Journal of Earth Sciences and Geotechnical Engineering, vol. 4, no. 3, 2014, 115-130
ISSN: 1792-9040 (print), 1792-9660 (online)
Scienpress Ltd, 2014

Weathered Layer Delineation in an 'X' Field in the Niger Delta Basin of Nigeria: The Uphole Data Acquisition Technique

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Abstract

A total of sixty-one (61) uphole refraction surveys carried out in the "X" field in the Niger Delta Basin of Nigeria were analysed using the time-intercept technique to evaluate the weathered layer. Results from the generated isopach and isovelocity maps suggest a three layer case comprising of weathered, sub-weathered and consolidated layers. With velocities varying from 318 – 1050 m/s, the first layer was interpreted to be a weathered layer whose thickness ranges from 1.6 – 8.6 m. The thickness of the sub-weathered layer ranges from 16.3 to 28.7 m while its velocity varies from 692 to 2549 m/s. The consolidated layer velocity ranges from 1100 to 3223 m/s with an average of 2427 m/s. The average thickness of the weathered layer to the first refractor consolidated layer is 25.5 m. This is therefore the suggested depth at which shots are to be taken to obtain high quality seismic reflection data. The results will be utilized in seismic data processing for a reliable delineation of structural and stratigraphic traps in oil and gas exploration in the Southern part of the Niger Delta.

Keywords: Niger Delta Basin, Up-hole survey, Low velocity layer, Seismic refraction, Time-intercept.

1 Introduction

The Niger delta is known as a prolific oil province where several oil and gas wells have been drilled. Reflection surveys are usually carried out in order to locate oil traps. In order to acquire a good quality reflection data, it is important to evaluate the unconsolidated layer which is also known as weathered layer or low velocity layer LVL. The unconsolidated layer is usually characterized by low seismic velocities. When shots are taken within the layer, the layer absorbs high frequency signals and releases low

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frequency signals. Consequently, the reflection signals observed in seismic sections are degraded causing an improper alignment of traces. For these reasons, it is thus necessary to take the shots below the weathered layer so as to obtain good quality seismic reflection data.

The uphole method is a seismic refraction method which is used to determine the thickness and velocity of the weathered layer and is a very important criterion used in deciding the charge depths in any seismic reflection survey. Information regarding the thickness and velocity of the weathered layer is also utilized during the processing of seismic reflection data to correct time delays (or simply static corrections). In engineering geophysical studies, the refraction survey method is also used to determine the foundation depths of major engineering structures.

Several uphole refraction studies undertaken in the Niger Delta have remained largely unpublished. Published uphole refraction studies in the Niger Delta include [1], [2], and [3], [4] and [5]. None of these published studies were undertaken in the swampy terrains of the Niger Delta. The aim of this study is to determine the variations in thickness and compressional velocity of the low velocity layer, and the consolidated layer in a swampy terrain using uphole refraction seismic survey method. The results will be useful for seismic exploration purposes as well as for construction purposes.

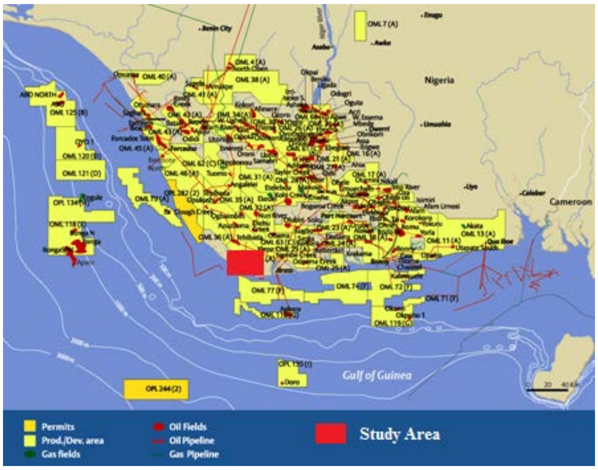


Figure 1: Map of the Niger Delta showing the Study Area

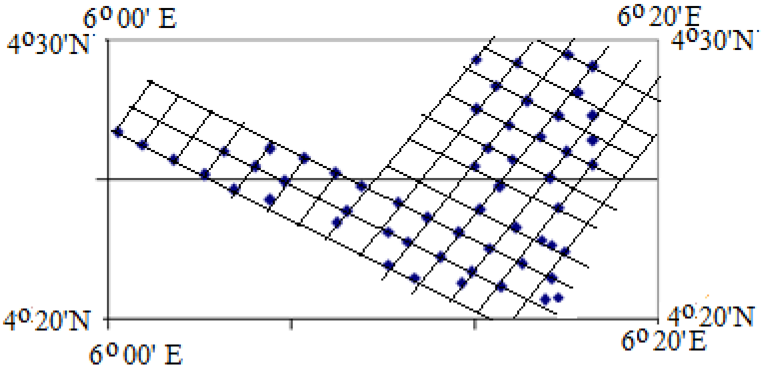


Figure 2: Uphole layout within the Study Area

2 Geological Setting

The study area lies within the area referred to as the Tertiary Niger Delta complex (Fig. 1). The study area is delimited by latitudes 4°20′N - 4°30′N and longitudes 6°00 - 6°20′E (Fig. 2). According to [6], the Niger Delta extends across an area of about 75,000 sq km and consists of regressive clastic sequence which attains a thickness of about 12,000m. The Anambra Basin and the Abakaliki Trough bounds the Niger Delta to the north, while it is bounded in the east by the Cameroun volcanic line, in the west by the Dahomey Embayment and in the south by the Gulf of Guinea.

