



## **Application of shallow seismic reflection in geoenvironment and geoengineering mapping**

UMAR HAMZAH, ABDUL RAHIM SAMSUDIN AND ABDUL GHANI RAFEK

Jabatan Geologi  
Universiti Kebangsaan Malaysia  
43600 Bangi, Selangor D.E.

**Abstract:** Shallow seismic reflection is one of the surface geophysical techniques to investigate indirectly subsurface structures within depths of 200 meters. Structures such as faults, sedimentary features, hydrogeological aquifers, depth to bedrock and limestone sinkholes are always related to the geological mapping. This paper presents some of the shallow seismic reflection results in imaging subsurface structures at a few selected localities. The presence of a limestone sinkhole as small as 20 m x 5 m was imaged at the old limestone quarry in Batu Caves, Kuala Lumpur. Sedimentary structures, aquifers and thickness of alluvium on granite bedrock were imaged from surveys at Pekan, Pahang and Bacok, Kelantan. Faults have also been detected using the same technique from a survey in Midland, England. Currently a minimum depth obtained is approximately 20 m and the vertical resolution is approximately 5 m.

**Abstrak:** Seismos pantulan cetek adalah satu daripada kaedah geofizik permukaan yang digunakan untuk mengkaji secara tidak langsung struktur bawah permukaan pada kedalaman sehingga 200 meter. Pemetaan geologi bawah permukaan selalunya melibatkan struktur-struktur geologi seperti sesar, gejala sedimen, akuifer hidrogeologi, kedalaman batuan dasar dan rerongga batu kapur. Kertas ini membincangkan beberapa keputusan survei seismos pantulan cetek yang dilakukan untuk mengimej struktur bawah permukaan di beberapa lokaliti terpilih. Kehadiran rerongga dalam batu kapur bersaiz sebesar 20 m x 5 m telah berjaya dikesan dalam batu kapur di Batu Caves, Kuala Lumpur. Beberapa struktur sedimen, lapisan akuifer dan ketebalan aluvium yang menindih granit telah dapat diimejkan dengan survei seismos dikawasan Pekan, Pahang dan Bachok, Kelantan. Struktur sesar juga telah dapat dikesan dikawasan Midland, England dengan menggunakan kaedah yang sama. Sehingga kini kaedah seismos pantulan cetek hanya dapat dapat mengesan struktur pada kedalaman melebihi 20 m dengan resolusi menegak disekitar 5 m.

### **INTRODUCTION**

Seismic reflection surveys have been used since 70 years ago to delineate subsurface structures in petroleum exploration (Miller *et al.*, 1994). The same technique has been modified to be used in exploring shallow structures since 1982 (Doornenbal and Helbig, 1983; Miller *et al.*, 1989; Miller and Steeples, 1991). The successful use of the technique for shallow applications depends on several factors such as most importantly the contrast in acoustic velocity and density of the subsurface materials. Another important factor is the ability of the near surface material to propagate high-frequency seismic signals (Steeple and Miller, 1990). Shallow seismic reflection profiles are very useful in characterizing shallow structures or anomaly at depth less than 200 m (Hunter *et al.*, 1984; Jongerius

and Helbig, 1988). The technique is cheaper compared to drilling and can increase its horizontal resolution. It is also effective in detecting faults and interpreting stratigraphic relationships with the help of borehole information. Fresh and salt water aquifers configurations have been imaged successfully at Pak Pura, Bachok, Kelantan. In Pekan, Pahang, the survey revealed the shape of silt and gravel deposit overlying granite bedrock. The technique also contributed successfully in delineating underground cavities in limestones at Batu Caves, Kuala Lumpur. Sinkholes and cavities have always been a problem in geoengineering. Cavities as deep as 20 m has been detected in the above survey. Faults in sedimentary deposit with vertical displacement of 40 m have also been detected in surveys carried out at Cirencester in the central part of England (Umar Hamzah, 1985).

