

Determination of the Physical Properties of Near Surface Layers of Omerulu Area, Nigeria, Using Seismic Refraction Method

Olowofela Joseph Adeniyi¹, Akinyemi Olukayode Dewunmi¹, Odumosu Olutayo²,
Ajani Olumide Oyewale^{3,*}

¹Department of Physics, Federal University of Agriculture (FUNAAB), Abeokuta, Nigeria

²Exploration Unit, United Geophysical Company, Warri, Nigeria

³Department of Physics and Solar Energy, Bowen University, Iwo, Nigeria

Email address:

aj_ani2000@yahoo.com (O. O. Ajani)

*Corresponding author

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Abstract: Seismic refraction method is a geophysical technique used to study physical properties of the subsurface such as layer thicknesses, travel times and velocities of seismic signals through the layers. The process of turning seismic refraction data to useful information involves use of first arrival times and offsets. In this study, the near surface investigation of the physical properties of the unconsolidated and consolidated layers was carried out in Omerelu, Rivers State of Nigeria. Omerelu lies between latitude 05° 08'N and 05° 13'N and longitude 06° 51'E and 06° 58'E. Previous investigations were based on reflection method in which the near surface effect caused misalignment in the deeper horizons observed in the final stack of the reflection data. This problem was solved by running a seismic refraction survey over the area. The study involved identification of points at which data would be acquired to give a good overview of the area under consideration. Twelve sampling points were picked with a grid of approximately 4 × 4 km. A 100 m line with two source points at each end was cleared at each data acquisition point after which the coordinates were taken using Leica Total station (TC 1203 survey equipment). Seismic signals were recorded using OYO McSeis 160M coupled with a 12-geophone harness along with a blasting unit. Upsphere processing software was used to plot time - offset graphs to determine the velocities of the unconsolidated and consolidated layers. The intercept times were also graphically obtained and used to determine the thickness of the unconsolidated layer. Results show that the thickness of unconsolidated/weathered layer in the study area varies between 12.25 and 13.60 m, while the velocities of the unconsolidated and the consolidated layers vary between 500 – 550 m/s and 1790 – 1875 m/s respectively. The results obtained when applied to the reflection data, were able to resolve the static problems; thereby increasing and improving the quality of data available on the lithology of the study area.

Keywords: Arrival Times, Offsets, Misalignment, Intercept Time, Seismic Refraction Data, Consolidated Layers, Unconsolidated Layers

1. Introduction

Refraction seismology is all about a geophysical method that maps geological structure using travel times of head waves. Head waves are elastic waves that enter a high velocity medium (refractor) near the critical angle and travel

in the high velocity medium nearly parallel to the refractor surface before returning to the surface of the Earth [18]. The objective in refraction surveys is to measure the arrival times of head waves as a function of source - receiver distance so that the depth to the refractors in which they travel can be determined.

The main variations among refraction methods lie in the

user's approach to interpretation; hence, in data processing. The classical refraction method is the intercept-time method. Other interpretation methods include the reciprocal method [9], based on [5], and the delay-time method [14]. Palmer [16] developed the generalized reciprocal method. An excellent reference by [12] and [19] discussed modern refraction techniques.

Seismic refraction is a geophysical principle governed by Snell's law. Named after Dutch mathematician, Willebrord Snellius, one of its discoverers, Snell's law states that the sine's of the angles of incidence and refraction is equivalent to the ratio of velocities in the two media, or equivalent to the opposite ratio of the indices of refraction and incidence:

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2} = \frac{n_1}{n_2} \quad (1)$$

$$\text{or } n_2 \cdot \sin\theta_1 = n_1 \cdot \sin\theta_2 \quad (2)$$

θ_1 and θ_2 are angles of incidence and refraction respectively; v_1 and v_2 are velocities of travel through layers 1 and 2 respectively; n_1 and n_2 are refractive indices of layers 1 and 2 respectively.

Snell's law follows from Fermat's principle of least time, which in turn follows from the propagation of light as waves.

The field methods used in refraction studies include reverse refraction, singled –ended profiles that do not allow the analysis of dip and classic fan-shooting of the type used in the oil industry for salt-dome exploration. For some near surface applications such as finding the edges of buried garbage dumps and locating near-surface voids.

More than ever before, people in academia and industry are using near-surface seismology as a non-invasive tool for determining the physical properties and geometry of the upper 200 meters of the subsurface [8].

Refraction experiments are based on the times of arrival of the initial ground movement generated by a source recorded at a variety of distances. Later arrivals in the recorded ground motion are discarded. Thus, the data set derived from refraction experiments consists of a series of times versus distances. These are then interpreted in terms of the depths to subsurface interfaces and the speeds at which motion travels through the subsurface within each layer. These speeds are determined by a set of physical constants, called elastic parameters that describe the material.

During data acquisition individual data records are displayed as variable area wiggle traces displaying travel time against distance. This provides an important check on the quality of the data. Following acquisition wiggle traces are used to display the data during picking of the first-arrivals for each geophone position and source [4].

Any existing ground information such as borehole and trial pit logs, is overlain on the depth profile in order to help calibrate the seismic results and then provide an indication of the level of correlation along the survey line. The refractor depth is displayed as a series of overlapping arcs that

represent the solutions for each geophone in the array. The refractor can lie anywhere on the arcs below the intersections with adjacent arcs.

A shallow refraction crew generates energy from a single source. It uses low frequency geophones (2 – 5 Hertz) and low frequency recording methods to obtain refraction data. The offset distance between source and detector is designed to record shallow refraction data [7].

2. Theoretical Background

When a force is applied to a material, it deforms. This means that the particles of the material are displaced from their original positions. Provided the force does not exceed a critical value, the displacements are reversible; the particles of the material return to their original positions when the force is removed, and no permanent deformation results. This is called elastic behavior [13].

The laws of elastic deformation are illustrated by the following example. Consider a right cylindrical block of height h and cross-sectional area A , subjected to a force F which acts to extend the block by the amount Δh .

Experiments show that for elastic deformation Δh is directly proportional to the applied force and to the unstretched dimension of the block, but is inversely proportional to the cross-section of the block. That is,

$$\Delta h \propto \frac{Fh}{A} \quad (3)$$

$$\frac{F}{A} \propto \frac{\Delta h}{h} \quad (4)$$

When the area A becomes infinitesimally small, the limiting value of the force per unit area (F/A) is called the stress σ .

$$\sigma = \frac{F}{A} \quad (5)$$

When h is infinitesimally small, the fractional change in dimension ($\Delta h / h$) is called the strain ϵ , which is a dimensionless quantity.

$$\epsilon = \frac{\Delta h}{h} \quad (6)$$

Equation (4) states that, for elastic behavior, the strain in a body is proportional to the stress applied to it. This linear relationship is called Hooke's law. It forms the basis of elasticity theory.

Beyond a certain value of the stress, called the proportionality limit, Hooke's law no longer holds.

Figure 1 illustrates progressive positions of the wavefront associated with energy travelling directly through an upper layer and energy critically refracted in a lower layer from a seismic source. Direct and refracted ray paths to a detector at D, a distance X from the source are also shown. The layer

velocities are V_1 , V_2 and the refracting interface is at depth Z .

The direct ray travels horizontally through the top of the upper layer from A to D at velocity V_1 . The refracted ray travels down to the interface and back up to the surface at

velocity V_1 along the slant paths AB and CD that are inclined at the critical angle θ and travels along the interface between B and C at the higher velocity V_2 . The total travel time along the refracted raypath ABCD is given by:

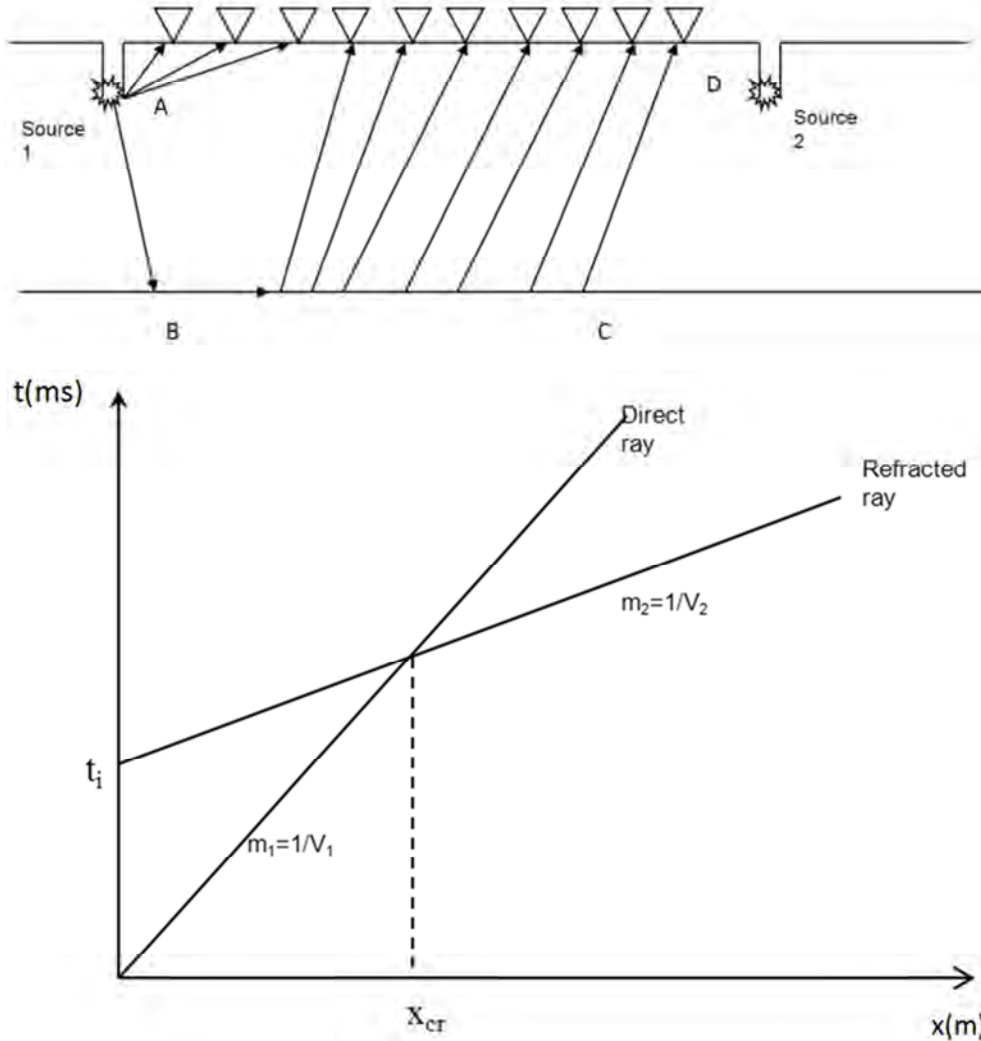


Figure 1. Analysis of refracted ray path.

