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Determination of Interval Depth of Subsurface Layers by Velocity Analysis of Seismic Reflection Data, in Part of Niger Delta Basin, Nigeria

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Abstract
Seismic reflection data obtained from 3 – D survey in part of the Niger delta basin, Nigeria was processed using Velocity Computation (VELCOM), an interactive velocity analysis interpretation program. The application uses the principle of Apparent Velocity Picking, Normal Moveout (NMO) Correction and Stacking. Velocity intervals and stacking velocity for 8 Common Depth Points (CDPs) were obtained. Interval velocity ranges between 1814 - 5579 ms^{-1} and Stacking velocity (V_s) ranges between 1814 – 3639 ms^{-1}. Both velocities increase with depth, with interval velocity more steeply than Stacking velocity within the same interval depth. The corresponding depths to the reflecting surfaces, ranging from 554 – 10033m, were obtained, which led to the interval depths of layers ranging from 31 – 1180m. The result of this velocity analysis can be applied in NMO correction, calculating depths from reflection times, horizons identifications, the recognitions of lithology, detection of high pressure zone and migration.
Keywords: Seismic reflection, Normal move -out, Velocity, Depth of layer

INTRODUCTION

Velocity analysis of Geophysics has attracted the attention of the processors and the end users over the years since the introduction of the reflection method of seismic data. The curvature of the alignments that could be seen on the field records was indicative of the delays undergone by the waves as they traveled through the earth. The delays could be as a result of some factors, like density of the rock layers, porosity, and pore fluid. It therefore became important to derive relationships between travel times and the acoustic velocities of the layers which comprise the earth. Because of the importance of velocity analysis in obtaining the true interval velocity of each layer, and thus the true interval depth of each layer, it is needed in hydrocarbon industry. This will enable the interpreter enough information to predict the actual presence of hydrocarbons and the porosity and permeability of the formation. In addition, accurate depth sections could be constructed which would enable the drilling operations to be carried out more efficiently. However, to derive true depth sections from time data, it is necessary to correct the data for the distortions introduced, by the assumptions that all data lie vertically below the geophone. This correction is dependent on accurate knowledge of the interval velocities.

GEOLOGY OF THE STUDY AREA

The Niger Delta situated at the west African margin of the Gulf guinea, is a large arcuate delta, which occupies an area located between longitude 4^o – 9^o E and 4^o – 6^o N (Kogbe, 1976). The geology of the area was controlled by three main tectonic phases: The first tectonic cycle is in the Albian which resulted in the formation of the Benue and Abakiliki troughs and infilling by Albian shales and sandstones. This period also marked the establishment of the Calabar and Benin flanks. The second tectonic cycle was marked by the folding of sediments during the Santonian. This episode was followed by considerable magnetic activity and mineralization. The third cycle, the late Eocene led to the establishment of the modern Niger Delta (Novelli, 1974).

There exist three subsurface stratigraphic units in the modern Niger Delta: Benin, Agbada and Akata formations (Short and Stauble, 1967). The Benin formation is the alluvial or upper coastal plain depositional environment of the Niger Delta Complex. It extends from the West Niger Delta area and to the South beyond the present coastline. The Benin formation consists of coarse-grained, gravelly sandstone with minor intercalation of shale. It is a continental deposit of Miocene to younger in age and has a thickness in excess of 1820m. Typical outcrops of the Benin formation can be seen around Benin, Onitsha and Owerri. The Agbada formation underlies the Benin formation. It was laid down in parallic brackish to marine fluviatile, coastal environments. The Agbada formation is made up primarily of alternating sandstones and shales and is of fluviomarine origin. It ranges in age from Eocene in the North to Pliocene in the South. These sands, sandstones and shales which make up the formation, attain a maximum thickness of about 4500m. The Agbada formation is time equivalent to the Asaba-Ameki formation further north. The Akata formation is the lowest unit of the Niger Delta Complex. Akata formation consists of shale with local interbedding of sands and sandstones. The formation becomes shalier with depth. It was deposited in a marine environment and the formation outcrops offshore in shale diapers (Mascle et al, 1973). The thickness may reach 7000m in the central part of the delta. The Akata formation ranges from Eocene to Recent (Short and Stauble, 1976; Ofoegbu, 1985).

