JOURNAL GEOLOGICAL SOCIETY OF INDIA
Vol.86, September 2015, pp.317-323

High Resolution Seismic Reflection Studies in Godavari Coal Fields: Mapping of Coal Seams and Associated Structural Features

P. Prabhakara Prasad, K. Dhanam*, P. Pavan Kishore, D. Mysaiah and T. Seshunarayana
National Geophysical Research Institute, Council of Scientific and Industrial Research,
Uppal Road, Hyderabad 500606, India
Email: dhanamk6@gmail.com

Abstract: High Resolution Seismic Reflection technique is one of the most suitable geophysical methods for mapping the shallow coal seams and associated structural features, which will provide essential input for adopting proper methodology for exploitation and mine planning of coal reserves. In the present study, depth of the coal horizons were determined and the geometry of the faults in Ramagundam area, Gondwana basin is illustrated which is located at the junction of the Bastar and Dharwar cratons. The High Resolution Seismic Surveys conducted along eight parallel profiles with coverage of surface area one km^2 in the study region. The study reveals (1) seismic sections up to 1000m depth with thick, gently dipping Barakar Formation, (2) thick coal horizons at a depth range of 200 to 500m, and (3) NW-SE striking and gently dipping normal faults are observed in coal horizons. The obtained results will provide better knowledge of the coal reserves in the study area.

Keywords: Gondwana Formation, High resolution seismic reflection, Faults, Coal seams.

INTRODUCTION

The Indian Gondwana basins contain a rich record of tectonic, sedimentary and volcanic history of Gondwanaland (e.g., Lisker and Fachmann, 2001; Biswas, 2003). The Peninsular Indian Shield contains many linear belts of Gondwana sedimentary rocks, which are occurring in the Damodar-Koel, Rajamahal-Purnea, Rewa, Satpura, Mahanadi and Godavari basins (Veevers and Tiwari, 1995). The major part of the coal reserves of the country exist in these basins and proper exploration will meet the demand of energy and fuel requirements.

Presently, coal production in the country is mainly from the coal seams lying under shallow to moderate depths by opencast, underground and long wall mining technology. These methodologies are not providing adequate results due to the lack of knowledge on sub-surface behavior of the geological layers such as dipping, faulting, splitting and merging of seams etc. The study of lithology and modeling of the geological layers through the borehole data requires huge investment. Hence, Indian coal industry is looking for alternative methods such as seismic studies for establishing the properties of geological layers for selection of suitable methodology or technique for coal exploration and exploitation. In this connection Ramagundam area is selected for conducting High Resolution Seismic Surveys (HRSS) for identification of coal horizon depth and associated structural features. Seismic techniques are successfully used for reliable imaging of sub-surface in conventional oil and gas reservoir exploration. Whereas, use of HRSS in delineation of structural features associated with coal horizons is scanty, even though the technique is well known for the last three decades (Ziolkowski and Lerwill, 1979; Harman, 1984; Palmer, 1987; Gochioco and Cotten, 1989; Henson and Sexton, 1991; Miller et al., 1992; Tselentis and Paraskevopoulos, 2002). The high frequency content of the HRSS data is significant in resolving thin-layered coal formations and enables the mapping of minor fault structures associated with coal mines. The coal interface at the roof as well as at the floor of a seam of thin coal formations have excellent acoustic wave impedance contrast due to low velocity and density of coal as compared to the coal bearing host rocks. As the coal exploration is confined to shallow depths and thin beds, it requires high frequency and high resolution seismic reflection data.

The study area Ramagundam (Fig.1) lies in the Pranhita-Godavari basin, situated at the junction of Dharwar and Bastar cratons. Geologically, the region contains a thick sequence of Gondwana Supergroup (Raja Rao, 1982; Chakraborty et al., 2003) cut by NW-SE trending normal faults (Chaudhuri and Deb, 2004). High resolution seismic

