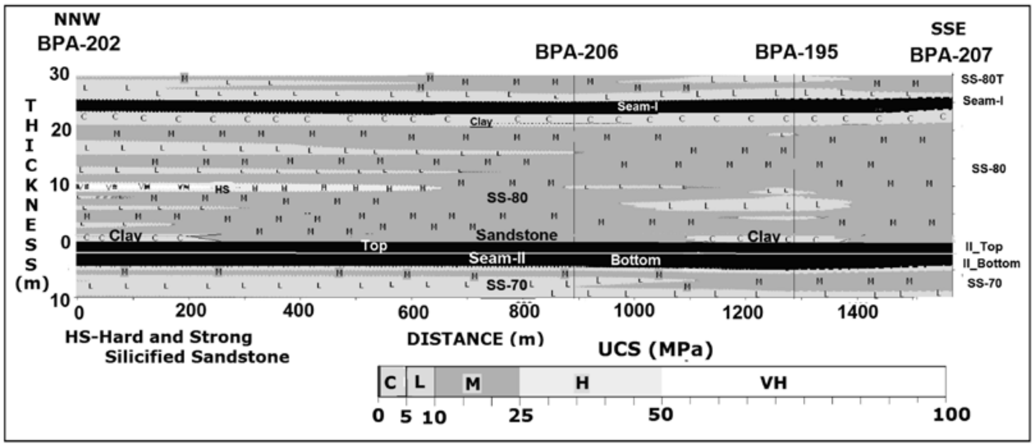


**Figure 10**. UCS Sections of SS-80 the overburden strata of Seam-IA, Shantikhani Block. 0MPa to 1MPa-Extremely Low, 1MPa to 5MPa-Very Low, 5MPa to 10MPa-Low, 10MPa to 25MPa-Medium, 25MPa to 50MPa-High and 50MPa to 100MPa-Very High (Larkin and Green, 2012).

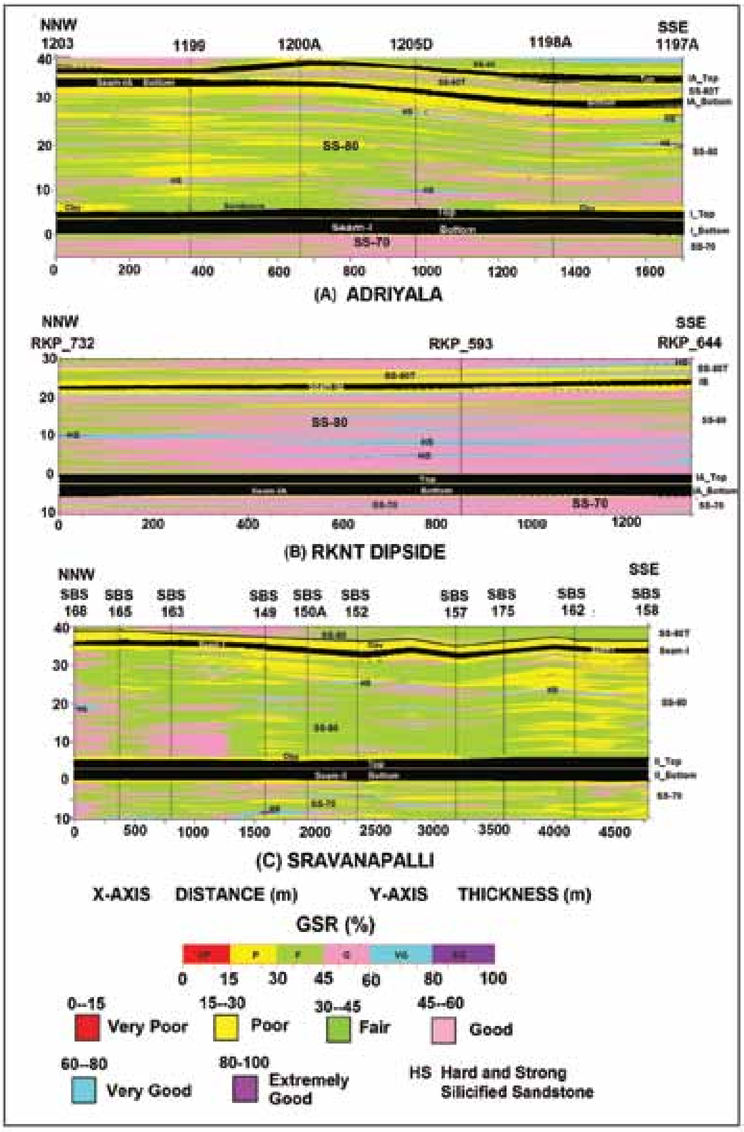


**Figure 11.** GSR Sections of SS-80 the overburden strata of Seam-I/IA/II at various blocks.

Development of Seam-I of 4m to 7m thickness took place in coal swamp occupying the entire Godavari sub-basin, which became possible by a major reorganisation in basin's tectonics and climatic conditions. Very stable and tranquil conditions favoured the development of two coal beds with gentler variations in their thicknesses. 0.40m to 0.60m dirt band of clay/carbonaceous clay resolving the Seam-I into two sections is a good manifestation of coal swamp being periodically invaded by flood basin thereby produced higher amounts of ash of 25% to 40%. Top section of Seam-I contains lesser amounts of ash of 25% to 30%.

The immediate roof rocks of Seam-I show distinct patterns of development of clay and sandstone within a block and also vary from one block to another. 17 to 33m thick SS-80 contains very thick to thick massive sandstones are low to medium strength rocks whose UCS and GSR of 5MPa to 15MPa and 45% to 60% to classify them as low strength and fair rocks, respectively. These massive beds also contain thin to thick beds of good (45% to 60% GSR) and very good (60% to 80% GSR) rocks. Some of them are also poor rocks having GSR of 15% to 30%. The very thick massive beds in the overburden can create conditions of heavy periodic weighting during longwall extraction while the thin beds contained by it can act as separation planes and reduce the effective thickness of sandstone that could otherwise contribute to periodic weighting. UCS and GSR maps provide the spatial distribution of these beds prone to periodic weighting, separation and delamination. GSR provides both petrophysical and geotechnical models unlike UCS indicating the intact strength only. It is also observed that intact strength of sandstones is lower than those of Australian and American sandstones for a given range of Vp values.

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