Jour. Geol. Soc. India (2022) 98:1541-1546
https://doi.org/10.1007/s12594-022-2209-5

ORIGINAL ARTICLE

Delineation of Coal Bed Geometry using High Resolution Seismic Reflection Data for Uninterrupted Directional Drilling Exploration

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Received: 17 February 2022 / Revised form Accepted: 13 May 2022

ABSTRACT

The utilization of innovative technology by the coal mine industry requires proper guidance of sub-surface information so that it can provide uninterrupted exploration with less time and minimum cost. Sufficient knowledge about the coal beds that is variation of thickness, depth, and associated structures will facilitate the mine engineer to run machinery systematically. Conventional geological reports based on borehole data may not sufficient to adopt state-of-the-art drilling technology. To address these issues, high-resolution seismic survey (HRSS) was conducted to delineate the thickness of coal seams and mapping of structural features which are associated with coal seams. An effort was made to demonstrate the high-resolution seismic reflection study for picking of minor faults locations and thickness of coal seams in the central part of the Sohagpur, Gondwana basin that occurs at the junction of the Mahanadi and Son-Narmada rift systems in central India. The study reveals thick Barakar Formation and coal seams at a depth range of 300 to 550 meters. The thickness of coal seams and the location of minor faults were interpreted with the help of attribute analysis from the seismic sections. The obtained results from the seismic survey were useful for the selection of potential target zones which are favourable for drilling.

INTRODUCTION

The Indian Gondwana basins contain a rich record of the tectonic, sedimentary, and volcanic history of Gondwanaland (e.g., Lisker and Fachmann, 2001; Biswas, 2003). The study area Sohagpur basin shares the boundaries with the Rewa basin in the north and the Mahanadi basin in the southeast. It is connecting two major rift systems (Son-Narmada and Mahanadi) (Fig.1). From the previous studies, it is confirmed that the Sohagpur basin contains a thick succession of Gondwana Supergroups (Raja Rao, 1983). The E-W trending normal faults exist in the study region (Pareek, 1987). Since the area lies in an active tectonic region, mapping of the sub-surface faults on a local scale is most important for adopting the state of the art technology like in-seam directional drilling for exploration of coal. The systematic mapping of sub-surface coal beds is required to avoid operational drilling problems/issues or otherwise structural discontinuities such as faults, folds, seam splitting and merging will increase the running time of large scale machines leads to loss of huge economy during mining activity. To avoid uncertainties during mining activity, high-resolution seismic reflection study was carried out in the Sohagpur basin (Fig. 2) that brought out detailed sub-surface information on the thickness, depth of coal seams, and associated structural features. In this connection, HRSS data along two profiles was acquired (profile-1 and profile-2) by covering an area of 0.71Lkm. The direction of the profile-1 and profile-2 is NNE-SSW and NE-SW respectively.

The high-frequency seismic waves (>80 Hz) were used in high-resolution seismic studies, which were reflected from the shallow horizons, and resolved small-scale geological features in the form of several reflectors (e.g., Gochioco and Cotten., 1989; Sheriff, 1991). The vertical resolution of the reflectors is approximately one-fourth of the wavelength of the seismic waves (Widess, 1973). The present study aimed to achieve a depth resolution of 5m, which depends on the interval velocity of 2000 m/s (obtained from the borehole sonic-log data) and the maximum reflector frequency of 100 Hz. In this paper, the application of high-resolution seismic survey is described and their significance is discussed in deciphering vital information for proper mine planning.

GEOLOGY OF THE STUDY AREA

The Sohagpur basin is a part of the large sediment-filled trough in the drainage basin of the Son River. The geology of the basin was described by Raja Rao (1983) and Pareek (1987). The study area Sohagpur basin is made up of thick sedimentary formations that unconformably overlie the Precambrian basement rocks. The sedimentary rocks of the Gondwana basin strike WNW-ESE to E-W and dip up to 5° towards the north (Pareek, 1987). The rocks of the Talchir Formation unconformably overlie the basement; it contains shale, siltstone, and boulder beds, with some marine fossils. The overlying Barakar Formation (Lower Permian) is composed of sandstones with bands of shale, carbonaceous shale, and coal seams. The coal bearing Barakar Formation is approximately 450 m thick and sub-divided into three members, of which the middle one is the thickest. The lower member contains a greyish-white feldspathic garnetiferous sandstone, siltstone, and shale, and is devoid of coal seams. The middle member includes cross-bedded feldspathic sandstones with garnet and thick workable coal seams in the lower portion. Ferruginous sandstones, shales, and siltstones characterize the upper unit.

