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Development of Seismic Survey Technology in Nigeria Oil Industry and the Volume of Seismic Acquisition 1997 – 2014

By

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Abstract

This paper presents an account of the development of seismic activities in Nigeria. Two dimensional seismic exploration for hydrocarbons started in 1937 and was concentrated in the southeastern part of the country where oil had been reported earlier. Following the drilling of the first commercially viable oil well in Nigeria in 1956 at Oloibiri, seismic activities increased. The first offshore and onshore 3D seismic surveys took place in 1984 and 1986 respectively. In 2001 the first 4D seismic was conducted at the Nembe swamp. The shooting pattern varied first from the brick wall to checker board while the recording equipment increased in sophistication from Sercel 368 to Sercel 428 XL capable of recording 10000 channels. From 1997 the Nigerian National Petroleum Corporation documented the volume of seismic acquisition and processing/reprocessing activities. 3D acquisition varied between 17,457 km^2 and less than 4000 km^2 between 1997 and 2012, and the same period saw a significant reduction in 2D acquisition. The volume of 3D seismic data processed/reprocessed was about 10,000 km^2 per year between 1997 and 2012. The increase in the volume and sophistication of seismic survey in Nigeria has contributed to the reduction of uncertainty in the whole exploration process and the boosting of the country's oil reserve.

Keywords: Seismic, Survey, Mapping, Imaging, Data, Stratigraphy, Technology.

Introduction

Oil exploration is known to have commenced in Nigeria in 1908 when a German company – the Nigeria Bitumen Corporation started exploration in the Araromi area of western Nigeria. This campaign was cut short by the outbreak of the First World War in 1914. In 1937 Shell D'Arcy was awarded the sole concessionary rights over the entire country and in the same year it conducted the first seismic exploration in Nigeria[1]. This was a 2D seismic survey which entailed having both the energy source and the receivers on the same line. Explosives (dynamite) were used as the seismic energy source. The initial seismic surveys in the country were not in the Niger Delta region as is presently the case but rather in the southeastern part of the country and

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[1] Kadafa, A. A. (2012). *Oil exploration and spillage in the Niger Delta of Nigeria*. Civil and Environmental Research, 2**(3)**, 38-51.

Enugu was used as a temporary base by Shell D'Arcy. The company conducted exploration in places like Nsukka, Okigwe, Afikpo, Port Harcourt, Benin City, Cross River area, and Forcardos[2]. The concentration of exploration in this part of Nigeria was probably informed by the finding of oil in the region four years earlier by Nigeria Bitumen Company. The outbreak of the Second World War put a halt to the exploration activities by Shell D'Arcy. It was not until 1947 that the company, under a new name, Shell British Petroleum Company (Shell BP) resumed seismic exploration in the country[3].

After 28 dry wells had been drilled elsewhere, onshore water-borne (swamp) seismic surveys were commenced in the Niger Delta by Shell BP and resulted in the first commercially viable well at Oloibiri in 1956. Following this success and increased seismic activities, initial daily production was 5,100 barrels in 1958. By 1972 Nigeria had become the sixth world largest oil producer, i.e. one year after it joined the Organization of Petroleum Exporting Countries (OPEC)[4]. Seismic survey activities later moved into the offshore, using airgun as seismic energy source. By the late 1980s, the whole land and swamp areas of the Niger Delta had been traversed by 2D seismic survey. 2D seismic is recorded using straight lines of receivers crossing the surface. The resulting data is only a single slice of the earth and rarely represents a true planar slice through the earth. The fold of 2D survey is linked to the maximum useable offset and the source interval.

$$Fold_{2D} = \frac{Number\ of\ traces\ per\ record}{2} \times \frac{\text{Re}\,ceiver\,\text{int}\,erval}{Source\,\text{int}\,erval} = \frac{Maximum\,useable\,offset}{Source\,\text{int}\,erval} \qquad (1)$$

Furthermore, the final stacked data in 2D is usually plagued by source-related noise, multiples, and incorrectly migrated events from out of the plane of seismic section[5].