MATERIALS AND METHODS

The seismic traces of CDP gather was corrected for NMO and then added together (stacked). The travel time, t at offset, x is assumed to relate to the zero – offset travel time, t_o by:

$t^2 = t_o^{\,2} + \frac{x^2}{V_s^{\,2}}$, where V_s is the stacking velocity, approximately equal to the RMS Average velocity to the reflector concerned. Determination of the NMO correction is therefore equivalent to analyzing the seismic velocity structure of the section.

The value of V_s when large volumes of data are involved requires an automated method rather than a plot of t^2 versus x^2, where $\frac{1}{V_s}$ is the slope of the graph. In this case, the constant velocity stacks (CVS), which assumed that the seismic velocity has a constant specific value throughout the ray path was applied. This method was preferred because of its effect on noisy data. It enhances signal to noise ratio. The alignments across the gather are always difficult to see if signal to noise ratio is poor (Dobrin, 1976). Calculation of NMO for each trace as a function of TWT (Two-Way-Time) can then be made. The traces of the gather are corrected for NMO using these calculated values. Where NMO has been correctly removed, a reflector will line up horizontally across the gather. If the true stacking velocity is less than that assumed in constructing the CVS, the event will be under corrected and will bend down towards the larger offset traces; if the true velocity is greater than that assumed, the event will be over-corrected and bend up at the larger offsets. Thus, the estimation of the TWT can be made successfully where the assumed velocity is equal to the desired stacking velocity.

An application, VELCOM was used in processing the 3 – D seismic reflection data obtained in part of Niger Delta Basin, Nigeria. VELCOM is an interactive velocity analysis interpretation program. It enables the view of seismic data on the screen and performs interactive interpretation. Analysis locations and density are defined in the processing flow interactive monitoring and editing of the velocity field is performed with displays including in-line or cross-line isovelocities, constant – time and constant horizon – velocities. NMO can be applied any time to the current CDP gather, enabling check on the validity of the picks. VELCOM allows for pick shift or transverse isotropic picking and to perform both the shifted hyperbola and transverse isotropic NMO correction. VELCOM gave the stacking velocities. The interval velocities therefore were calculated from the Dix's expression:

$$V_{in}^{\;2} = \frac{V_{sn}^{\;2} t_n - V_{sn-1}^{\;2} t_{n-1}}{t_n - t_{n-1}}.$$

That is, the square of the interval velocity between successive reflecting interfaces at the base of layer n-1 and n is given by the difference in the product of the stacking velocity, V_s and vertical reflection time, t divided by the difference in reflection times, t.

The depth (vertical distance, D) to the reflecting interface, which is the principle of seismic reflection profiling can be determined from two – way reflection travel time (t) recorded by a geophone at the shot – point, once velocity, v is known. The expression is given by: $D = \frac{Vt}{2}$.

The interval depth of layers therefore can be known from the depth of the reflecting interfaces using the expression: $\mathbf{d_{in} = D_n - D_{n-1}}$, where d_{in} is the interval depth of different layers and D_n is the depth of n^{th} layer.

RESULTS AND DISCUSSION

The data acquired courtesy of Companie Generale de Physique (C.G.G.) consisted:
(1) Velcom ministack (2) Velcom spectrum and scale semblance profile (3) Velcom CDP gathers prior to NMO correction (4) Velcom CDP gathers after NMO correction (5) Velcom Isovel
(6) Velcom stacks and (7) Velcom plots.

A velocity analysis of a CDP traces composed of high quality reflections as shown in figure 1 was made. Apparent velocity picks were made in this trace, which gives the plot of velocity versus time, the velcom spectrum and scaled semblance profile of figure 2. The picks were made on sharpest points of events. Figure 2 enables events showing high amplitude to be seen.

