Technique for the Reduction of Seismic Uncertainties in the Oil Exploration Business

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Abstract

Establishing a link between well data and seismic data by the technique of the Well Seismic Profiling (WSP) is at the heart of this study. This procedure is at the forefront of emerging technologies that oil companies invoke in order to reduce seismic uncertainties to the barest minimum. To establish such a link 3-D seismic data, WSP data, and log data (especially density, sonic, and gamma) from Field XX in the Niger delta were used. Synthetics were generated using a petrophysical software called LOGIC. GX-II package was used for the modeling of the WSP dataset. The matching of various dataset were carried out using a programme module called ZCOMPOSE. The result obtained showed that WSP dataset were clearer and more consistent in depicting seismic anomalies, position of faults than the corresponding surface seismic dataset.

Introduction

The idea of using boreholes for seismic measurements date back to 1917 with Fessenden's patent to detect ore bodies by means of locating an acoustic source and receiver in drilled holes (Jauffred,1990). Up until the second world war, geophone observation in boreholes were made almost exclusively for the measurement of travel times from surface to specified station in the borehole so that a seismic velocity distribution for that location could be derived (Anstey and Geyer, 1996). Form then until the mid-1950s, some work was performed mainly by research individuals to study wave propagation and absorption in addition to the regular velocity (checkshot) surveys. With the advent of the continuously recorded acoustic velocity log at about this time, the emphasis on the use of borehole geophone observations shifted to the calibration of these logs and until about 1970 the this remained the primary use for surveys. During this time and almost unnoticed by the West, geophysicists in the former Soviet Union were developing the new technology of vertical seismic profiling (VSP), building up a very large body of technical data and literature. It wasn't until the early 1970s that western explorationists began to take notice of this tool and even with the considerable volume of information available the method was slow to gain favour in the west. It is a matter of historical fact that the USSR opened a gap of about 20 years in the development of this technology. That gap is now considered closed. This is due is part to the easy availability of much faster computing technology to western geophysicists enabling a faster rate of development of the necessary computational tools (Paul and Taylor, 1997).

Well seismic profiling (WSP) covers a series of techniques, which can be used to investigate the subsurface in a scale between well log data and conventional surface seismic (Staal *et al*, 1996). The name VSP (vertical seismic profiling) is poor description for many types of well seismic survey now being made because of the large number of highly deviated and horizontally drilled wells. WSP is now a general name covering all types of borehole seismic measurements including the classical VSP and well shoot techniques, drillbit listening, cross-well surveys, and intra-well survey (Stauble, 1996).

WSP Modeling

The computer modeling of seismic wave propagation has become an important component of the seismic method. One of the applications of this modeling is in the context of seismic interpretation, Fig. 1. After geological data have been interpreted and translated into a geological model, a computer simulation of the seismic data acquisition can be used to calculate the anticipated seismic response.

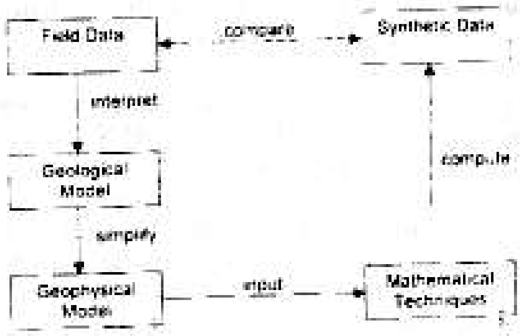

Fig. 1: Flow Chart Illustrating the Modeling Process

If the synthetic (calculated) data compare satisfactory with field-acquired data, the geological interpretation is verified. If, however, the comparison between the field data and synthetic data is unsatisfactory, the validity of either the geological model or the computer simulation procedure must be reviewed. Modification of the geological interpretation followed by computer simulation of the *geophysical response can be performed* repeatedly until a good comparison between field and synthetic data is achieved (Young *et al*, 1984), Fig. 2