0016-7622/2015-86-3-317/$ 1.00 © GEOL. SOC. INDIA

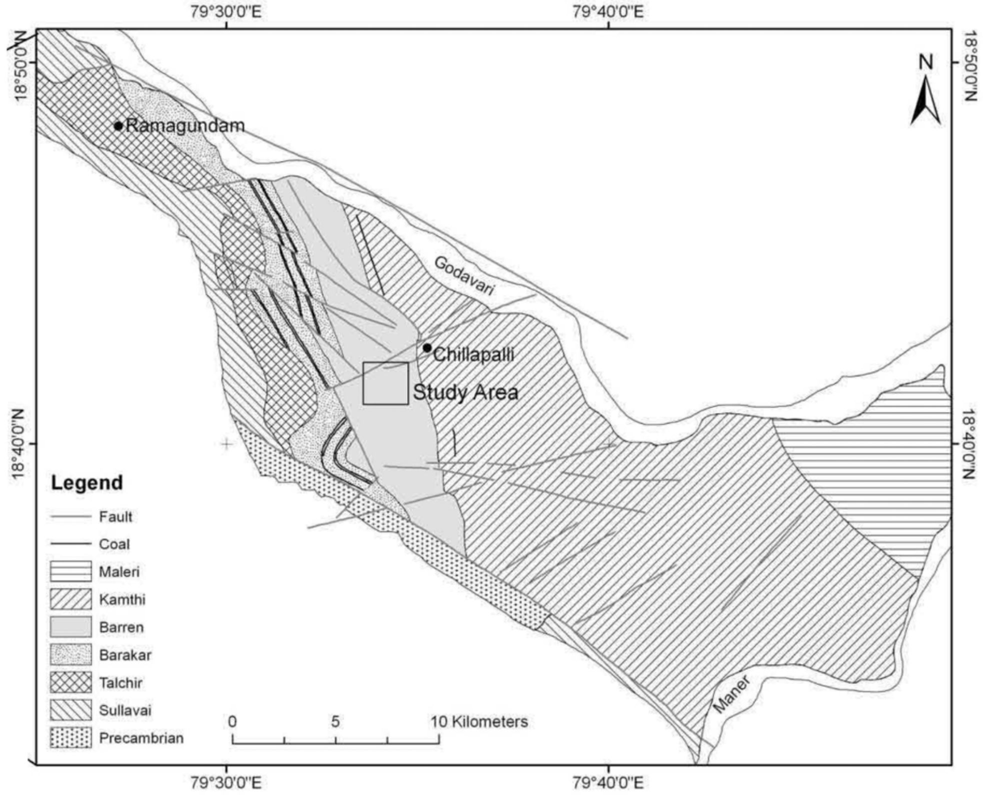

Fig.1. (a) Geological map of the study area and **(b)** the location of the seismic profiles (after Raja Rao 1982).

reflection study in the Ramagundam area asserts new geophysical inferences on the nature of coal-bearing sedimentary rocks and associated structures.

The present study uses high-frequency seismic waves (>80 Hz), which were reflected from the shallow horizons, and resolved small-scale geological structures in the form of several reflectors (e.g., Gochioco and Cotton, 1989; Sheriff, 1991). The targeted vertical resolution of the reflectors is approximately one-fourth of the wavelength of the seismic waves (Widess, 1973) and the resolution obtained from the predominant reflector frequency data is shown in Fig.2. The corresponding P wave velocities in coal horizons, clay formations and sandstone are in the range of 1500 to 2200m/s, 1400 to 1900m/s and 2000 to 3500m/s respectively as obtained from the nearby sonic-log data. The present study exemplifies the economically effective exploration of the coal reserves using HRSS and provided coal horizon thickness, fault structures in the Ramagundam coalfields, India.

GEOLOGY OF THE STUDY AREA

The study area is located 15 km away from southeast of Ramagundam, nearer to the Chillapalli village, in the Pranhita-Godavari (PG) graben (Fig.1, Raja Rao, 1982) is one of the Gondwana sedimentary basins (Pranhita-Godavari basin) of the peninsular India (Veevers and Tiwari, 1995). The PG graben structure is located in between the boundaries of Bastar and Dharwar cratons, which are composed of Archaean gneisses and granites overlain by Proterozoic sedimentary basins. Majority of the sedimentary rocks

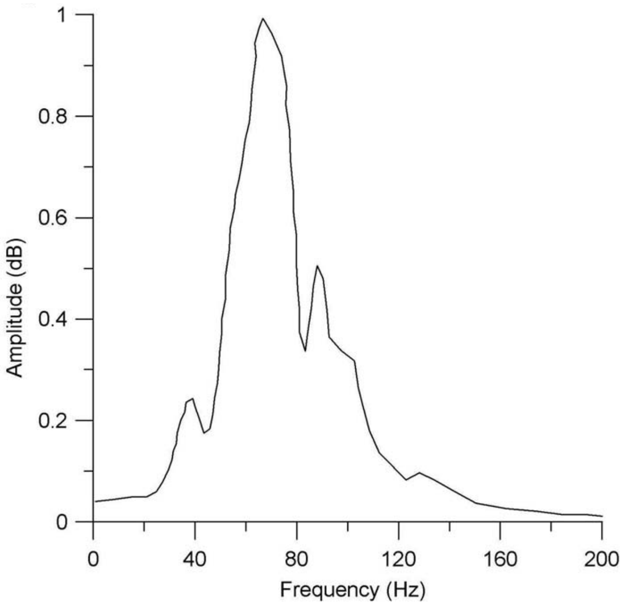

Fig.2. The frequency spectrum of the migrated seismic section.