[7] suggested that the siliciclastic system of the Niger Delta began to prograde across pre-existing continental slope into the deep sea during the Late Eocene and is still active today. [8] recognized three distinct lithostratigraphic units in the Niger Delta, which include the Akata, the Agbada and the Benin Formations, with depositional environments varying from marine, transitional to continental settings respectively. The age of these sediments vary from Eocene to Recent but they are time boundary transgressive.

The basal stratigraphic unit in the Niger Delta is the Akata Formation which consists of uniform dark grey over-pressured marine shales with sandy turbidites and channel fills. Its age ranges from Late Eocene to Recent. In deep water environments, these turbidites are the potential reservoirs. The thickness varies from 2000 m to 7000 m ([9]; [10] and [11]).

The major oil bearing unit in the Niger Delta is the Agbada Formation. It overlies the Akata Formation and consists of alternation of sands and shale layers. The Agbada Formation is characterized by parallic to marine-coastal and fluvial–marine deposit mainly composed of sandstone and shale organized into coarsening upward off – lap cycles [12]. It is about 3500 km thick [11]. It is the main objective for oil and gas exploration in the delta.

The Benin Formation overlies the Agbada Formation and consists of Late Eocene to Recent deposits of alluvial and upper coastal plain deposits that are up to 2000 m thick [13]. It consists mainly of coarse grained pebbly to fine grained sandstones and thin beds of shales.

3 Theoretical Background

In seismic refraction surveys, the first wave to arrive at the geophone is called the first arrival and is used in analysis. The basic procedure starts with the generation of a seismic wave at a point source, recording the time it takes the wave energy to get to the refractor and back to a known detector following a refracted path [14].

The first arrival of seismic waves is either the direct waves or the refracted wave (Fig. 3). The direct wave travels from O – R at a slower velocity V_1 while the refracted wave travels from O - R through P and Q where it is critically refracted and travels at velocity V_2 between P and Q. This implies that at short OR distances the direct wave arrives first because it has a short distance to travel but when the distance between O and R increases, the refracted wave will arrive first due to the faster travel time between P and Q which overcomes the difference in distance travelled. This therefore implies that the velocities of the layers and depth to the interface can be analyzed.

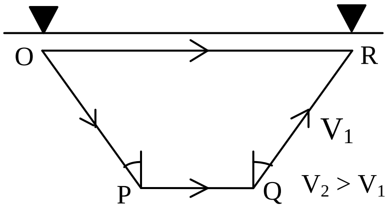


Figure 3: Direct and refracted waves in a 2 layer medium [15]

The velocities are determined by plotting the travel times against the distance between the source and the receiver points (Fig. 4). The reciprocal of the gradient of the direct arrivals gives the velocity of the weathered (top) layer while the reciprocal of the gradient of the refracted arrivals is used to compute the velocity of the second layer (bedrock velocity). The intercept time of the refracted arrivals and the two calculated velocities is used to calculate the depth to the interface. The depth to the interface is calculated using the following equation.

$$z = \frac{tV_1V_2}{2\left(V_2^{\,2} - V_1^{\,2}\right)} \tag{1}$$

Thus the parameters (Vw, Dw and VB) can be computed from the uphole survey data (Fig. 4b). Here also, the reciprocal of the slopes of the segment XY and YZ equals V_W and V_B respectively while XW is the thickness of the weathered layer, where W is the base of the LVL.

For a three layer case as given in Fig. 4c, the parameters can be computed using the following equation as given by [16] and [17].

$$Zo = \frac{t_1}{2}\left[\frac{V_1V_o}{\sqrt{\left(V_1^{\,2} - V_0^{\,2}\right)}}\right] + \frac{D_s}{2} \tag{2}$$

$$Z_1 = \left[\frac{t_2 - 2Z_0\sqrt{\left(V_2^{\,2} - V_0^{\,2}\right)}}{V_2V_0}\right]\left[\frac{V2}{2\sqrt{V_2^{\,2} - V_1^{\,2}}}\right] \tag{3}$$

Where t_1 and t_2 = intercept times on the distance – time graph.

V_o = Velocity of the first weathering layer

V_1= velocity of the second weathering layer

V_2 = velocity of the bedrock

D = Depth of shot (m)

Total thickness (m) of the weathering layer = $Z_w = Z_o + Z_1$

Isopachs and isovelocity maps were constructed using the geostatistical kriging technique. This was applied in the Surfer 9.0 software and used to generate the isopachs and isovelocity maps.