## FIELD TECHNIQUES

The Common Mid Point (CMP) technique also known as Common Depth Point (CDP) was used to acquire data in the field and to produce seismic sections displayed in this paper. ABEM and Nimbus multichannel seismographs, hammer and explosive sources and 14 hertz geophones were used for the data acquisition. After each recording, the source and all geophones are shifted by a distance of one geophone position to produce a maximum of 12-fold CDP gathers. Data processing involved editing to remove the refracted events, amplitude gain recovery, muting the air-coupled waves and reducing the air and surface waves amplitude by frequency filtering. The following stages of processing included velocity scan analysis, normal moveout correction and common depth point stacking.

## RESULTS AND DISCUSSION

### Case 1: Alluvial and bedrock mapping at Pekan, Pahang

Seismic horizons which are identified as reflections are marked on the stacked section (Fig. 1). Reflections recognized where the quality of data is good include two continuous and slightly undulating reflections R1 and R2 and continuous to discontinuous R3 and R4 which are generally

parallel to earlier two reflections. Beside these reflections there are some short and weak alignments which may be reflections, such as indicated by reflection R5. Geological interpretation is very sensitive to velocities especially in depth conversion. Since interval velocities were not available, depth conversion was carried out by using stacking velocities obtained from velocity analysis. An estimated velocity value of about 1,000 m/s was used for the conversion and production of stacked sections. The nearest boreholes were used for geological interpretation. The layer above the reflection R1, which is approximately 25 m thick correlate with silty clays. Below R1 is sand and gravel of varying thickness, from 25 m in the middle to 75 m at both ends of the profile. Within the sand layers are thin layers of clay and silt of 5 to 10 m thickness marked by reflections R2, R3 and R4. The zone of poor alignment in the middle and bottom of the profile is interpreted as granite bedrock at depth approximately 55–60 m. Figure 2 shows The geological interpretation of the profile.

### Case 2: Mapping of saturated sand and gravel at Pak Pura, Bachok, Kelantan

Several reflections from less than 100 m can be clearly identified on the stacked section (Fig. 3). Based on borehole data, the first strong and continuous reflecting horizon at depth of 17 m to 23 m correlates well with the top of the second aquifer. A continuous and high-amplitude horizon at depths

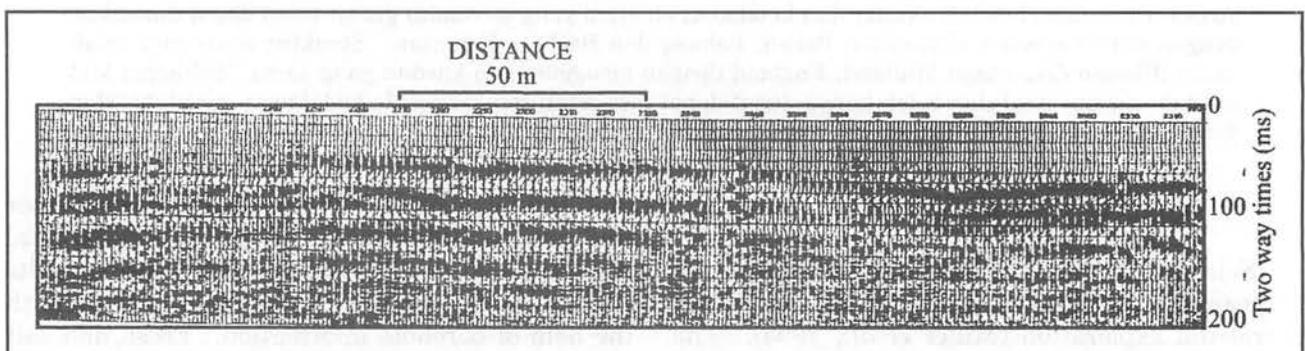


Figure 1. Stacked seismic section at Permatang Pasir, Pekan, Pahang (after Umar Hamzah *et al.*, 1995).

