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Evaluation of optimal reservoir prospectivity using acoustic-impedance model inversion: A case study of an offshore field, western Niger Delta, Nigeria

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A B S T R A C T

The evaluation of economic potential of any hydrocarbon field involves the understanding of the reservoir lithofacies and porosity variations. This in turns contributes immensely towards subsequent reservoir management and field development. In this study, integrated 3D seismic data and well log data were employed to assess the quality and prospectivity of the delineated reservoirs (H1–H5) within the OPO field, western Niger Delta using a model-based seismic inversion technique. The model inversion results revealed four distinct sedimentary packages based on the subsurface acoustic impedance properties and shale contents. Low acoustic impedance model values were associated with the delineated hydrocarbon bearing units, denoting their high porosity and good quality. Application of model-based inverted velocity, density and acoustic impedance properties on the generated time slices of reservoirs also revealed a regional fault and prospects within the field.

1. Introduction

Determination of hydrocarbon bearing sands is a primary goal of most reservoir characterization projects and efforts are made to increase the confidence levels and reduce to the barest minimum the associated risks in drilling and exploration activities. Seismic inversion technique is principally a sophisticated process of inverting the seismic data into the elastic properties of the earth's subsurface. Elasticity and density are seismic characters of subsurface strata that are principally affected by the subsurface properties of rocks and fluids like lithology, porosity, fractures, textures, permeability, viscosity, fluid type and saturations (Mavko et al., 2009; Bosch et al., 2010). The quantitative characterization of these subtler fluid properties from seismic responses would go a long way to improve hydrocarbon reservoir characterization and reserve estimation within a hydrocarbon field (Russel, 1988; Doyen, 2007). Seismic inversion of the acoustic impedance property primarily involves the conversion of seismic traces into reflection coefficient time series, which are then converted back into acoustic impedance traces (Lavergne and Willim, 1977; Lindseth, 1979).

These generated acoustic impedance traces have the capacity to improve the accuracy of geological interpretations (e.g. environments of deposition and stratigraphy) and subsequent correlations with several petrophysical properties derived from the wireline logs (Xinyang et al., 2015). Benefits of seismic acoustic impedance data over conventional seismic data have been discussed by several researchers (Duboz et al., 1998; Connolly, 1999; Latimer et al., 2000; Yilmaz, 2001; Pendrel, 2006). Seismic inversion converts the seismic reflection data into an acoustic impedance section where band-limited seismic reflection data are transformed into quantitative rock properties for effective reservoir identification and description. Where the acquired exploration data involve high quality seismic and better distribution of well control, the interpretations of acoustic impedance model inversion often facilitates an improved estimation of reservoir porosity, acoustic impedance and uncertainty (Pendrel, 2001; Alshuhail et al., 2009;

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Jalalalhosseini et al., 2015). Seismic acoustic impedance inversion section elucidates subsurface layers thereby enhancing visualization both in terms of layering and vertical resolution unlike reflection coefficient of raw seismic data that reveal only the interface. However, the major limitation of this method is that it suffers major setback when the reservoir thickness falls below a quarter of wavelength (1/4 λ). These thin beds and other small targets can be resolved on seismic data in two ways. The first involves increasing the dominant frequency of the stacked data simply by raising the bandwidth of the seismic data. The other involves conducting a phase shift or phase rotation of the seismic data through the use of advanced data processing algorithms and other inversion techniques such as seismic coloured inversion (Oyeyemi et al., 2016; Oyeyemi et al., 2017). The values of acoustic impedance derived from seismic inversion process are suitable to infer zones of high and low porosity within the delineated reservoirs. The relationship between the derived acoustic impedance and porosity is such that when the former is low, the later and the reservoir potential in terms of hydrocarbon saturation would be high (Dolberg et al., 2000; Farajpour et al., 2010; Çemen et al., 2014). Varela et al. (2006) reiterated the importance of acoustic impedance seismic inversion in reduction of uncertainty associated with reservoir production forecast, while Kadkhodaie-Ilkhchi et al. (2014) stated categorically that acoustic impedance section from a model-based seismic inversion technique is a robust tool for tight sandstone reservoir characterization. There are several methods for seismic inversion analysis and they are broadly categorized into either deterministic or stochastic process. The deterministic seismic inversion include band-limited, sparse-spike and model-based techniques. The focus of this study is to use a model-based deterministic seismic inversion technique to evaluate the hydrocarbon potential and prospectivity of the delineated reservoirs within the study area in western Niger Delta.