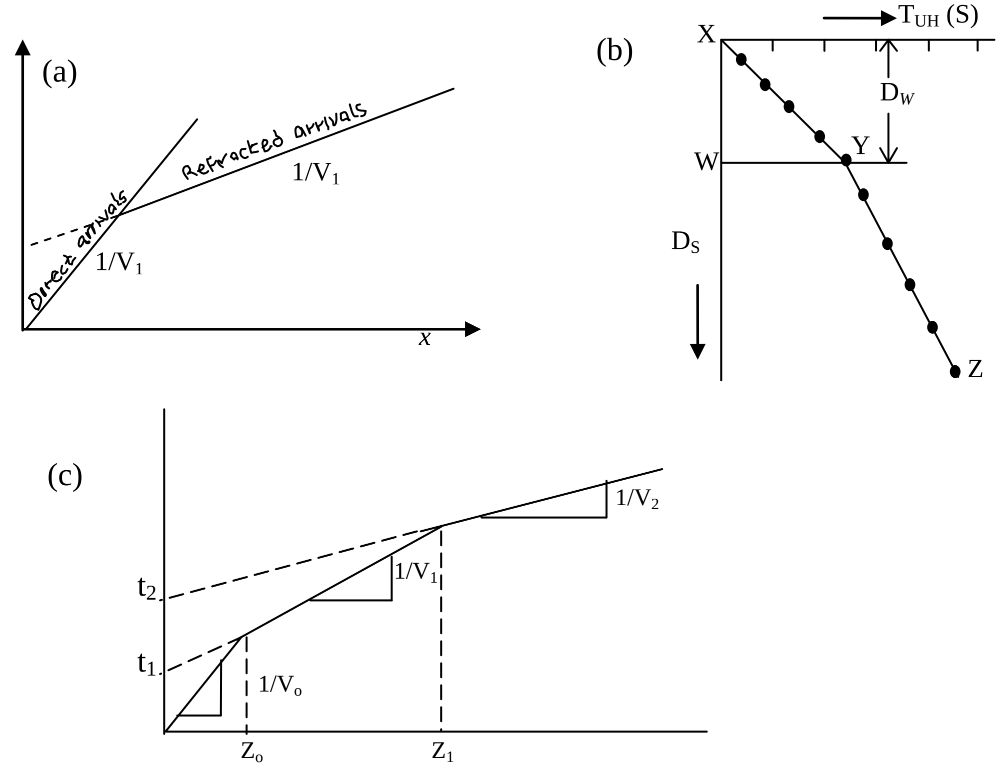


Figure 4 (a) Travel time versus distance plot
(b) Uphole survey time depth relationship
(c) Typical time-depth graph for a three layer case uphole refraction profile

4 Materials and Methods

4.1 Equipments

The equipments used in this study include

(i) Oyo McSeis – 160 m portable 12 or 24 channel seismograph system recorder
(ii) Geophone arrays
(iii) Explosives (Dynamite / Detonators) to generate energy
(iv) A power supply system
(v) A starter model high voltage blaster
(vi) A graduated carote cable

4.2 Location and Layout

The Uphole locations are shown in Fig. 2. Uphole locations are usually planned before the commencement of any seismic program. The program layout and location map was prepared and handled by the Uphole crew to enable them have access to the Uphole positions. Each uphole position was assigned a serial number, a line number and a receiver point. The drilling and uphole crew traces each uphole location using the line number and receiver point assigned to the position, which had been cut and pegged by the survey crew in advance before the commencement of the seismic operations. In some cases uphole positions can be offset as a result of poor accessibility, water logging and swampy terrain, sandiness if the formation resulting in caving in while drilling, and positions fall within or at the edge of the creeks and rivers. The uphole crew reports these problems to the Chief Seismologist who then offsets the uphole to a new position.

The layout consists of three sets of geophones planted at the intervals of 1m, 2.5 m and 5m away from the hole (Fig. 5). The geophones are then connected with the Oyo Geospace equipment as well as synchronized blaster equipment used in the detonation of caps. A power supply source of 12 – volt ordinary motor battery is used to energize the system. A graduated carote ranges from 1 cap to 6 caps depending on the resolution and the depth. A hole of 63 m was dug for each of the positions and the carote wire with the detonators attached with an anchor iron as weight was lowered into the hole and properly tapped to avoid shoot out. A reference plate with the different graduations was kept on the surface to distinguish the level of shots to be taken beginning from the deepest 60m to the first at 1m. The readings picked were then recorded by the Oyo machine in an analog form (signal) and stored in a diskette as well as printed on a hard copy and taken to the office for processing and interpretation.