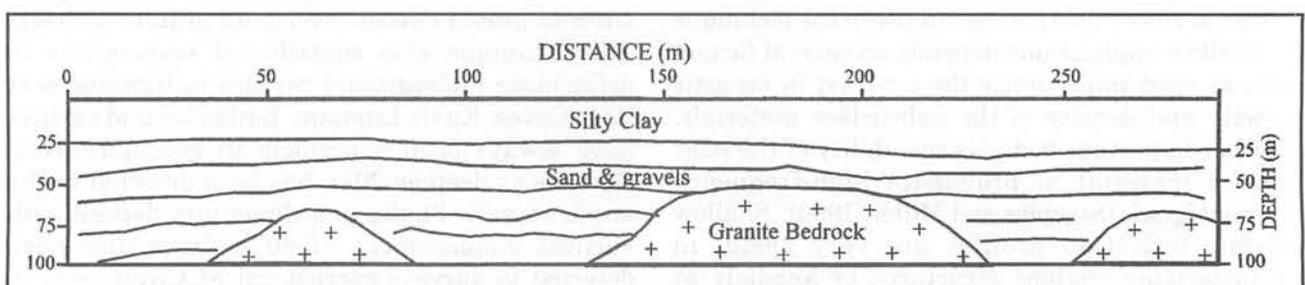


Figure 2. Geological interpretation of the Pekan seismic line (after Umar Hamzah *et al.*, 1995).

of 41 m to 51 m is closely related with the bottom of the second aquifer overlying the clay layer. The thickness of the second aquifer varies from 24 m to 28 m. The clay layer which separates the second and the third aquifers has a thickness of approximately 6 m. The depths to the top of the third aquifer vary from 50 m to 60 m. Figure 4 shows the interpreted profile along the survey line. The bottom layers of coarse sand and gravel represent an alluvial deposit which had been deposited directly on the older rock basement. Similar facies have also been encountered in other parts of the eastern area. The facies is of continental origin. The deposition of the sediments occurred in the continental setting which could have existed during the holocene sea-level fall. This makes the bottom layer of the fresh water aquifer as indicated earlier. The subsequent sea-level rise had resulted in the encroachment of sea-water into the area and given rise to the deposition of the second layer which consists of clay and gravel. It is interpreted that the sediments of the second layer were deposited in a brackish environment. As the sea-level continued to rise, the area was inundated and a shallow marine environment developed. At the same time the deposition of a medium to coarse sand (layer 2) took place. This would explain why

the second aquifer layer contains salt water. The deposition of the topmost layer i.e. the present day beach sand which consists of fine sands with soft clays and shells occurred during the last period of sea-level fall which took place about 5000 y B.P. (Tjia, 1992). The deposition occurred progressively as the sea-level retreat to its present position. It is detected that the former coastline was about 10 km inland (Kamal Roslan Mohamad and Che Aziz Ali, 1995).

### Case 3: Mapping of limestone cavities at Batu Cave, Kuala Lumpur

Figure 5 shows the seismic section from a line surveyed in the area. It clearly shows the first reflector representing the top of the karstic limestone underlying the quaternary alluvium at depth of approximately 15.3 m. This depth correlates well with the borehole results. The second reflector at depth of 25.5 m shows poor continuity and is slightly undulating as compared to the first one. From the borehole, it could be referred to the top of limestone layer beneath several cavities of thicknesses varying from 0.9 to 4.4 m occurring in between the limestone. Figure 6 shows the interpreted geological section. It is estimated that

