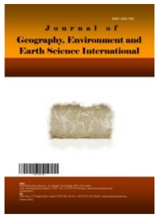

Journal of Geography, Environment and Earth Science International

23(4): 1-9, 2019; Article no.JGEESI.50264
ISSN: 2454-7352

Petrophysical Application towards Achieving Optimum Secondary Recovery in Heterogeneous Reservoirs

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Authors' contributions

This work was carried out in collaboration among all authors. Authors IEU and EA designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors IEU, EA and NJG managed the analyses of the study. Author EA managed the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JGEESI/2019/v23i430176
Editor(s):
(1) Dr. Kingsley Eghonghon Ukhurebor, Lecturer, Department of Physics, Edo University, Iyamho, Edo State, Nigeria.
Reviewers:
(1) Eyankware Moses Oghenenyoreme, Ebonyi State University, Nigeria.
(2) Vinay Kumar Pandey, India.
Complete Peer review History: https://sdiarticle4.com/review-history/50264

Original Research Article

Received 11 May 2019
Accepted 25 July 2019
Published 15 November 2019

ABSTRACT

Globally the challenge to meet the increasing energy demand is on with the application of game-changing technologies to maximize recovery from proven reserves in mature assets. Production studies have shown that some Niger delta fields have heterogeneous reservoirs with low to fair recovery factor derived in most cases by software simulations without adequate field acquired reservoir parameters before embarking on the secondary development plan for such reservoirs. Failures recorded in most secondary recovery strategies for heterogeneous reservoirs are accountable for lack of in-depth studies of the reservoir characteristics. There is a direct relationship between reservoir recovery factor and the petrophysics of the reservoir. A sand body in the field can exhibit variable petrophysical changes at different positions in the field. Therefore optimum secondary recovery plan for such reservoirs are designed with the combination of field acquired (not simulated) petrophysical data (porosity and permeability), the environment of deposition, special core analysis and formation evaluation studies. This study emanates from the recently developed project in a field in Niger delta.

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Keywords: Heterogeneous reservoirs; petrophysical data; software simulations; porosity and permeability.

1. INTRODUCTION

Heterogeneous reservoirs are reservoirs with complex petrophysical characterization in the given field [1]. Reservoir heterogeneity is a function of the porosity/permeability distribution due to lithologic variation during sedimentary deposition which is further complicated by mechanical processes related to deformation and chemical processes associated with diagenesis. Fluid flow in reservoirs is affected by heterogeneity at a range of scales, from submeter up to 10's of metres, but the predominant control is exerted by bedding, pore fluid changes, and diagenetic effects at the metre-scale (Grammer, et al, 2004).

The temporal and spatial resolution necessary for characterization of reservoir heterogeneity at the metre-scale can be achieved through cross-well seismic imaging [2] by avoiding near-surface effects that attenuate high frequencies and by reducing absorption through shorter propagation distances. These two factors allow for high-resolution sampling (~1m) directly at reservoir depths (Lazaratos, 1993).

Anda field was discovered in 1999, with several wells drilled into the main reservoir in the field. The field was brought into production in 2011 with a daily production rate of about 19,146 barrels of oil per day. In 2009 the daily production declined to 1,144 barrels per day. The secondary recovery plan was proposed for the entire field using water injection but negation recovery responses were observed in some parts of the field. This study was necessitated by irregular responses of the secondary recovery measures adopted in the field. Anda field main reservoir displays heterogeneous petrophysical properties with consequent production irregularities in wells producing from the reservoir. This reservoir poses irregular production performances in the field. Secondary recovery plan for these reservoirs is designed with field acquired data for optimum development. Design based on simulation data for secondary recovery in such fields results in under exploitation of the reserve and sometimes reservoir damage due to over stimulation. An optimum recovery strategy for such reservoirs involves integration of multi-geoscience data for field wide reservoir studies which may give rise to field compartmentalization for effective reservoir management and optimum discovery [3].

1.1 Field Location

Anda field is an onshore field location in the south western part of the Niger delta with a total area of about 70 square kilometer (see Fig. 1).

The Niger Delta is the most prolific sedimentary basin within the Western African sub-continent. It is known to be one of the world's top twelve accumulations of recoverable petroleum; having reserves over thirty four billion barrels of crude oil and ninety three trillion cubic feet of gas. The tectonic setting of this basin has been attributed to the divergence of the African and South American Plates and creation of Southern Atlantic it has also being proposed that a triple junction developed. Grant [4] suggested RRF (ridge-ridge fault) mechanism for the initiation of this separation. Wright, [5] on the other hand proposed an RRR (ridge-ridge-ridge) mechanism. The inactive rift of this triple structure is the Anambra/Benue rift valley where the Oceanic crust was inactive. The rivers' depositional centers moved seawards and in consequence, the coastal plain deposits became progressively younger in that direction. The Niger Delta complex has undergone little deformation at the upper level but the subsurface had experienced major deformation by large scale syn sedimentary features such as growth fault, rollover anticlines and diapers.