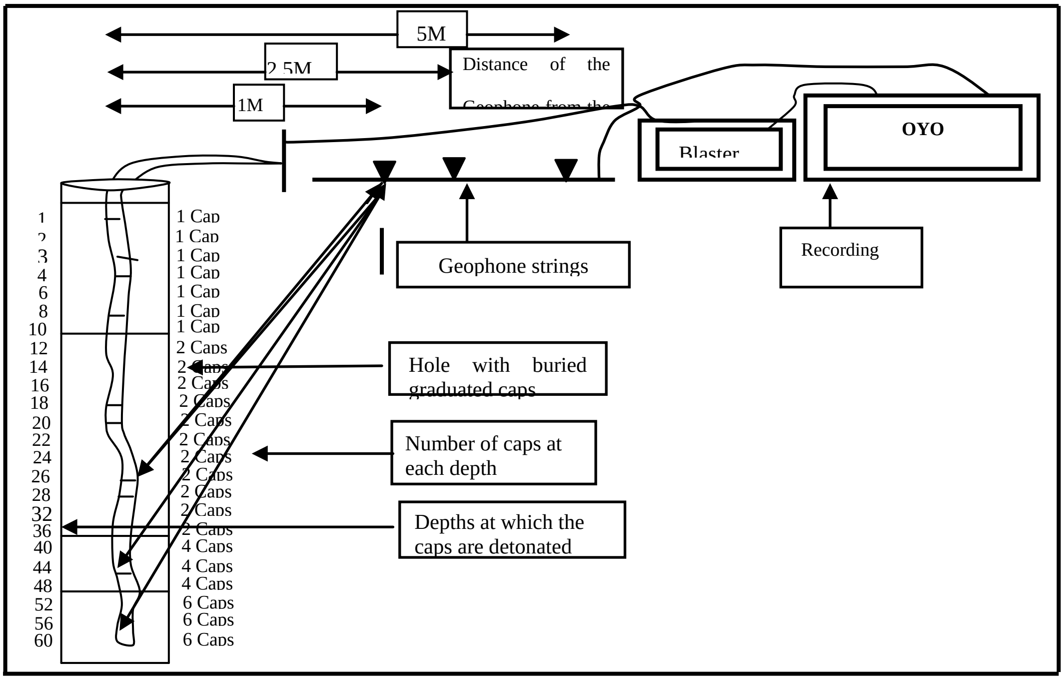


Figure 5: Layout for uphole acquisition

4.3 Data Processing

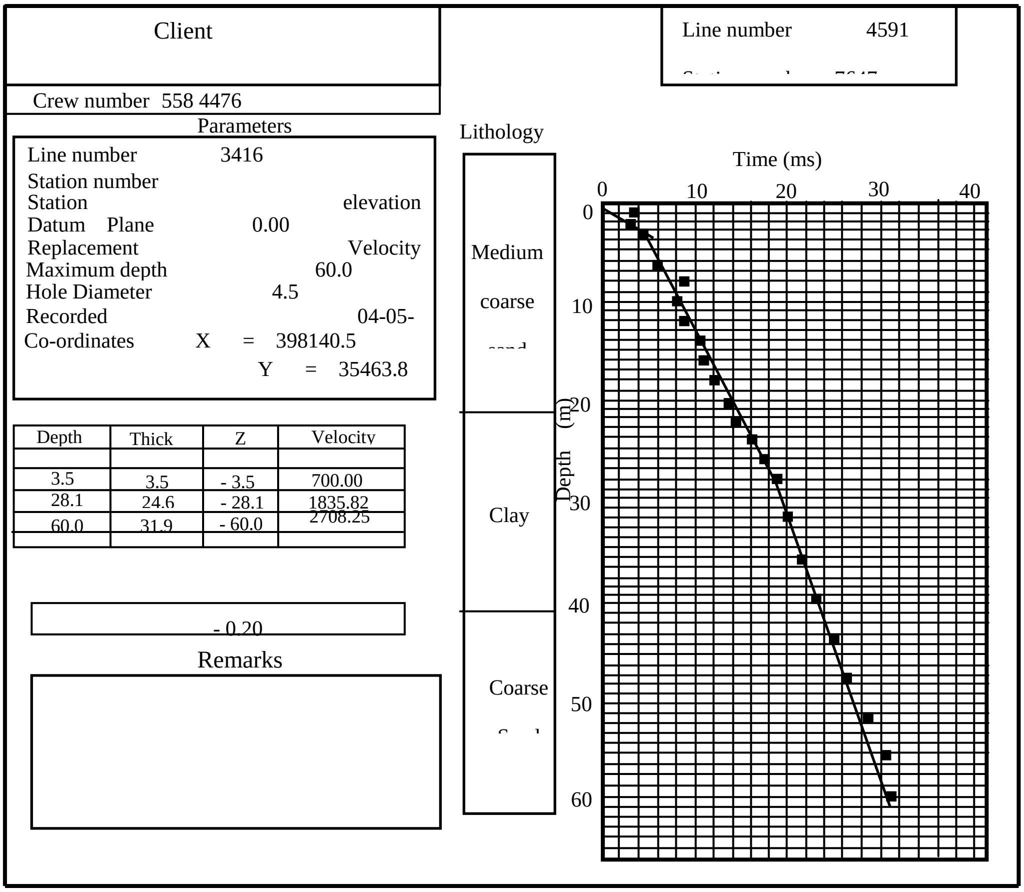
The recorded data was computer processed and field results of the signal display for the three (3) geophone positions were used to pick the first – time arrivals / breaks.. This was done manually by visual inspection of the plots. The heading on the plotted form is as follow;

Job: R4591 SP 7647
File: 1
Date: 06/19/12
Filter: 1536 (HZ)
Stack: 1
Sampling: 100[µSec]
Delay 00[µSec]
Time lines: 2[mSec. /Line]
Gain: 50 - 96∂β. This is adjusted in the field depending on the display.

The picked first time arrivals for any of the geophone positions is then entered into a column in the excel database (Table 1). These points are then interpolated linearly to give the lines of best fit (Fig. 6). From the interpolation, the depth and thickness of the various layers, layer velocities and statics were computed. Station elevation, datum plane and co-ordinates of position are also imputed.

Table 1: First break listing

Offset from Hole		2.5 m	
Shot	Depth in metres	Time in secs	Corrected Time in secs
1	1	9.365	3.5
2	2	5.0	3.1
3	3	5.9	4.5
4	4	0.0	0.0
5	6	6.3	5.8
6	8	9.1	8.7
7	10	8.1	7.8
8	12	8.7	8.5
9	14	10.2	10.1
10	16	10.9	10.8
11	18	12.0	11.9
12	20	13.5	13.4
13	22	14.2	14.1
14	24	15.7	15.6
15	26	17.2	17.1
16	28	18.5	18.4
17	32	19.5	19.4
18	36	20.8	20.8
19	40	22.3	22.3
20	44	24.2	24.1
21	48	25.3	25.2
22	52	27.4	27.4
23	56	29.4	29.4
24	60	29.7	29.7



Client

Line number 4591

Crew number 558 4476

Parameters

Line number 3416
Station number
Station elevation
Datum Plane 0.00
Replacement Velocity
Maximum depth 60.0
Hole Diameter 4.5
Recorded 04-05-
Co-ordinates X = 398140.5
Y = 35463.8

Depth	Thick	Z	Velocity
3.5	3.5	- 3.5	700.00
28.1	24.6	- 28.1	1835.82
60.0	31.9	- 60.0	2708.25

- 0.20

Remarks

Figure 6: Linear interpolation of picked first arrival times to generate the line of best fit

5 Results and Discussion

The results of the Uphole / LVL/ refraction survey data analysis is given in Table 2 and 3, and Figs. 7 – 10. Isopachs and isovelocity maps (Fig. 7 - 10) deduced from the refraction survey data using geostatistical methods were used to illustrate the near surface characteristics weathered layer in the southern part of the Niger Delta region. The geophysical properties of the study area deduced include (i) the variations in the thickness and the seismic velocity of the weathered layer, (iii) the variations in the thickness and seismic velocity of the sub-weathered layer (iv) seismic velocity or competence of the consolidated layer.