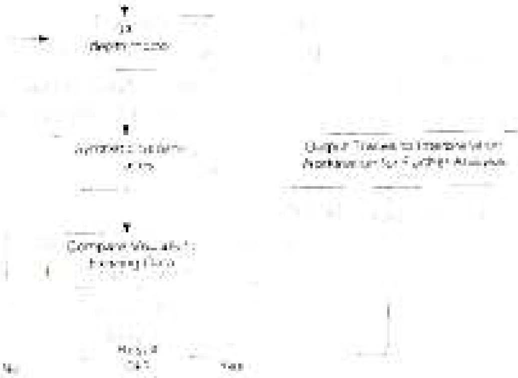

Fig 2: Simplified Flowchart for Seismic Modeling.

Seismic modeling also provides an inexpensive means of evaluating the potential effectiveness of a proposed data acquisition procedure. Using an approximate geologic model based on information from previous work in the area, proposed source, receiver, and recording parameters can be included in the preliminary design of a seismic survey (Young *et al*, 1984).

Significance of Well Seismic Profiling (WSP)

Optimal use of WSP data to reduce seismic uncertainties such as correct identification of reflectors, calibration, and modeling of seismic loops which correspond to a particular zone of interest in a well is of considerable interest in the petroleum industry. It is recognized as an effective tool for quick time to-depth conversion process and identification of reflectors. Investigation of amplitude anomaly using WSP modeling of fluid contact will result in accurate hydrocarbon prediction.

Geological Character of Study Area

The field of study is located in the coasted swamp area of the Eastern Niger Delta about 25 km southwest of Port-Harcourt. Delta development in this area is characterized by thick sand sequences down to about 3658m as a consequence of high subsidence rates in fluvio-marine paleo-environment. Below this depth, the sand/shale ration decreases but thickness of individual sands may still be up to 107m. These areas are small footwall closures bounded to the north by an antithetic fault which form part of a *complex collapsed crest fault system. This field* has a very *high potential* for hydrocarbon (Van Luik and Ekejiuba, 1996).

A delta is a river-fed depositional system that produces an irregular progradation of the shoreline. The entire, sub-aerial and sub-aqueous, contiguous sediment mass is included in the delta system. The sediments are partly marine and partly fluvial in origin. The delta basin is the most prospective of the six major basins that are of interest to hydrocarbon prospectors in Nigeria. The other basins are the Bida, Bornu-Chad, Anambra, Sokoto, and Dahomey Benin. These six basins in all occupy roughly half the onshore of Nigeria. The Niger Delta complex consists of Cenozoic formation deposited in a high-energy deltaic environment.

Well Seismic Profiling Techniques

Although WSP is generally considered to be a somewhat specialized technique it is basically an extension of the surface seismic reflection method with different configuration of sources and receivers. In the surface seismic method, the sources and receivers are positioned on the earth's surface. In the simplest case of WSP data are acquired with the source on the surface and receivers at known depths in the borehole. The basic configuration illustrated is in Fig 3, and the correspondence between the two survey types can be clearly seen (Paul and Taylor, 1997). The WSP configuration has considerable advantages over the surface method in that the seismic response of the geological section from surface to the deepest point drilled, and beyond, can be observed as functions of time and depth. Thus the propagation of seismic energy can be continuously monitored and important information concerning the origins of primary and multiple reflections, the nature of signal attenuation, and the presence of discontinuities, etc., can be determined (Staal, 1996). Unlike a surface seismic detector a well geophone buried somewhere in the subsurface records seismic motion due to energy traveling both downward and upward past the geophone position. At every geophone station the recorded seismic trace contains several types of events, viz:

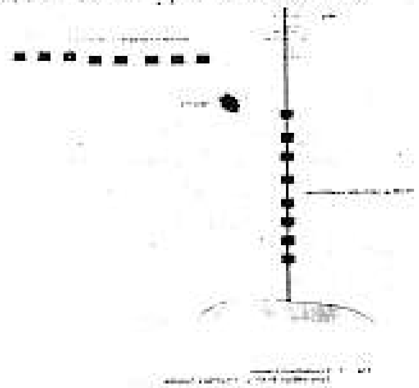

Fig 3: Acquisition geometry Zero Offset WSP and Surface Seismic

- The downgoing first arrivals which have propagated directly from the source to the geophone;
- The downgoing multiples generated at the underside of the interfaces above the geophone;
- The upgoing primary events reflected from the interfaces beneath the geophone;
- The upgoing multiples reflected from the interfaces beneath the geophone.