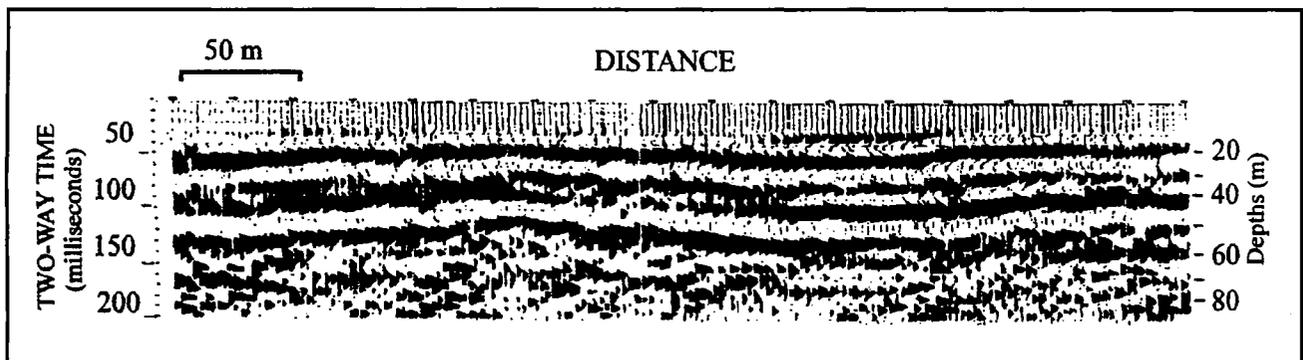


Figure 3. Stacked seismic section at Pak Pura, Bachok, Kelantan (after Umar Hamzah *et al.*, 1997).

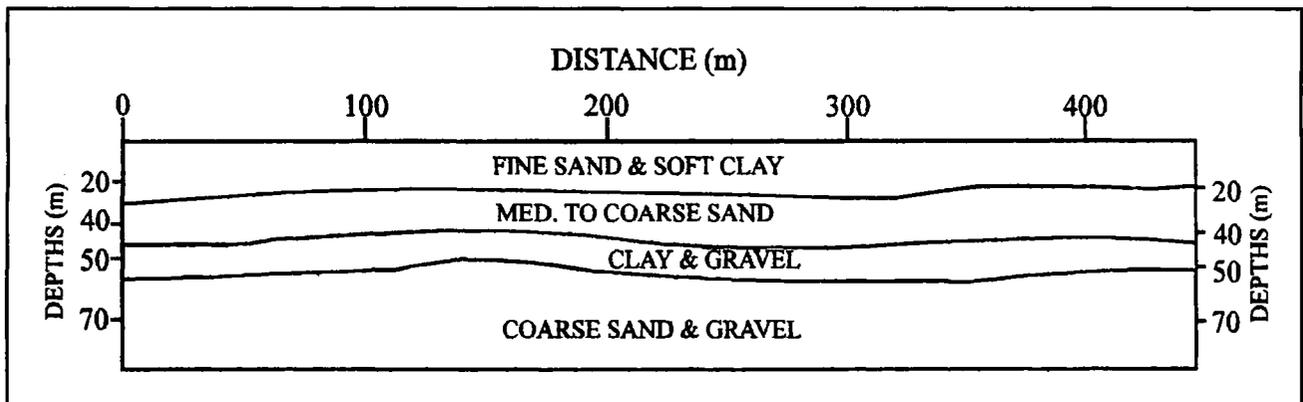


Figure 4. Interpreted profile along Pak Pura survey line (after Umar Hamzah *et al.*, 1997).

the cavities found in the borehole are part of the 20–30 m long limestone underground channel.

#### Case 4: Mapping of groundwater aquifer at Pantai Irama, Bachok, Kelantan

Three major reflections are clearly defined on the stacked section Figure 7 and are consistent with the borehole geology (Abdul Rahim Samsudin *et al.*, 1996). The first reflector at depth of approximately 29 m correlate well with the top of second aquifer. The second reflector at a depth of

41 m represent the bottom of the aquifer. The third reflector at 55 m depth represents the top of third aquifer. The interpreted stacked section Figure 8 clearly shows the configuration of second and third aquifers. Overlying the third aquifer is the clay layer of 15 to 20 m thickness. A striking feature on the seismic profile is the occurrence of channel fill at the eastern part of the section. The deepest event interpreted on the section is probably the dipping bedrock shown by the weak alignment of reflections at depth of about 90 to 110 m.