$$t = t_{AB} + t_{BC} + t_{CD} = \frac{z}{v_1 \cos \theta} + \frac{x - 2z \tan \theta}{v_2} + \frac{z}{v_1 \cos \theta} \quad (7)$$

$$\text{or } t = \frac{x}{v_2} + t_i \quad (10)$$

Since Snell's law states that $\sin \theta = \frac{v_1}{v_2}$ and $\cos \theta = \sqrt{1 - \frac{v_1^2}{v_2^2}}$, the travel time equation may be expressed in a number of different forms, the most general form being:

$$t = \frac{x \sin \theta}{v_1} + \frac{2z \cos \theta}{v_1} \quad (8)$$

$$\text{or } t = \frac{x}{v_s} + \frac{2z(v_2^2 - v_1^2)^{\frac{1}{2}}}{v_1 v_2} \quad (9)$$

where plotting t against x , t_i is the intercept on the time axis of a travel-time curve or time-distance curve having a gradient of $\frac{1}{v_2}$. t_i known as the intercept time, is given by:

$$t_i = \frac{2z(v_2^2 - v_1^2)^{\frac{1}{2}}}{v_1 v_2} \quad (11)$$

v_1 = velocity of 1st layer = 1/slope of 1st line segment from origin

v_2 = velocity of 2nd layer = 1/slope of 2nd line segment from intercept

Solving for refractor depth:

$$z = \frac{t_1 \cdot v_1 \cdot v_2}{2 \cdot \sqrt{v_2^2 - v_1^2}} \quad (12)$$

$$V_p = \sqrt{\frac{\frac{4}{3}\mu + k}{\rho}} \quad (13)$$

$$V_s = \sqrt{\frac{\mu}{\rho}} \quad (14)$$

Thus by analysis of the travel-time curves of direct and refracted arrivals, v_1 and v_2 can be derived (reciprocal of the gradient of the relevant travel-time curve) and from the intercept time t_1 , the refractor depth z can be determined [15].

Seismic body waves which can either be P-waves (propagating through the medium in the same direction as the particles constituting the medium) or S-waves (propagating in a perpendicular direction to the particle constituting the medium). In an homogenous, isotropic media, the velocities of P and S - waves are given by

where V_p and V_s are the P and S wave velocities of the medium, ρ is the density of the medium, μ and k are referred to as the shear and bulk moduli of the medium (also known as the elastic parameters of the medium).

Any change in rock or soil property that causes ρ, μ or k to change will cause seismic wave speed to change, thereby offering the potential enabling the mapping of many subsurface features.

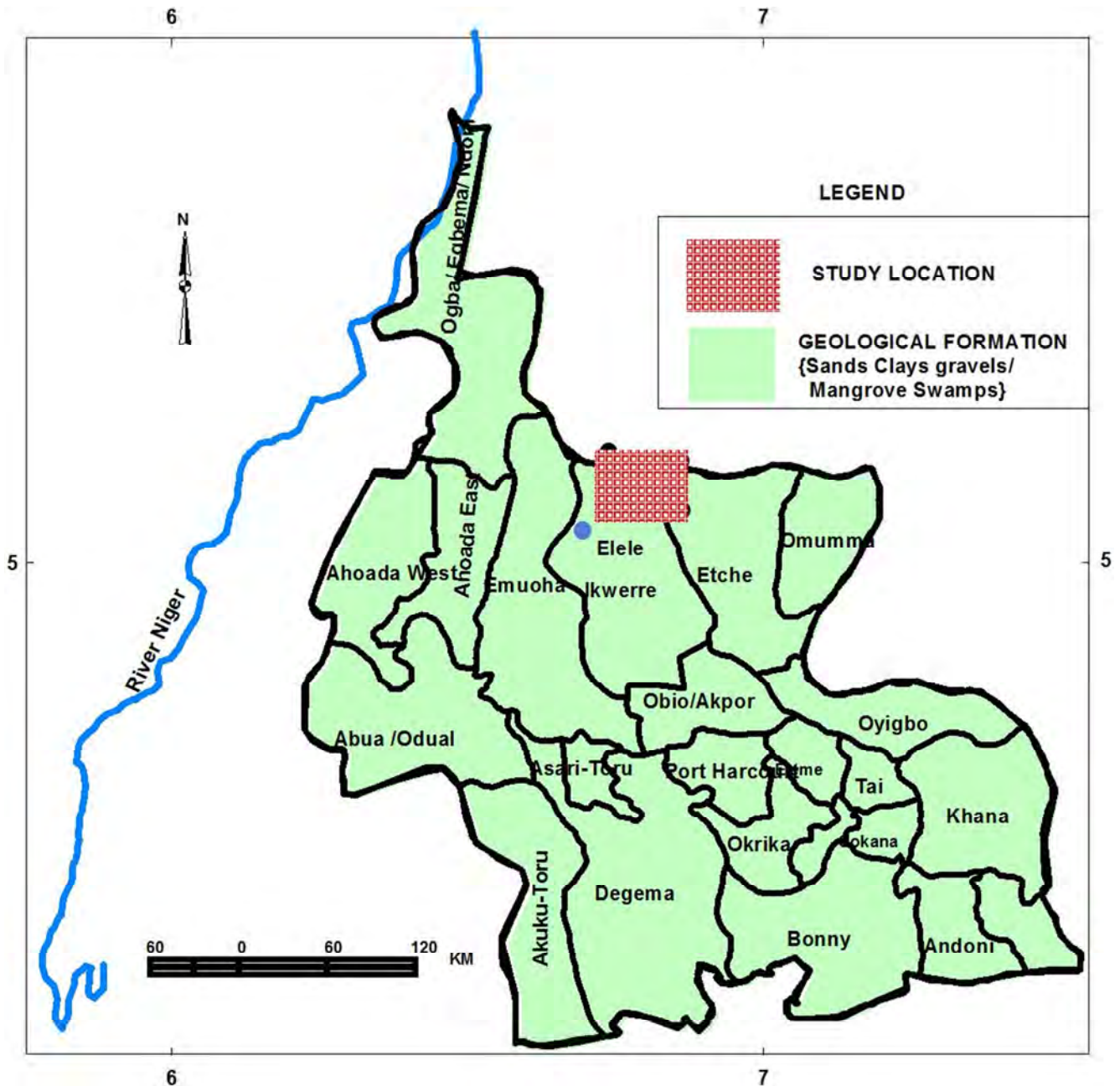


Figure 2. Map showing location of the study area (Adapted from Nigerian Geological Survey Agency 2006).

3. Field Work in Omerulu Area

An earlier work reported in Ajani, et al [1], describes the geographic formation of the study area, the study area lies between latitude $05^{\circ} 08'N$ and $05^{\circ} 13'N$ and longitude $06^{\circ} 51'E$ and $06^{\circ} 58'E$. It is situated in the River State part of the Niger Delta, Nigeria. Some of the relatively large urban settlements around study area are Omerulu, Apani, Umuapu, Isu-Etche and Rison palm plantation. The vegetation of the area is mainly farm land, palm plantation, thick bush and rubber plantation. At the time of this study, it was during raining season and humidity was high at this period.

The tertiary lithostratigraphic sequence of the Niger delta consists in ascending order, of the Akata, Agbada and Benin formations, which make up an overall regressive elastic sequence about 30,000 - 39,000ft(9,000 - 12,000m) thick [6].

The study took place using 4km x 4km grid between acquisition points. Leica Total station TC 1203 survey instrument was used for taking survey field data which were converted to coordinates and elevations using GP Seismic software. This is a specialized survey processing data.

The source points were drilled manually using what is commonly called thumping method. This involved an individual using 3m steel casing to make 1m hole. The drilled hole was loaded with 0.2kg dynamite with detonator and firing line attached to connect the dynamite to the instrument for initiation of seismic energy source. The sources were buried so that most of the source energy could penetrate the subsurface.

OYO McSeis 160M and 12- receiver geophone string is then deployed to acquire seismic data. The 12- receivers were planted across the cleared line and covered 85m. Two holes were drilled at both ends of the laid geophone string.

The instrument was used to initiate the dynamite while the signal was received by the receiver and transmitted to the instrument for recording.

After the field data acquisition the data were further analysed and processed. The seismic refraction data were processed using excel-based software called Upsphere.

The first and the main template has fields where general description of the study, identification number of each data set, depth of the source, the coordinates of the study area, etc can be inputted. It also has fields to input offset for each receiver deployed and first arrival times for each offset. It has fields where type of soil encountered during drilling can be entered.

The data obtained were then plotted. Each plot shows points on the time-offset graph and the break-point can be defined for each data set after choosing lines of best-fit for various layers. The program has ability to plot and display as much as 4 layers.

At this point the subsurface velocities and depth of unconsolidated are displayed by the program. This process was repeated for each data sets. The results were inputted into Surfer computer program to create the contour map.

4. Results and Discussion

Velocities and results of thickness of the unconsolidated layer are obtained from the field work and analysis. These results indicate the type of waves received at each geophone – direct or refracted waves.