Well Seismic Profiling Configurations

WSP surveys were always recorded with the source at the surface and the receiver in the well. With the development of new technology and especially of downhole sources, there are several WSP configurations that can be envisaged, depending on the objective of the survey (i.e. on the portion of the surface to be investigated), Fig. 4.

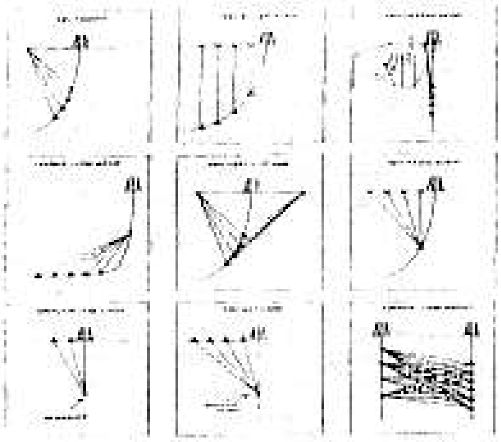

Fig 4: WSP Configuration

Zero – Offset WSP

The classical WSP acquired in vertical wells with the source located at the surface close to the well bore and a geophone in the well. The so-called saltprox surveys constitute of specially processed zero-offset WSPs designed to define the boundaries of a salt dome (Hardage, 1985).

Walk – Above WSP

A zero offset (vertical incidence) WSP in a deviated well with source positions located vertically above receivers.

Offset WSP

The source is positioned at a fixed location away from the wellhead, typically 2 – 5 km, depending on the subsurface area to be investigated. The downhole tool is moved up the well with shots stacked at each level.

Walk- Away WSP

The geophone is positioned in the well while the source is passed along a surface line and fixed at 25-30m intervals. In this way detailed covering can be obtained below the geophone depth on each side of the wall.

Multi-Offset WSP

In this method a number of regularly-spaced sources are kept stationary at a distance of 2 – 5km from the wellhead. The downhole receiver is moved up the well.

Intra-Well Survey

In this method the source and the receivers are located in the same borehole.

Cross-Well Survey

This method involves well-to-well recording where the source is located in one well and a geophone in an adjacent well.

Inverted WSP

The source is located in the well and the receiver at the surface so that for one shot a large number of geophone, can be recorded.

Drillbit Listening

This is a special type of inverted WSP where the noise created by the drillbit is recorded at the surface and specially processed (MacDonald and Marsden, 1996).

Multi-Component or 3-Component (3-C) WSP

The term 3-C WSP does not correspond to a special WSP geometry but refers to a surveys that has been recorded with a special tool, i.e. a 3-component geophone, formed of three individual geophones arranged orthogonally to record all the component of the seismic wavefield (Pion and Pearce. 1986). Usually in seismic studies two type of waves propagating through the subsurface are considered, viz.:

- The P-wave or pressure wave for which the particle motion is in the direction of propagation:
- The S- ware or shear ware for which the particle motion is perpendicular to the direction of propagation.

