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ORIGINAL PAPER

Investigation of the weathering layer using seismic refraction and high-resolution seismic reflection methods, NE of Riyadh city

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Abstract Five seismic refraction and five high-resolution seismic reflection (HRSR) profiles were carried out in northeastern part of Riyadh city to investigate depth of the weathering layer. Results obtained from seismic refraction survey reveal the depths of weathering layer at 12, 25, 17, 12, and 16 m, respectively. On the other hand, HRSR stack sections illustrate the depths of weathering layer at 14, 28, 20, 13, and 18 m, respectively. The weathering layer is composed of alluvial sediments and gravel, which is underlain by a sequence of limestone and dolomite layer. Seismic results from site no. 2 have been found to be in good agreement with lithological information reported from the adjacent water well. The HRSR data generally reveal better signal-to-noise ratio and enhanced resolution compared to the refraction data. Although, the HRSR data failed in achieving high-quality common midpoint (CMP) stacking profile at site no. 3, it provide an improved image of the subsurface features than the refraction data, recognizing it as a potential seismic technique.

Keywords Seismic refraction · High-resolution seismic reflection · Stack sections · The weathering layer

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Introduction

The seismic method (particularly seismic reflection) represents one of the most important geophysical techniques for oil and gas exploration (Kearey and Brooks 1984) due to its high accuracy, high resolution, and deep penetration. On relatively reduced scale, this method has been applied to groundwater, environmental and civil engineering problems, and to some extent, mineral exploration (Burger et al. 1992). One of the affective tools in shallow exploration is the seismic refraction, which can be used for engineering and environmental investigations, including the depth of bedrock, depth of the ground water, and lateral/vertical changes in lithology. In addition, investigation of the subsurface structural features, such as cracks in the rock bodies, is an attractive target for shallow seismic refraction (Sheriff and Geldart 1999).

The shallow seismic reflection technique is relatively straightforward in terms of conceptual perspective. Ideally, a high-frequency, short-duration pulse of acoustic energy is generated at the earth's surface, and the arrival times and magnitudes of “echos” are measured and are reflected from subsurface acoustic horizons (i.e., water table, bedrock, lithologic and facies contacts, etc.) and returned to the earth's surface (Steeples 2000). During the past 30 years, growing interest in engineering and environmental problems has increased the application of seismic reflection to study shallow targets of hydrogeological, engineering, environmental, archeological, and geotechnical aspects. The most important consideration connected with this method is the recording of reflections with broad bandwidth (spectra shifted towards high frequency) and the attenuation of the coherent noise (air

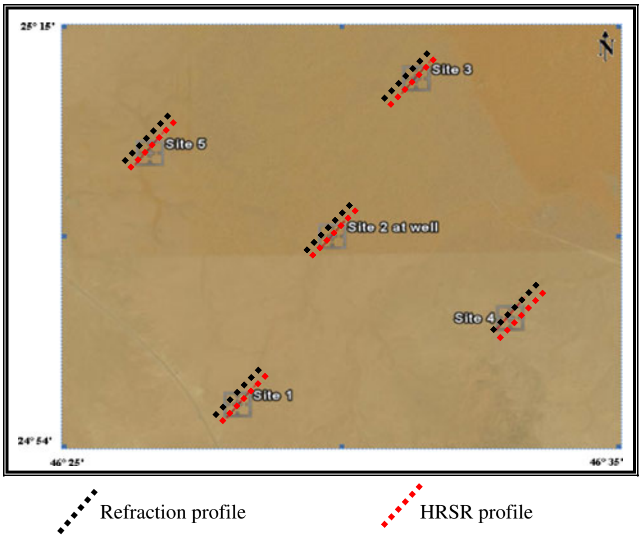

Fig. 1 Location map of seismic profiles

wave and ground roll) in a much possible way (Feroci et al. 2000). However, the main challenge in using high-resolution seismic reflection (HRSR) data for estimating near surface features is the maintenance of high frequency reflections from shallow interfaces in the face of attenuation and possible aliasing. In order to acquire high-resolution seismic data for shallow subsurface investigations, spacing between source and receiver must be established perfectly to ensure un-aliasing of the data.

Keeping in view the usefulness of these methods, data from five seismic refractions and five HRSR profiles were acquired in the study area (Fig. 1). Main objective of this study is to determine the thickness of near-surface sedimentary layer, a so-called weathering or low-velocity layer.

Geologic setting

The area of Riyadh quadrangle forms part of the eastern Najed province and is located between the latitudes 24° and 25°N and longitudes 46°30′ and 48°E. As shown in the geological map of the study area (Fig. 2), the Riyadh quadrangle is generally covered by Mesozoic to Cenozoic sedimentary rocks of the Arabian Shelf. The Jurassic to Early Cretaceous rocks cropped out in Riyadh area has

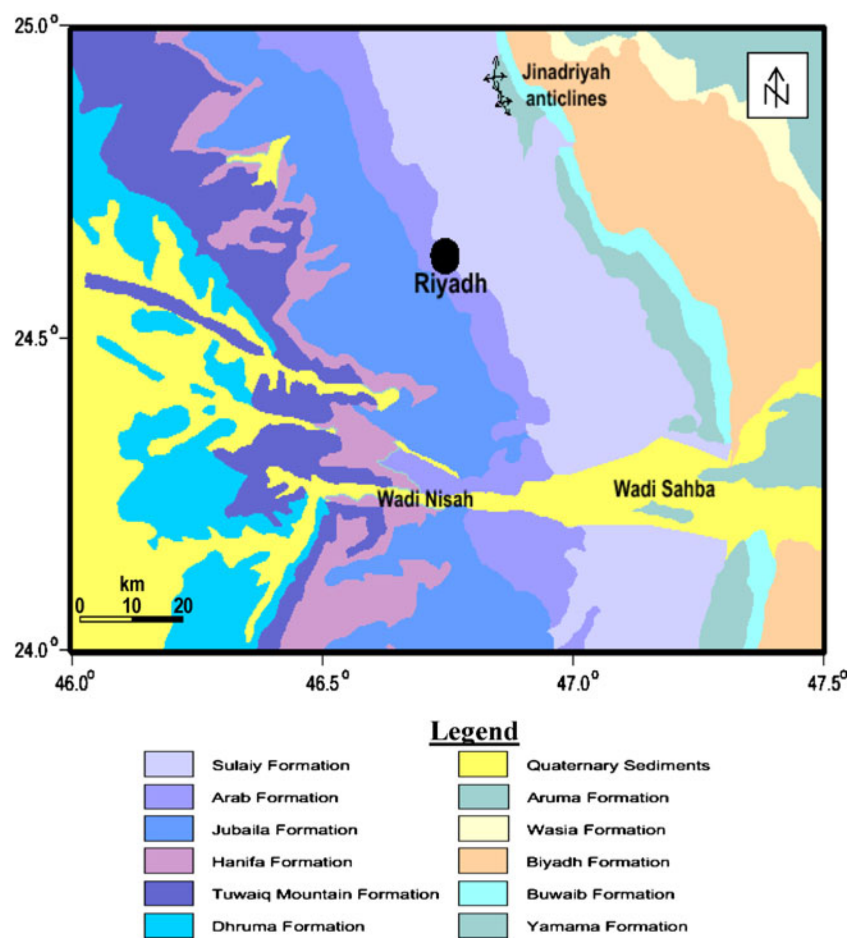

Fig. 2 Surface geological map of Riyadh and surrounding areas (Al-Mahmud et al. 2009)