The Pali Formation (Triassic) that overlies the Barakar Formation is approximately 350 m thick and contains three members. The lower member comprises coarse-grained sandstones and shales. The middle member contains coal-bearing medium- to fine-grained sandstones, shales, and carbonaceous shales. The Parsora Formation (upper

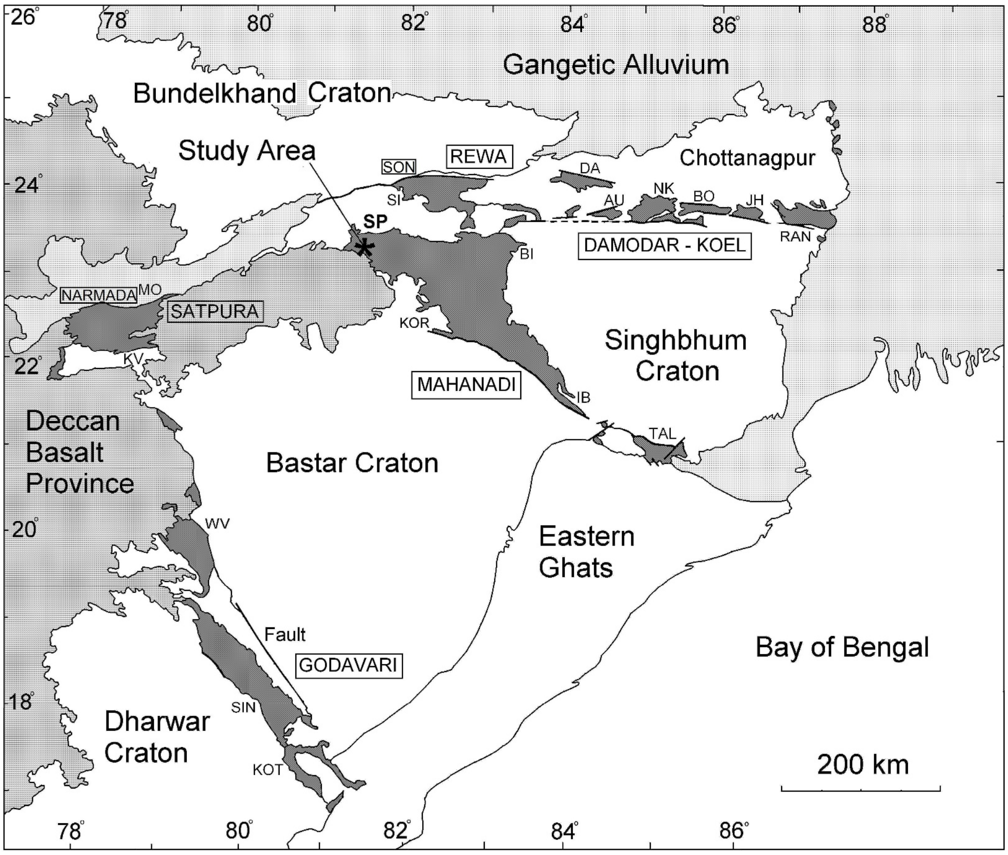

Fig. 1. Geological map of the peninsular India showing the distribution of Gondwana sedimentary basins, shown in dark grey color (after Veevers and Tiwari, 1995).