Well Seismic Profiling Acquisition Modeling

In the past, a large number of WSPs were considered to have been failures (for instance 60%s of Shell's WSPs in 1984). The most important causes were the absence of clearly defined objectives and in adequate preparation (Heer. 1996). To property plan the acquisition geometry and specifications, it is strongly recommended to define the objectives of the WSP, and to undertake a modeling exercise to ascertain that those objectives can be met (Staal *et al.*1996). The modeling should address issues like the subsurface illumination of specified horizons, dips, and velocity effects. The modeling must also address the seismic response of the earth, ideally including effects due to absorption, transmission losses, multiples, mode conversions, size of reflection coefficients, etc. Also synthetic dataset should be generated in order to enable an assessment of problems that arise during processing. Finally the input models should be as accurate as possible in order to incorporate velocity variations and structure. In addition to designing WSP surveys, modeling can greatly help interpretation of WSP data. For example, simple ray-trace techniques can be used to derive a crude locus of reflection points to provide a basis for imaging the WSP data.

Sources

Due to the nature of WSP operations, source requirements are different from those needed in surface seismic work. Because of the down-wave WSP deconvolution, the wavelet is known exactly, and so tuning of the array is not necessary. The main criterion for a good source is stability, i.e. that the source will provide a consistent signal when fixed at short intervals. It is recommended to place a geophone close to the source in order to monitor the signal. This allows for corrections to be applied during processing. Vibroseis (on land) and airguns (in water or mud-filled holes) are the most common sources. Offshore, air or water guns are use, singly or in an array (de Bruin, *et al.* 1988). For an offset or walk-away WSP, a vessel has to be used (Staal *et al.* 1996).

Receivers

Because of the harsh conditions downhole well geophone tool are significantly more rugged than standard surface geophones. The downhole tool has to be able to stand up to very high pressure regime and downhole temperatures of more than 200 c. In order to couple the geophone with the borehole wall the tool should have a hydraulic or electromechanically-operated arm which can be extended to force the body of the tool against the side of the well. The ratio of the clamping force to the weight of the tool is often used to indicate the quality of the clamping. Single component receivers consist of a geophone polarized vertically. These are still used for zero-offset surveys in vertical wells, but 3-component geophones are becoming more common, and are recommended for deviated wells and offset/walk-away WSPs. Some tools have facilities (pinger or barkers) to test the quality of the coupling. An alternative locking mechanism is a magnetic clamping device (the limitation here is that tool can be used only in cased hole). Additionally, even with a high magnetic clamping, there is a possibility of micro slippage of the tool (Pion and Pearce, 1986).

Well Seismic Profiling Processing

The basic processing sequences for all types of WSPs are broadly similar and they generally entail the use of exactly the same processes for the majority of the processing route (Ginn, 1983). The sequences are data preparation and editing, separation of up going and down going wavefields, deconvolution of up going wavefield, enhancement of upgoing wavefield, and suppression of noise and unwanted signals.

Procedure

The well seismic profile data (i.e. 3-D seismic data, WSP data, and logs) used for this study were provided courtesy of the Shell Petroleum Development Company (SPDC), Port Harcourt.

Synthetic Seismogram Generation

LOGIC (an SPDC proprietary petrophysical software package) was used for the generation of the synthetic seismic data. Synthetic seismogram was used to establish the relationship between the seismic data (time) and the well data (depth). The geological section was assumed to be multilayered earth, with petrophysical parameters constant along the horizontal but vary vertically downwards. The sonic, density and gamma ray logs acquired from selected wells in the field of study were fed into the LOGIC program. Trend curves were generated for each well using a batch program in LOGIC specifically designed for generating trend curves. These trend curve indicate hydrocarbon position and water bearing sands. The program uses the sonic and density logs to generate an acoustic impedance log in depth. The acoustic impedance is the product of density and velocity (Coffeen, 1986). The reflectivity is generated and filtered. The final synthetic was the sum of the individual reflection pulses, see Fig. 5, for Well 2. These synthetics were matched with the seismic traces and WSP data using a program called ZCOMPOSE. The modeling was carried out on the GX-II package (another SPDC proprietary software), and the geological models were built up based on the table of material properties, see Table1 and Fig.6 for Well 2. The ray tracing (ray trace through the model was carried out using zero-offset WSP option (Domhoo, 1995).