exposed in the PG graben belong to the Gondwana Supergroup of Paleozoic-Mesozoic age in the axial part of the graben, and are underlain by the Godavari Supergroup sedimentary rocks of Proterozoic age along the margins of the PG valley (Raja Rao, 1982; Pareek, 1986).

Pareek (1986) and Raja Rao (1982) have described the geology of the basin. The lower Gondwana rock formations of Ramagundam area comprises with Sullavai, Talchir, Barakar, Barren, Kamthi and Maleri formations, which unconformably overlie the Precambrian Sullavai Formation and granites and gneisses of eastern Dharwar craton, with thickness of ~545m. Among the Gondwana formations, the Talchir Formation consists of glacial deposits, mainly tillites, with a thickness of ~350 m. The Barakar Formation overlies the Talchir with a gradational contact. It is composed of white-to-grey coloured sandstones with a cumulative thickness of ~250-300 m, clay seams and shales are intruding into the sandstones. The thickness of individual coal seams, at places, is found to be >30m (Murthy and Rao, 1994). The ~ 500m thick Barren Measures conformably overlies the Barakar Formation, and is composed of sandstones. The Kamthi Formation overlies the Barren Measures with a gradational contact, and has a maximum thickness of ~ 600m. Maleri Formation overlies the Kamthi Formation with thickness of ~1000m. The effect of complex faulting on rock formations of the study area generated a general eastern tilting, followed by erosion resulting in the successive exposure of the younger rocks towards east. The overall strike is ~ NNW-SSE and dips gently towards ENE. A major NW-SE trending faults runs through the middle of the Ramagundam coalfield (Das et al., 2003; Chaudhuri and Deb, 2004). In general, the fault systems observed in the study area are related to either to Permian or Mesozoic fault systems (Biswas, 2003; Chaudhuri and Deb, 2004). Therefore, the faults exposed in the study area have implications for interpreting overall tectonic history of the PG basin.

SEISMIC DATA ACQUISITION AND PROCESSING

The high resolution seismic reflection data is acquired using 60 channel acquisition system by geode of M/S geometrics along eight profiles. The quality of the high-resolution seismic data depends mainly on the data acquisition geometric parameters (e.g., Ziolkowski and Lerwill, 1979; Knapp and Steeples, 1986a). Guided by the walkaway noise test (e.g., Vincent et al., 2006), we have selected the optimal data acquisition geometry and recording parameters in the field. The explosives produce energy with highest frequency and, therefore, we can get the high resolution to resolve thin formation. Similar to Miller et al. (1994), 2kg emulsion based explosive was used as the energy source. In the present study, we employed Common Mid Point (CMP) technique along with end-on shooting geometry (e.g., Knapp and Steeples, 1986b; Gochioco and Kelly, 1990; Tselentis and Paraskevopoulos, 2002) with a geophone interval of 5m, and an average shot hole depth of about 15m with an interval of 10 m. The near and far offsets were 120 and 415m, respectively. Each receiver station consists of a bunch of 10 geophones with natural frequency of 10 Hz in series. Each shot gather contains 60 channels with 0.25ms sampling interval and 2s recording length. This recording geometry could achieve a nominal CMP fold of 15.

Data was processed using Industry standard processing software Focus* marketed by Paradigm geophysical services. Table 1 indicates the seismic reflection data processing steps used in the present study (NGRI, 2006). Initially we have edited the high amplitude noise, polarity reversals, the signals related to the direct and refracted waves in the data. After that, true amplitude of the data was

Table 1. Generalized sequence used for processing the high resolution seismic reflection data

Data Input (SEG-Y)
↓
Field geometry
↓
Editing
↓
Gain recovery
↓
Elevation static corrections
↓
Frequency filtering (Bandpass, FK)
↓
Band limited de-convolution
↓
Velocity analysis (1)
↓
NMO correction
↓
Residual static corrections
↓
Velocity analysis (2)
↓
Stacking
↓
FX de-convolution
↓
Time varying filter
↓
Kirchhoff time migration
↓
Automatic gain control
↓
Time to depth conversion