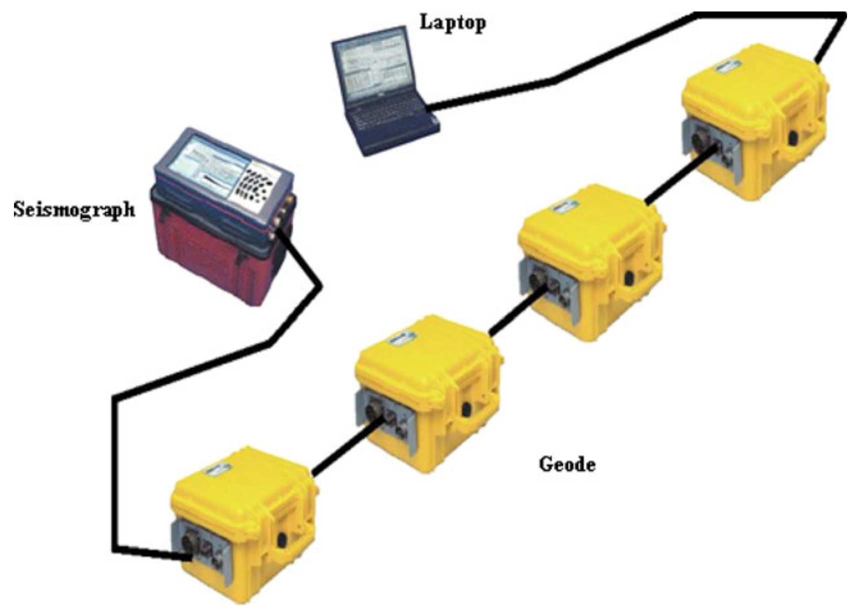

Fig. 3 Seismic data acquisition system

been assigned to a newly named Diriyah Supergroup (Vaslet et al. 1991) that consists of:

(1) Byradah group, comprising the Late Permian to Triassic deposits, mostly cropped out in western part of the quadrangle.
(2) Shaqra group of the Middle to Late Jurassic age.
(3) Thamama group of the Early Cretaceous age.

About 30% of the Riyadh city (especially its central and eastern parts) is covered by recent sediments, which is mainly composed of clay, silt, sand, and gravel deposits (Al-Othaman 2002).

Acquisition of the seismic data

In order to record seismic data for present study, a multi-channel signal enhancement seismograph of GEOMETRICS INC. (Geode and Strata Visor NZ model) has been used (Fig. 3).

Five seismic refraction profiles have been acquired in the target area using hammer as a source of energy. The intra-

Table 1 Acquisition parameters for seismic refraction profiles

Data formatting	SEG2
Geometry	In-line-end-on offset
Number of receivers	32
Receiver spacing	3 m
Receiver type	Model, GS–20 DH, response, 365 Ω, 40 Hz, 0.70 damping
Shot spacing	−5,0, 46.5, 93, 98 m
Source type	Hammer (6 Kg)
Minimum offset	1 m
Maximum Offset	98 m
Number of stacking	10
Sampling interval	0.25 ms
Record length	1 s
Filter type	Out
Gain	Out

Table 2 Acquisition parameters for HRSR profiles

Data formatting	SEGD
Geometry	Split spread
Number of receivers	48
Receiver spacing	1 m
Receiver type	Model, GS–20 DH, response, 365 Ω, 40 Hz, 0.70 damping
Shot spacing	1 m
Source type	Hammer (6 Kg)
Minimum offset	0.5 m
Maximum Offset	24.5 m
Number of stacking	5
Sampling interval	0.125 ms
Record length	1 s
Filter type	Out
Gain	Out

geophones spacing of 3 m have been used for all five profiles. The first shot is a normal shot within 5-m distance from geophone 1 (geophone 1 at 0 m), the second shot at a 0 m, the third one (a midpoint shot) at 46.5-m distance between geophone 16 and 17, the fourth one at 93 m at geophone 32, and the last one (a reverse shot) at 98 m next to geophone 32. Among these five shots, only three shot-points distributed throughout the profile have been chosen. Acquisition parameters of all the seismic refraction profiles are listed in Table 1.

In addition to seismic refraction, five HRSR profiles were acquired at different locations in the study area using hammer as a source of energy. For all five profiles, intra-geophone spacing of 1 m has been maintained. Acquisition parameters of all these profiles are listed below in Table 2.