Advent of 3D Seismic

The introduction of digital recording and processing techniques in the 1960s facilitated enhanced 2D subsurface imaging and the introduction of 3D in the 1970s. In Nigeria, the first 3D seismic survey was conducted by Western Geophysical Company for Gulf Oil Company on behalf of Nigeria National Petroleum Corporation (NNPC) between August 1984 and March 1985 in Malu-Parabe offshore field northwest Niger Delta using airgun sources and streamed cable. About 6,865 km of 48% seismic data were acquired equivalent to approximately 300 km^2 located in water depths varying between 6.1 m to 30.5 m. The first 3D seismic survey on land/swamp was conducted at Nun River by the same seismic contractor, Western Geophysical, for SPDC in

2 Aghalino, S. O. (2009). Crude Oil Business in the Western Niger Delta, Enugu: Rhyce Kerex Publishers, 30-45.

3 Kadafa, A. A. (2012). Environmental impacts of oil exploration and exploitation in the Niger Delta of Nigeria. Global Journal of Science Frontier Research Environment & Earth Sciences, 12(3).

4 Atsegbua, L. (1999). The development and acquisition of oil licenses and leases in Nigeria. OPEC review, 23(1), 55-77.

5 Tsinidis, G; Heron, C; Pitilakis K, (2014) Physical modeling for the evaluation of the seismic behavior of square tunnels; Seismic Evaluation and Rehabilitation of Structures. Springer International Publishing, 389-406.

1986[6]. Since then the industry has witnessed an increasingly rapid expansion in the application of this technology which is presently applied to exploration to development and exploitation. Commercially available 3D survey design programs have enabled the analysis of bin attributes; effective fold, regularity of offsets, and azimuth distribution[7].

3D seismic data shows a volume of the earth and can be seen as a collection of individual 2D profiles (eq. 2).

$$Fold_{3D} = \frac{Useful\ surface\ area\ of\ \ patch}{4 \times Source\ line\ spacing \times \mathrm{Re}\, ceiver\ line\ spacing} \qquad (2)$$

Three dimensional subsurface imaging information is continuous, unlike 2D which shows only strips of information of the subsurface.

Azimuth is a statistic unique to 3D recording and not a contributor to 2D processes. Azimuth adds a dimension of statistical diversity that is very helpful to the imaging procedure. Although 3D does not remove all exploration risk, it generally improves success rates and productive wells will more often be on optimal locations and should deliver better production and exhibit slightly longer life[8].

In 2001, the first 4D (four-dimension) seismic survey on land/swamp in Nigeria was conducted at Nembe. This is a 'repeat 3D seismic survey` after some time (five or more years) interval between the surveys. Similar techniques were employed at Imo River, Cawthorne Channel, Akaso and other land/swamp areas of the Niger Delta. Integration of multidisciplinary knowledge and data with 4D seismic has provided valuable information for detailed reservoir characterization, planning and execution of enhanced oil recovery strategies, and monitoring of the changes in reservoirs as they are developed and produced.

Oil exploration in Nigeria remained in the hands of multi-nationals while government played only regulatory role until 1969. The Department of Petroleum Resources (DPR) and Nigerian National Petroleum Corporation (NNPC) were formed in 1969 and 1977 respectively as government organs to participate in oil exploration and exploitation, and this led to a rapid growth in exploration activities. To enhance crude production and boost the national economy, the government of Nigeria liberalized exploration activities. As a result, seismic activity

[6] Steyn, M. S, (2009). '*Oil Exploration in the Colonia Nigeria 1903-58*', Journal of Imperial Commonwealth History, 37**(2)**, 249-289.
[7] Osagiede, E.E; Duffy, O.B; Jackson, CA-L; Wrona, T. (2014). *Quantifying the growth history of seismically imaged normal faults*, Journal of Structural Geology, Vol: **66**, Pages: 382-399, ISSN: 0191-8141.
[8] Barkved, O.I., Baerheim, A.G., Howe, D.J., Kommedal, J.H., & Nicoe, G., (2003). *Life of Field Seismic Implementation "First at Valhall"*. Implementing 4D Seismic in the Management of Producing Reservoirs. 65th Annual Conference and Exhibition of the European Association of Geoscientists and Engineers, Work- shop proceedings.