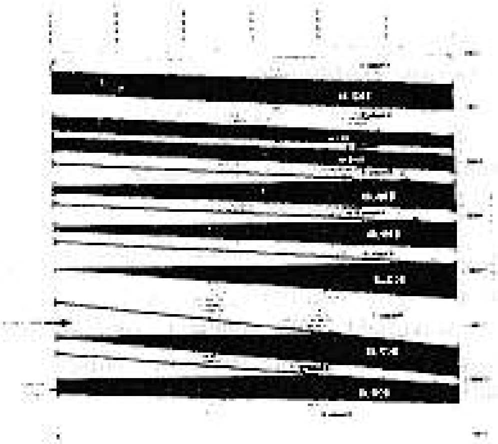

Fig. 5.1: Geological models of Onakpa field (well 1)

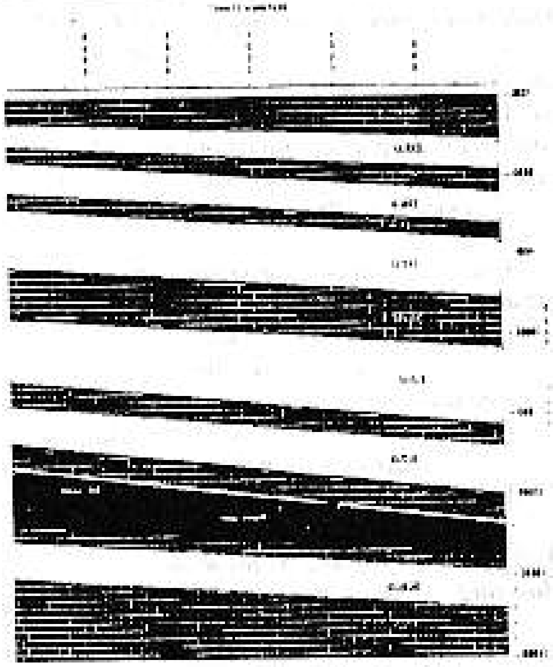

Fig. 5.2: Geological models of Onakpa field (well 2)

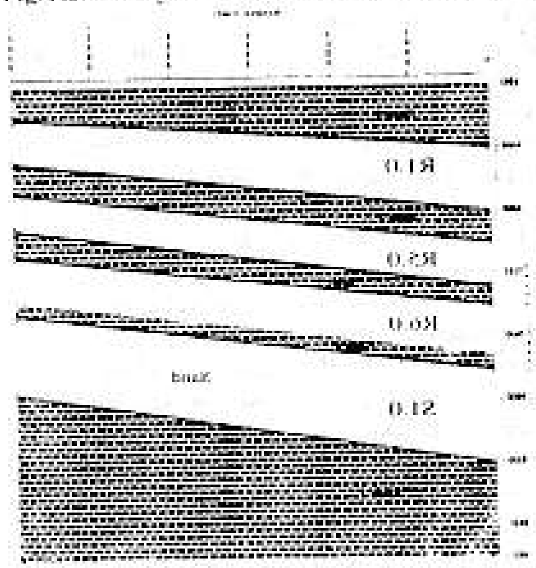

Fig. 5.3: Geological models of Onakpa field (well 3)

Analysis of Fluid Substitution

The GX-II package was used for the investigation of the GASSMAN fluid replacement. Horizon K3 for Well 2 was used. The material properties of water, oil, and gas obtained from an interpreted report were fed in. For example, in modeling oil-water interface, the upper part was filled with oil and the lower part filled with water. The material properties of these fluids were fed in and zero-offset ray were applied. Traces were generated and the resulting amplitude anomaly was observed. The same step was followed for gas-water interface and gas-oil interface. Figs 7, 8, 9.