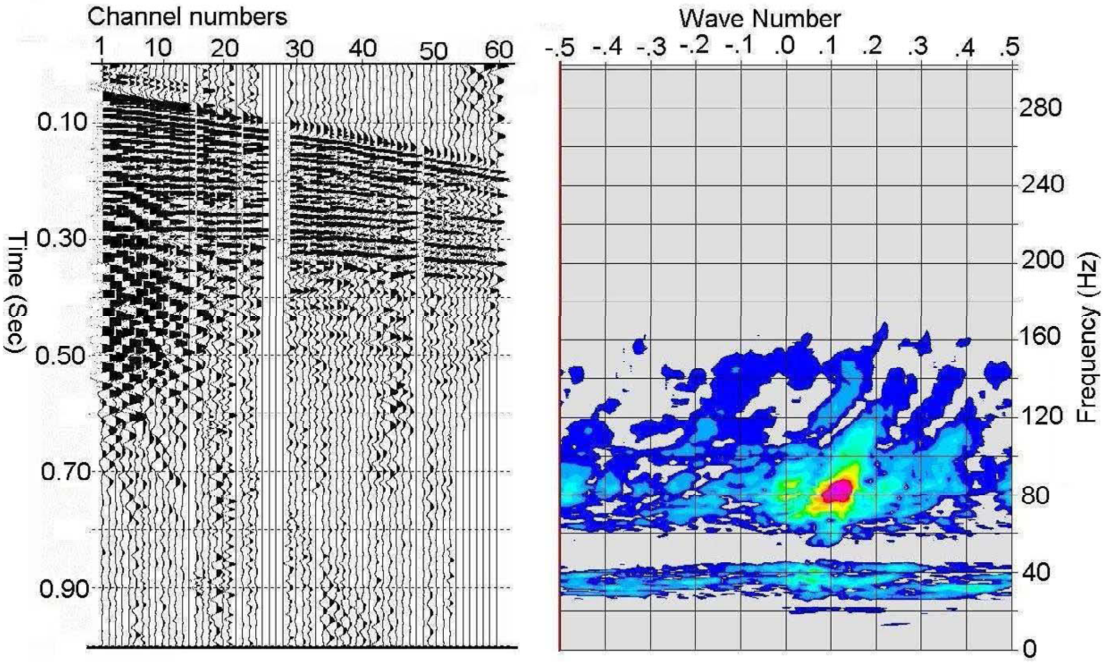

Fig.3. The raw seismic record and its representation in f-k domain.

recovered using power function through spherical divergence correction (VT). Elevation statics applied to correct the effect of topography and near-surface heterogeneity such as weathering. The improved signal–to–noise ratio achieved through the removal of coherent and incoherent noise present in the data using the band pass and frequency-wave number filters. Shot gather plotted in F-K domain to identify the ground roll and reflection events on seismogram (Fig.3). To improve the vertical resolution of the seismic section, deconvolution has been applied with an operator length 80m (Peter Cary, 2006). Figure 4 depicts the deconvolved field record. The data was converted to CMP gather to carryout primary velocity analysis using constant velocity for Normal Move Out (NMO) correction. In this process, best aligned velocity taken as the stacking velocity. After the residual static corrections, the final velocity analyses performed to obtain final stacking velocity. Finally, the CMP data corrected for NMO and stacked using the stacking velocity. The F-X deconvolution and time varying band pass filtering techniques employed for further improvement of the seismic sections by attenuating the random noise (Bekara and Van der Baan, 2009). Post stack