After the picks were made, a Dix equation, already in the application, was applied. This is known as the normal move out correction. The primary reflections in each CDP trace gather were corrected for NMO prior to trace summation.

The synthetic record, uncorrected for NMO, is shown in figure 3. It consists of one CDP trace, CDP 1102 of line 5184, distance interval of 500m. All reflections have equal peak amplitudes; that is, reflection and transmission coefficients are ignored, as well as spherical spreading loss. Instead of aligning horizontally, the events trace a hyperbolic shape, thus the need for correction.

The corresponding NMO-corrected record is shown in figure 4. The application used in correction uses the principle of constant velocity gather (CVG). The horizontal alignments of the reflections indicate the apparent velocity required to remove that reflection NMO.

The application (VELCOM) was aimed at getting the stacking velocity with the corresponding total depth of layers, as displayed in the Velcom isovel of fig. 5. The isovel displays the stacking velocities and the corresponding depths for eight CDPs of the same line. The stacking velocities vary with time and increases with depth. The Velcom plots compares stacking and interval velocities in relation to zero- offset time. Stacking velocity increases with time in proportion, while that of interval velocity increases in a discrete manner.

Tables 1 – 4 show the variation of time with stacking velocity and total depth of layers, as measured from the Velcom isovel. The corresponding interval velocities and interval depth of layers as calculated from the Dix's equation and the expression for the two – way – travel time respectively, was also shown. For each CDP, the interval depth of layer indicates the thickness of each layer. This thickness of different layers accounts for the distortion encountered as the seismic wave enters another layer as seen in the curvature of the alignments on the field records of Velcom CDP prior to NMO correction (fig.3).