2. MATERIALS AND METHODS

The materials used for this study include the following: Base map of the study area showing well locations, Log suites which include Gamma ray logs, resistivity logs; Neutron density logs, and porosity logs, Biofacies data, Paleobathymetric environment of deposition, 3D seismic section of the field, and Niger Delta Cenozoic chronostratigraphic chart. Methodology A sequence stratigraphic approach modified,after Posamentier et al. (1988), Van Wagoner et al. (1990).

2.1 Data Set and Methodology

The following data set were utilized in the study.

1. Ten years production data from the field was utilized to observe production

irregularities in the main reservoir in the field.

2. Formation evaluation data of the reservoir from selected wells in the field were used to carry out detailed correlation studies for determination of environment of deposition (Fig. 4) and depicting stratigraphic system tracts in the reservoir after, Reijers [6] and Schlumberger [7].

3. Ditch cutting samples of the reservoir were analyzed for the diagnosis of paleodepositional studies and paleobathymetry of the reservoir (Table 2).

4. Special core analysis data of the reservoir were utilized for the interpretation of the petrophysical properties of the reservoir.

5. Biostratigraphic data sets (Tables 3 and 4) from the reservoir were utilized for correlation and horizons dating of the reservoir using biostratigraph marker species of Petters [8] and Oboh [9] Fig. 2.

6. Seismic data were used for correlation and reflection character analysis (Fig. 3).

7. Production profiles of the reservoir, from first oil date to present were used in the observation of the production decline pattern for the field (Table 1).

Table 1 shows production irregularities from the study reservoir in Anda field. Deviation from the expected production forecast was observed from the production decline pattern of the field. None uniform responses were also observed from in some wells when secondary recovery measures were applied in the field after ten years of production.

Petrographic studies show that the reservoir exhibits immature sediments in most part of the field with a preponderance of feldspar while some part depicts mature sediments with a higher percentage of quartz (Fig. 4).

3. RESULTS AND FINDINGS

Integration of multi geoscience data from the reservoir shows that the study reservoir exhibits gross heterogeneous characteristics from one location to the other within the field. This directly impacts on the production irregularities of wells producing from the reservoir.

Table 1. Ten years production profile of anda field

Wells	Prod. in 2001(Bbl/d)	Prod. in 2009(Bbl/d)	ERT. Prod.(Bbl/d)
1	3013	233	501
2	2020	102	203
3	1010	61	122
4	1009	64	151
5	2019	104	214
6	2021	106	200
7	2011	62	140
8	1009	60	101
9	2019	115	213
10	3015	237	508
Total	**19,146**	**1,144**	**2,353**

Table 2. Study reservoir thicknesses encountered in ten wells

Selected wells	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Well 7	Well 8	Well 9	Well 10
Reservoir interval(ft.)	6120-6300	6925-7725	6350-6600	6700-7100	6500-6800	6200-7700	6300-6620	6070-6400	6810-7100	5910-6110
Reservoir thickness(ft.)	180	150	250	310	300	200	320	330	290	210
No. of samples	18	15	25	31	30	20	32	32	30	31
Sample intervals(ft.)	10	10	10	10	10	10	10	10	10	10