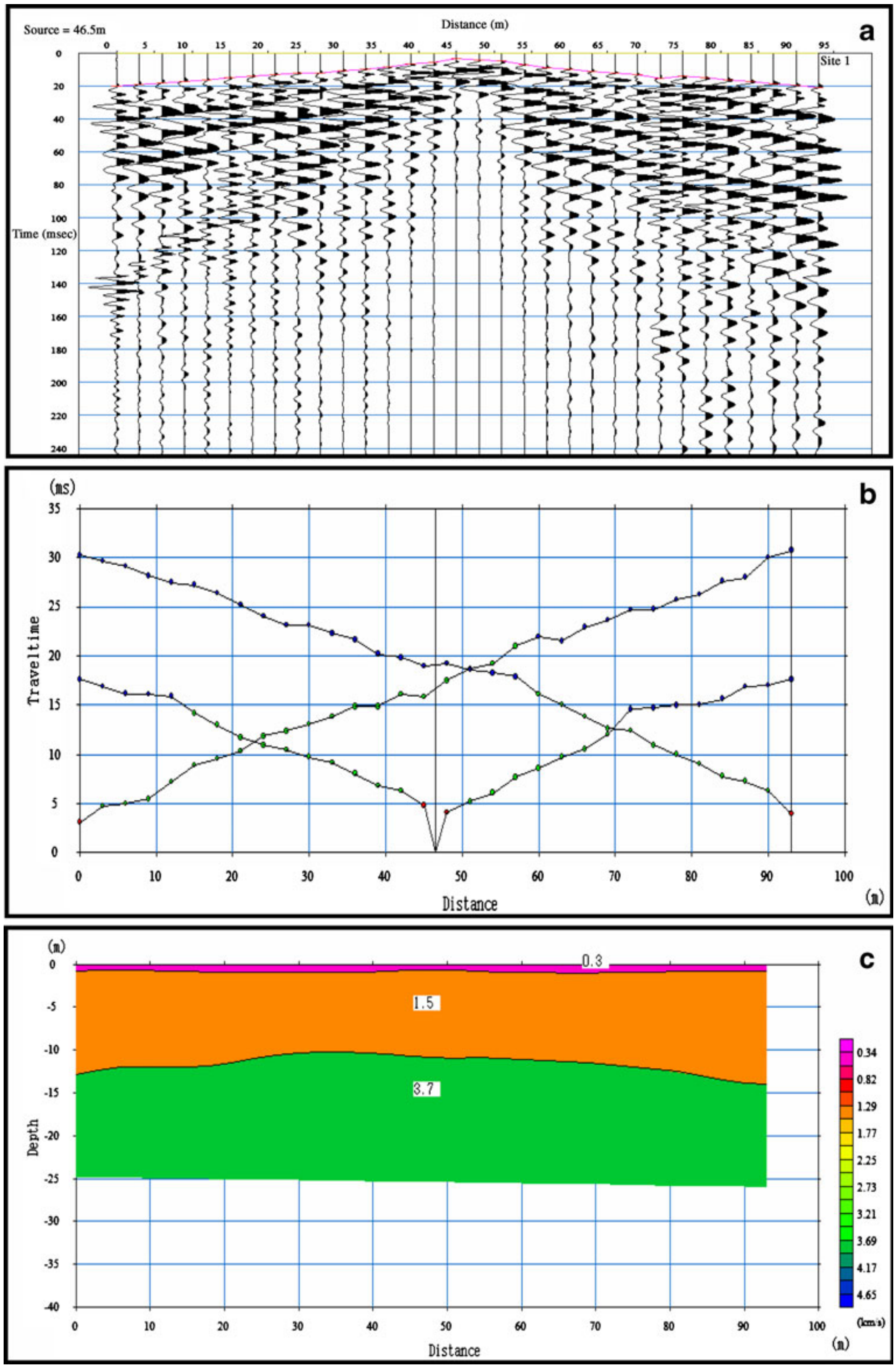

Fig. 4 **a** P-wave first break picking of profile 1, **b** P-wave travel-time curve for profile 1, and **c** final velocity–depth model for profile 1

Analysis and interpretation of the seismic refraction data

Seismic refraction method has been widely used in determining the thickness and velocities of the near-surface layers. In order to apply this method successfully, an accurate picking of the first arrival times is required. Using SeisImager Software Package (Geometrics Inc., 2005), the first break picking was made for the digitized seismic waveforms from all channels along the surveyed profiles. After picking a first break from all profiles, the travel time–distance (T–D) curves have been established for each of them. Following this, the layers assignment

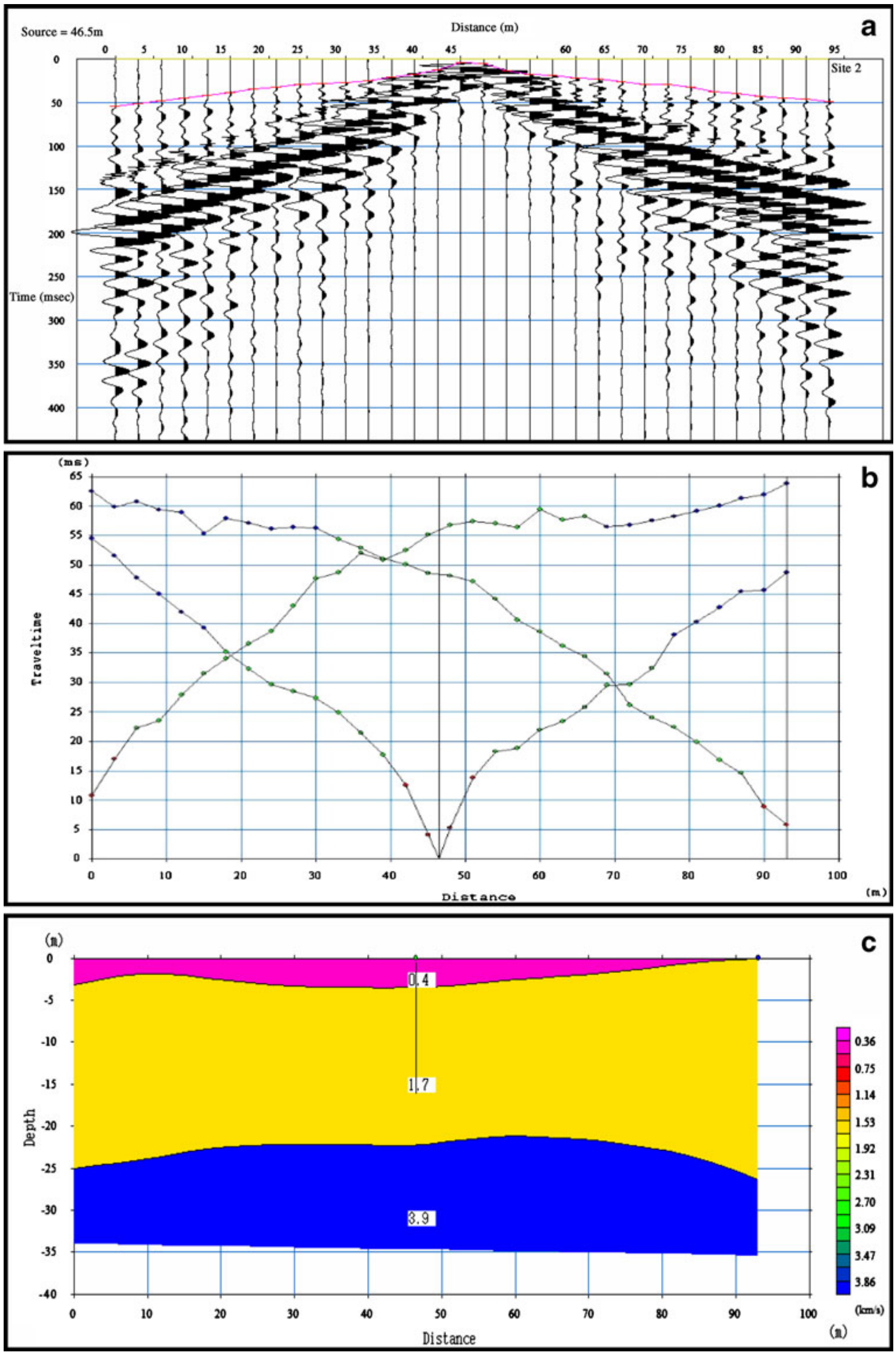

Fig. 5 **a** P-wave first break picking for profile 2, **b** P-wave travel-time curve for profile 2, and **c** Final velocity–depth model for profile 2

procedure has been achieved for each T–D curve. Finally, depth models for the detected layers under each profile have been constructed as a step forward in the processing procedure (Figs. 4, 5, 6, 7 and 8). After the estimation of ground model profiles for various velocities and depths (Table 3), it has been noticed that a thin and limited layer of lose sediments is present just under the ground surface, which has been added to the overall thickness of the weathering layer.