increased tremendously both onshore and offshore[9]. The notable seismic companies that were involved included Western Geophysical Company, Bureau of Geophysical Prospecting (BGP), Compagnie Generale de Geophysique Nigeria Limited (CGG), Geco Prakla Nigeria Limited, Integrated Data Services Limited (IDSL), Mabon Geophysical Corporation Nigeria Limited, Massoil Field Services Limited., Petroleum Geo Services Nigeria Limited (PGS), Pioneer-Alfa Petroleum Services Limited (PPS), Schlumberger Geco Prakla Nigeria Limited., Schlumberger Geoquest, Schlumberger WesternGeco, United Geophysical Nigeria Limited (UGNL) and Veritas Geophysical Nigeria Limited.

The shooting geometry during the 2D era from the 1950s to the 1980s was the typical single source line array[10]. At the introduction of 3D the most widely used shooting array was the brick wall pattern (Figure 1.)

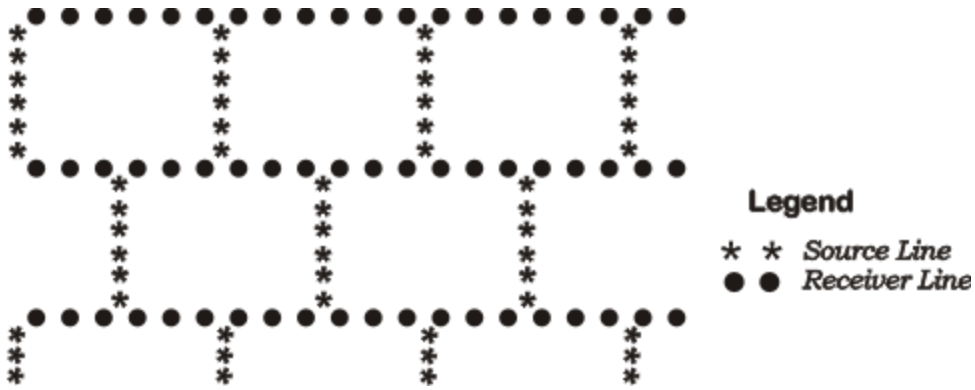

Figure 1: Brick wall shooting pattern

[9] De Groot, P., Ligtenberg, H., Oldenziel, T., Connolly, D. & Meldahi, P.(2004)*Examples of multi-attribute, neural network- based seismic object detection*. In: Davies, R. J., Cartwr1ght,J. A., Stewart, S. A., Lappin, M. & Underhill, J. R. (eds) 3D Seismic Technology: Application to the Exploration of Sedimentary Basins. Geological Society, London, Memoirs, 333-337.

[10] Shenglin, S. and Xizun, W.(2004), *Application Results of 3D seismic exploration Technology in coal Mines*. Acta Geological Sinica, Journal of the Geological Society of china, 78**(3)**729-735.