2. Geological setting

The hydrocarbon field of study is situated between Longitudes 5°00′E–5°02′E and Latitudes 5°50′N–5°52′N lying within the western parts of the continental margin shallow offshore Niger Delta basin (Fig. 1). The basin is bounded in the South by the Gulf of Guinea and in the North by the cretaceous tectonic elements including the Abakaliki uplifts, Afikpo syncline and the Anambra basin (Fig. 1). The siliciclastic deposits within this basin are of Tertiary age with three lithologic formations termed Akata, Agbada and Benin Formations (Fig. 2). The basal marine shale Akata Formation extends down to the basement and is a pro-delta shale unit with characteristic dark-grey and medium hard with floral fossils within its upper portion. The overlying paralic sequences of Agbada Formation house the oil and gas bearing reservoir units in Niger Delta; this geologic formation is composed of sandstone with interbeds of shale units that are typical of the delta front, distributaries channels and deltaic plain depositional facies (Avbovbo, 1978). Agbada Formation is characterized with increasing shale content from the upper to the lower portion denoting the seaward advance of the Niger Delta basin over some geologic time. The topmost Benin Formation is composed of massive continental plain sands that are highly porous with relatively low minor shale interbeds connoting an alluvial environment of deposition. The predominant structural styles within the Niger Delta are syn-sedimentary structures also referred to as the growth faults, deforming the delta under the Benin continental sandstone facies. These growth faults, generally trending in NE-SW and NW-SE directions (Hosper, 1971), are byproducts of that gravity sliding during the sedimentation of the deltaic deposits and they are polygenic in nature as their complexity increase in a down-dip direction of the delta (Merki, 1972; Corredor et al., 2005). According to Orife and Avbovbo (1982) the stratigraphic traps that are associated with unconformity surfaces

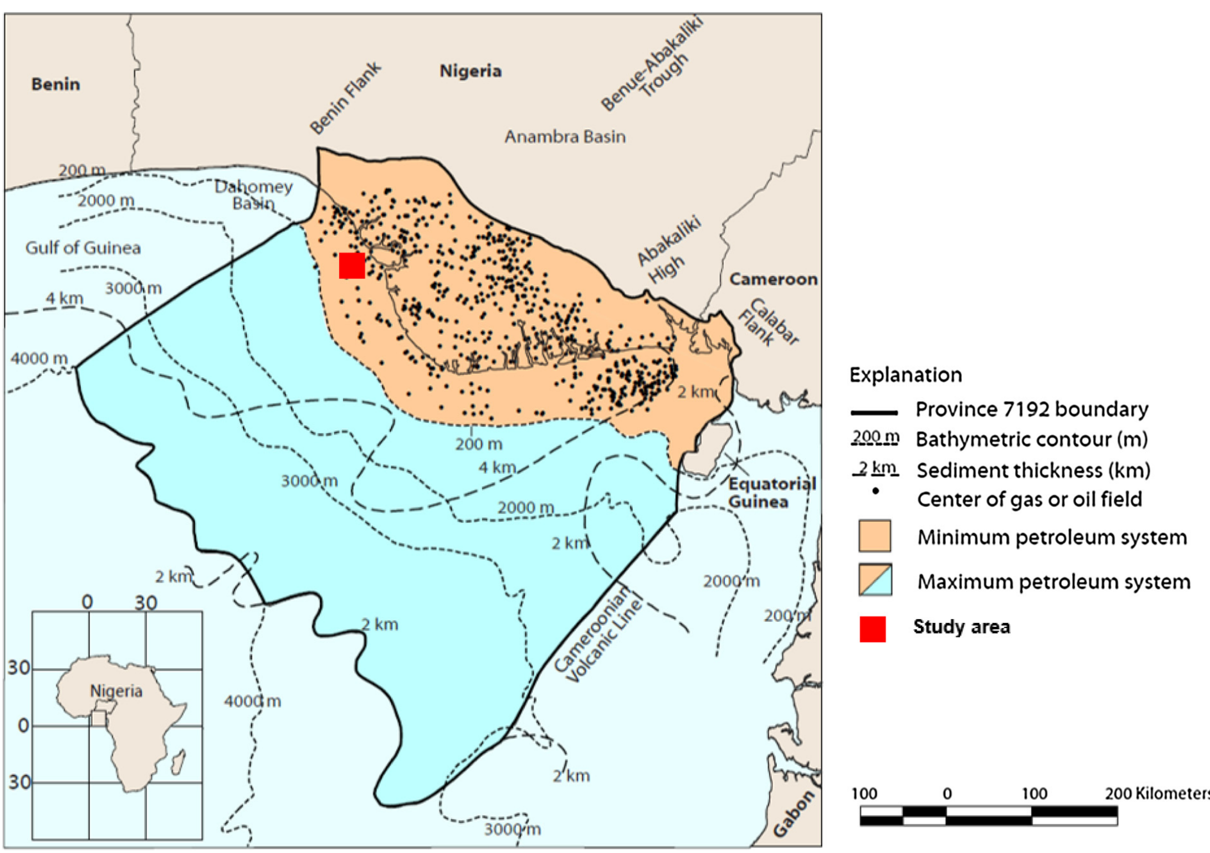

Fig. 1. Index map of the Niger Delta showing province outline bounding structural features and minimum petroleum system (After Michele et al., 1999).

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