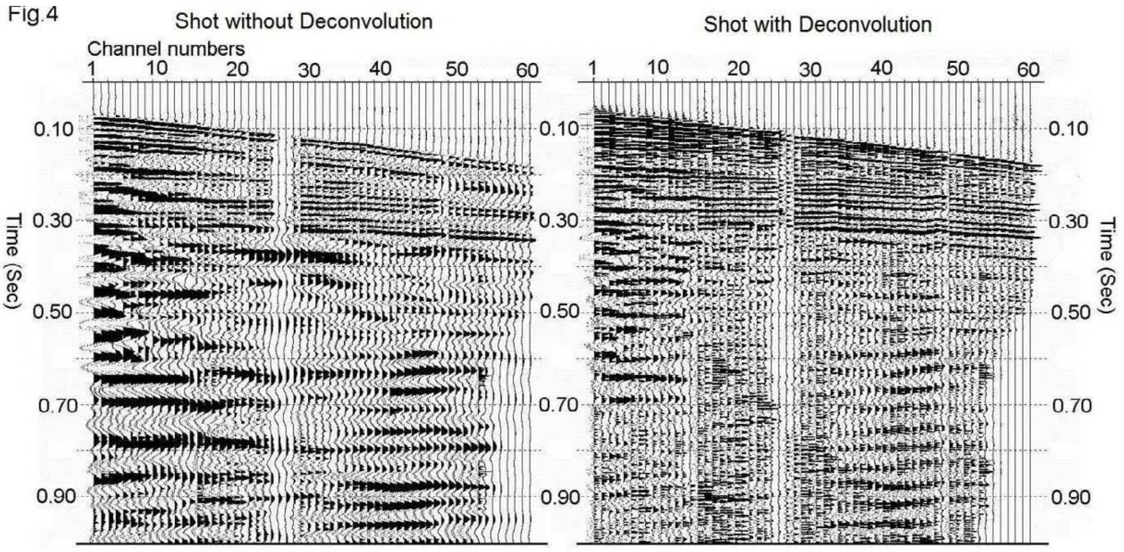

Fig.4. Comparison of the field record with deconvolved section.

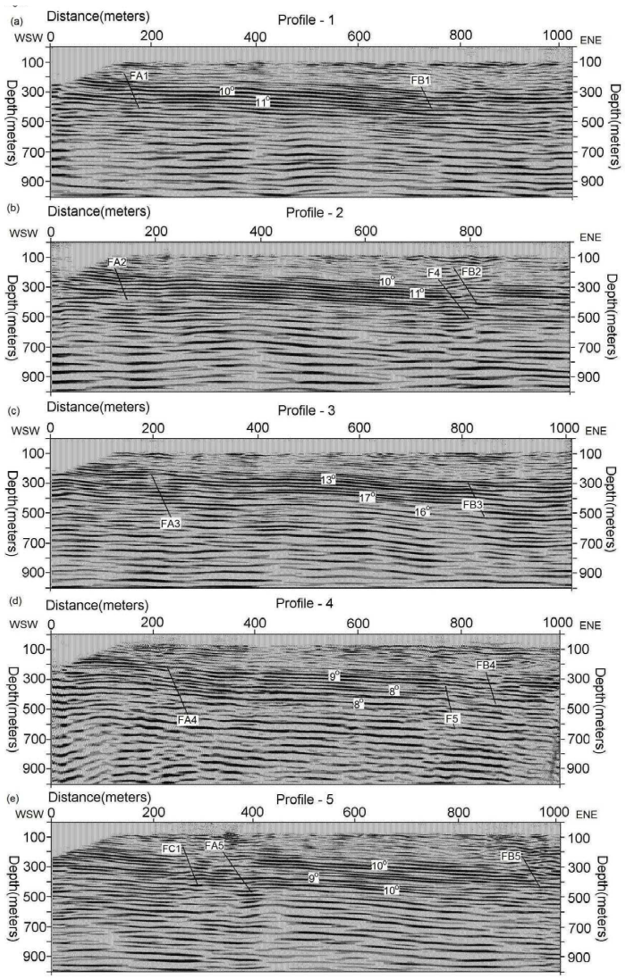

Fig.5. High-resolution seismic reflection sections of the profiles 1, 2, 3, 4 and 5.

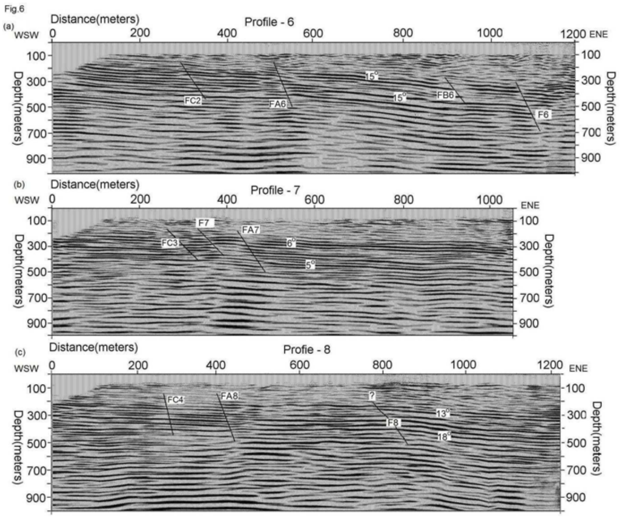

Fig. 6. High-resolution seismic reflection sections of the profiles 6, 7 and 8.