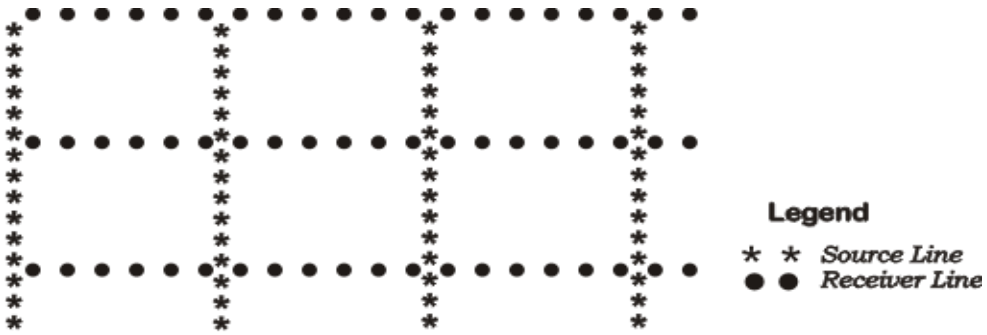

Figure 2: Checker board shooting system

The brick wall requires high maneuvering and is therefore time consuming and costly to implement. In the 1990s many companies changed to checker board (roll-along) pattern (Figure 2). This requires the least maneuvering, is faster and cheaper, and has not been found to be technically inferior to the brick wall pattern. The pattern has persisted to date. The recording equipment has equally seen a dramatic increase in sophistication starting with Sercel 348 in the 80s to Sercel 428 XL capable of handling up to 10,000 channels introduced in the late 1990s[11].

Volume of Acquisition and Processing

Nigerian National Petroleum Corporation compiled the figures on seismic acquisition and processing between 1997 and 2014. The acquisition companies are grouped as Joint Venture (JV) Partners, Production Sharing Contract (PSC) and Service Contract (SC) Companies. In 1997, the operating companies acquired a total 17,457.63 km^2 of 3D seismic data (Figure 3) while a total of 750 km were covered by 2D seismic survey (Figure 4)[12]. The following year seismic activities were undertaken by 5 Joint Venture Companies and 2 other Oil Producing Companies, operating under Production Sharing Contracts (PSC). The companies acquired a total of 2,739.40 km^2 of 3D seismic data while a total of 864.00 km were covered by 2D seismic survey. In the same year, only 5,689.7 km^2 of 3D (Figure 5) and 111 km of 2D (Figure 6) was processed/re-processed. There was a decline of about 84% and 5% in total area covered by 3D and 2D seismic activities respectively over 1997 activities. This was due to lack of funds and host communities disturbances[13]. There was a further reduction in seismic acquisition in 1999. The 3D subsurface acquisition in 1999 shows a shortfall of 751.40 km^2 compared to 1998 and 15469.63 km^2 compared to 1997. This was attributed to increased community unrest and the fact that one of the seismic crews started late[14]. A total of 1051 km^2 and 1419.27 km^2 of 3D subsurface data were acquired in 2001 and 2005 respectively. These years witnessed the lowest acquisition activity within the period under review[15],[16]. There are no data of seismic acquisition for 2011. A total of 4695.6 7 km^2 and 1668 km^2 of 3D data were acquired in 2013 and 2014

[11] Obaje, S. O. (2013). *Seismic interpretation of Tomboy Field, offshore western Niger Delta, Nigeria*. International Journal of Science and Technology, 2**(9)**, 648-660.
[12] Nigeria National Petroleum Corporation (NNPC) Annual Statistical Bulletin Report 1997.
[13] Nigeria National Petroleum Corporation (NNPC) Annual Statistical Bulletin Report 1998.
[14] Nigeria National Petroleum Corporation (NNPC) Annual Statistical Bulletin Report 1999
[15] Nigeria National Petroleum Corporation (NNPC) Annual Statistical Bulletin Report 2001
[16]Nigeria National Petroleum Corporation (NNPC) Annual Statistical Bulletin Report 2005

respectively. Two dimensional (2D) seismic survey are now seldom embarked upon in Nigeria[17]. In the 18-year period of 1997 – 2014, 2D seismic surveys was registered only in 4 years.