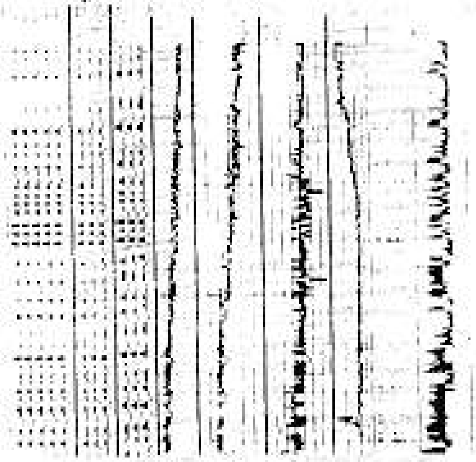

Fig. 6: Synthetic for well 2

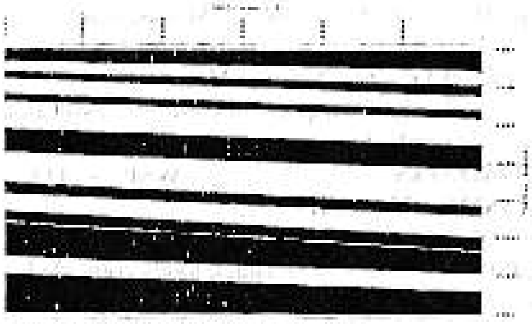

Fig. 7.1: Oil- Water interface model

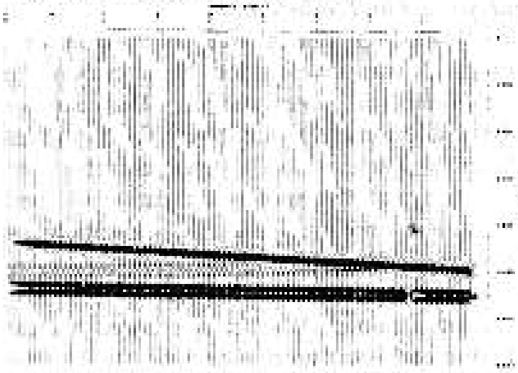

Fig. 7.2: Oil- Water interface response

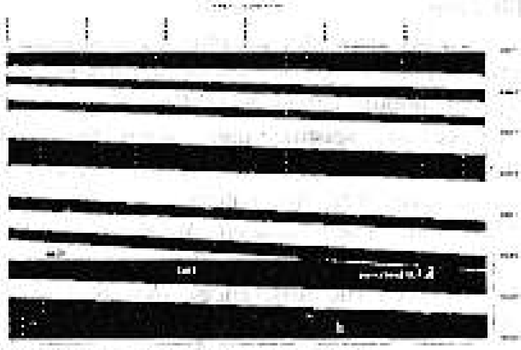

Fig. 8.1: Gas- Water interface model

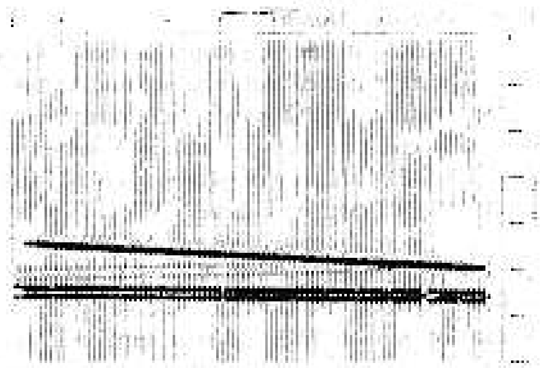

Fig. 8.2: Gas- Water interface response

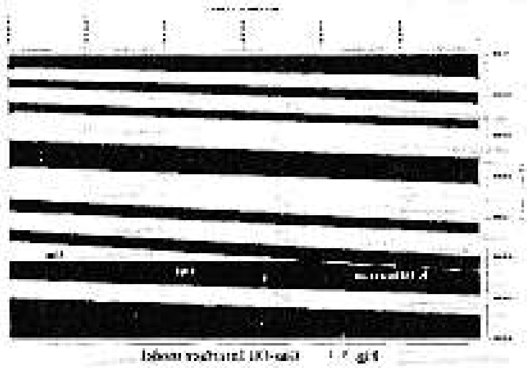

Fig. 9.1: Gas- Oil interface model

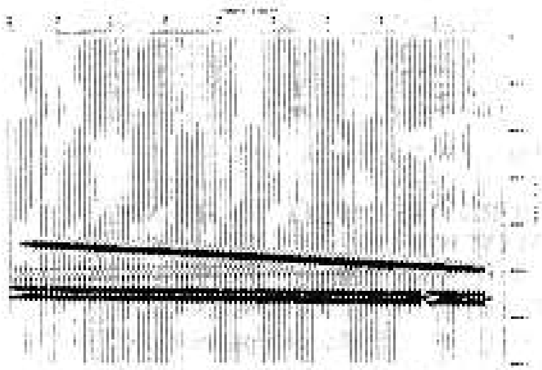

Fig. 9.2: Gas- Oil interface response

Matching

The generated synthetic seismogram were exported to workstations where the program module called ZCOMPOSE was used to splice the seismic data along the well trajectory and the synthetic placed at the center for a deviated well, the matching was manually carried out. The modeled WSP were also compared with the well synthetic and surface seismic trace. The differences and similarities were noticed.

Discussion of Results
Well-to-Seismic Match