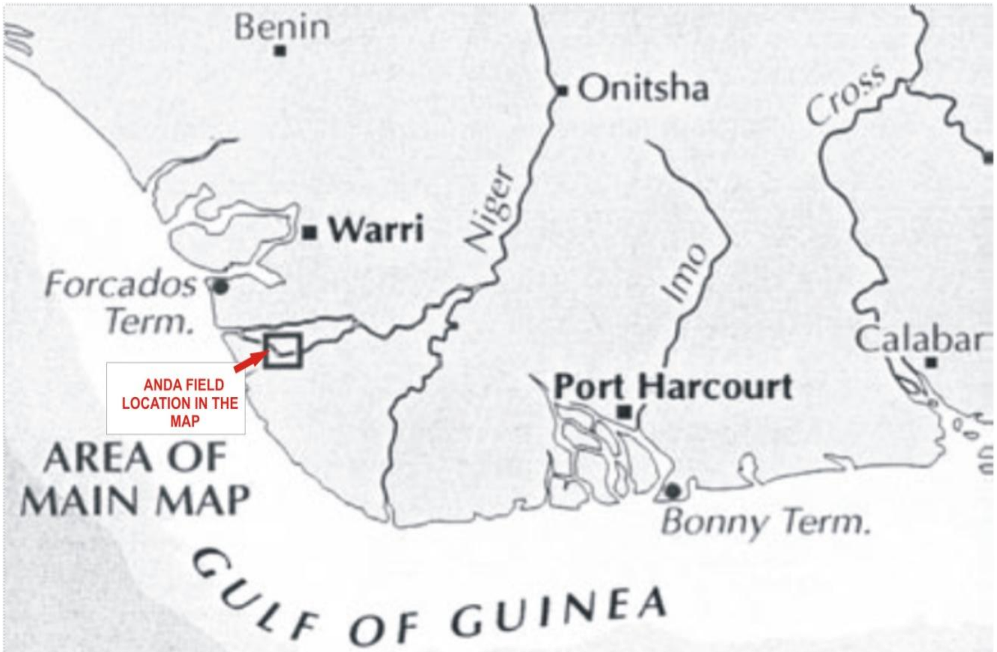


Fig. 1. Geology of Niger Delta Basin

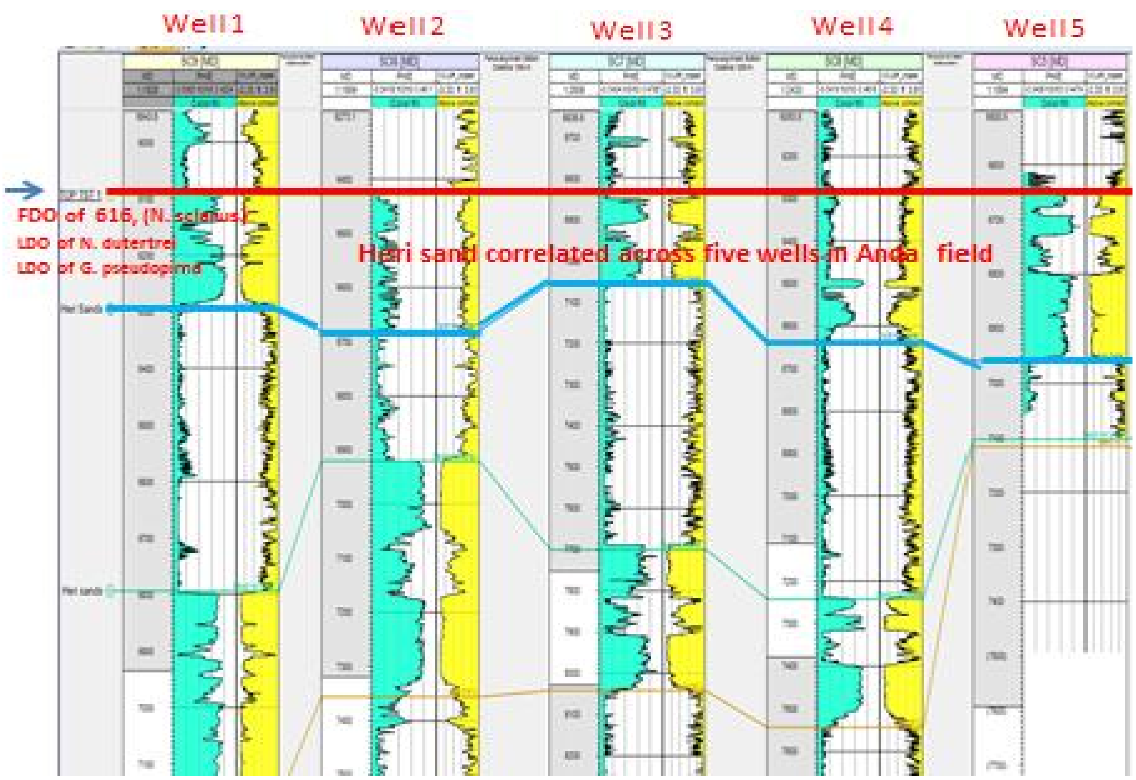


Fig. 2. Correlation of the reservoir across wells using well logs and biostratigraphic marker indexes typified in Nigeria delta basin