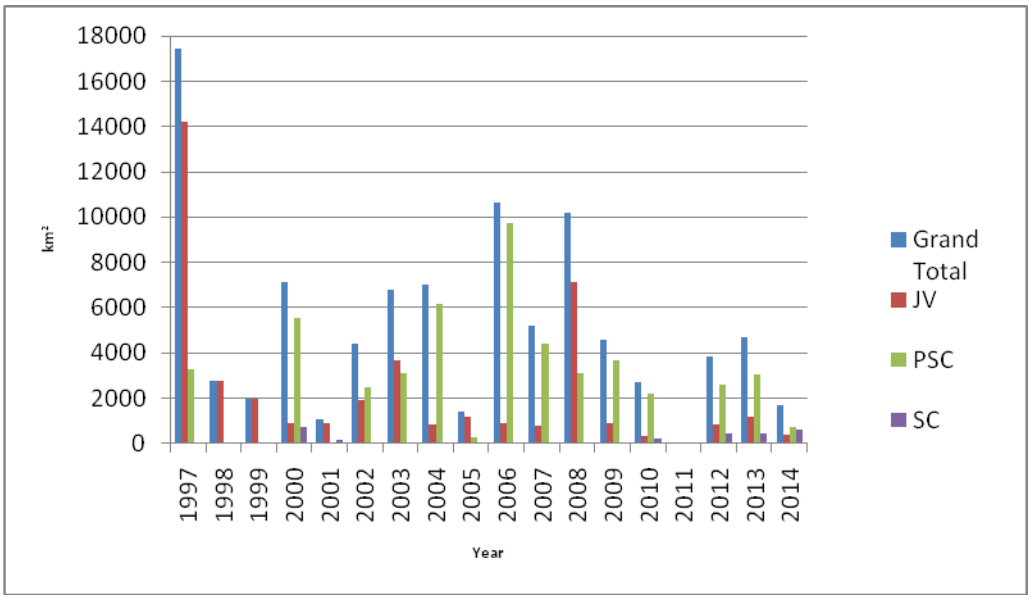

Figure 3: 3-D Seismic Acquisition in Nigeria (1997 – 2014)

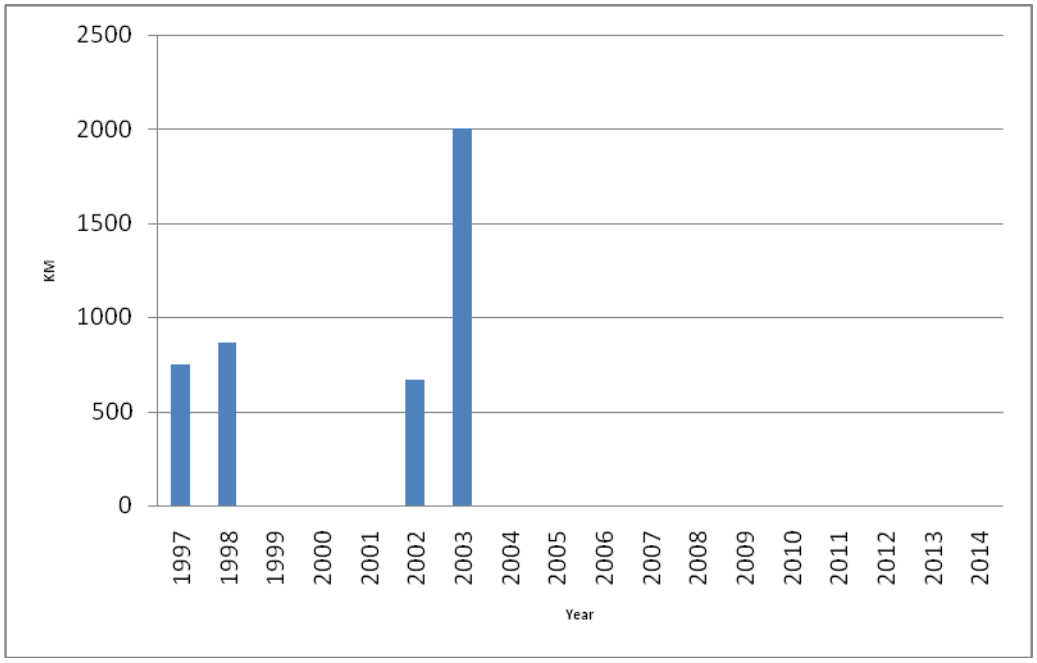

Figure 4: 2-D Seismic acquisition in Nigeria (1997 – 2014)