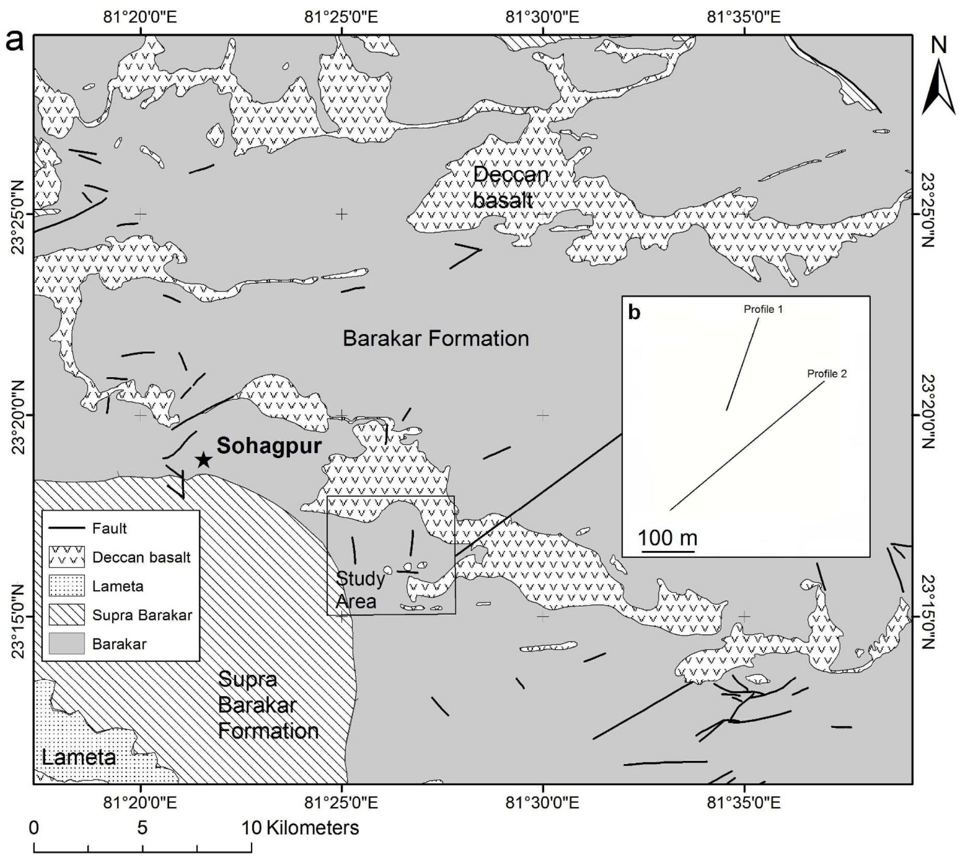

Fig. 2. (a) Geological map of the study area and **(b)** the location of the seismic profiles (after Raja Rao (1983). Note the presence of two NW-SE faults and one NNW-SSE fault in the study area.

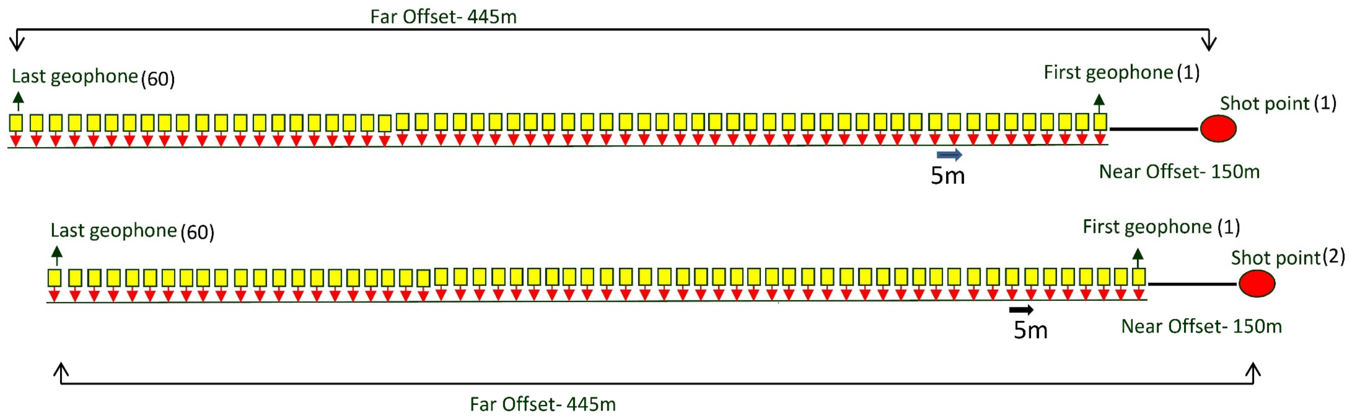

Fig. 3. Geometry map for the 2D High resolution seismic reflection survey

Triassic) occurs in the northern part of the basin and comprises coarse-grained to pebbly ferruginous sandstones and shales. The succeeding Lameta Beds (upper Cretaceous) include greenish and reddish poorly consolidated sandstones and shales with nodular limestone at the top. A marked unconformity separates the Lameta Beds from the Parsora Formation. The Sohagpur coalfield is profusely intruded by dykes and sills (Deccan trap, upper Cretaceous-Eocene), and dolerites are also emplaced along the fault (Sarkar and Singh., 2005; Sheth, 2009). The study area largely exposes the Barakar Formation overlain by the exposures of the Supra-Barakar Formation.