Analysis and interpretation of the HRSR data

The acquired HRSR data was processed to enhance signal-to-noise (S/N) ratio, for which Landmark's ProMax Software Package has been used. In general, the processing procedure of shallow seismic reflection data is similar to that of conventional seismic reflection data (Steeples and Miller 1990; Feroci et al. 2000). However, the near-surface layers generally carry low-velocity values that vary abruptly with

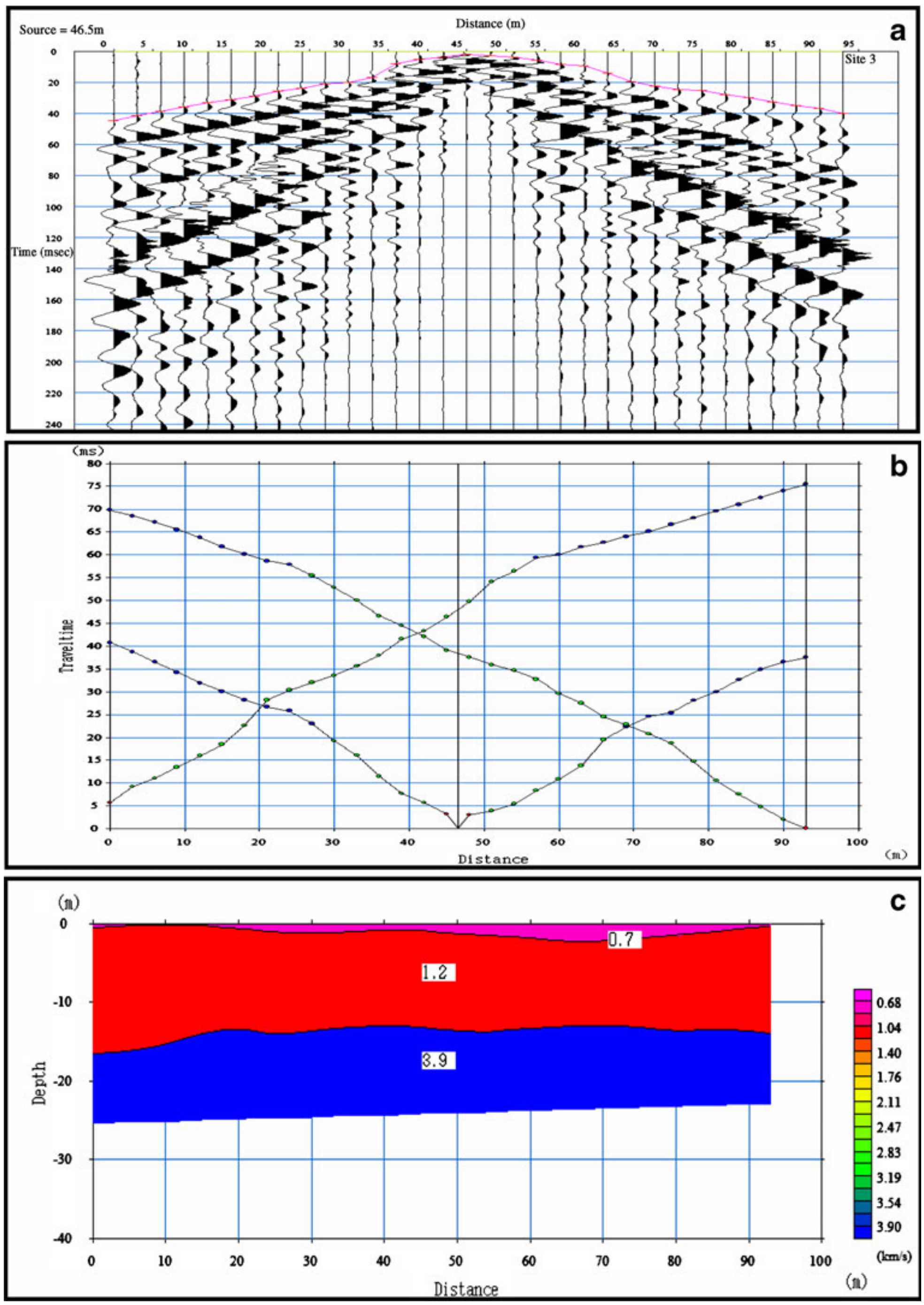

Fig. 6 **a** P-wave first break picking of profile 3, **b** P-wave travel-time curve for profile, 3 and **c** Final velocity–depth model of profile 3