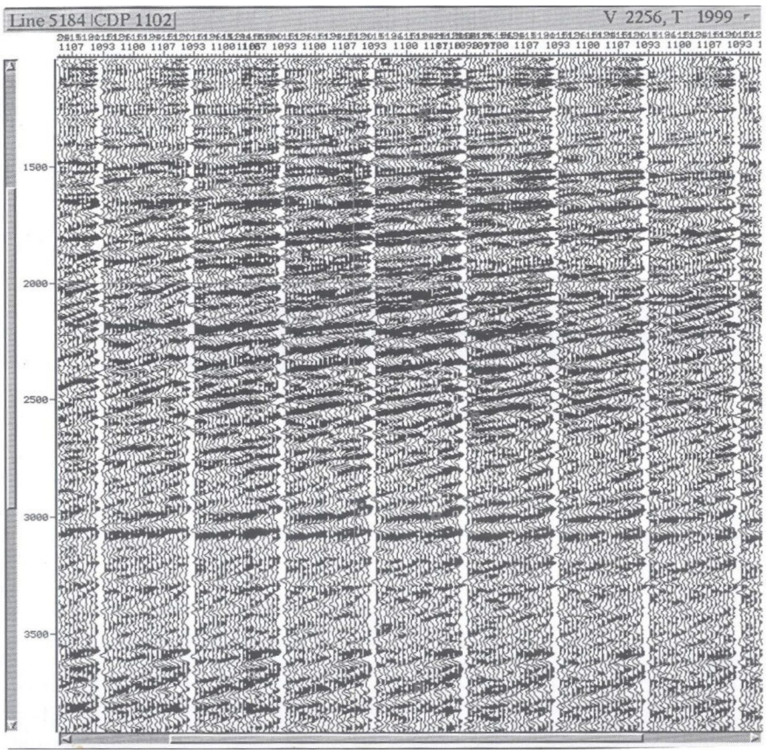

Fig. 1: VELCOM MINISTACK, Comprising CDP Gathers of the same line

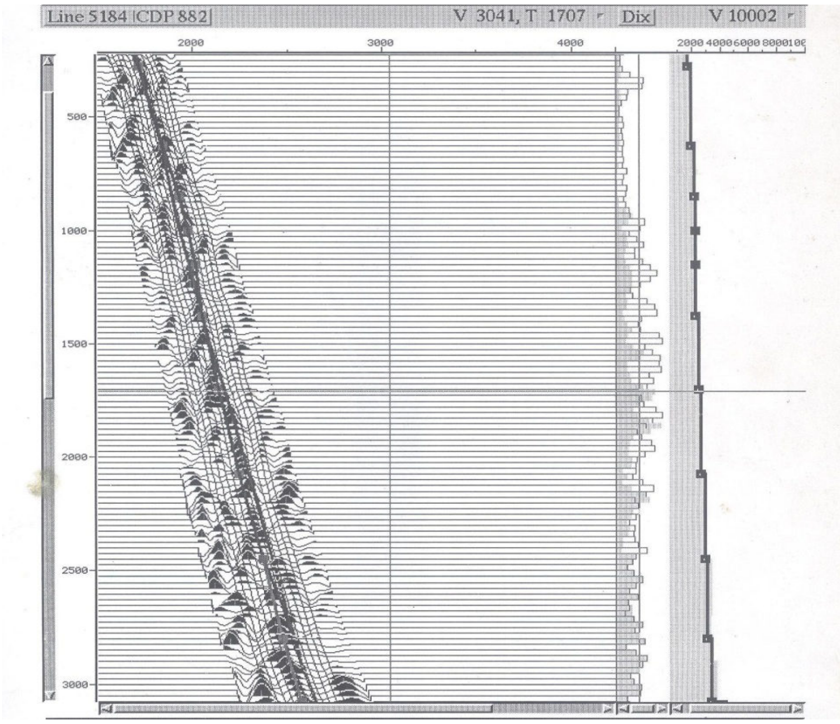

Fig.2: VELCOM Spectrum and Scale Semblance Profile

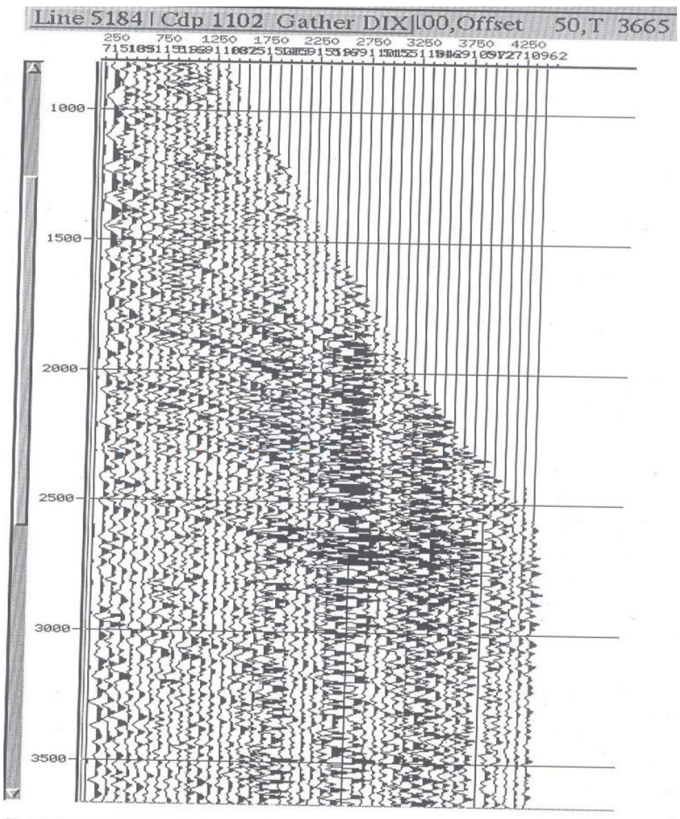

Fig. 3: VELCOM CDP Gather prior NMO correction, showing the curvature of the alignments.