At the acquisition point 1 which is at the south west corner of the study area as shown in Figure 11, the recording was first done and the first breaks were obtained before the reverse recording and obtaining the first breaks. The plots of the data obtained from the forward recording are shown Figure 4 in blue while the plots of the reverse recording are displayed in red.

Four data points fell on the straight line arising from the origin while one data point was slightly offset from the straight line. The data were direct waves received at the five geophones nearest to the source. The reciprocal of the slope gave 522 m/s as velocity at which seismic waves travelled through the layer. The remaining seven points defined the second layer. Four data points fell on the straight line, two data points had slight offset below the straight line and one data point was slightly offset above the straight line. These data were refracted waves received by the seven geophones farther away from the source. The reciprocal of the slope gave 1804 m/s as velocity at which seismic waves refracted by the second medium travelled to the receivers planted at the surface. The thickness of the unconsolidated layer was derived using equation (12) to be 12.2m.

The results from the reverse recording indicated a two-layer model as shown in Figure 12. The first layer was derived from five data points recorded by geophones which received the direct waves. Four data points fell on the straight line arising from the origin and one data point had very slight offset from the straight line. The reciprocal of the slope of the straight line gave 514 m/s as velocity at which direct seismic waves travelled through the first layer. The second straight line for the reverse recording indicated the second layer. It was derived from the plot of the remaining seven points. Four of the data points were on the straight line, two data points were slightly offset above the straight line and one data point was slightly offset below the straight line. The straight line gave a slope whose reciprocal worked out to be 1806 m/s. This is the velocity at which seismic waves travelled through the second medium. The thickness of the unconsolidated layer was 12.1m.

The difference in the velocity results for the first medium and the difference in the velocity results for the second medium are insignificant when compared in reference to the list of seismic velocities of materials in Table 1. The velocity bands have not been exceeded in both cases and therefore the first medium can be considered as homogenous and likewise the second medium.

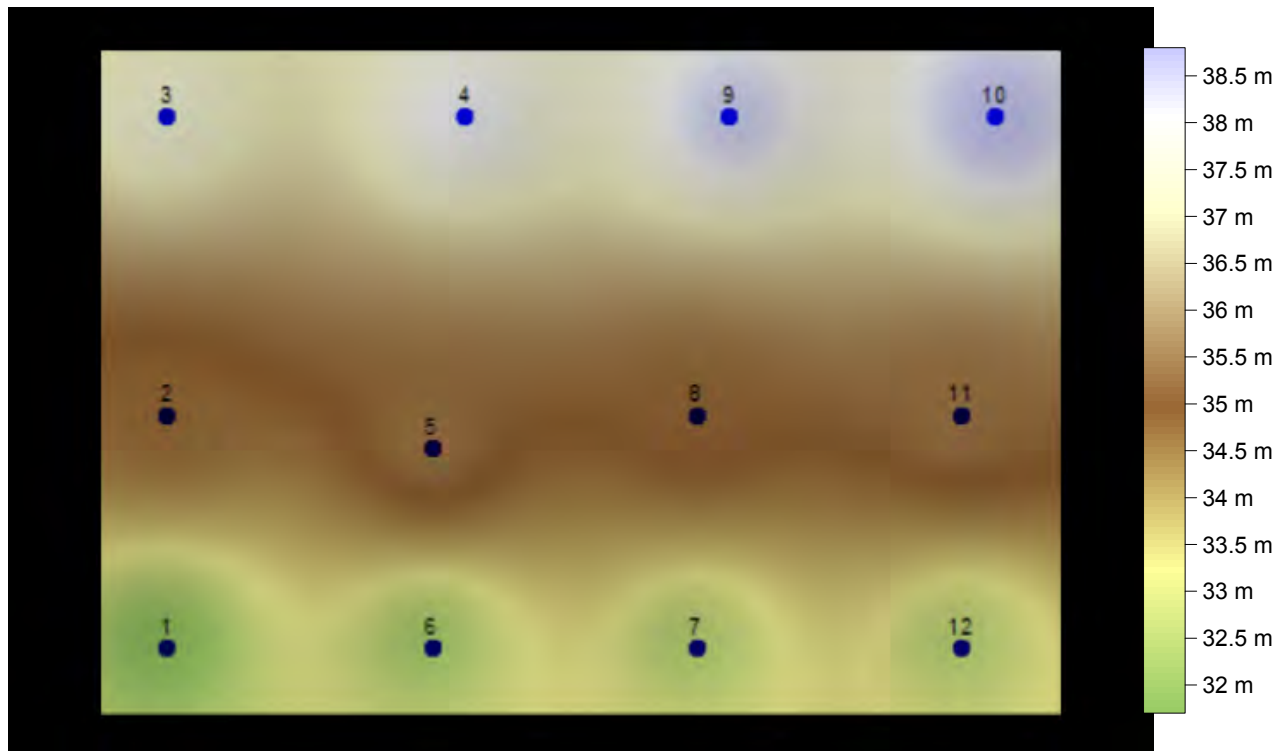
The average velocity of the first layer from the two recordings is 518 m/s and the average velocity for the second layer is 1805 m/s. The average thickness is 12.15m.

Table 1. Seismic velocities of some earth materials.

Materials	P wave Velocity (m/s)	S wave Velocity (m/s)
Air	300 – 332	NA
Petroleum	1300 – 1400	NA
Water	1400 – 1500	NA
Clay	1000 – 2500	400 - 1000
Sand (Unsaturated)	200 – 1000	80 – 400
Sand (Saturated)	800 – 2200	320 – 880
Sandstone	1400 – 4300	700 – 2800
Glacial Till (saturated)	1500 – 2500	600 – 1000
Concrete	3600	2000
Granite	5500 – 5900	2800 – 3000
Limestone	5900 – 6100	2800 – 3000
Basalt	6400	3200

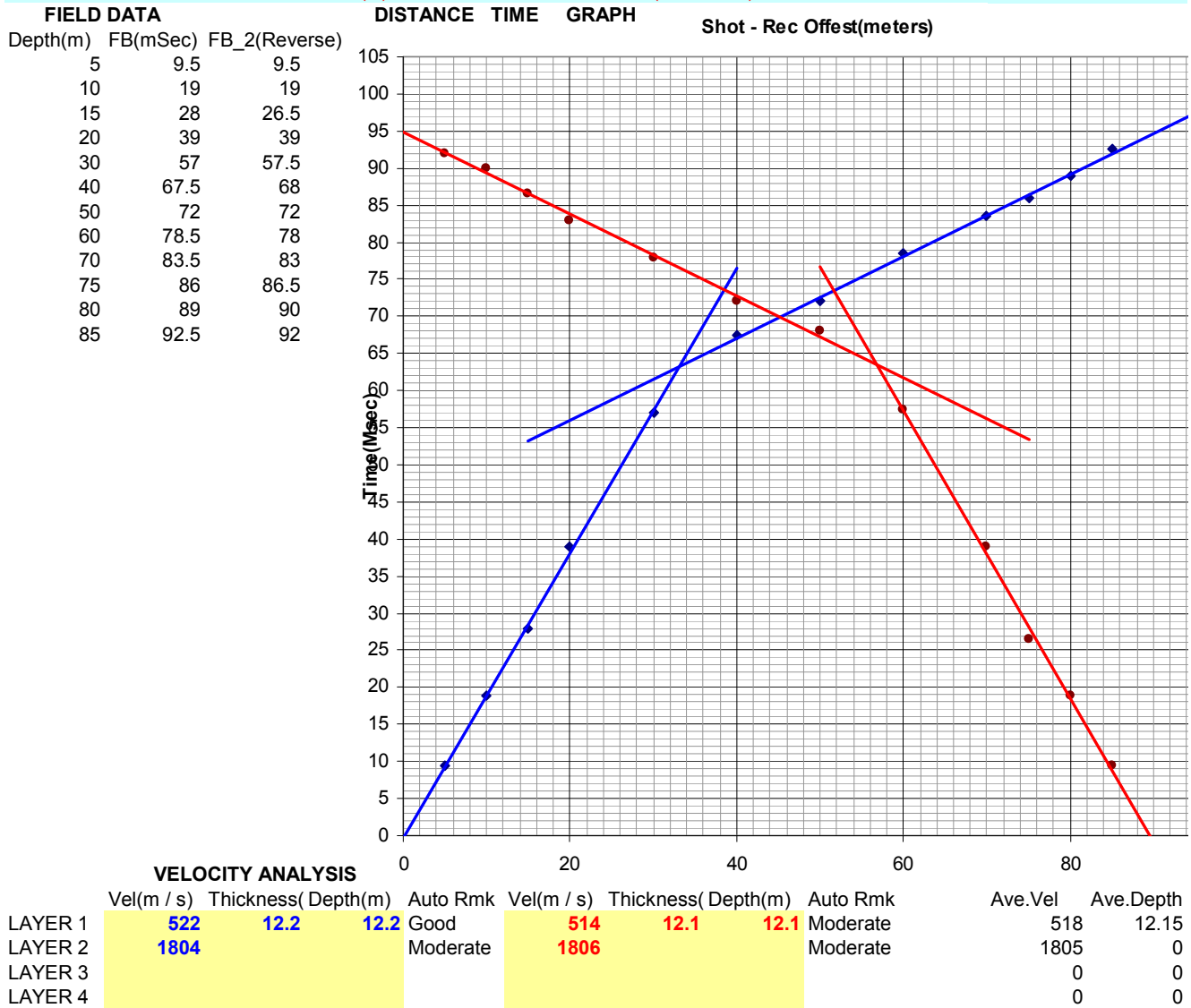
(Source: Okwueze, 1996)

Similarly, for the remaining 11-acquisition points, same discussion is applicable with their different layer thickness estimated from the different seismic velocities recorded and calculated.