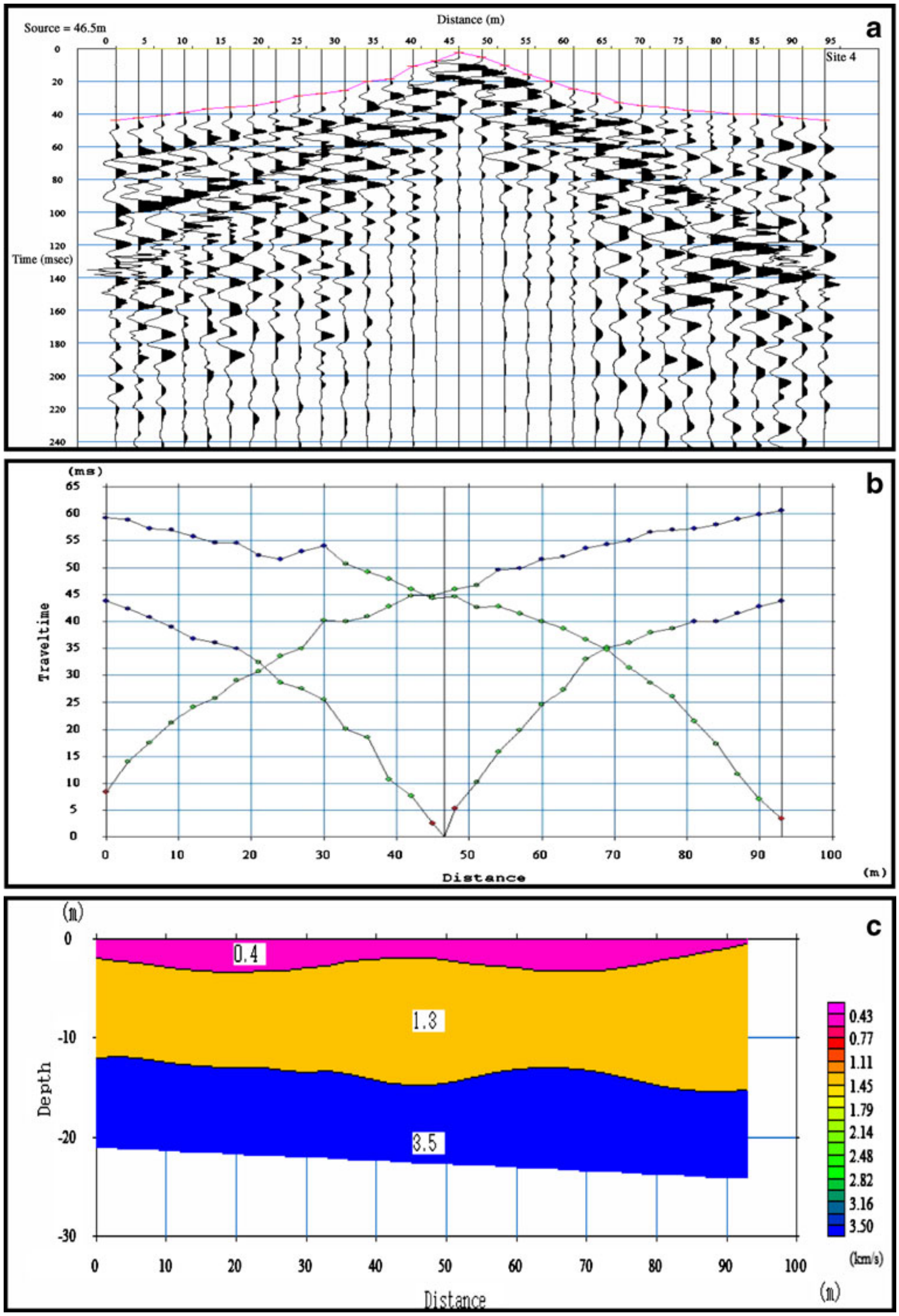

Fig. 7 **a** P-wave first break picking for profile 4, **b** P-wave travel-time curve for profile 4, and **c** Final velocity–depth model for profile 4

lateral extension, which often make seismic reflections subtle and noisy. Hence, as compared to conventional processing techniques, more attention should be paid to some pitfalls of shallow reflection data, e.g., spatial aliasing, removing of the air-blast noise, ground roll, and refraction muting (Steeples and Miller 1998; Steeples 2000). A conventional pre-stack processing procedure included:

1. Geometry assignment and trace editing.
2. Elevation static corrections and amplitude scaling using 100-ms AGC.
3. Amplitude compensation; the 2 db/s correction was finally selected after comparing the results.
4. An Ormsby 0-phase band pass filter was applied to remove residual low frequency with a frequency (HZ) range of 30–40 to 150–180.
5. Common midpoint (CMP) sorting.
6. Mute refraction arrival.

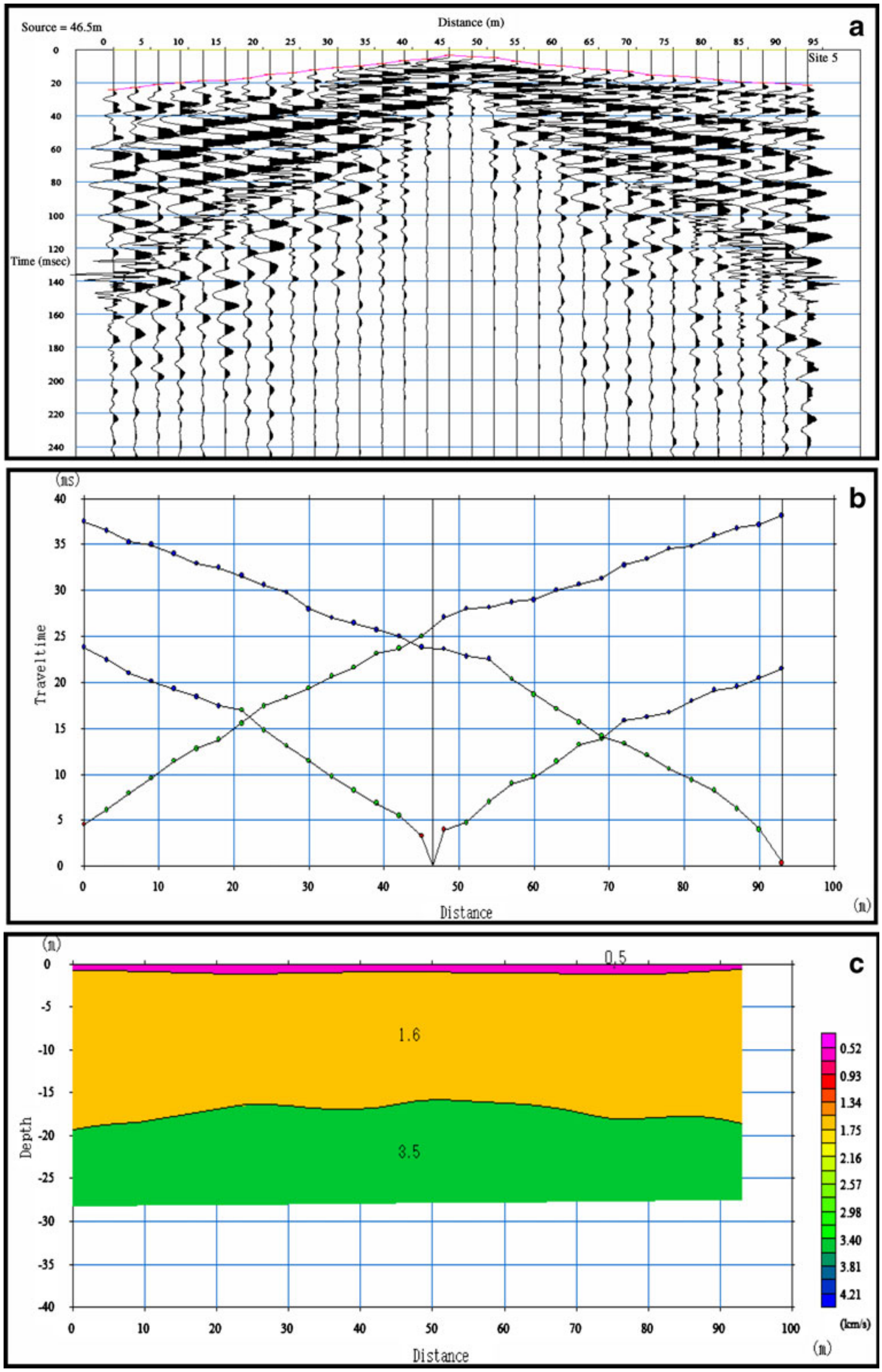

Fig. 8 **a** P-wave first break picking for profile 5, **b** P-wave travel-time curve for profile 5, and **c** Final velocity–depth model for profile 5