SEISMIC DATA ACQUISITION AND PROCESSING

The high-resolution seismic reflection data were acquired along with two profiles as shown in Fig.2b. The total lengths of the profiles are 710m. The optimum data acquisition geometry and recording parameters were selected in the field after analysis of the walkaway noise test (e.g., Vincent et al., 2006). 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) and the energy source (e.g., Miller et al., 1994). In the present study, the common depth point (CDP) technique was used that fits in an end-on shooting geometry (e.g., Knapp and Steeples, 1986b; Gochioco and Kelly, 1990; Tselentis and Paraskevopoulos, 2002) with a geophone interval of 5 meters, and a shot point interval of 10 meters. The near and far offsets were 150 and 445 meters, respectively. Each receiver station contains a group of 10 geophones of 10 Hz frequency. Each seismic record (shot gather) was composed of 60 channels. A maximum record length of 1 sec and a sample interval of 0.25 ms were chosen. The recording geometry provides a nominal CMP fold of 15. Seismic data acquisition geometry map for two shots was shown in Fig. 3. The acquisition geometry pattern was same for entire seismic survey. One of the seismic shot record is shown in Fig.4

In the seismic data processing, the seismic data acquisition parameters (geometry merging) were applied to the seismic records. Mono frequency noise, high amplitude noise, polarity reversals, and first arrivals (direct and refracted waves) in the data were eliminated. Static corrections were applied to correct the effect of topography and near-surface heterogeneity such as weathering. Spherical divergence correction (VT) was applied to retrieve the lost amplitude in the data. The dominant ground roll present in the data was removed using the bandpass filter (Fig. 4) (30-150Hz) and the frequency-wave number filter was also applied on shot gather to enhance the signal–to–noise ratio (Ziolkowski and Lerwill, 1979; Arun et al., 2011). The band-limited spiking-deconvolution using operator length 80ms to improve the vertical resolution by compressing the wavelet of the seismic data with improved frequency bandwidth (Peter Cary; 2006). The shot gathers data were converted to common midpoint gathers (CMP). The primary velocity analysis was carried out using the CMP gathers based on the best alignment of normal-moveout corrected data and quality of stacking. The final velocity analysis was performed again after the residual static corrections. The final stacking velocity was used for normal-moveout correction for CMP gathers. NMO corrected CMP gathers were used in the stacking. The random noise was suppressed by F-X deconvolution (Bekara and Van der Baan; 2009) and the time-varying bandpass filter was also applied for further improvement. Post stack Kirchhoff migration (time) was applied to collapse the diffracted energy and correct dip events (Gray et al., 2001). The final processed time sections are shown in Fig. 5(a) and 6(a). The time sections were converted into depth sections using interval velocities guided by the borehole lithology and sonic log data. The final interpreted seismic depth sections are shown in Fig. 5(c) and 6(c). Table 1 indicates the high resolution seismic reflection data processing steps used in the present study.

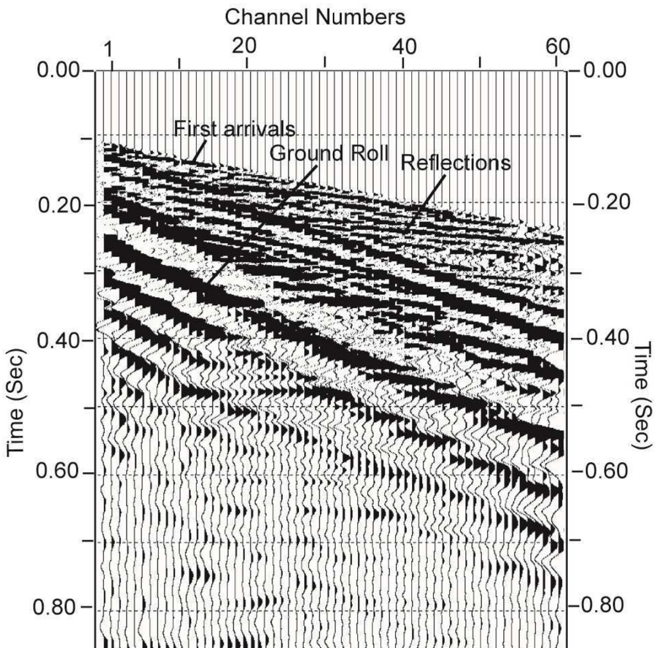

Fig. 4. Seismic shot gather from field contains first breaks, ground roll and seismic reflections.