5.1 Thickness and Velocity of the Weathered Layer

The isopach map in Fig. 7a shows the variations in the thickness of the weathered layer. The map suggests that the thickness of the weathered or low velocity layer varies from 1.6 to 8.6 m. This map thus indicates a northerly increase in the thickness of the LVL from 2m in the southern part to about 4 m in the northwest and about 8 m in the northeast. This observation thus suggests a northerly increase in the LVL thickness in the study area.

The variation of the velocity of the weathered layer across the study area is presented by an isovelocity map as shown in Fig. 7b. It is observed from the figure that the velocity of the weathered or unconsolidated layer range from 318 m/s to 1650 m/s^{-1}. In the northern part of the area, the velocity values generally vary between 300 m/s^{-1} to about 800 m/s^{-1}. In the southern part, or coastal region, the velocity values range between 800 m/s^{-1} and 1650 m/s^{-1}. The anomalously high values of near surface or weathered layer velocity may be attributed to the high salinity of water in the sediments.

5.2 Velocity of the Consolidated Layer

An isovelocity map showing the pattern of variations of the velocity of the consolidated layer is presented in Fig. 8. Throughout the study area the consolidated layer velocity varies from 1100 to 3223 m/s, with an average value of 2427 m/s. It is observed that the seismic velocity of the consolidated layer varies from 1100 m/s in the northwestern part to 2300 m/s in the southwestern part. The consolidated layer velocity also increases from 1100 m/s in the west to about 2700 m/s in the eastern part. The velocity of the consolidated layer is thus observed to increase in a southeasterly and easterly direction from the north. It can thus be concluded that the eastern and southern parts possess the most competent bedrock because they have maximum velocities of 2700 m/s and 2500 m/s respectively. The velocity contrast of the consolidated layer which is about 2113 m/s therefore suggests that the layer is inhomogeneous. The inhomogeneity of the consolidated layer may be as a result of variations in compaction of the sediments constituting the layer.

5.4 Thickness and Velocity of the Subweathered Layer

The variation in the thickness of the subweathered layer is given in Fig. 9a. It is observed that the thickness of the subweathered layer varies from 12 to 34 m. The variation in the velocity of the subweathered layer is also given in Fig. 9b. From the figure, the subweathered layer velocity varies from 692 to 2549 m/s with an average value of 1631 m/s.

Using a sampling density of 60 uphole / LVL points, the average thickness of the weathered layer to the first refractor consolidated layer was evaluated to be 25.5 m with an average refractor consolidated layer velocity of 2427 m/s.

6 Conclusion and Recommendation

The average thickness of the weathered / sub-weathered layer suggests that where possible, shots should be located at depths of about 25.5 m below the top of the weathered layer where signals will travel at depths devoid of time delays during 3D/4D seismic surveys in the area. An advantage to this is that it helps to by-pass and thus minimizes the spurious effects of the low velocity weathered layer during acquisition and initial processing of the field tape in which static and dynamic corrections are applied.

Table 2: Summary on the interpretations of isopach and Isovel Models.

Geological property	Thickness (m)		Velocity (ms^{-1})	
	Zone of High	Zone of Low	Zone of High	Zone of Low
Weathered Layer	northeast	Southern part	South/ Coastal region	Northern region
Sub –weathered Layer	Northwest	northeast	South	North
Consolidated Layer.			East / south	Northeastern part

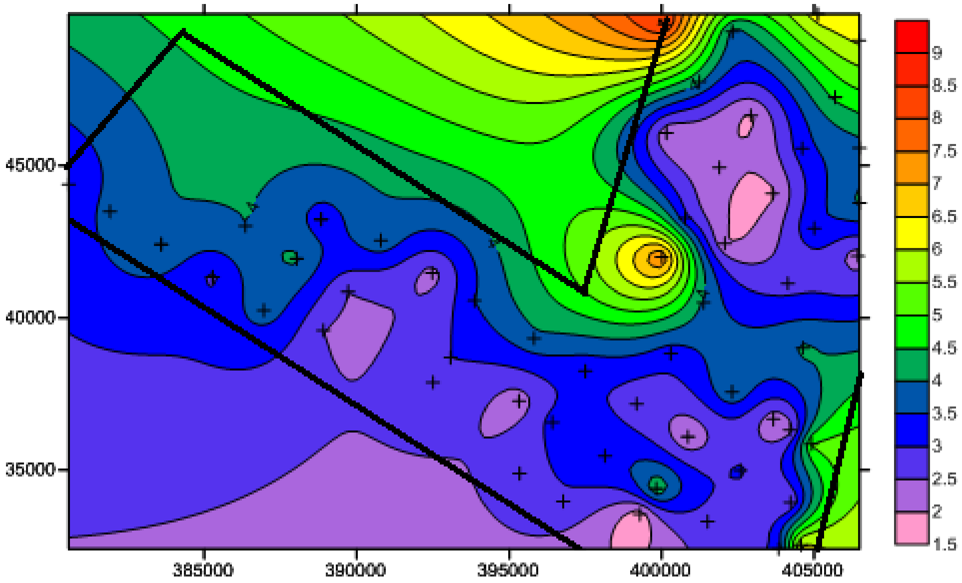


Figure 7a: Weathered layer thickness isopach with overlay of uphole points survey grid