7. Velocity analysis.
8. Normal moveout (NMO) and stacking.

After the application of optimal processing sequence to the acquired seismic reflection data using Landmark's ProMax Software, the brute stacks have been drawn to produce and process the results. As shown in Figs. 9, 10, 11, 12, 13, stacked sections for sites 1–5 have been drawn to demarcate a reflector using time window. Depths of the weathering layer were then estimated on the basis of root

Table 3 Depth of the weathering layers at the surveyed sites, estimated by seismic refraction and HRSR methods

Site No	Well depth (m)	Depth from refraction (m)	Depth from HRSR (m)
1		12	14
2	27	25	28
3		17	20
4		12	13
5		16	18

mean square (RMS) velocity. Finally, these stacked sections have been successfully used to determine thickness of the weathered sedimentary layer in most cases, except site no. 3 where weak and unresolved seismic signal has been encountered.

Conclusions

Main purpose of the present study is to determine thickness of the weathered sedimentary layer using five seismic refractions and five HRSR profiles. According to seismic parameters obtained from these profiles and their comparison with the available water-well data, the following conclusions and recommendations can be made.

1. Using seismic refraction data from five profiles, it has been noticed that just beneath the ground surface, a thin layer of lose sediments overlies the main layer of the weathered materials. In order to count them both as a single unit, the thin layer of sediments is added to overall thickness of the main weathering layer. The depth of this weathering layer at sites 1–5 is estimated at 12, 25, 17, 12, and 16 m, respectively. Lithology of this targeted layer consists of sediments and gravel, which make a distinguishable contact with the underlying bedrock layer of limestone and dolomite.
2. Similar to seismic refraction profiles, five HRSR profiles were acquired as a part of this study. Based on the processed data, depths of the weathering layer at sites 1–5 are estimated at 14, 28, 20, 13, and 18 m, respectively.
3. As an additional support, seismic refraction results from site no. 2 got verification from lithological information available from the adjacent water-well as well as by the HRSR data.
4. At site no. 3, penetration-related problems have been encountered with hammer method during the field operation. It is, therefore, recommended that an alternative seismic source (including weight-drop or