Table 1. Generalized processing 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

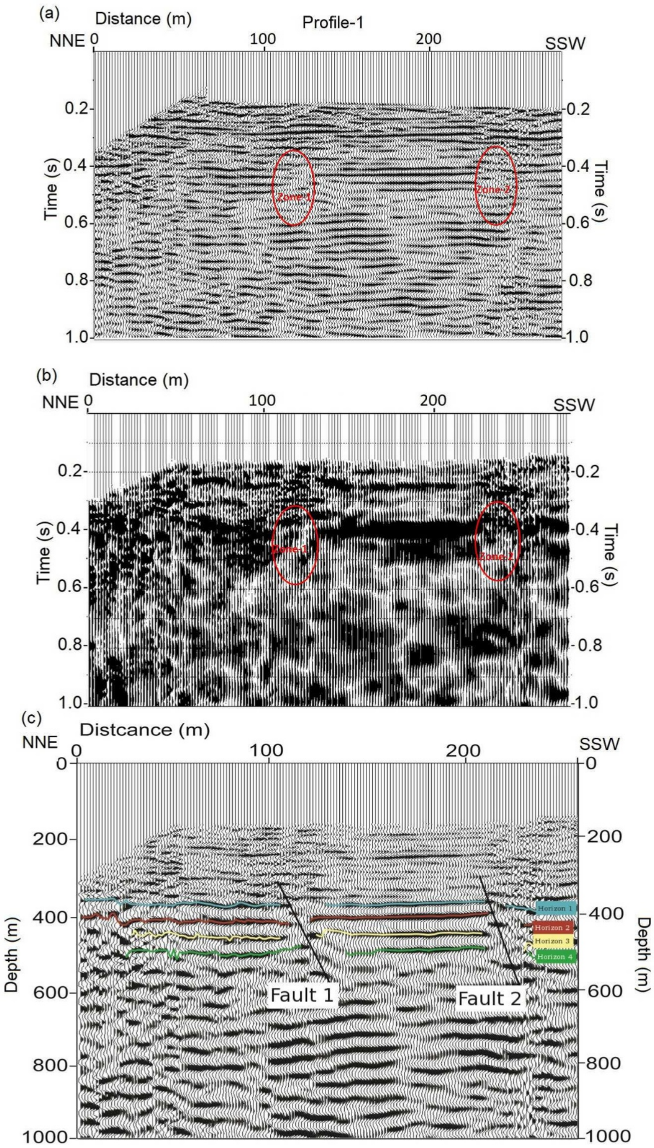

Fig. 5. (a) High-resolution seismic time section **(b)** Instantaneous energy attribute of seismic time section **(c)** Interpreted depth section of profile-1. Highlighted the seismic disturbed zones with red color.

RESULTS

Figure 5 (a) is the seismic section of profile 1. The length of the profile is 260m. The direction of the profile is NNE-SSW. Seismic reflections were observed at 0.3 to 0.5s in the time section. Seismic amplitude disturbances are present in the time section at 120m and 230m distance from the NNE end (Figure 5(a)). Instantaneous energy attribute was calculated from the time section to identify the discontinuities and disturbances in the seismic amplitudes. There is a lateral variation in the instantaneous energy at 120m and 230m from the NNE end representing the trace of faults (Fig. 5b). Two seismic disturbed zones are marked as Zone-1 and Zone-2 which are attributed to presence of faults. Figure 5(c) shows the interpreted seismic depth section. The strong reflectors at a depth range of 300m to 500 m indicate the presence of coal seams. A major disturbance is observed at a distance of 120m from the NNE end, where the seismic amplitude changes, and is interpreted to be a trace of fault1. The fault2 was also observed at a distance of 230m from the NNE end. Four coal horizons/reflectors were mapped and named as horizon 1 to horizon 4 respectively. The varying reflector thickness across the faults may be due to syn-sedimentation subsidence, as the rate of sedimentation changes across the fault, which causes the variation in the bed thickness (Childs et al., 2003).