The synthetic seismograms from wells 1, 2, 3 were matched with the seismic section. Let us examine Well 2 here, which in real sense is cross section of wells 1 and 3. A subset of field XX 3-D volume (line 4695 – 4705, Trace 1000 – 13000, Two Way Time (TWT) of 1000 – 3000ms) were accessed using SEISWORKS software. The synthetics for Well 2 was loaded and ZCOMPOSE assisted the matching process. A shift of zero millisecond was applied in the matching. Fig.10. The following horizons corresponding to key reservoir levels were identified in this well.

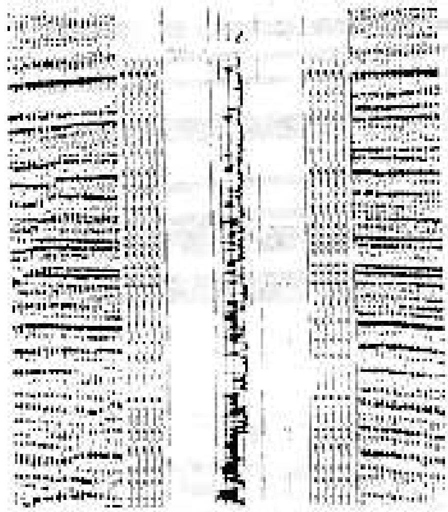

Fig. 10: Well to Seismic match

HORIZONS	WELL-TO-SEISMIC MATCH
D1.0	Black loops effective coincided
D2.0	Black loops coincided
D3.0	Black loops coincided
Below E2.0	Black loops coincided
E3.0	Black loops coincided
Above E7.0	Black loops coincided
Below K2.0	Black loops coincided

Well 2 showed a fairly good well-to-seismic match. Beyond K2.0 the match became very poor. The time-depth conversion was carried out, tabulated in Table 2 and plotted in Fig. 11.

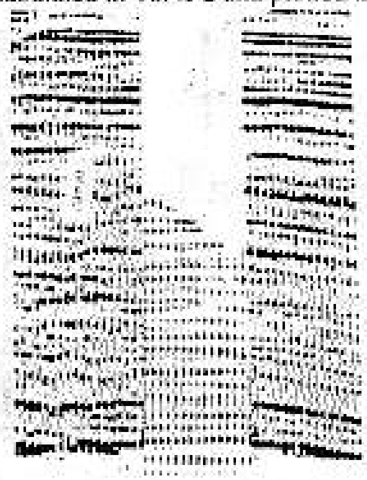

Fig. 11: Actual WSP to Surface Seismic match

Actual WSP – to – Seismic Match

Fig. 12. displays the WSP- to-seismic tie. The result shows a fairly good match.