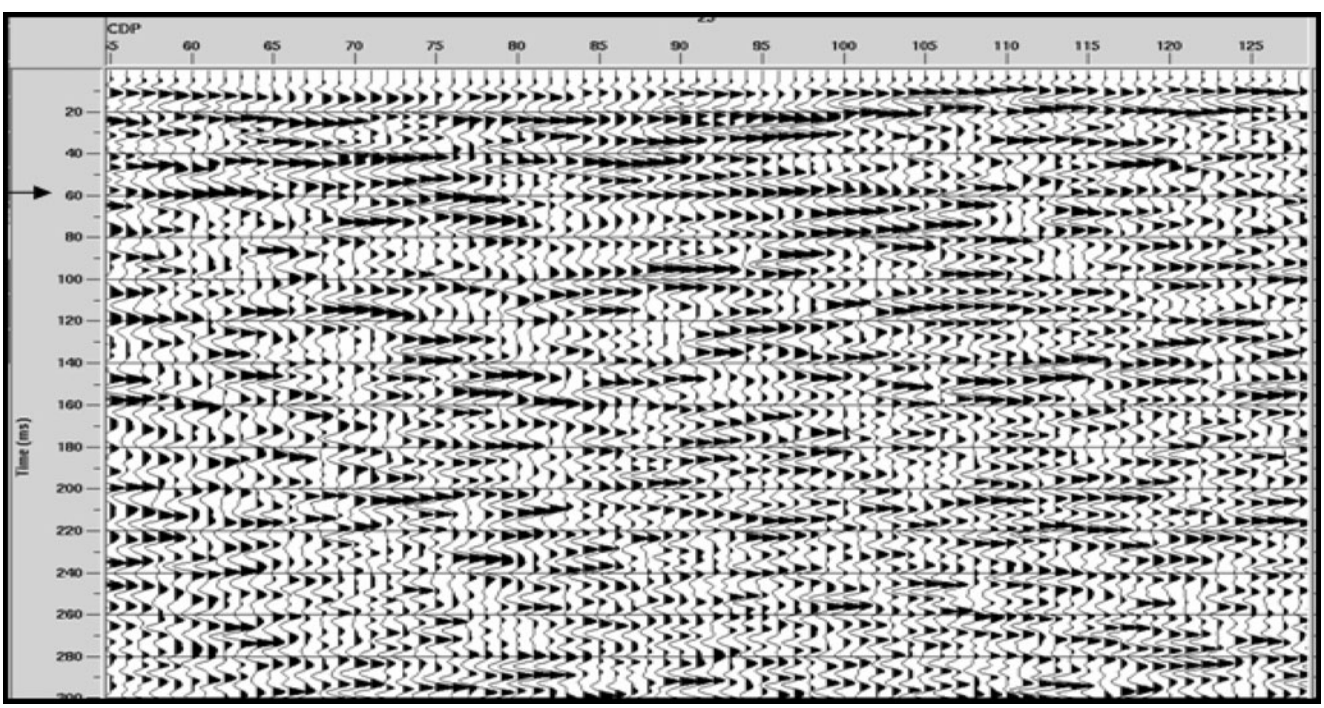

Fig. 9 Brute stack for site no. 1

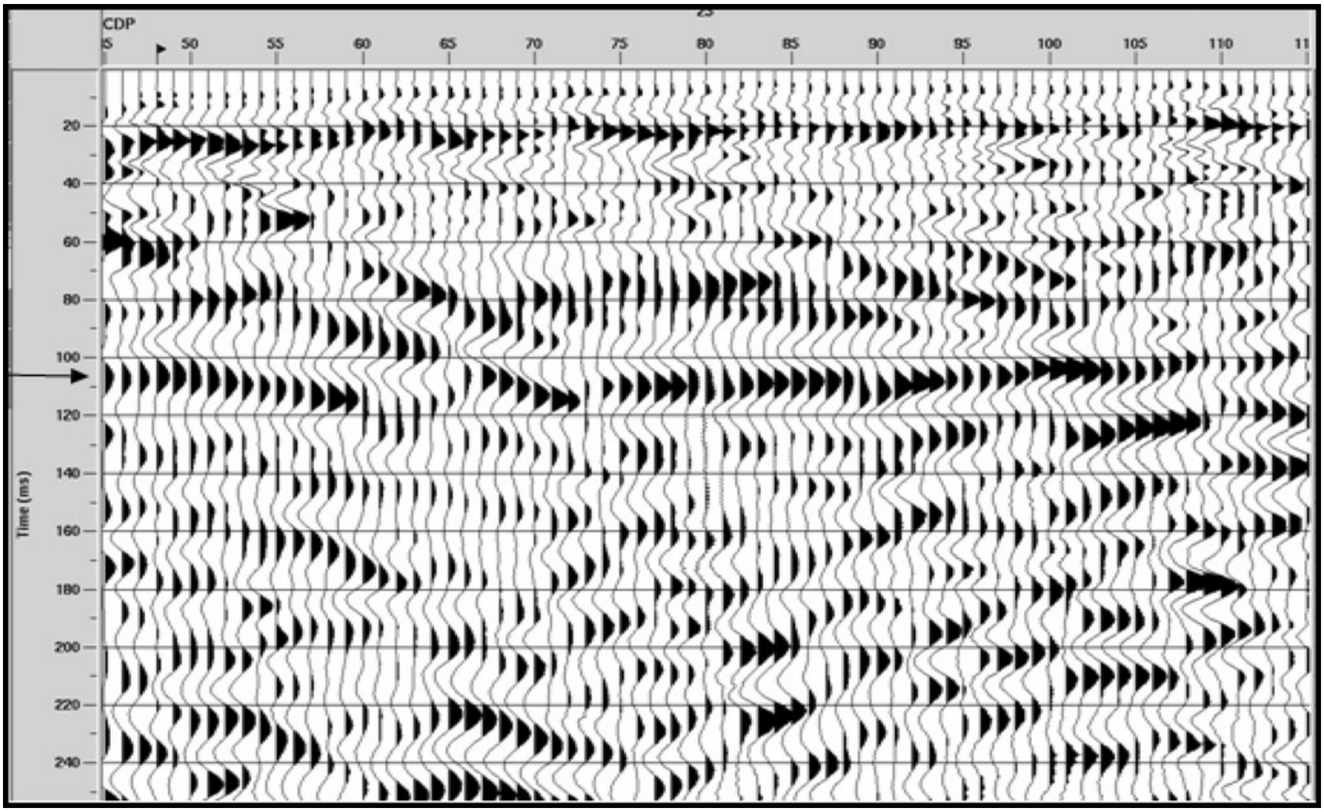

Fig. 10 Brute stack for site no. 2

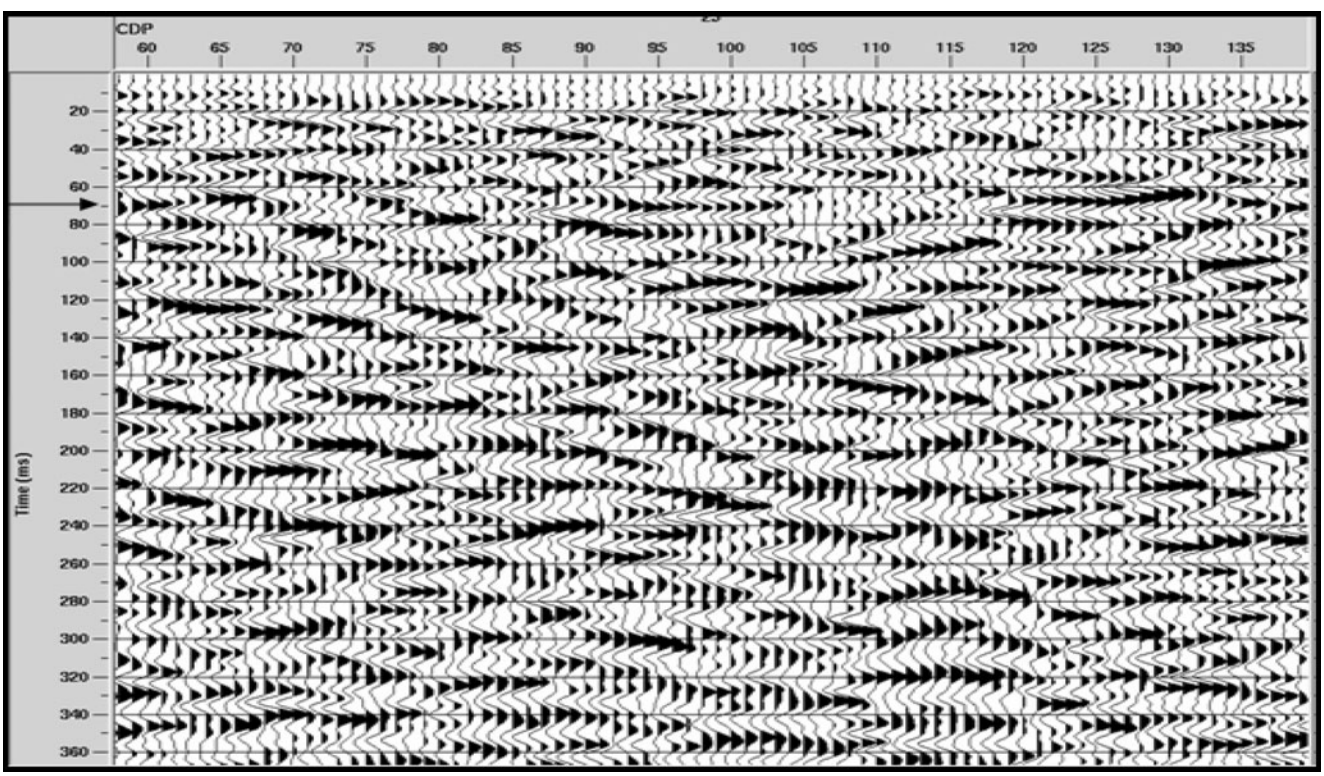

Fig. 11 Brute stack for site no. 3

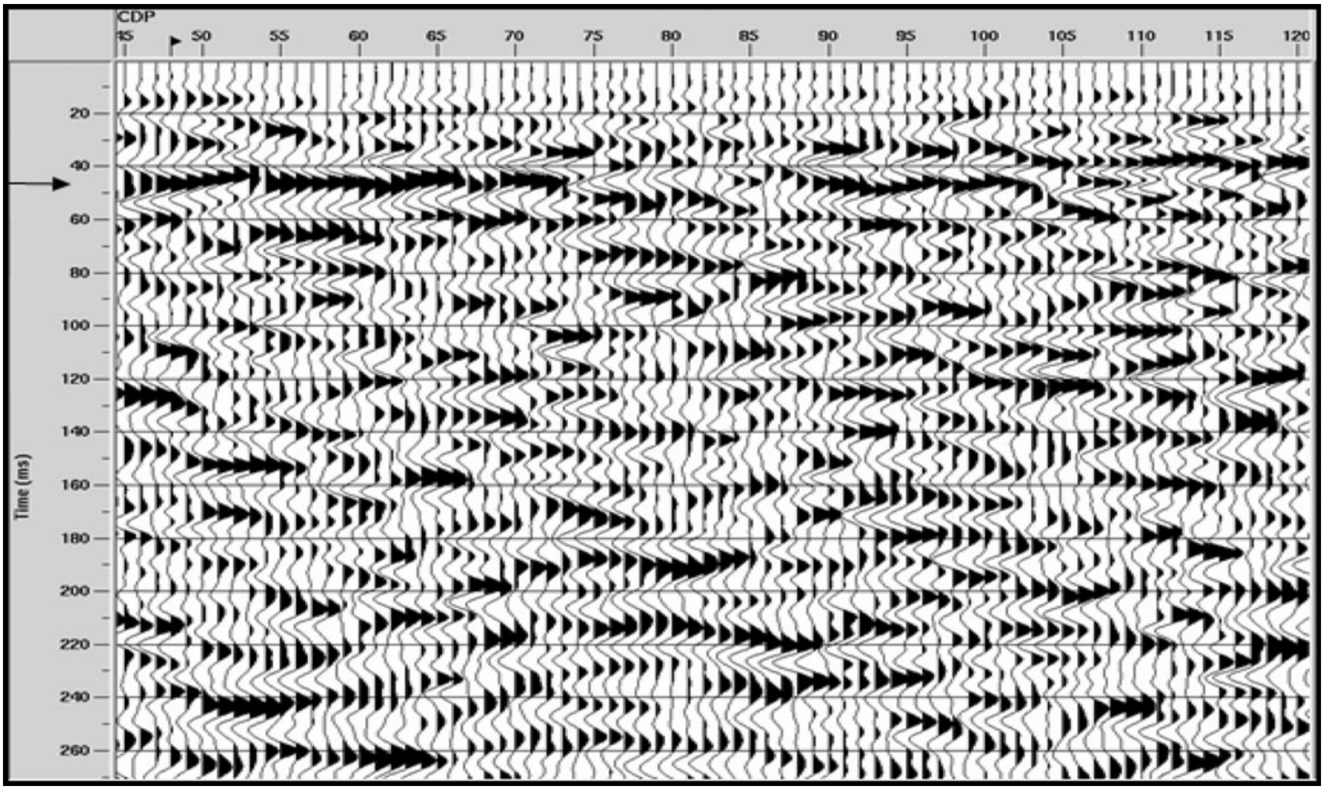

Fig. 12 Brute stack for site no. 4

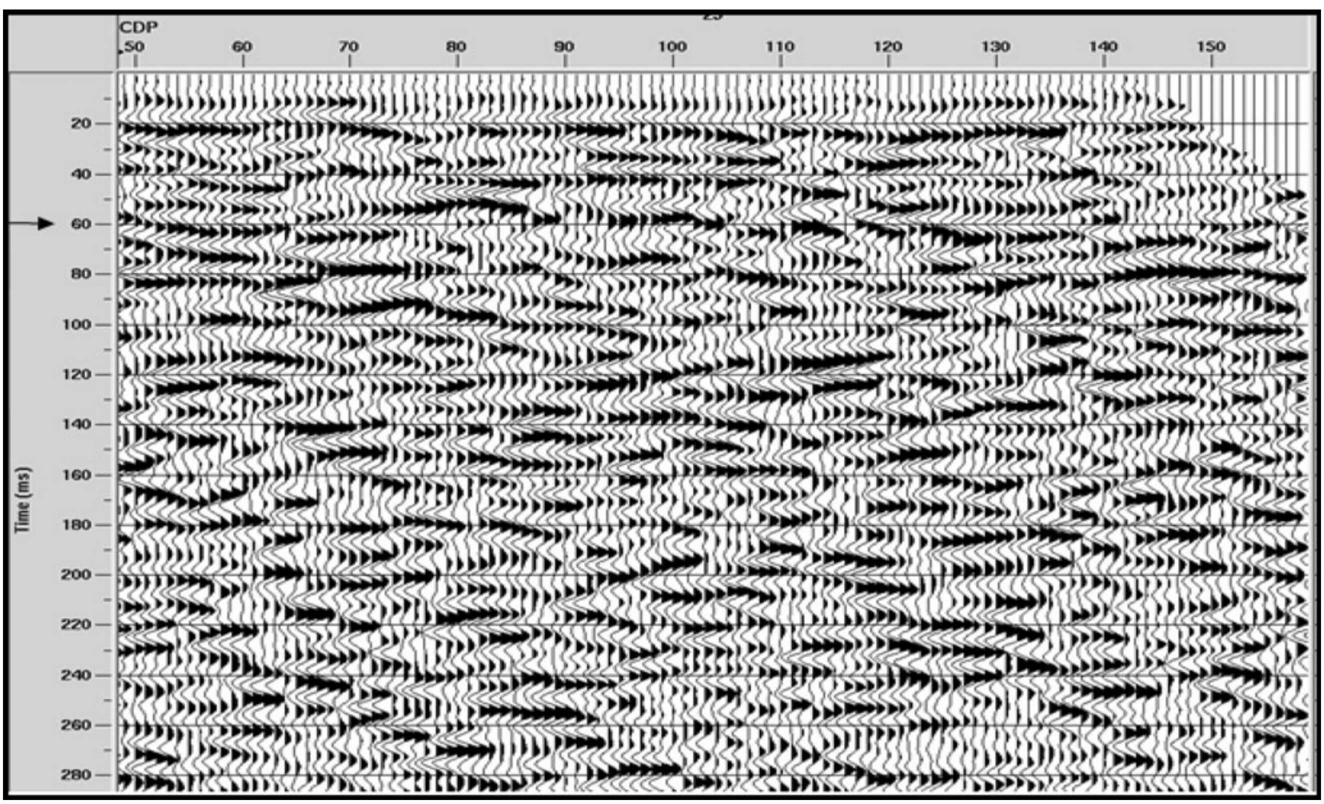

Fig. 13 Brute stack for site no. 5

vibroseis) should be used in any future seismic survey in the study area.

5. In order to obtain an improved image of subsurface features in the study area, the use of 3D-HRSR method is strongly recommended.
6. Additional information about the local up-hole lithology from the oil companies can significantly improve the level of interpretation in any future geophysical endures.

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