Figure 6(a) is the seismic section of profile 2. The length of this profile is 450 m. The direction of the profile is NE-SW. The seismic reflections were observed at 0.3 to 0.5s in the time section. The disturbances in seismic amplitude were noticed at 80m and 250m from the NE end. The instantaneous energy attribute was computed from the time section shown in Fig. 6(b). The variation in the reflection strength at 80m and 250m was observed, this may be due to the presence of the fault in the seismic section. Two seismic disturbed zones are marked as zone-3 and zone-4 which are indicating the presence faults. The horizon and fault-interpreted depth sections were shown in Fig. 6(c). The strong reflectors at a depth of 350 to 550 m indicate the presence of coal seams, as observed in the borehole (Dhanam et al., 2013). Five coal horizons/reflectors were mapped and named as horizon 1 to horizon 5 respectively. A major disturbance was observed at a distance of 80 m from the NE, where the seismic amplitude changes, which is interpreted to be a trace of a northerly dipping normal fault. Another fault 2 is observed about 250 m away from the NE end of the profile; this fault shows strong displacement in the intermediate depth level. Therefore, these structures are interpreted to have formed by syn-sedimentation faulting.

The present study also shows a 200 m thick subhorizontal strong reflector zone at a depth range of 350 m to 550 m depth from the surface. This zone corresponds to the coal seams found at a depth of 371 m, 393 m, 422 m, 454 m, and 465 m, having a thickness of 2 m, 0.5 m, 0.3 m, 5 m, and 1 m, respectively, as observed in the cored borehole (Fig. 7) (Dhanam et al., 2013).

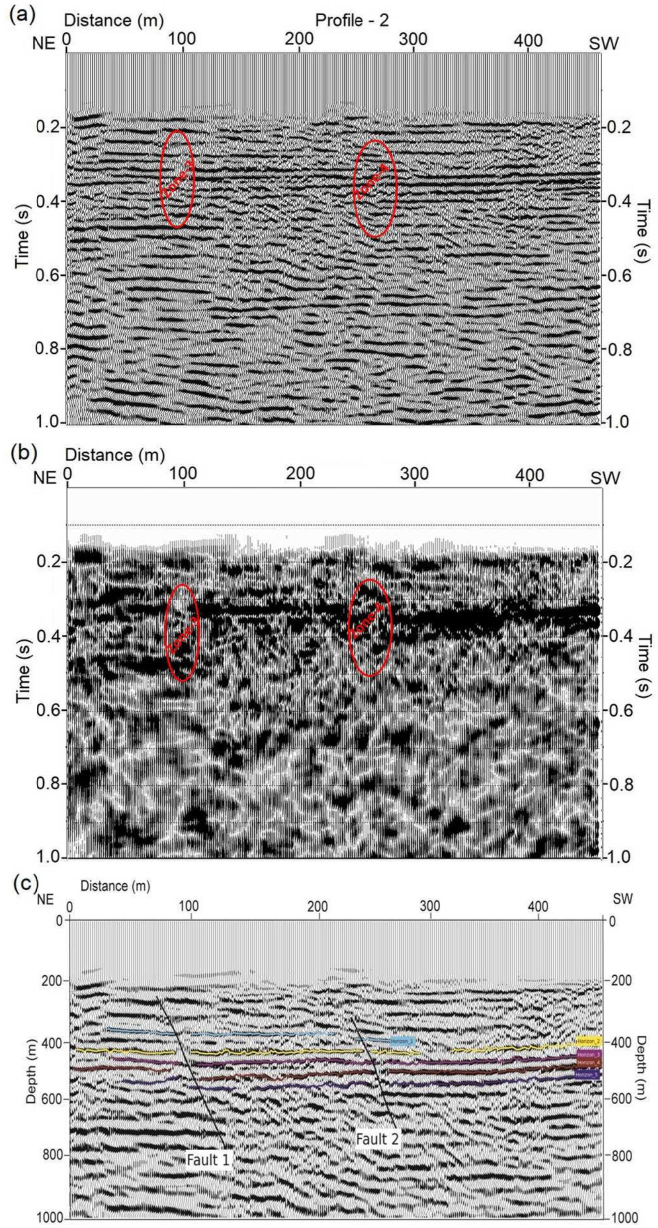

Fig. 6. **(a)** High-resolution seismic time section **(b)** Instantaneous energy attribute of seismic time section **(c)** Interpreted depth section of profile-2. Highlighted the seismic disturbed zones with red color.