Kirchhoff migration (time) was applied to collapse the diffracted energy and correct dip events (Gray et al., 2001). The coal horizons and fault features are clearly identified in the final depth sections of all the eight profiles (1 to 8) and are presented in Fig.5 (a to e) and 6 (a to c) respectively. For the comparison of the seismic section with lithology, we have converted the time sections into depth sections using interval velocities derived from seismic data and guided by near borehole lithology (Fig.7). The depth of the coal horizons are correlated with the litholog (Fig.7).

DISCUSSION OF RESULTS

The processed seismic sections (Profile 1 to 8) are presented in Figs.5 and 6 up to a depth of 1000 m. The orientations of the seismic profiles are in WSW-ENE direction with 100m interval. The seismic results indicate that coal horizon of thickness ~200m situated in between 200-500m depth in the study area. The seismic sections reveal the depth and thickness of the coal horizons and location of the faults (see Table 2). Based on seismic sections and characteristics of the displacement of faults, it is confirmed that the fault numbers FA1 to FA8 picked on each profile 1 to 8 represents fault-1. Similarly, the faults FB1to FB6 in the seismic sections corresponds to another one, named as fault-2. Faults FC1 to FC4 in the seismic sections correspond to Fault 3. The rest of the faults F4 to F8 observed in the seismic section do not show any lateral continuity in adjacent seismic profiles. Hence, these faults are treated as

Table 2. Description of the seismic profiles and interpreted depths, thickness, dip and associated faults of the coal bearing formations

Profile No.	Length of the profile (m)	Depth of the reflections from coal horizons (m)	Thickness of the horizon (m)	Dip of the reflectors	Fault name	Fault location(m)
Profile 1	1010	200-450	250	~10°, 11°	FA1, FB1	150, 760
Profile 2	990	200-400	200	~10°, 11°	FA2, F4,FB2	1200,720, 750
Profile 3	1010	200-400	200	13°, 16°, 17°	FA3, FB3	180, 800
Profile 4	1000	200-500	300	8°, 9°	FA4,F5, FB4	210, 750, 830
Profile 5	1010	200-500	300	9°, 10°	FC1,FA5, FB5	250, 339, 900
Profile 6	1200	200-500	300	15°	FC2, FA6FB6, F6	300, 510900, 1070
Profile 7	1040	200-500	300	5°, 6°	FC3, F7, FA7	250, 350, 410
Profile 8	1230	200-500	300	13°, 18°	FC4, FA8, F8	250, 400, 770

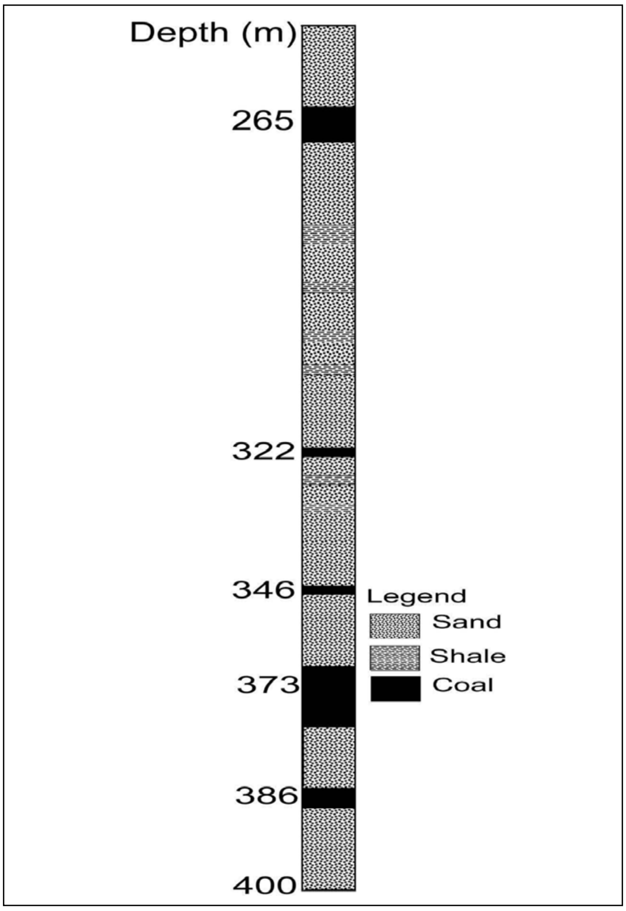

Fig.7. Borehole (BH-6) lithologyin the study area.