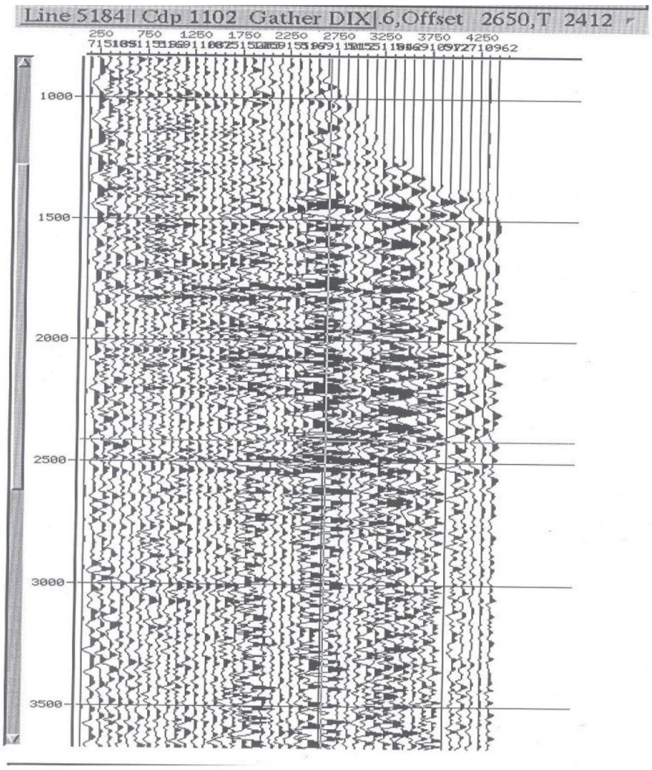

Fig.4: VELCOM CDP Gather after NMO correction, the curvature of the alignment corrected.

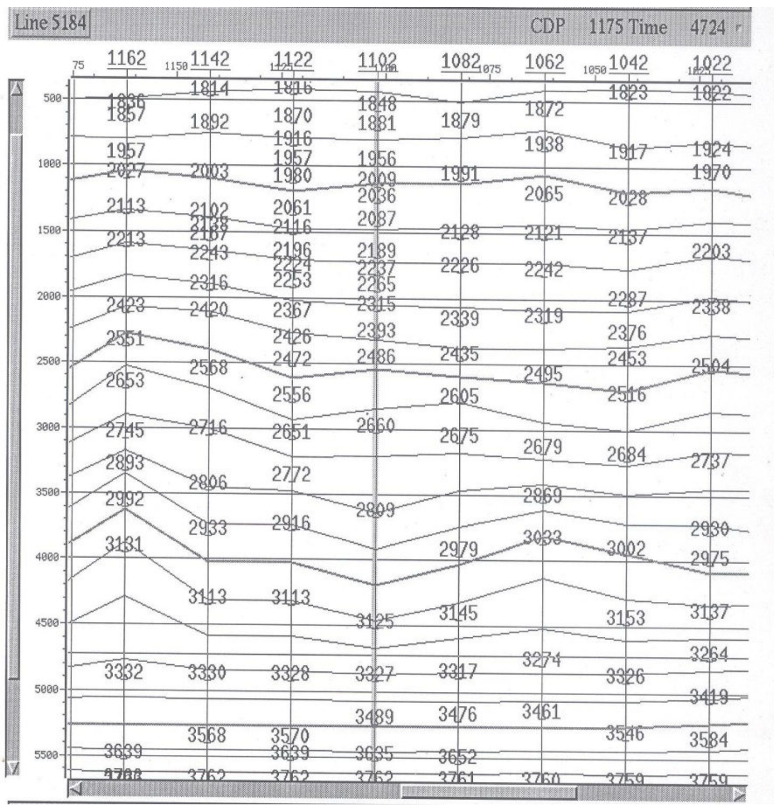

Fig.5: VELCOM ISOVEL, displaying stacking velocities in variation with offset time for different CDP Gather.