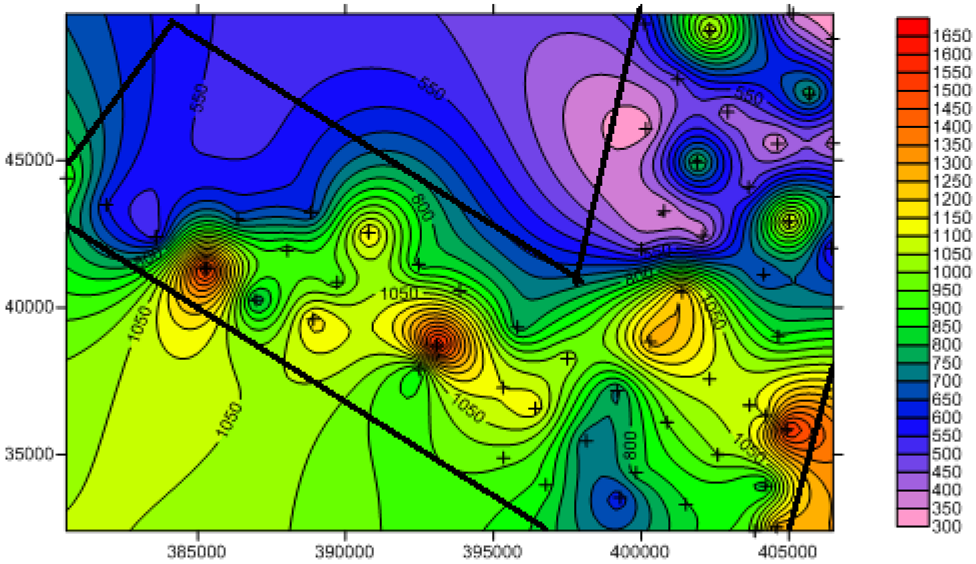


Figure 7b: Weathered layer velocity field with overlay of uphole points survey grid

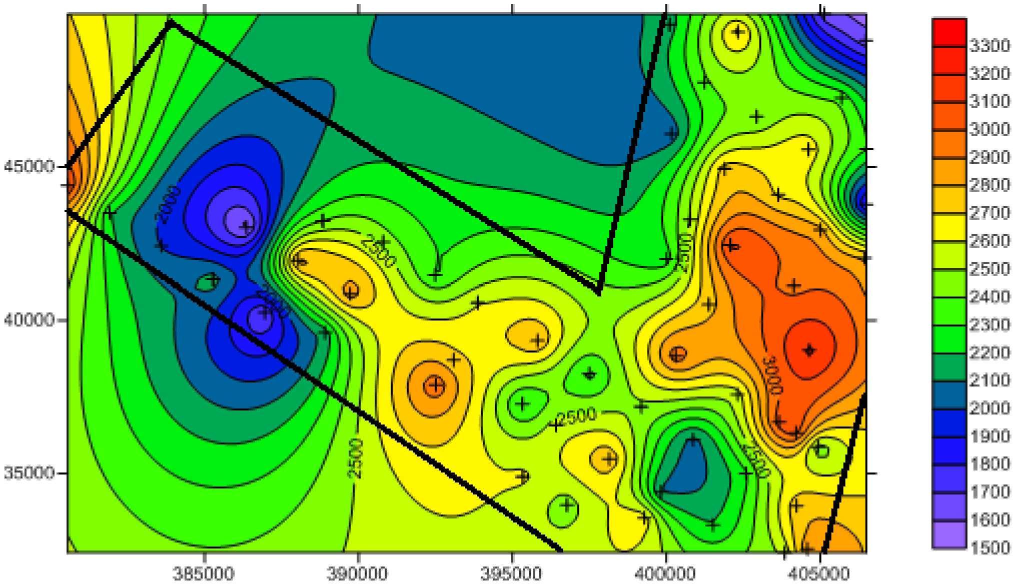


Figure 8: Consolidated layer velocity field contour map with overlay of uphole point's survey grid

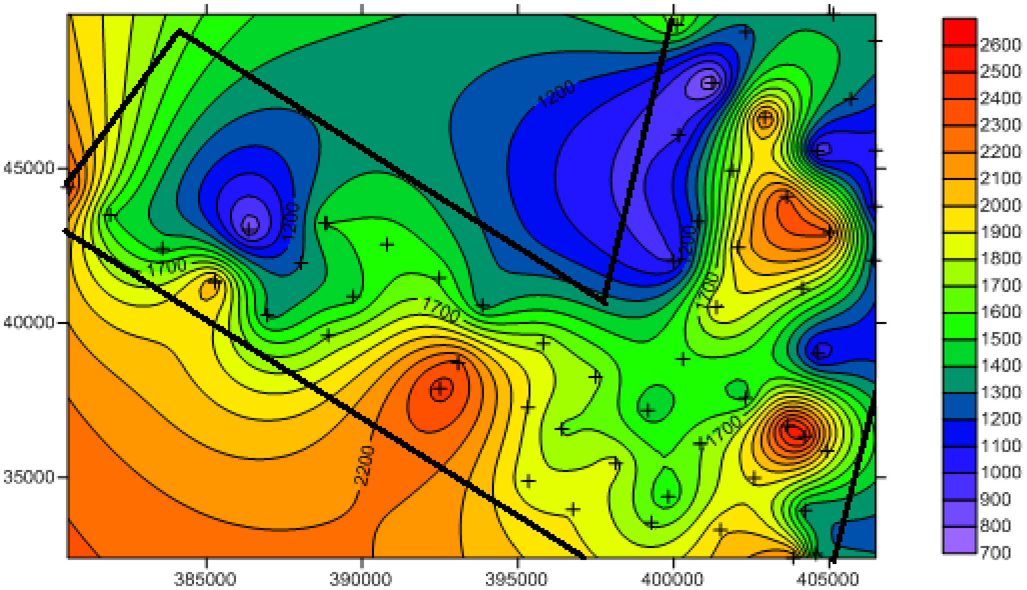


Figure 9a: Sub-weathered Layer thickness isopach with Uphole/LVL points survey grid overlay