**Figure 3.** Elevation contour map showing the twelve acquisition points.

L V L DATA PROCESSING

Project Name: LVL STUDY Contractor: Party/Proj M: Date Logged: 6/20/2008 InstrU Type: McSEIS-160M Processed by: TAYO Record No: 1	UPole No: 1 Station No: 5453-2339 Easting: 489359.5 Northing: 127202.1 Elevation: 31.7 Drilled by: Datum(m): 0	Drilled Depth(m): 1 Logged Depth(m): 0.8 Shot Depth(m): 0.8 Offset Dist(m): 0 Source Type: DYNAMITE Delay Time Break: Static(milliseconds): 34
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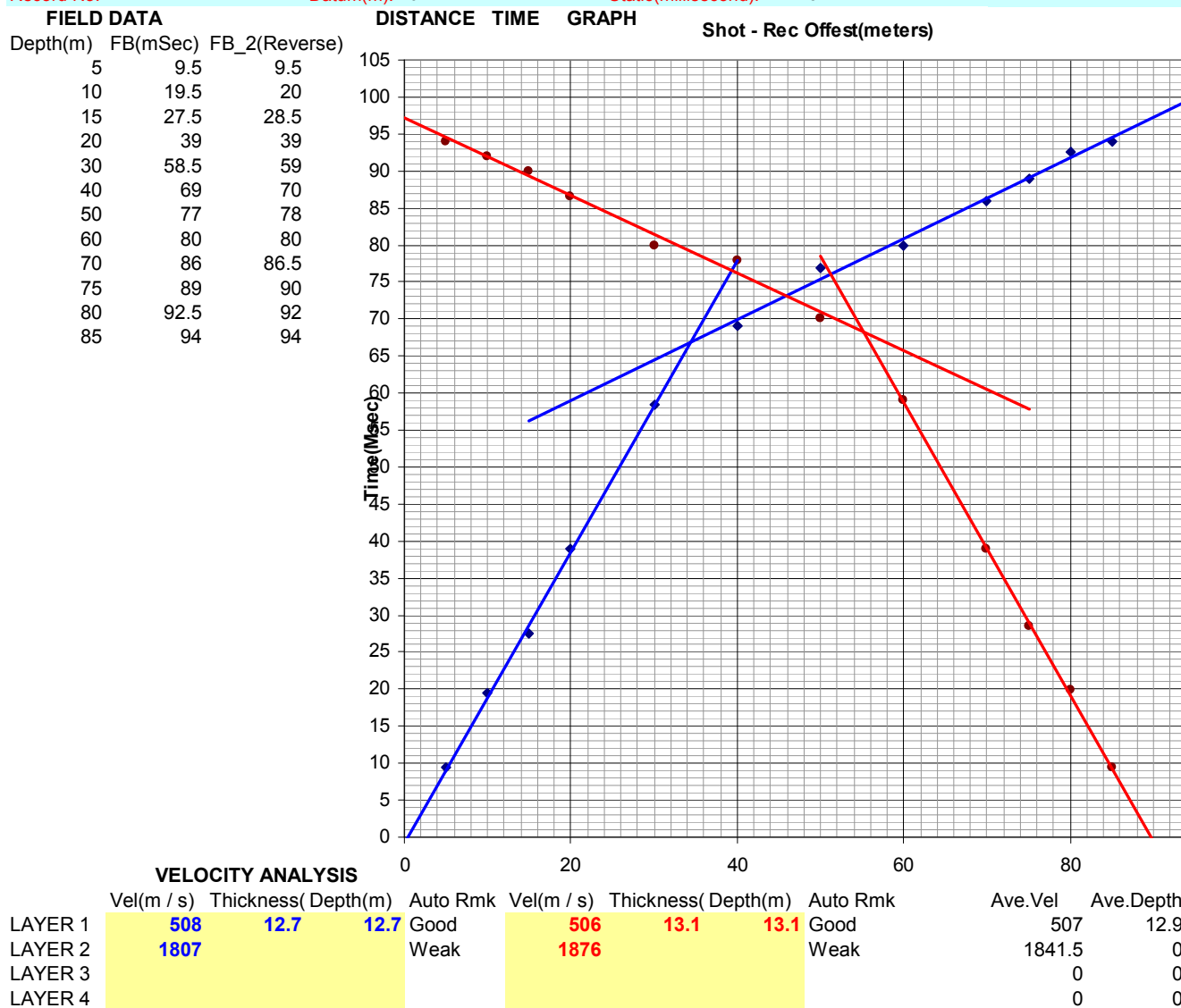


REMARK:

Figure 4. First arrival times vs receiver offsets (Acquisition Point 1).

L V L DATA PROCESSING

Project Name: LVL STUDY	UPhole No: 2	Drilled Depth(m): 1
Contractor:	Station No: 5523-2339	Logged Depth(m): 0.8
Party/Proj M:	Easting: 489359.5	Shot Depth(m): 0.8
Date Logged: 6/20/2008	Northing: 130702.3	Offset Dist(m): 0
InstrU Type: McSEIS-160M	Elevation: 34.8	Source Type: DYNAMITE
Processed by: TAYO	Drilled by:	Delay Time Break:
Record No: 2	Datum(m): 0	Static(milliseconds): 37

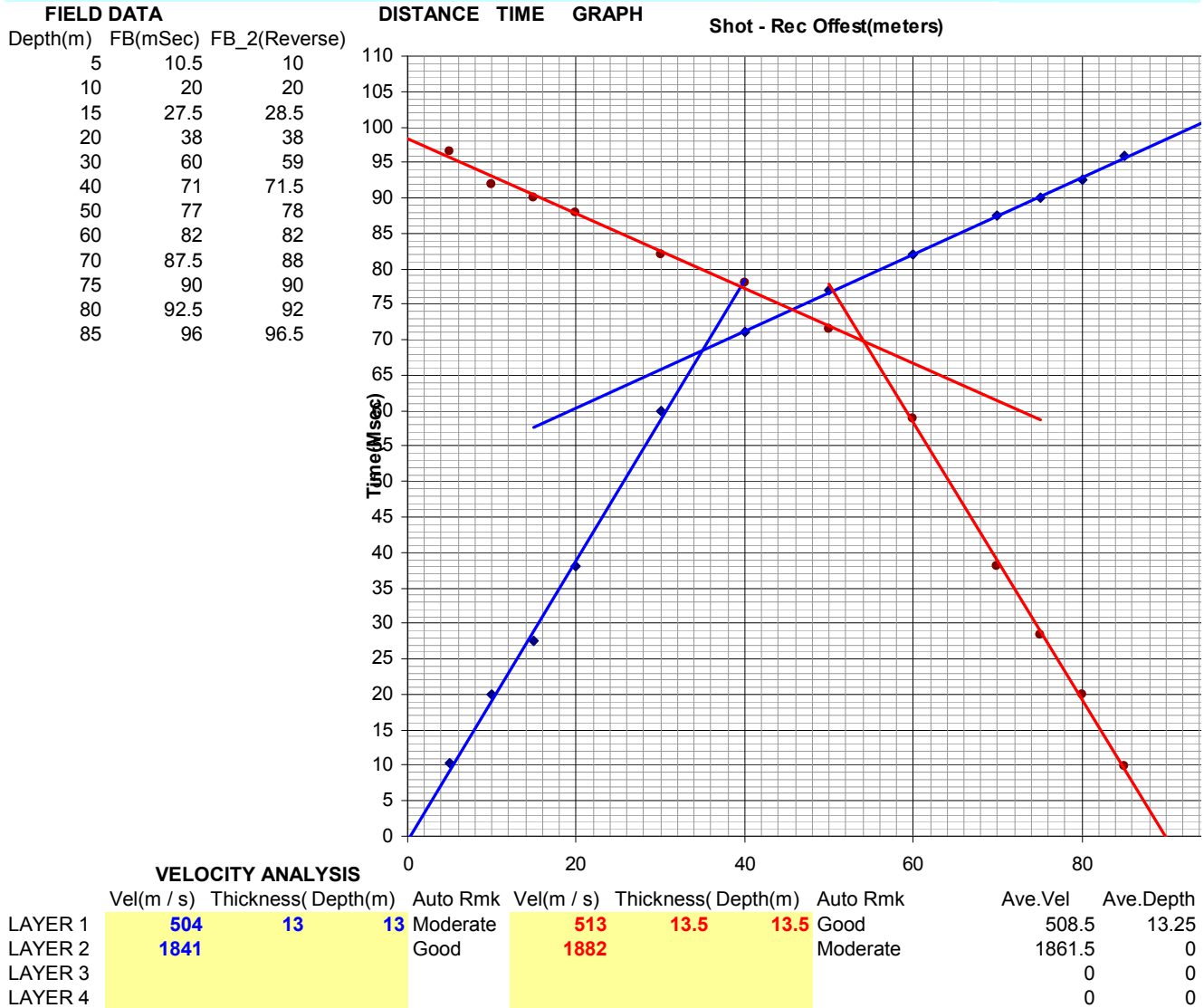


REMARK:

Figure 5. First arrival times vs receiver offsets (Acquisition Point 2).