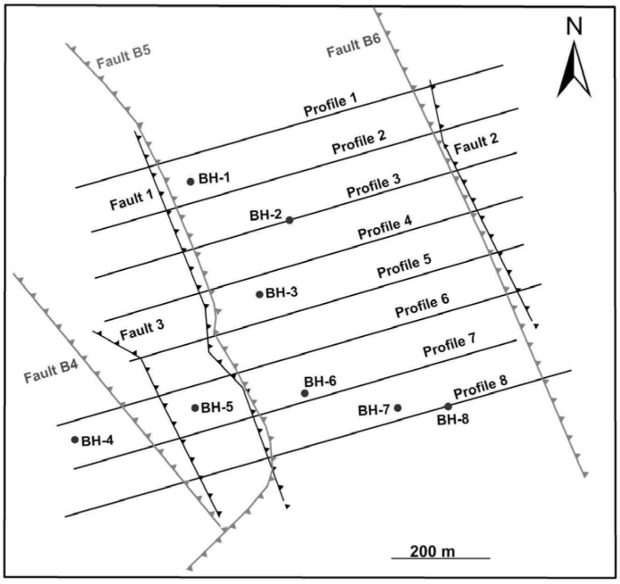

Fig.8. Distribution of major faults delineated by the seismic study.

minor faults, whose lateral extension is less than profile interval i.e. 100m, with NNW-SSE direction.

Comparison of the identified coal horizons from seismic sections matched well with the available borehole data from the study region. The present study shows a 200 m thick sub-horizontal strong reflector zone at a depth range of 200 m to 500 m from the surface. This zone resembles the presence of the coal seams at a depth of 265 m, 322 m, 346 m, 373 m and 386 m, with a thickness of 5.5 m, 2 m, 2 m, 10 m and 3 m, respectively, as observed in the borehole (BH-6) core, that was drilled nearby profile 7 (Fig.7). A model based on the available (borehole) geological information and the traces of faults observed in seismic sections was prepared and presented in Fig.8. Three normal faults, namely fault 1, 2 and 3 mapped based on the seismic sections are correlating well with the faults B4, B5 and B6 identified based on the available borehole data. The comparison of fault structures identified in HRSS investigation with geological mapping reveals that the location of fault-1 and fault-2 are conflicting within few meters only, Whereas fault-3 location is mismatching within few tens of meters in the SE and its NW continuation could not be traced due to the shortage of seismic data along profile 1 to 5.

CONCLUSIONS

The high resolution seismic images obtained in the study region provide insight in to the coal horizon depths and fault features, which are in correlation with the geology and lithology. The coal horizons with ~200m thickness evidently shown in all the profiles by high amplitude reflections within the depth range of 200 to 500 m. Apart from the coal seams, the characteristic faults associated with Pranhitha-Godavari graben structures (fault-1, fault-2, and fault-3) identified clearly on the seismic section with NW-SE to NNW-SSE directions. The identified minor faults with lateral extension less than 100 m are also in the NW-SE to NNW-SSE direction. The fault kinematics identified in the study region agrees with the regional scale faults of the PG basin, which will be adequate in the exploitation of coal.

Acknowledgements: We thank members of the Engineering Geophysics Division for their support in the field data acquisition; Singareni Collieries Company limited for the financial support and encouragement for R&D activity. Director, CSIR-NGRI and SHORE Project is acknowledged for the encouragement and permission to publish this paper. We also thank Dr. B. Rajendra Prasad for his useful suggestions. We thank the reviewer for the constructive comments which improved the manuscript.

References

Biswas, S.K. (2003) Regional tectonic framework of the Pranhita–Godavari basin, India. Jour. Asian Earth Sci., v.21, pp.543-551.

Bekara, M. and Van Der Baan M. (2009) Random and coherent noise attenuation by empirical mode decomposition; Geophysics., v.74, pp.89-98, DOI: 10.1190/1.3157244.

Chakraborty, C., Mandal, N. and Ghosh, S.K. (2003) Kinematics of the Gondwana basins of peninsular India. Tectonophysics, v.377, pp.299-324.

Chaudhuri, A.K. and Gautam, K. Deb. (2004) Proterozoic Rifting in the Pranhita-Godavari Valley: Implication on India-Antarctica Linkage. Gondwana Res., v.7, pp.301-312.