[17] Nigeria National Petroleum Corporation (NNPC) Annual Statistical Bulletin Report 2011

Processing/Reprocessing

Seismic data, in Nigeria like many other countries are often not all processed/reprocessed the same year the data is acquired. The amount of processed/reprocessed data may therefore not reflect what was acquired that year[18]. Between 1997 and 2012, more than ten thousand square kilometers of 3D seismic data were processed and reprocessed each in the years 2000, 2002, 2004, 2006 and 2010 with the highest figure of 17,800.4 km^2 process/reprocessed in 2002 (Figure 5)[19,20,21]. In 2001 only 1,966 km^2 were process/reprocessed. No data were processed/reprocessed in 2005 and 2011[22,23].

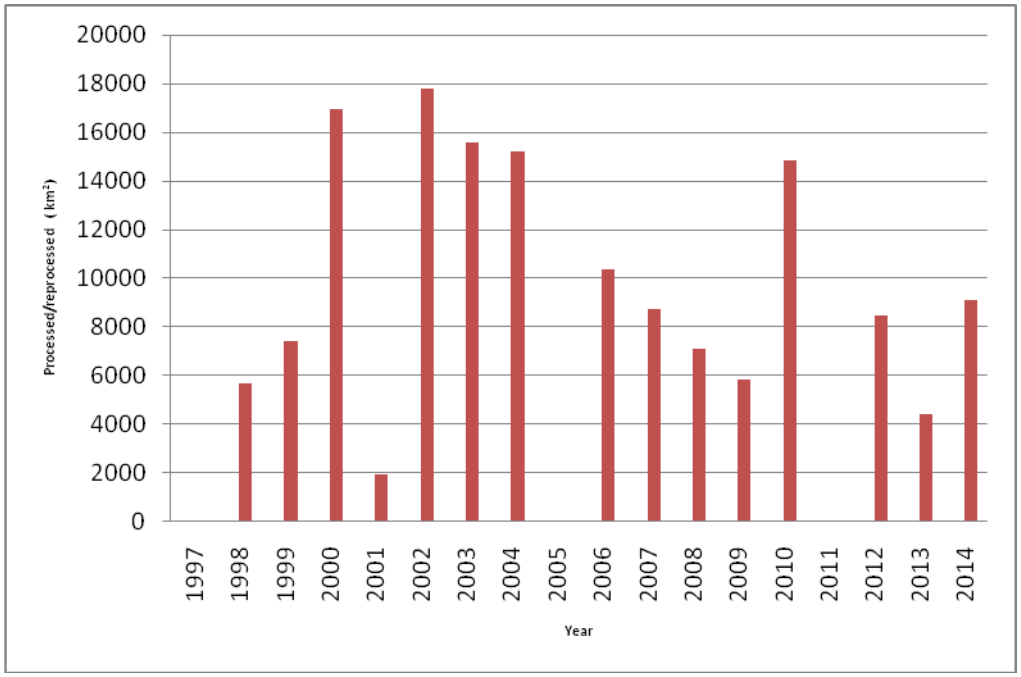

Figure 5: Processed/reprocessed 3-D seismic data (1997 – 2014)

Processing/reprocessing of 2D data took place only in 1998, 1999 and 2002 (Figure 6)[24,25,26].The processing of the relatively high volume of 2D data acquired in 2003 has not been documented[27].

[18] Yilmaz, O. (2001) Seismic Data Analysis: Processing, Inversion, and Interpretation of seismic Data. Invest. Geophysics series, 10-14.
[19] Nigeria National Petroleum Corporation (NNPC) Annual Statistical Bulletin Report 2002
[20] Nigeria National Petroleum Corporation (NNPC) Annual Statistical Bulletin Report 2000
[21]Nigeria National Petroleum Corporation (NNPC) Annual Statistical Bulletin Report 2003
[22] Nigeria National Petroleum Corporation (NNPC) Annual Statistical Bulletin Report 2004
[23] Nigeria National Petroleum Corporation (NNPC) Annual Statistical Bulletin Report 2006
[24] Nigeria National Petroleum Corporation (NNPC) Annual Statistical Bulletin Report 2010
[25] Nigeria National Petroleum Corporation (NNPC) Annual Statistical Bulletin Report 2007
[26] Nigeria National Petroleum Corporation (NNPC) Annual Statistical Bulletin Report 2008
[27] Nigeria National Petroleum Corporation (NNPC) Annual Statistical Bulletin Report 2009