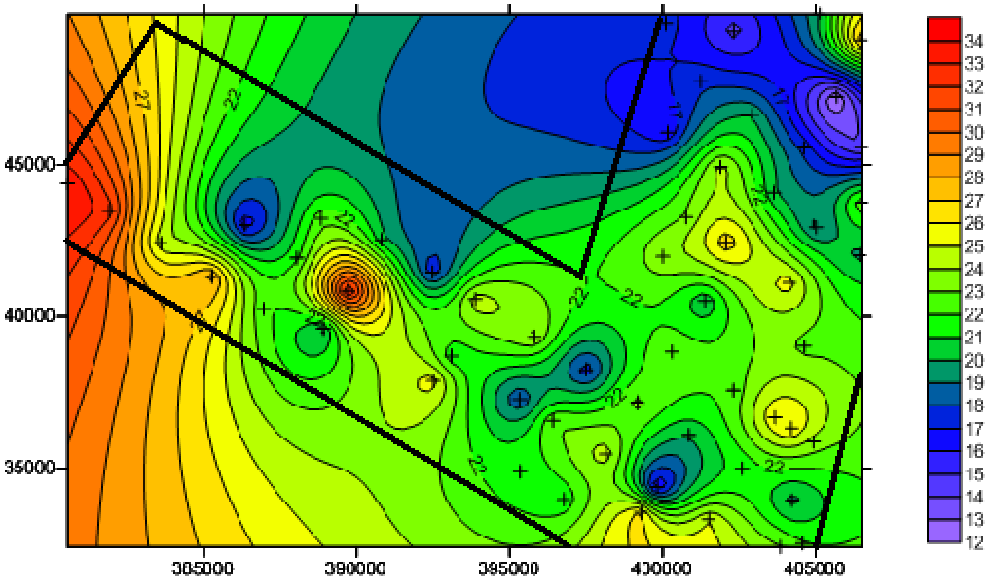


Figure 9b: Sub weathered layer velocity field with overlay of uphole points survey grid

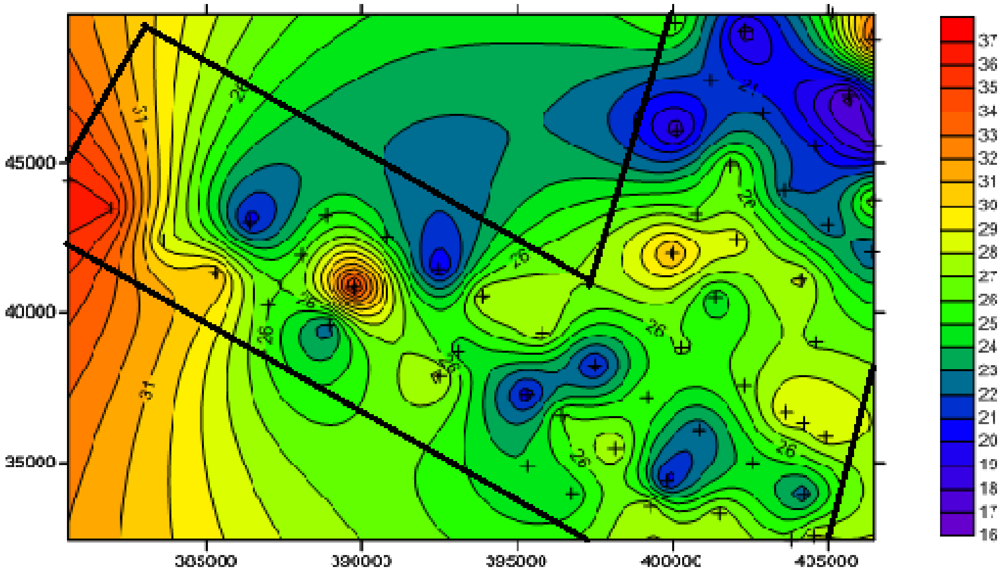


Figure 10: Total Thickness of weathered layer thickness isopach with uphole/LVL points survey grid overlay