L V L DATA PROCESSING

Project Name: LVL STUDY Contractor: Party/Proj M: Date Logged: 6/15/2008 InstrU Type: McSEIS-160M Processed by: TAYO Record No: 3	UPole No: 3 Station No: 5613-2339 Easting: 489360.2 Northing: 135202.4 Elevation: 37.5 Drilled by: Datum(m): 0	Drilled Depth(m): 1 Logged Depth(m): 0.8 Shot Depth(m): 0.8 Offset Dist(m): 0 Source Type: DYNAMITE Delay TimeBreak: Static(millisecond): 39
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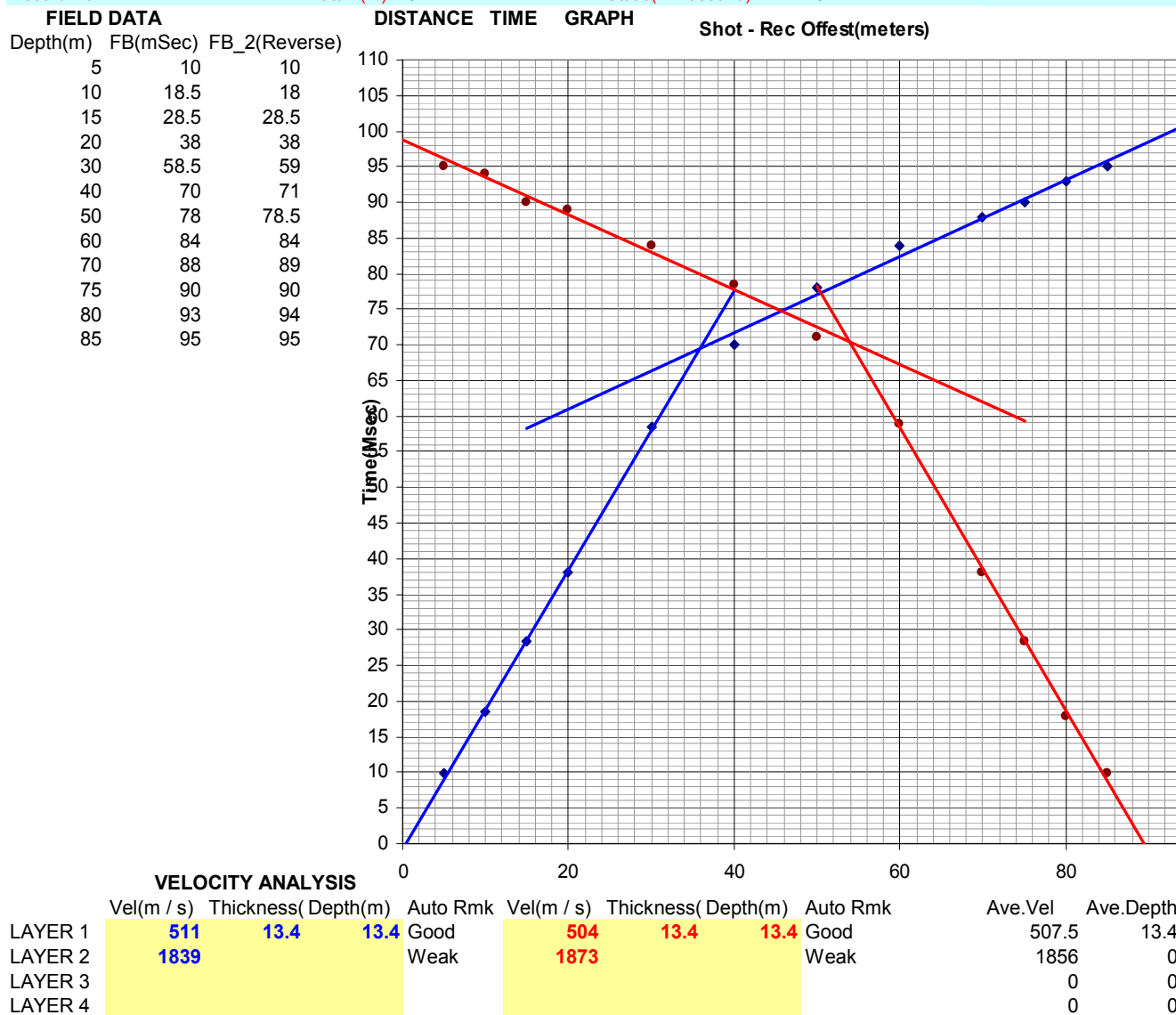


REMARK:

Figure 6. First arrival times vs receiver offsets (Acquisition Point 3).

L V L DATA PROCESSING

Project Name: LVL STUDY	UPhole No: 4	Drilled Depth(m): 1
Contractor:	Station No: 5613-2419	Logged Depth(m): 0.8
Party/Proj M	Easting: 493860.2	Shot Depth(m): 0.8
Date Logged: 6/15/2008	Northing: 135202.4	Offset Dist(m): 0
InstrU Type: McSEIS-160M	Elevation: 38.2	Source Type: DYNAMITE
Processed by: TAYO	Drilled by:	Delay Time Break:
Record No: 4	Datum(m): 0	Static(milliseconds): 40

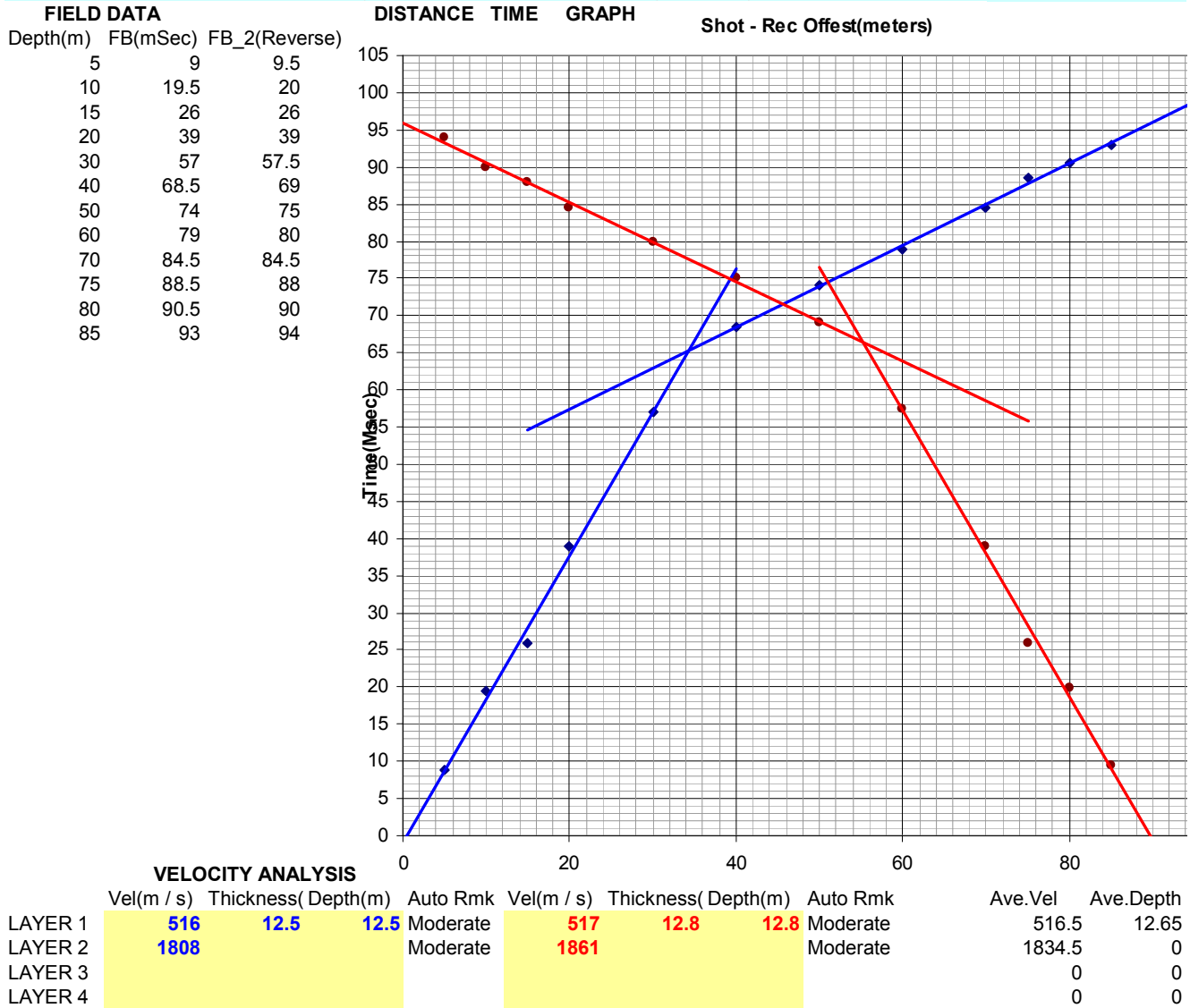


REMARK:

Figure 7. First arrival times vs receiver offsets (Acquisition Point 4).