HORIZONS	WSP – TO – SEISMIC MATCH
E9.0	Black loops coincided
K4.0	Black loops coincided
K7.0	Black loops coincided

Analysis of Fluid Substitution

The amplitude anomaly of horizon K3.0 on Well 2 was investigated by interchanging various fluids (oil, water, and gas). The result for each substitution and models were shown in Figs 7, 8, and 9. There is now a strong corroboration of the fact that flat spot is indicative of fluid contact and bright sport an indication of hydrocarbon. Thus the amplitude anomaly is an indication of hydrocarbon. As can be seen from the result obtained, WSP data showed a clear and more consistent amplitude anomaly than the surface seismic data. In this respect, then, the WSP data are known to give clearer position of faults than surface seismic data. Whenever mismatches are observed these could be attributed to wrong identification of the reservoir on the seismic and poor data quality of both seismic and well synthetic data. This is why WSP is always recommended where velocity/synthetic data are of poor quality and could not cover the objective sequence.

Table 1.1: Reservoir properties for Well 1

Horizon	Depth (ft)	Densities (g/cc)			Velocity (ft/s)			Time (ms)
		Shale	HC sand	Water sand	Shale	HC sand	Water sand	
Shale 1	5300-6540	2.3			9680			1800
D2.0	6540-7100			2.2			9047	1900
Shale 2	7100-7431	2.31			9580			2000
D3.0	7431-7600			2.1			9805	2150
Shale 3	7600-7704	2.25			9523			2150
D4.0	7704-8100			2.2			9[illegible]	2190
Shale 4	8100-8457	2.4			9524			2200
D6.0	8457-8800		2.18	2.17		9000	9174	2300
Shale 5	8800-9143	2.4			10000			2350
D8.0	9143-9500		2.2	2.25		9000	9174	2450
Shale 6	9500-9800	2.45			10000			2500
E2.5	9800-10500		2.2	2.3		9523	9803	2600
Shale 7	10500-11400	2.5			11200			2770
E7.0	11400-11600		2.21	2.25		9800	9523	2800
Shale 8	11600-12000	2.55			11764			2850
E9.0	12000-12400		2.1	2.18		10526	11111	2950
Shale 9	12400-13000	2.5			11764			3000

Table 1.2: Reservoir properties for Well 2

Horizon	Depth (ft)	Densities (g/cc)			Velocity (ft/s)			Time (ms)
		Shale	HC sand	Water sand	Shale	HC sand	Water sand	
Shale 1	7000-7500	2.25			11111			2000
E5.0	7500-7800			2.15			10204	2100
Shale 2	7800-8200	2.18			10436			2110
E6.0	8200-8600			2.0			10204	2200
Shale 3	8600-8700	2.3			10526			2210
D7.0	8700-9500			2.12			10989	2400
Shale 4	9500-10100	2.28			10526			2500
E5.0	10100-11100			2.15			10989	2700
Shale 5	11100-11400	2.31			12195			2750
F7.0	11400-12000			2.18			11764	2800
Shale 6	12000-12300	2.32			12048			2920
K3.0	12300-12700		2	2.2		11764	11904	2960
Shale 7	12700-13000	2.47			12048			3050
K6.0	13000-13300			2.25			11764	3050
Shale 8	13300-13700	2.45			12820			3150

Table 1.3: Reservoir properties for Well 3

Horizon	Depth (ft)	Densities (g/cc)			Velocity (ft/s)			Time (ms)
		Shale	HC sand	Water sand	Shale	HC sand	Water sand	
Shale 1	6000-6400	2.26			11111			1800
R1.0	6400-6800			2.1			10526	1850
Shale 2	6800-7000	2.40			15384			1880
R5.0	7000-7300			2.3			10204	1930
Shale 3	7300-7400	2.30			11111			1960
R6.0	7400-7700			2.0			10526	2010
Shale 4	7700-7800	2.30			10989			2020
S[illegible].0	7800-8400			2.35			10526	2180
Shale 5	8400-8800	2.21			15384			2230

Acknowledgement

We wish to thank Shell Petroleum Development Company (SPDC), special studies group (DTE-ISS) for making available to facilitate this study.

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