Das, D.P., Chakraborty, D.K. and Sarkar, K. (2003) Significance of the regional lineament tectonics in the evolution of the Pranhita-Godavari sedimentary basin interpreted from the satellite data. Jour. Asian Earth., v.21, pp.553-556.

Gray, S.H., Etgen, J., Dellinger, J. and Whitmore, D. (2001) Seismic migration problems and solutions; Geophysics, v.66(5), pp.1622–1640. DOI:10.1190/1.1487107

Gochioco, L.M. and Cotton, S. (1989) locating faults in underground coal mines using high-resolution seismic reflection techniques. Geophysics, v.54, pp.1521–1527.

Gochioco, L.M. and Kelly, J.I. (1990) High-resolution seismic survey to map paleochannels in an underground coal mine. Canadian Jour. Explor. Geophys., v.26, pp.87-93.

Harman, P.G. (1984) High resolution seismic reflection techniques applied in coalfields: Cook Colliery, Queensland - A case history. Explor. Geophys., v.15, pp.220-228.

Henson, H. Jr. and Sexton, J. L. (1991)Premine study of shallow coalseams using high-resolution seismic reflection methods: Geophysics, v.56, pp.1494-1503.

Knapp, R.W. and Steeples, D.W. (1986a) High-resolution common-depth- point seismic reflection profiling:Field acquisition parameter design. Geophysics, v.51, pp.283-294.

Knapp, R.W. and Steeples, D.W. (1986b) High-resolution common-depth-point seismic reflection profiling: Instrumentation. Geophysics, v.51, pp.276-282.

Lisker, F. and Fachmann, S. (2001) Phanerozoic history of the Mahanadi region, India. Jour. Geophys. Res., v.106, pp.22, 027–22,050.

Miller, R.D., Saenz, V. and Huggins R, J. (1992) Feasibility of CDP seismic reflection to image structures in a 220-m deep, 3-m thick coal zone near Palau, Coahuila, Mexico. Geophysics, v.57, pp.1373-13811.

Miller, R.D., Pullant, S.E., Steeples, D.W. and Hunter, J.A. (1994) Field comparision of shallow P-wave seismic sources near Houston, Texas. Geophysics, v.59, pp.1713-1728.

Murthy, B.V.R. and Rao, C.M. (1994) A new Lithostratigraphic classification of Permian (Lr. Gondwana) succession of PG Basin with special reference to Ramagundam coal belt, A.P. India: Gondwana Nine, Oxford and IBH publishing, v.1, pp.67.

Palmer, D. (1987) High resolution seismic reflection surveys for coal. Geol. Explor., v.24, pp.397-408.

Pareek, H.S. (1986) The role of coal petrographic characteristics in evaluating the non-coking nature of the coals of Ramagundam and Kothagudem coalfields, Godavari valley basin, Andhra Pradesh, India. Internat. Jour. Coal Geol., v.6, pp.181-198.

Peter Cary (2006) Reflections on the Deconvolution of Land Seismic Data; CSEG RECORDER, Special Edition.

Raja Rao, C.S. (1982) Coalfields of India.Vol-II, Coal resources of Tamil Nadu, Andhra Pradesh, Orissa and Maharashtra. Geol. Surv. India Bull. Ser. A, v.45.

NGRI (2006) Report on High Resolution Seismic Surveys for coal exploration in Jallaram Block of Godavari Khani, Ramagundam area, SCCL: Technical Report number: NGRI-2006-Exp-559.

Sheriff, R.E. (1991)Encyclopedic Dictionary of Exploration Geophysics, Third Edition. Soc. Explor. Geophys., pp.148.

Tselentis, G.A. and Paraskevopoulos, P. (2002) Application of a high-resolution seismic investigation in a Greek coal mine. Geophysics, v.67 pp.50–59.

Veevers, J.J. and Tewari, R.C. (1995)Gondwana master basin of Peninsular India between Tethys and the interior of the Gondwanaland Province of Pangea. Geol. Soc. Amer. Mem., no.187, pp.1-73

Vincent, P., Tsoflias, G.P., Steeples, D.W. and Sloan, S.D. (2006) Fixed-source and fixed-receiver walkaway seismic noise tests: A field comparison. Geophysics, v.71, pp.41-44.

Widess, M.B. (1973) How thin is a thin bed? Geophysics, v.38, pp.1176-1180.

Ziolkowski, A. and Lerwill, W.E. (1979)A simple approach to high resolution seismic profiling for coal. Geophys. Prospect., v.27, pp.360-94.

(Received: 27 February 2013; Revised form accepted: 9 June 2014)