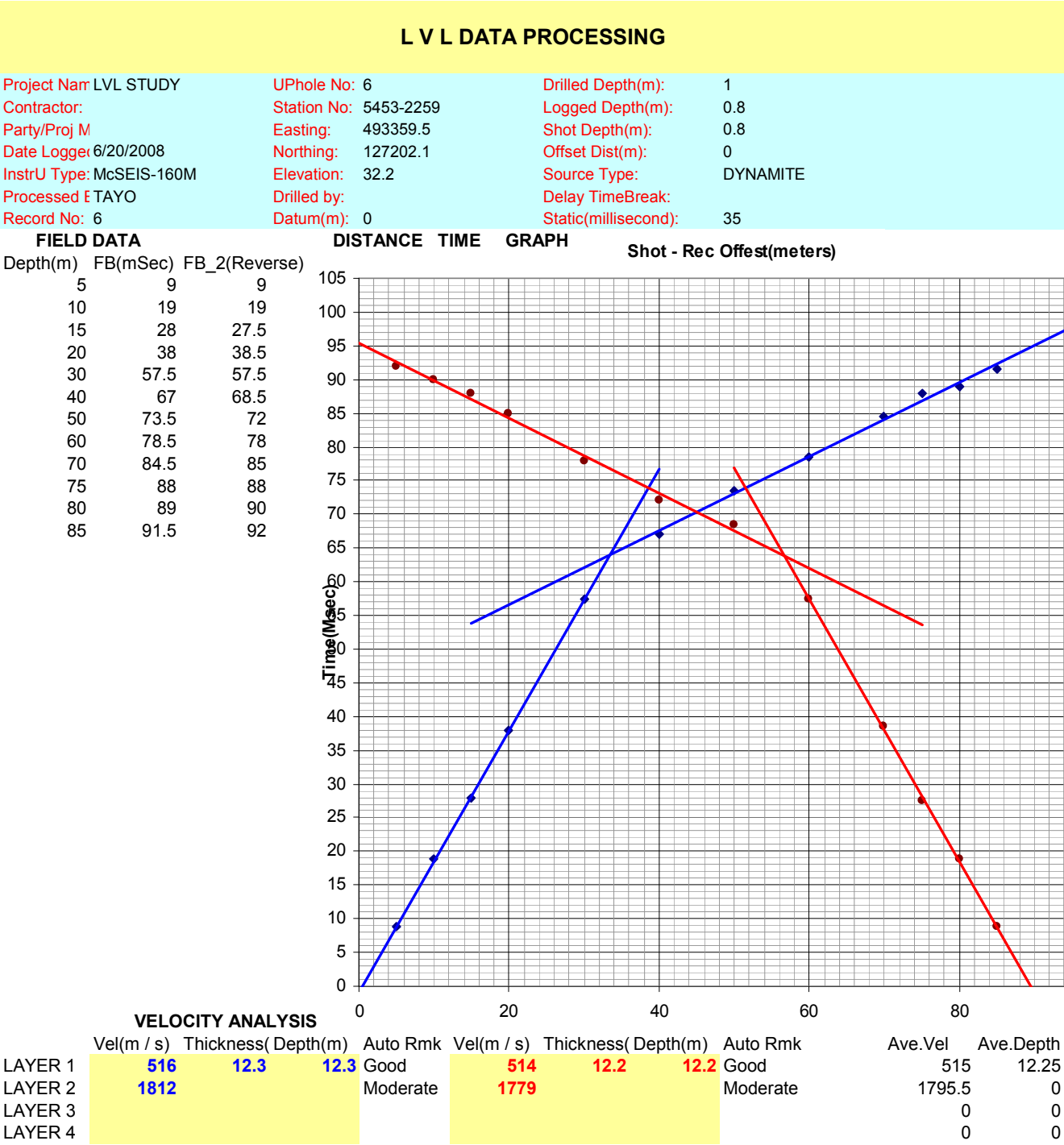
L V L DATA PROCESSING

Project Name: LVL STUDY	UPHole No: 5	Drilled Depth(m): 1
Contractor:	Station No: 5513-2259	Logged Depth(m): 0.8
Party/Proj M	Easting: 493359	Shot Depth(m): 0.8
Date Logged: 6/20/2008	Northing: 130202.3	Offset Dist(m): 0
InstrU Type: McSEIS-160M	Elevation: 35.3	Source Type: DYNAMITE
Processed by: TAYO	Drilled by:	Delay TimeBreak:
Record No: 5	Datum(m): 0	Static(milliseconds): 37



REMARK:

Figure 8. First arrival times vs receiver offsets (Acquisition Point 5).

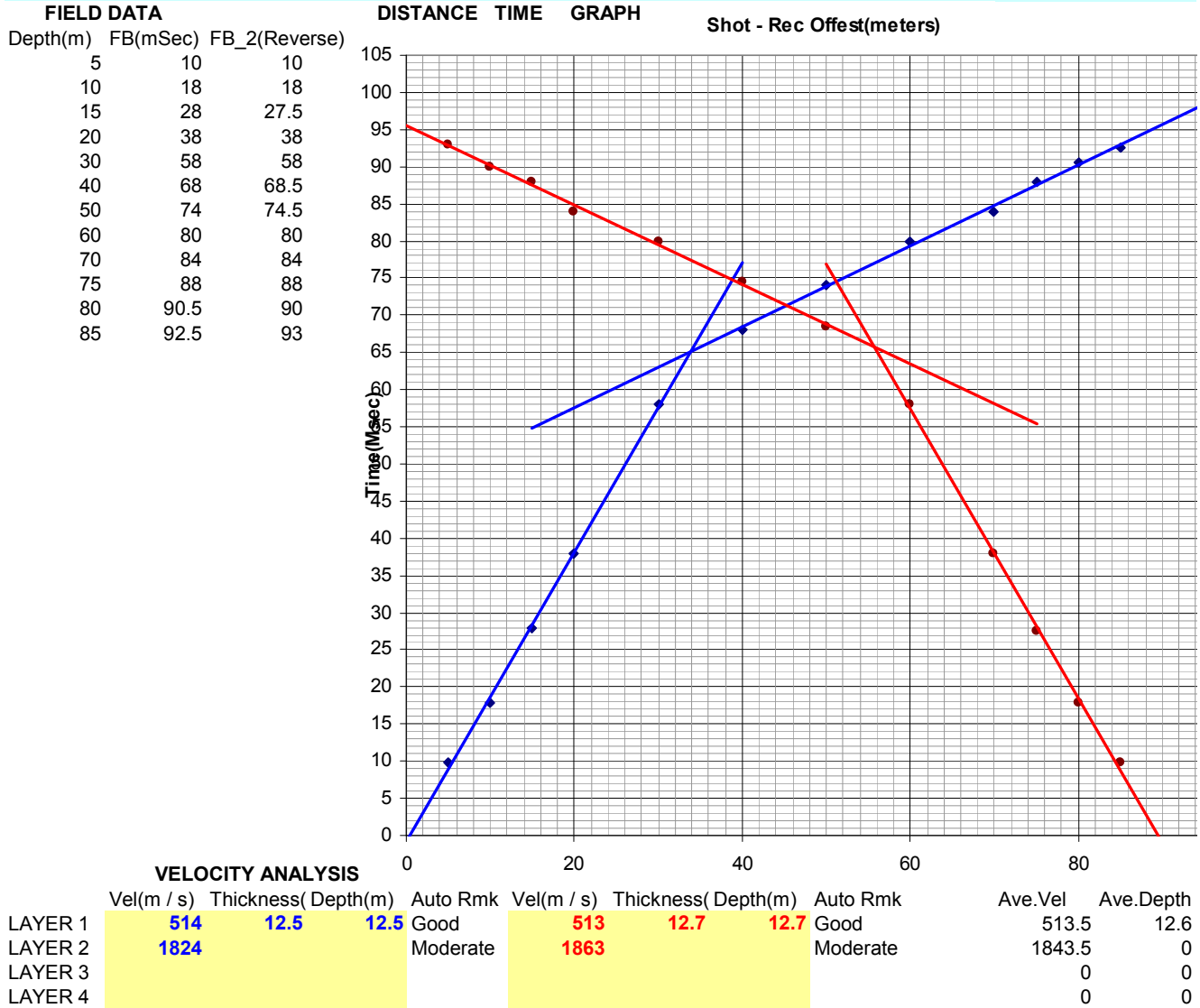


REMARK:

Figure 9. First arrival times vs receiver offsets (Acquisition Point 6).

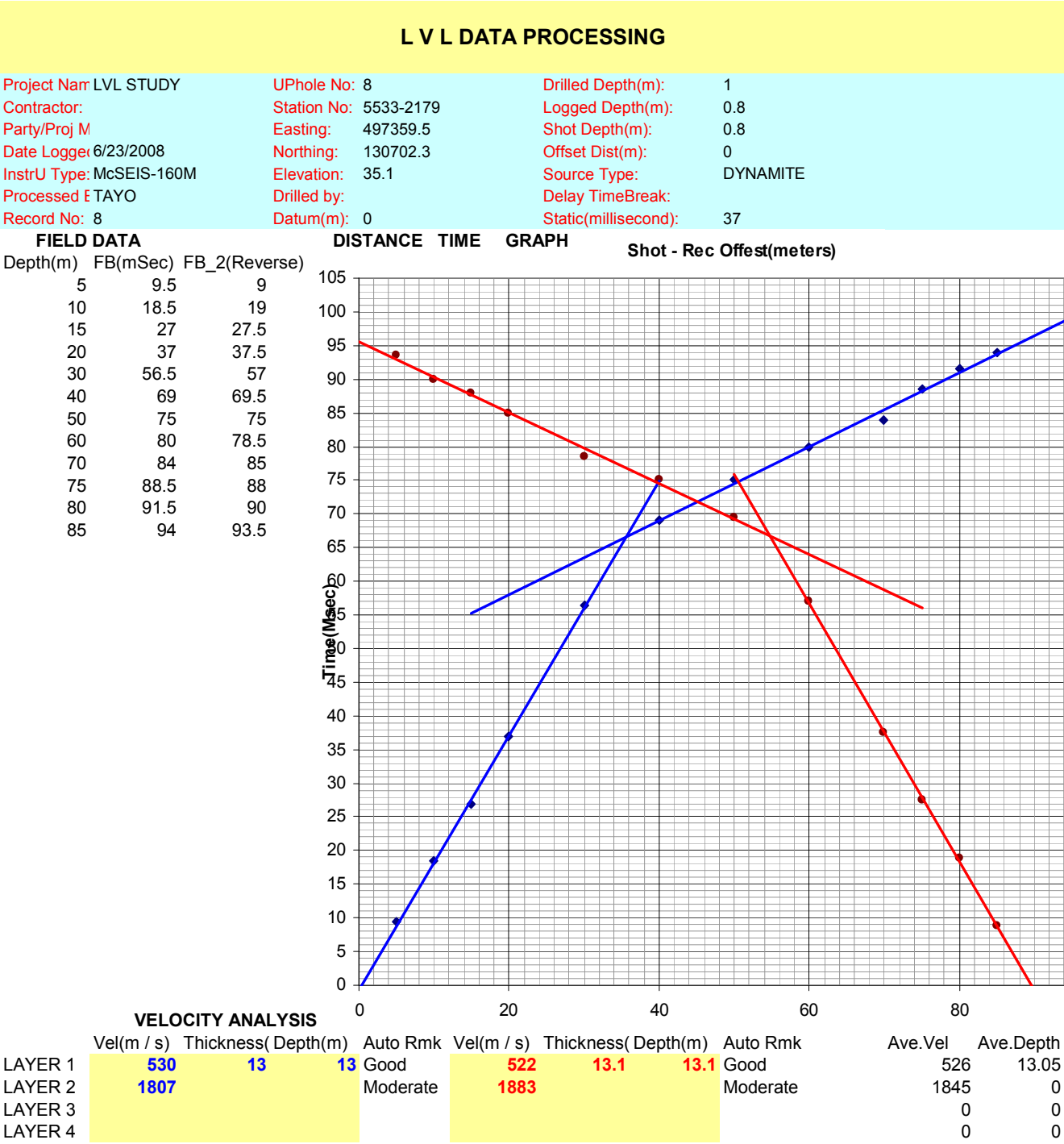
L V L DATA PROCESSING

Project Name: LVL STUDY	UPhole No: 7	Drilled Depth(m): 1
Contractor:	Station No: 5453-2179	Logged Depth(m): 0.8
Party/Proj M	Easting: 497359.5	Shot Depth(m): 0.8
Date Logged: 6/23/2008	Northing: 127202.1	Offset Dist(m): 0
InstrU Type: McSEIS-160M	Elevation: 32.4	Source Type: DYNAMITE
Processed by: TAYO	Drilled by:	Delay TimeBreak:
Record No: 7	Datum(m): 0	Static(milliseconds): 35



REMARK:

Figure 10. First arrival times vs receiver offsets (Acquisition Point 7).