#### Case 5: Underground fault mapping in Cirencester, Central England

Prior to an extensive geophysical survey including seismic refraction, resistivity, gravity and magnetic which was planned in the area by the Thames Water Authority, a trial test of multifold seismic reflection had been made to locate small-scale NW-SE faulting. The resulting seismic section with the depth scale on the left hand side of the section is displayed in Figure 9. Comparison made with the nearest borehole clearly indicate the presence of two reflectors namely the Great Oolite limestone and the Cornbrash limestone. Both of them are respectively at 95 and 70 m depth on the seismic section. On the other hand, according to the borehole information the depth to the Great Oolite limestone was at 97 m and to the top of Cornbrash was at 69 m i.e. with the difference of about 1–2 m. The thickness of Cornbrash and Great Oolite limestones are estimated to be about 6 and 15 m respectively. This interpretation was only for the southern part of the section. Difficulties were experienced in interpreting the northern part of the section. Apart from being quite far from the borehole, this part of the section seemed to have quite shallow reflectors and hence poor resolution. The strong events at about 35 and 53 m depth could again be the Cornbrash and the Great Oolite limestone even though with different waveforms compared to the one in the southern part section. The difference in depth between the Great Oolite beds at both ends indicated the presence of probably a normal fault with a vertical displacement of about 40 m and a horizontal separation of about 50 m. Figure 10 sketches the geological description of the seismic line.

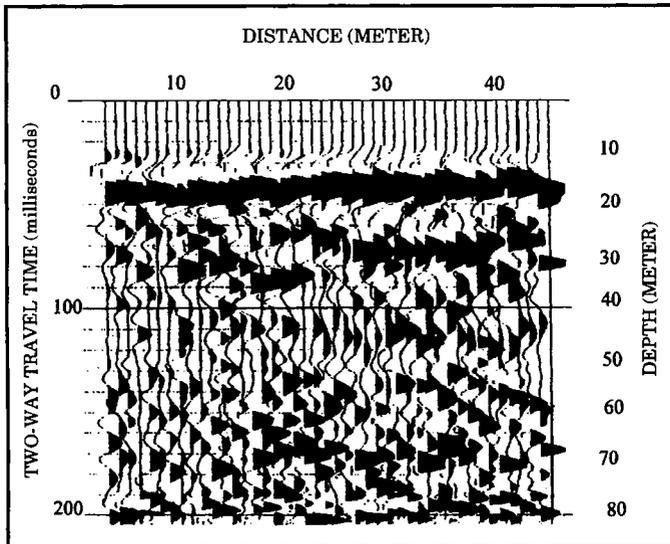


Figure 5. Seismic section at the old limestone quarry, Batu Cave (after Abdul Rahim Samsudin *et al.*, 1997).