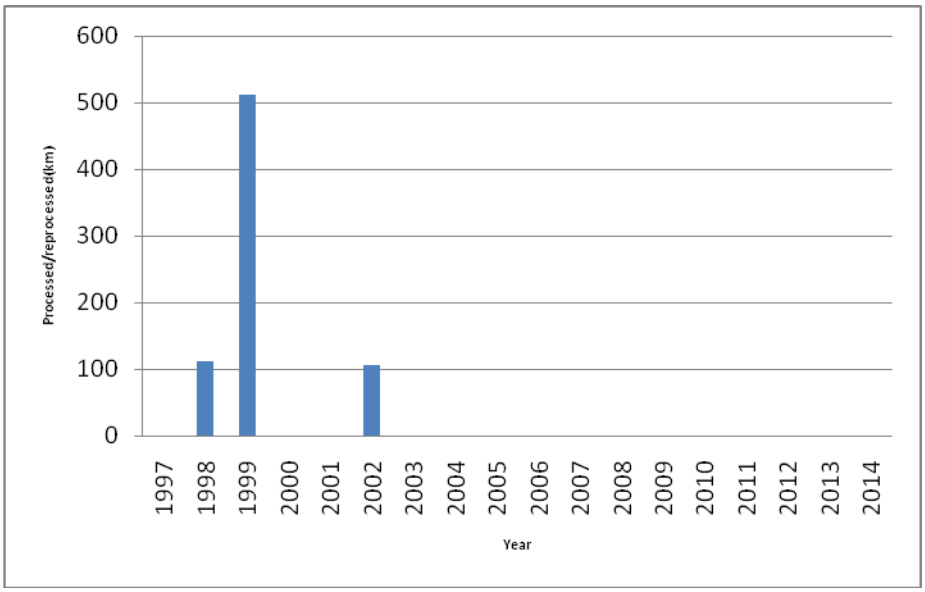

Figure 6: Processed/reprocessed 2-D seismic data (1997 – 2014)[28]

Summary

Seismic survey has witnessed a rapid growth in Nigeria in terms of volume of acquisition and improvement in technology. In 1937 Shell D'Arcy carried out the first 2D seismic survey in Nigeria, but it was not till 1956 that its successor company, Shell BP, made the Oloibiri commercial discovery. By late 1980s, up to fourteen seismic companies were involved and the whole land and swamp areas of the Niger Delta had been traversed by 2D seismic survey. The first 3D seismic survey on land was conducted in 1984 and in 1986 on swamp area. 3D seismic generally improves success rates by facilitating the optimal placement of development wells and allowing for longer productive life. It took up to the turn of the century for time lapse (4D, which is a repeat 3D) seismic to be used in Nigeria. Between 1997 and 2012, over 10,000 km^2 per year of 3D seismic were processed and reprocessed with the highest figure of 17,800.4 km^2. Two dimensional seismic surveys are gradually losing application while 4D seismic is increasingly being undertaken.

Conclusions and Recommendations

Rapid development in 3D seismic survey technology has helped Nigeria to continually increase her proven oil reserve in the last 30 years. Four dimensional (4D) seismic survey techniques have been successfully employed for reservoir characterization. The shortfall in the volume of seismic data acquired in some years was largely caused by security challenges in the Niger Delta Area. During such periods increased reprocessing of seismic data is recommended to augment the shortfall in acquisition.

[28] Nigeria National Petroleum Corporation (NNPC) Annual Statistical Bulletin Report 2012