Table 1: The variation of offset time with Interval depth of layers for CDP 1114.

Time (s)	Stacking Velocity (V_S) m/s	Interval Velocity (V_{in})m/s	Depth, D (m)	Interval depth, d_{in} (m)
0.60	1836	1836	551	551
0.69	1857	1991	641	90
0.96	1957	2192	939	298
1.10	2027	2454	1115	176
1.39	2113	2411	1469	354
1.64	2213	2703	1815	346
2.12	2423	3033	2568	753
2.39	2551	3392	3048	480
2.70	2653	3336	3582	534
3.09	2745	3313	4241	655
3.32	2893	4425	4356	115
3.60	2992	3983	5486	1030
3.95	3131	4308	6184	798
4.93	3332	4042	8213	2029
5.52	3639	5579	10044	1831

Table 2: The variation of offset time with Interval depth of layers for CDP 1162.

Time (s)	Stacking Velocity (V_s)m/s	Interval Velocity (V_{in})m/s	Depth, D (m)	Interval depth, d_{in} (m)
0.47	1814	1814	426	426
0.70	1892	2042	662	236
1.10	2003	2184	1102	440
1.38	2102	2453	1450	348
1.58	2189	2714	1729	279
1.70	2243	2860	1907	178
1.95	2316	2762	2258	351
2.15	2420	3265	2602	344
2.61	2568	3169	3351	749
3.06	2716	3451	4155	804
3.47	2806	3403	4868	713
3.83	2933	3953	5617	749
4.35	3113	4208	6771	1154
4.90	3330	4706	8159	1388
5.89	3568	4567	10508	2349

Table 3: The variation of offset time with Interval depth of layers for CDP 1122

Time (s)	Stacking Velocity (V_s)m/s	Interval Velocity (V_{in})m/s	Depth, D (m)	Interval depth, d_{in} (m)
0.45	1816	1816	409	409
0.70	1870	1964	655	246
0.88	1916	2085	843	188
1.00	1957	2235	979	136
1.15	1980	2127	1139	160
1.38	2061	2426	1422	283
1.51	2116	2630	1598	179
1.92	2253	2698	2163	505
2.18	2367	3081	2580	417
2.38	2426	2995	2887	307
2.55	2472	3044	3152	265
2.82	2556	3244	3604	452
3.09	2651	3492	4096	492
3.40	2772	3772	4712	616
3.80	2916	3933	5540	828
4.35	3113	4231	6771	1231
4.94	3328	3319	8220	1449
5.38	3570	5611	9603	1383
5.52	3639	5688	10004	441

Table 4: The variation of offset time with Interval depth of layers for CDP 1102

Time (s)	Stacking Velocity (V_s)m/s	Interval Velocity (V_{in})m/s	Depth, D (m)	Interval depth, d_{in} (m)
0.60	1848	1848	554	554
0.70	1881	2068	658	104
1.15	2009	2332	1125	467
1.25	2036	2325	1156	31
1.45	2087	2381	1476	320
1.70	2189	2706	1861	385
1.80	2237	2935	2013	152
1.90	2265	2720	2152	135
2.10	2315	2745	2431	275
2.30	2398	3140	2758	327
2.50	2486	3335	3108	350
3.02	2660	3373	4017	909
3.70	2809	3393	5197	1180
4.51	3125	4281	7047	1850
4.85	3327	5321	8068	1021
5.27	3489	4992	9194	1126
5.52	3635	5928	10033	839

CONCLUSION

The application, VELCOM successfully removed the curvature of the reflection data and gave the best possible stack after processing. With the true interval velocities of layers correctly obtained and hence the true interval depth of layers, interpreters can successfully locate the actual position of hydrocarbon subsurface. For the interpreter, the interval velocity is the target of any form of velocity analysis. It helps predict the actual presence and locate the actual position of hydrocarbon subsurface. In addition, accurate depth sections could be constructed which would enable the drilling operations to be carried out more efficiently.

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