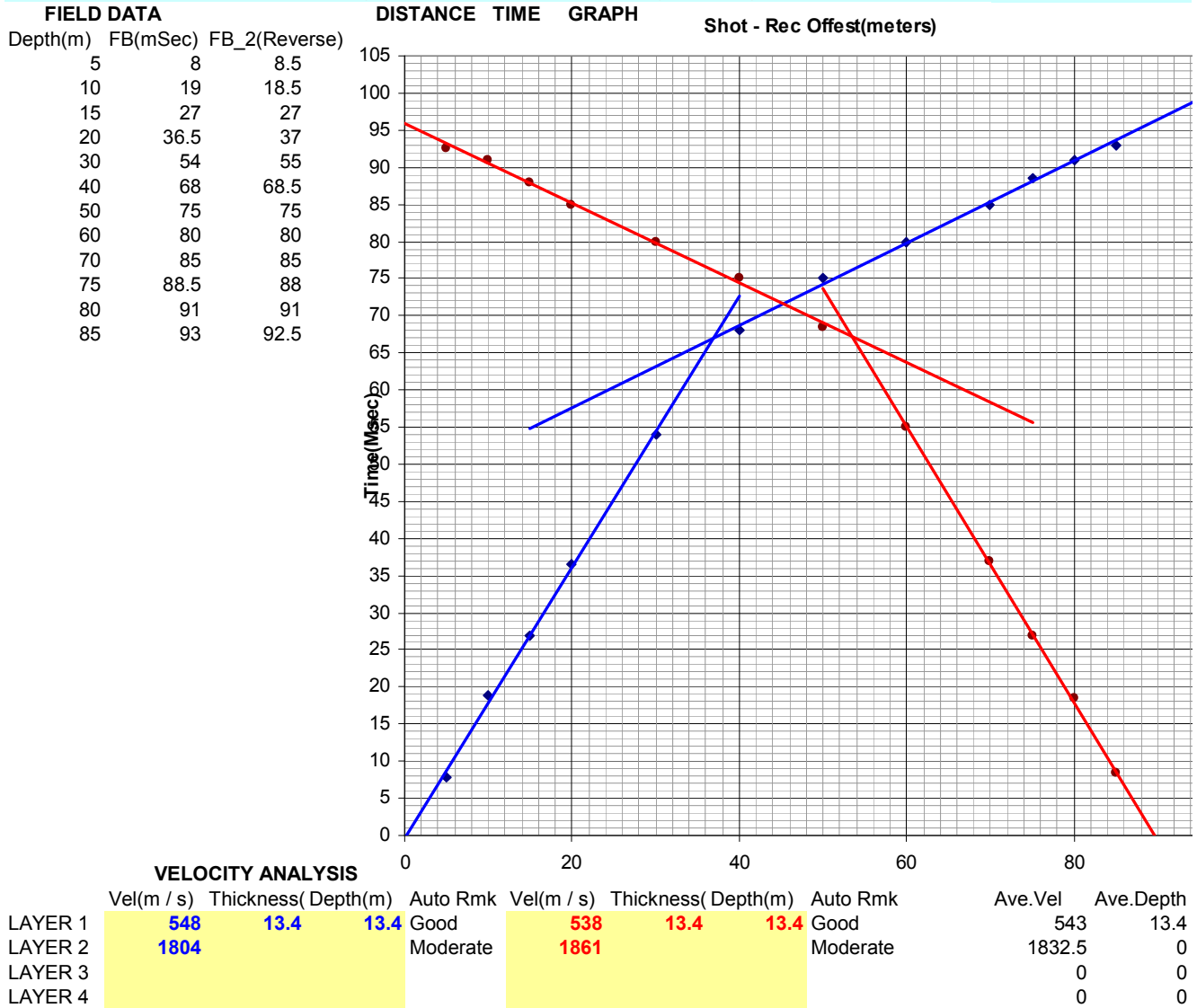


REMARK:

Figure 11. First arrival times vs receiver offsets (Acquisition Point 8).

L V L DATA PROCESSING

Project Name: LVL STUDY	UPhole No: 9	Drilled Depth(m): 1
Contractor:	Station No: 5613-2179	Logged Depth(m): 0.8
Party/Proj M	Easting: 497860.2	Shot Depth(m): 0.8
Date Logged: 6/23/2008	Northing: 135202.4	Offset Dist(m): 0
InstrU Type: McSEIS-160M	Elevation: 38.6	Source Type: DYNAMITE
Processed by: TAYO	Drilled by:	Delay TimeBreak:
Record No: 9	Datum(m): 0	Static(milliseconds): 38

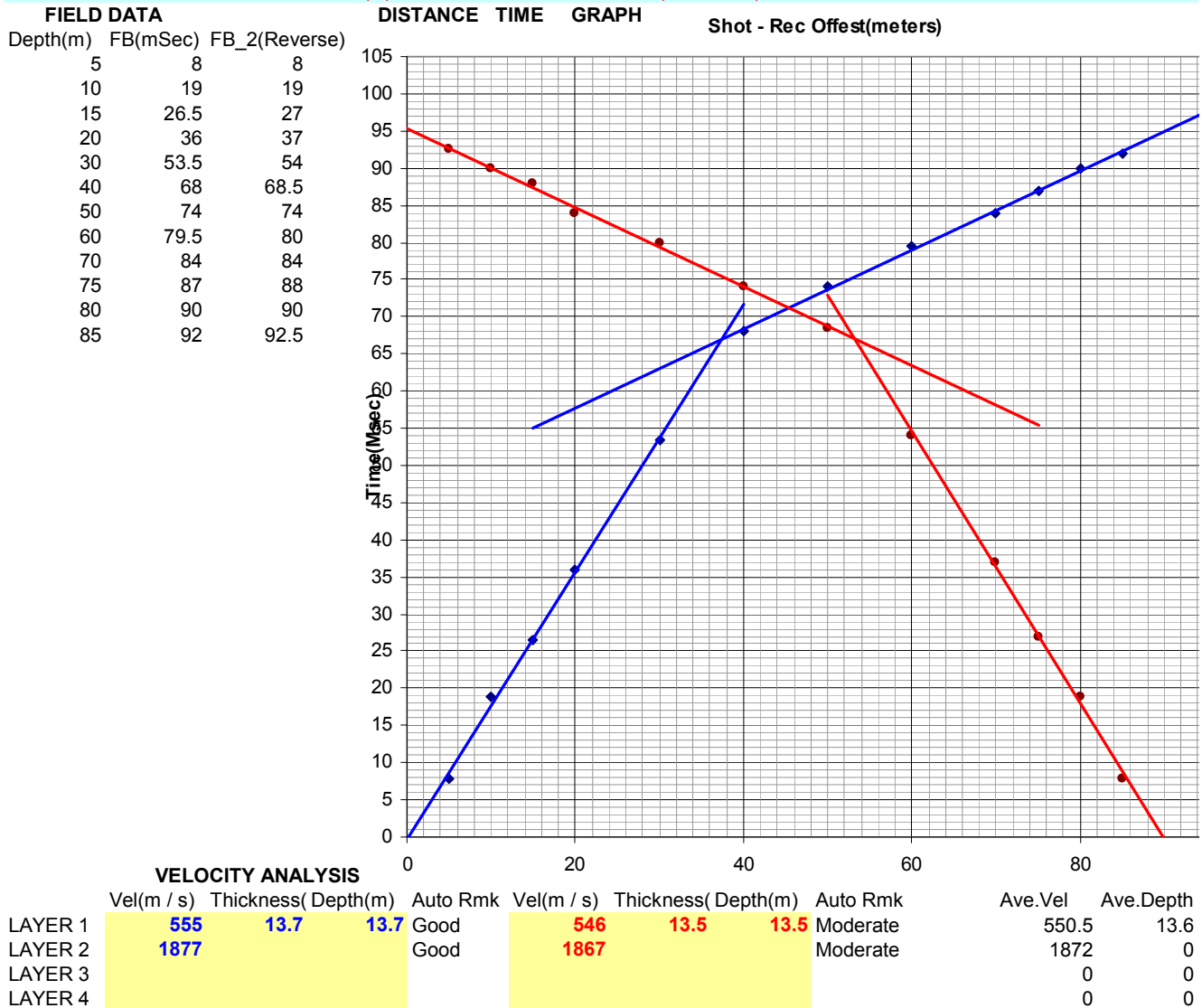


REMARK:

Figure 12. First arrival times vs receiver offsets (Acquisition Point 9).