Table 3: Summary of Uphole (LVL) Refraction Survey Results

	SHOT POINT	EASTINGS	NORTHINGS	Zo (m)	Z1 (m)	Vo (m/s)	V1 (m/s)	Vc (m/s)
1	4487 / 7255	380551.1	43241.2	2.4	33.7	800.0	2246.7	3194.8
2	4627 / 7397	38883.7	43235.2	2.3	22.7	638.9	1367.5	2468.5
3	4687 / 7287	381905.4	43490.2	3.7	32.5	596.8	1504.6	2201.8
4	4567 / 7327	382352.1	43490.1	2.8	21.2	1217.4	1876.1	1989.7
5	4587 / 7367	386352.4	43016.3	4.0	16.3	666.7	806.9	1556.9
6	4487 / 7327	383589.5	42411.2	4.0	24.3	519.5	1455.1	1993.7
7	4497 / 7367	385273.5	41332.3	2.9	28.3	1611.1	2096.3	2153.3
8	4567 / 7397	388036.9	47937.4	4.1	21.7	931.8	1299.4	2851.2
9		389720.5	40858.4	2.5	23.1	915	1458	2857
10	4487 / 7397	386957.5	40253.4	3.8	22.2	745.1	1362.0	1691.5
11	4499 / 7447	388911.3	39595.5	2.5	19.7	1190.5	1698.3	2141.2
12	4647 / 7447	390799.4	42542.5	3.9	20.3	1181.8	1561.5	2455.8
13	4647 / 7487	392483.4	41463.5	2.3	17.3	821.4	1587.2	2286.5
14	4647 / 7519	393872.7	40573.4	3.5	24.6	945.9	1344.3	2593.5
15	4567 / 7527	393088.5	38700.6	3.0	21.3	1666.7	2340.7	2725.2
16	4527/ 7527	392507.21	37885.71	2.9	25.5	852.9	2451.9	2981.1
17	4647 / 7567	395809.3	39332.6	3.9	24.1	764.7	1772.1	2807.0
18	4647/ 7597	397493.37	38253.75	3.1	17.3	1033.3	1730.0	2262.9
19	4567 / 7383	395319.8	37271	2.2	18.0	1100.0	1894.7	2259.9
20	4567 / 7597	396414.25	36569.52	3.2	23.0	1142.9	1678.8	2548.9
21	4487 7597	395335.78	34886.06	2.7	21.4	964.3	1829.0	2615.9
22	4647 / 7647	399176.89	37174	2.7	23.3	729.7	1438.3	2481.8
23	4647/ 7687	400861.98	36095.76	2.0	20.1	952.4	1689.1	2064.9
24	4527/ 7647	398140.5	35463.8	3.5	24.6	700.0	1835.8	2798.2
25	4567 / 7687	399824.6	34384.9	4.5	15.8	833.3	1519.2	2078.5
26	4487 / 7639	396766.9	33968.6	2.9	21.2	878.8	1892.9	2439.2
27	4527 / 7687	399285.1	33542.9	1.6	26.3	615.4	1675.2	2652.9
28	4647 / 7627	402587.9	34990.8	3.1	21.3	1000.0	1918.9	2282.1
29	4647/ 7667	404229.49	33937.85	2.5	19.6	806.5	1315.4	2766.4
30	4567 / 7727	401508.6	33305.9	2.8	25.0	848.5	1984.1	2205.5
31	4587 / 7777	403841.16	32405.06	3.2	23.1	969.7	2221.2	2514.9
32	4527 / 7647	400298.4	38831.8	3.2	23.0	1280.0	1575.3	2964.9
33	4727/ 7695	402311.7	37571.6	4.0	22.4	1081.1	1454.5	2545.5
34	4727 / 7741	404213.7	36323.3	2.2	26.0	1100.0	2549.0	3057.7
35	4727 / 7759	404929.4	35864.8	5.1	23.6	1593.8	1934.4	2428.2
36	4847 / 7719	404636.2	39021.7	4.1	22.7	854.2	1013.4	3223.3
37	4597 7718	404574.3	32529.59	6.2	22.1	1291.7	1372.7	2881.8
38	4797 / 7647	401377.4	40515.8	3.9	20.1	1258.1	1914.3	2748.1
39	4887 / 7688	404140.49	41121.12	2.8	25.5	636.4	1758.6	2962.6
40	4887 / 7639	402077.19	42442.17	2.0	26.7	363.6	2022.7	3130.0
41	4887 / 7597	400772.3	43278.8	3.1	23.1	340.7	1241.9	2503.7
42	4967 / 7597	401893.3	44935.8	2.3	24.4	851.9	1730.5	2752.1
43	6536 / 3864	403634.1	44087.52	1.9	20.1	475.0	2337.2	2676.1
44	4967/ 7567	400159.6	46076.3	2.1	16.1	318.2	987.7	2029.1
45	4957/ 7683	405008.7	42939.8	3.5	18.7	1166.7	2337.5	2842.1
46	3967 / 7719	406440.1	42022.7	2.2	19.7	523.8	1246.8	2801.5

	SHOT POINT	EASTINGS	NORTHINGS	Zo (m)	Z1 (m)	Vo(m/s)	V1 (m/s)	Vc(m/s)
47	4947/ 7647	404614.2	45567.9	3.3	17.7	347.4	903.1	2671.2
48	4927/ 7699	406494.4	43769.81	4.1	22.9	719.3	1026.9	1755.3
49	4947/ 7597	402930.1	46646.8	1.9	20.0	404.3	2272.7	2396.2
50	4947 / 7567	401238.6	47760.3	4.1	17.8	482.4	692.6	2381.3
51	4727 / 7741	403666.4	36674	3.2	26.0	1100.0	2549.0	3057.7
52	5127/ 7567	402325.1	49409.8	3.8	14.6	1117.6	1269.6	2736.8
53	4987/ 7527	400101.6	49646.7	8.6	17.4	537.5	1641.5	2151.9
54	5123 / 7647	405693.1	47251.9	4.6	12.0	807.0	1304.3	2371.6
55	5998 / 8789	406493.8	45582	3.8	14.0	358.5	1068.7	2305.0
56	5197 / 7597	405130.1	49987.9	6.3	20.0	353.9	1369.7	1637.8
57	5191 / 7639	406477.3	49124.7	6.1	27.9	346.6	1379.7	1637.8
58	4827 / 7597	400005.2	41988.8	7.6	23.9	463.4	981.9	2342.2
59	4627 / 7397	388837.8	43235.2	3.2	22.9	640.0	1506.6	2391.6
60	4647 / 7356	387431.4	44700.4	3.0	24.9	697.7	1020.5	1773.5
61	4647/7367	400005.2	41988.8	7.6	16.3	463	981.9	2242.3

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