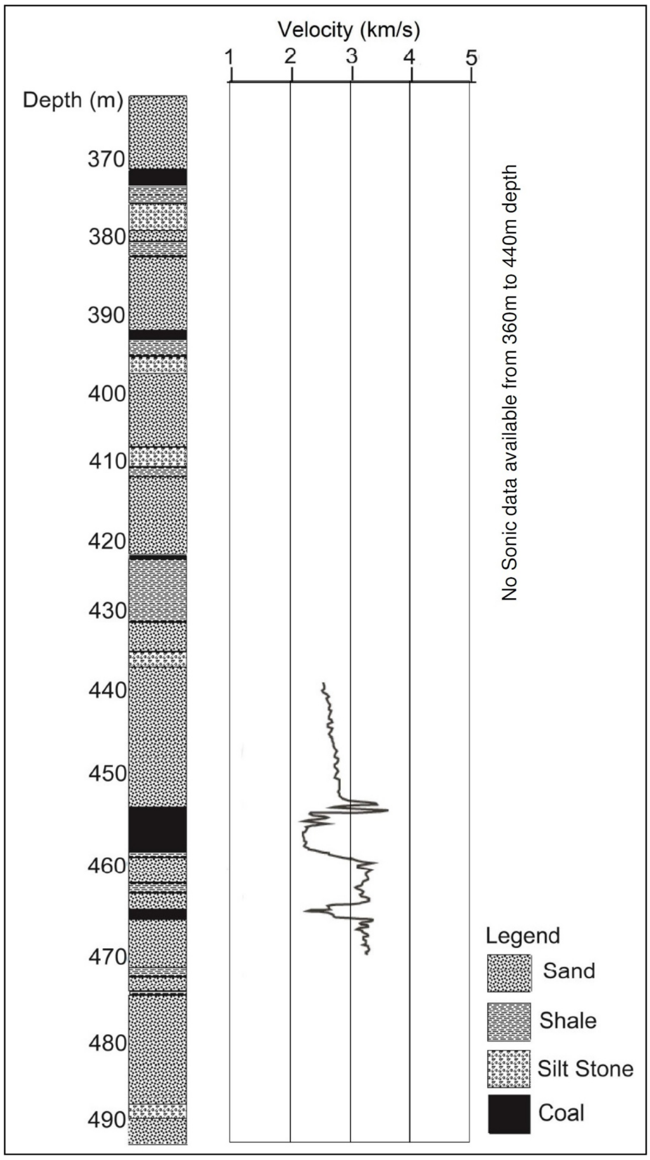

Fig. 7. Bore hole lithology and interval velocities from sonic log data.

DISCUSSIONS

The present seismic study establishes two normal faults in NW-SE directions. Although the geological map (Fig. 2) shows the presence of two E-W and an N-S trending fault in the study area, these are not reflected in the seismic profiles. The seismic profiles were not crossed some of the surface geological faults. So, all the faults present on geological map were not traced on seismic depth sections. On the other hand, the seismic sections show new faults that cannot be mapped through surface geological mapping as these are syn-sedimentary faults that do not intersect the surface. Therefore, these faults are new additions to the geologic map of the study area (Fig. 2).

The NW-SE normal faults can thus be related to the formation of the NW-SE-oriented Mahanadi rift system (Fig. 2). The faults in the Barakar Formation indicate the syn-sedimentation subsidence in the Sohagpur basin. Although these faults disrupt the Barakar Formation, the sedimentary layers in the upper level partially bury them (Fig. 5 and 6). This is an example of syn-sedimentation faults. The Permian sedimentary rocks in the Sohagpur and Mahanadi basins were derived from the Precambrian basement in central India. The present seismic study also delineates coal-bearing sedimentary layers at the depth range of 300 m to 550 m, which has been further confirmed by the drilling results.

CONCLUSIONS

The present study provides high-resolution seismic images of the Sohagpur basin and the fault systems present in them. These faults are identified with the help of attribute analysis. The seismic sections show about a 200 m thick zone of strong reflections of coal seams at a depth of 300-550 m. These images also provide, for the first time, the geophysical evidence for the NW-SE-oriented faults in the Sohagpur basin. These faults have characteristics of syn-synsedimentary faulting. These results were very useful for coal mine planning.

Acknowledgements: We thank members of the Engineering Geophysics Division for support in the field data acquisition; Reliance Industries Limited for the financial support; Director, CSIR-NGRI for encouragement and permission to publish this paper.

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