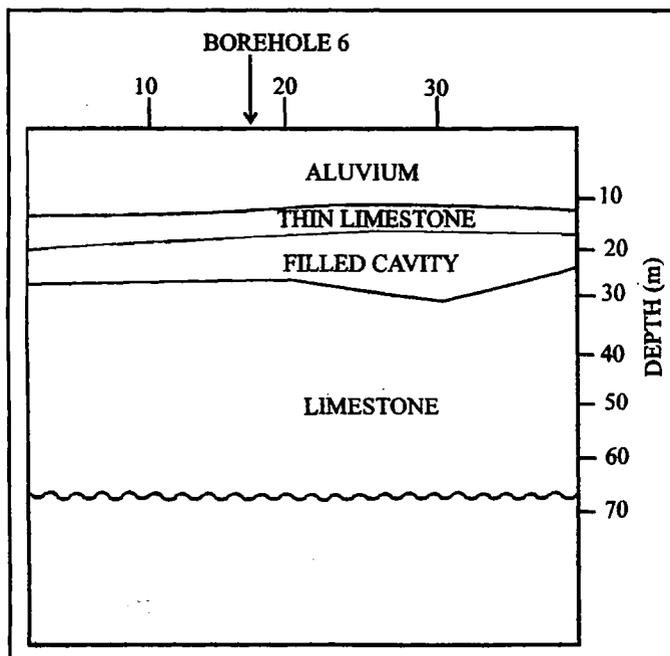


Figure 6. Interpreted geological section of Batu Cave seismic line (after Abdul Rahim Samsudin *et al.*, 1997).

## CONCLUSION

High resolution shallow seismic reflection is an effective geological technique to map subsurface geologic features in areas where drilling represents the primary source of data. The seismic survey employing Common Mid Point technique has been very successful in many areas to locate features

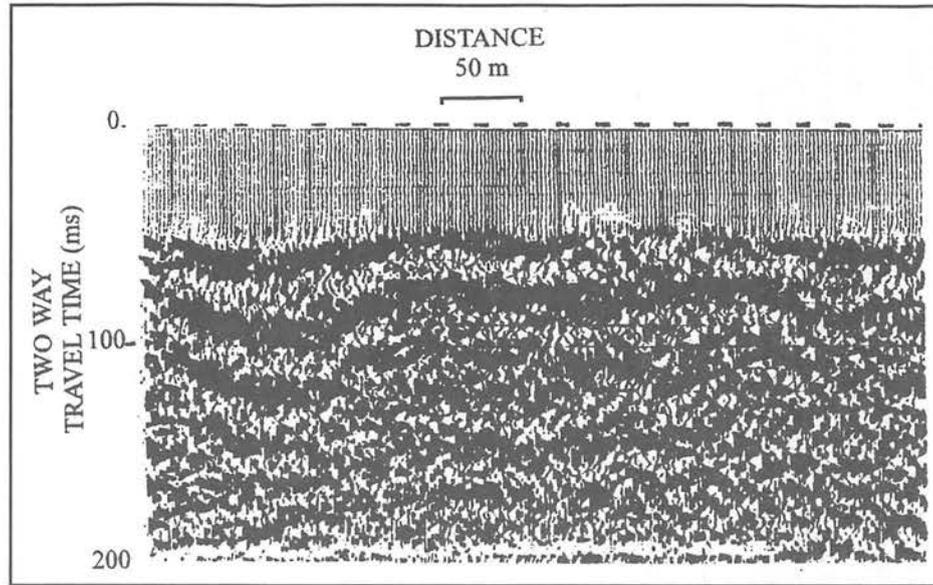


Figure 7. Stacked seismic section of Pantai Irama survey line (after Umar Hamzah *et al.*, 1996).