L V L DATA PROCESSING

Project Name: LVL STUDY	UPhole No: 10	Drilled Depth(m): 1
Contractor:	Station No: 5613-2099	Logged Depth(m): 0.8
Party/Proj M	Easting: 501860.2	Shot Depth(m): 0.8
Date Logged: 6/27/2008	Northing: 135202.4	Offset Dist(m): 0
InstrU Type: McSEIS-160M	Elevation: 38.8	Source Type: DYNAMITE
Processed by: TAYO	Drilled by:	Delay Time Break:
Record No: 10	Datum(m): 0	Static(milliseconds): 38

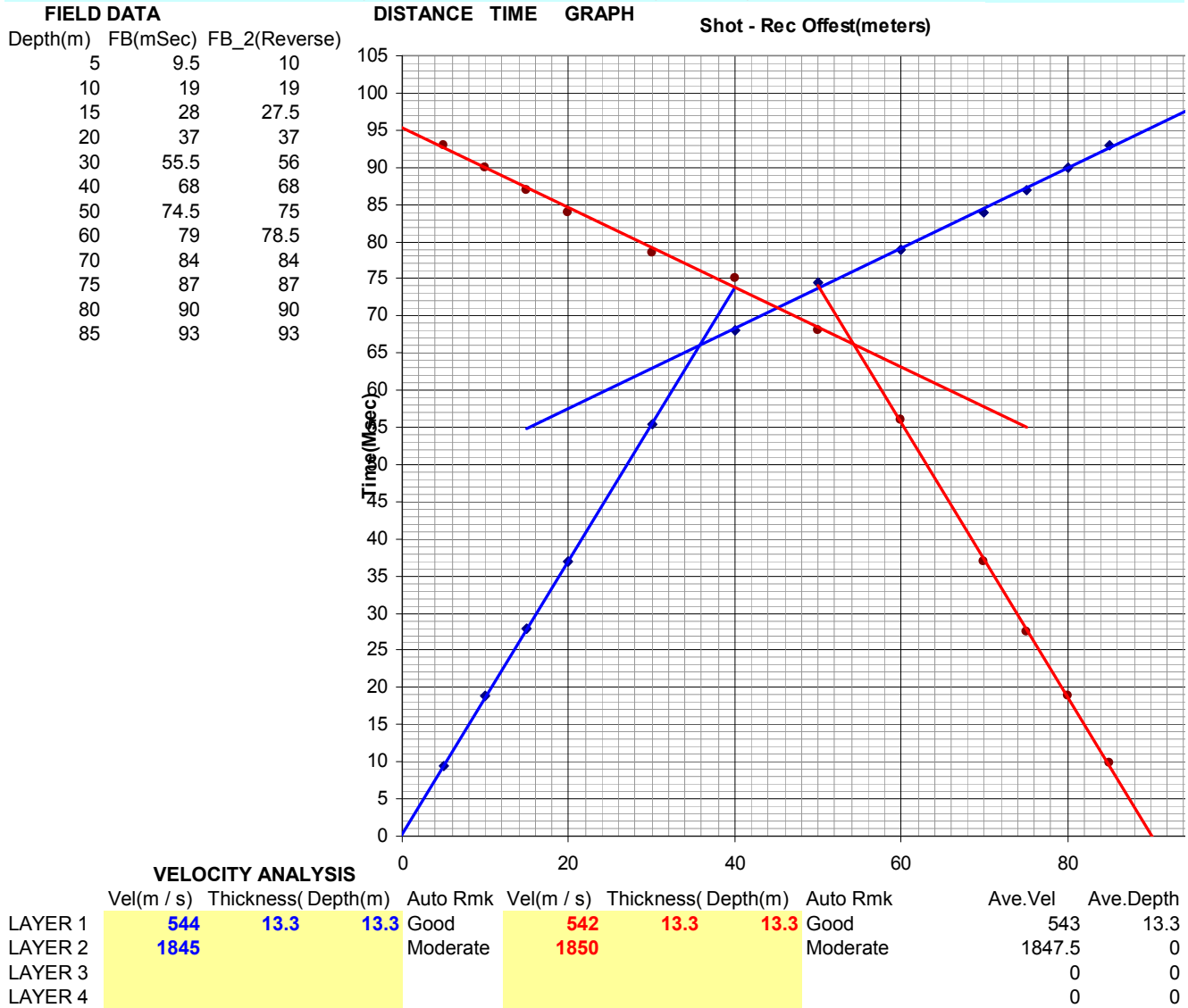


REMARK:

Figure 13. First arrival times vs receiver offsets (Acquisition Point 10).

L V L DATA PROCESSING

Project Name: LVL STUDY	UPHole No: 11	Drilled Depth(m): 1
Contractor:	Station No: 5533-2099	Logged Depth(m): 0.8
Party/Proj M	Easting: 501359	Shot Depth(m): 0.8
Date Logged: 6/27/2008	Northing: 130702.4	Offset Dist(m): 0
InstrU Type: McSEIS-160M	Elevation: 35.3	Source Type: DYNAMITE
Processed by: TAYO	Drilled by:	Delay TimeBreak:
Record No: 11	Datum(m): 0	Static(milliseconds): 36



REMARK:

Figure 14. First arrival times vs receiver offsets (Acquisition Point 11).

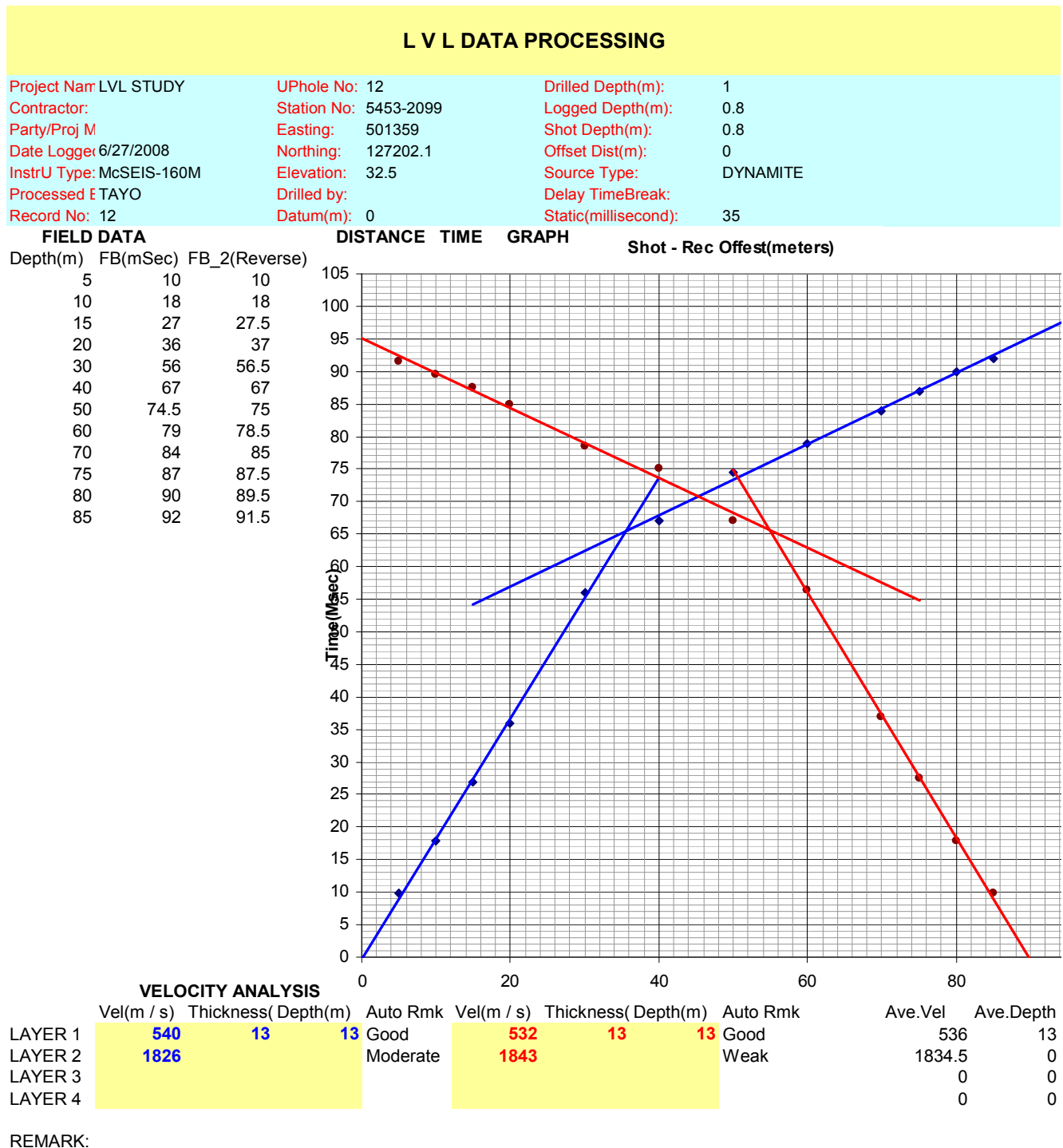


Figure 15. First arrival times vs receiver offsets (Acquisition Point 12).

5. Conclusion

The near surface investigation of the physical properties of the unconsolidated and consolidated layers has been carried out at Omerelu in Rivers State of Nigeria. Omerelu lies between latitude 05° 08'N and 05° 13'N and longitude 06° 51'E and 06° 58'E. Refraction method was used to acquire the data. This involved identifying acquisition points and preparing the points for deployment of field equipment which

included 12-geophone receiver array and OYO McSeis 160M recording instrument with capability to initiate the source and record signals from the subsurface transmitted through receivers.

In order to achieve the main of this study, the data were processed using Upsphere computer software which was written based on intercept time method. The slopes of the graphs gave velocity results and thickness of the unconsolidated layer was calculated. The depth of

unconsolidated in the study area varied between 12 and 13.7 m. The depth obtained indicates that in order to improve the signal to noise ratio, source depth should be placed below the unconsolidated layers. The velocities of the unconsolidated and the consolidated layers varied between 500 m/s – 550 m/s and 1790 m/s – 1875 m/s respectively help to remove near surface effect. The results were applied to carry out static correction on reflection data and this produced alignment of the early arrivals.

This study also provides a baseline for single deep hole operations in the area.

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