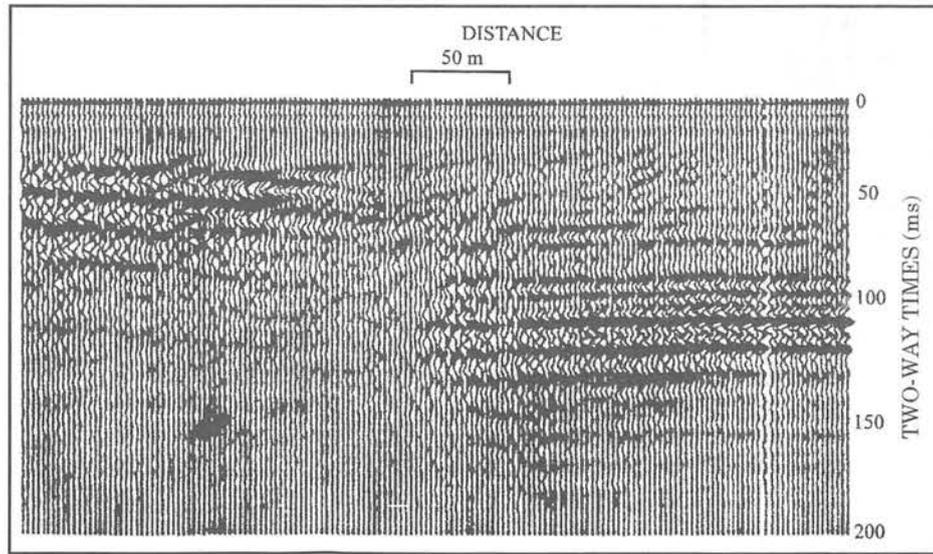


Figure 9. Seismic section from a survey in Cirencester, England (after Umar Hamzah, 1985).

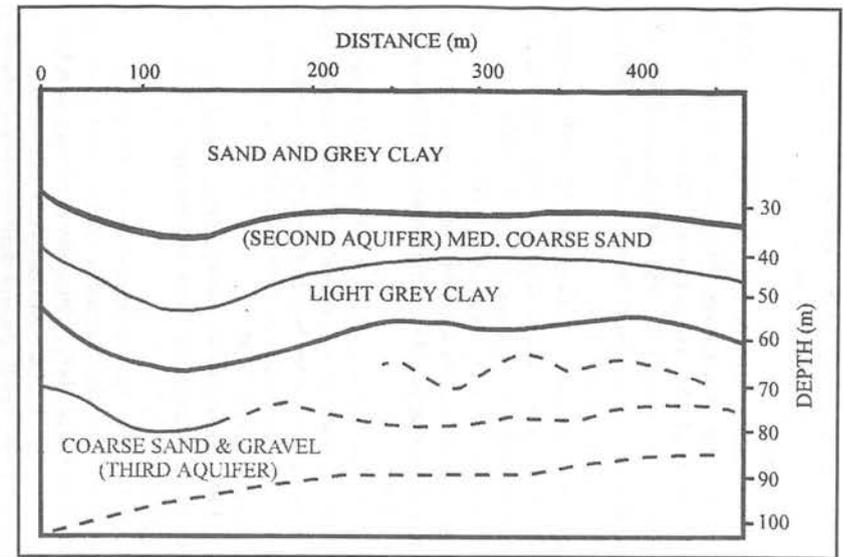


Figure 8. Interpreted geological section of Pantai Irama line (after Umar Hamzah *et al.*, 1996).

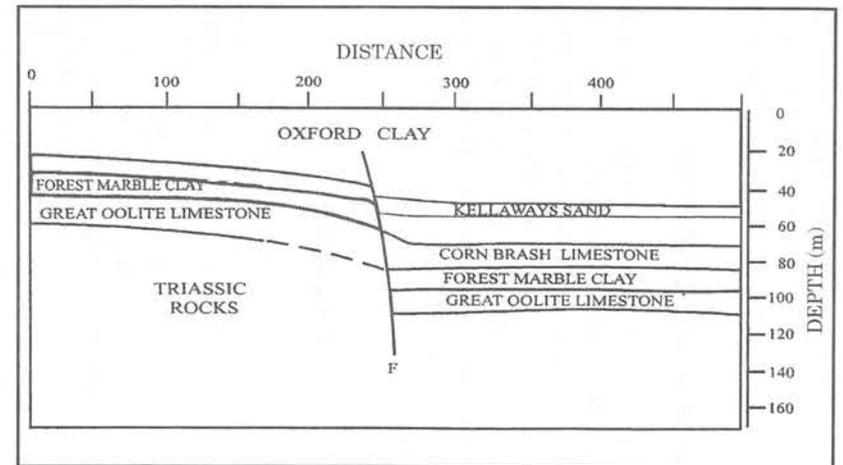


Figure 10. Interpreted geological section of Cirencester seismic line (after Umar Hamzah, 1985).

within one to five meters at a depth of 20 m. Better results and resolution would be obtained provided higher source and geophone frequency are employed.

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