Table 3. Deductions from biostratigraphic data of the study reservoir

Wells	Fossil frag.	Foram div	Bent. pop	Plank pop	P/B ration	Bathy metry	Depsn 1 envi	Paly debris	Paly div.	Mang. Paly	Poace ace	Acc. mini
Well 1	High	High	Moderate	High	>1	Inner neritic	Dist. Chan.	High	High	Low	High	Pyrite.
Well 2	Moderate	High	High	Moderate	1	Middle neritic	Barrier bar	Low	Low	High	High	Pyrite
Well 3	Low	Low	High	Low	<1	Outer neritic	Mouth bar	Low	Low	Low	Low	Glauc.
Well 4	Low	Low	High	Low	<1	Outer neritic	Mouth bar	Nil	Low	Moderate	Low	Glauc.
Well 5	High	Moderate	High	Low	1	Middle Neritic	Barrier bar	High	High	High	High	
Well 6	High	High	Low	Low	1	Middle neritic	Barrier bar	High	Low	Low	High	
Well 7	Low	High	High	Low	1	Middle neritic	Mouth bar	Low	Low	High	Low	Flakes
Well 8	Low	High	High	Low	<1	Middle neritic	Mouth bar	Low	Low	High	Low	
Well 9	High	High	High	Low	<1	Middle neritic	Dict. Chan.	High	High	Low	High	Muscu. Vite.
Well 10	High	High	Moderate	High	>1	Inner neritic	Dict. Chan.	High	High	Low	High	Pyrite, flakes

Table 4. Paleobathymetric result interpretation from the bio-stratigraphic data

Paleobathymetric Environment of Reservoir in Wells

INNER NERITIC	MIDDLE NERITIC	OUTER NERITIC
Well 1	Well 2	Well 3
	Well 5	
Well 9	Well 6	Well 4
	Well 7	
Well 10	Well 8	

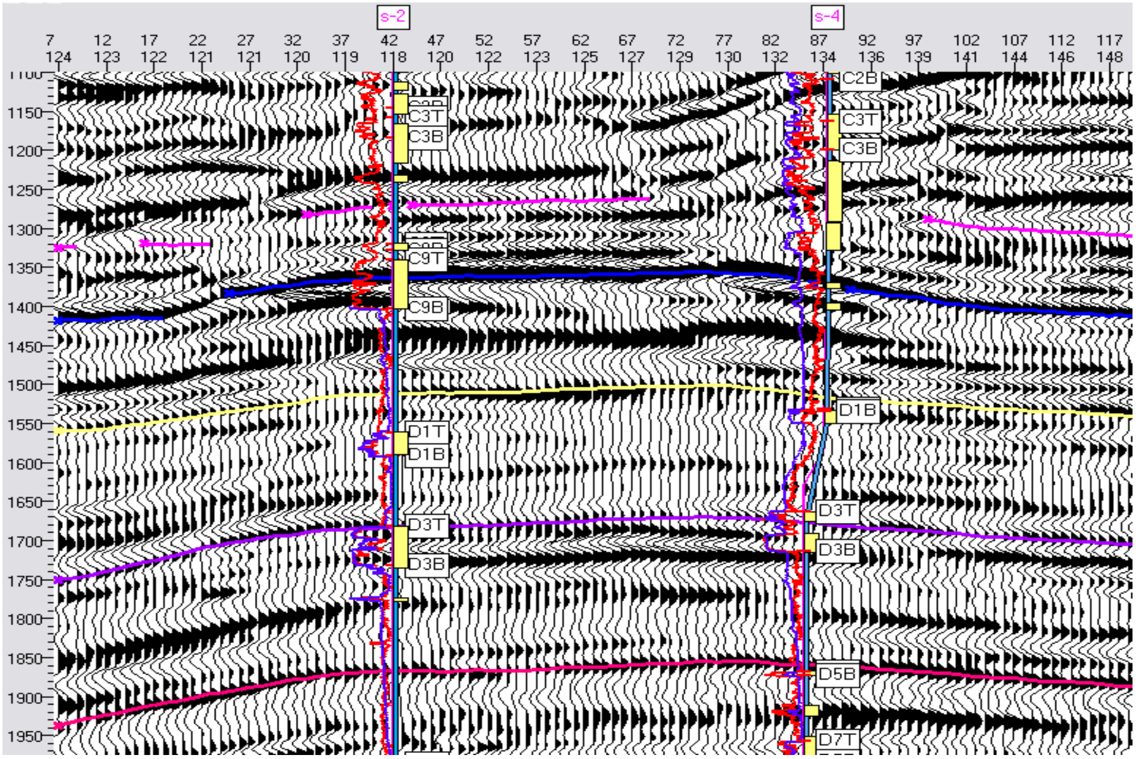
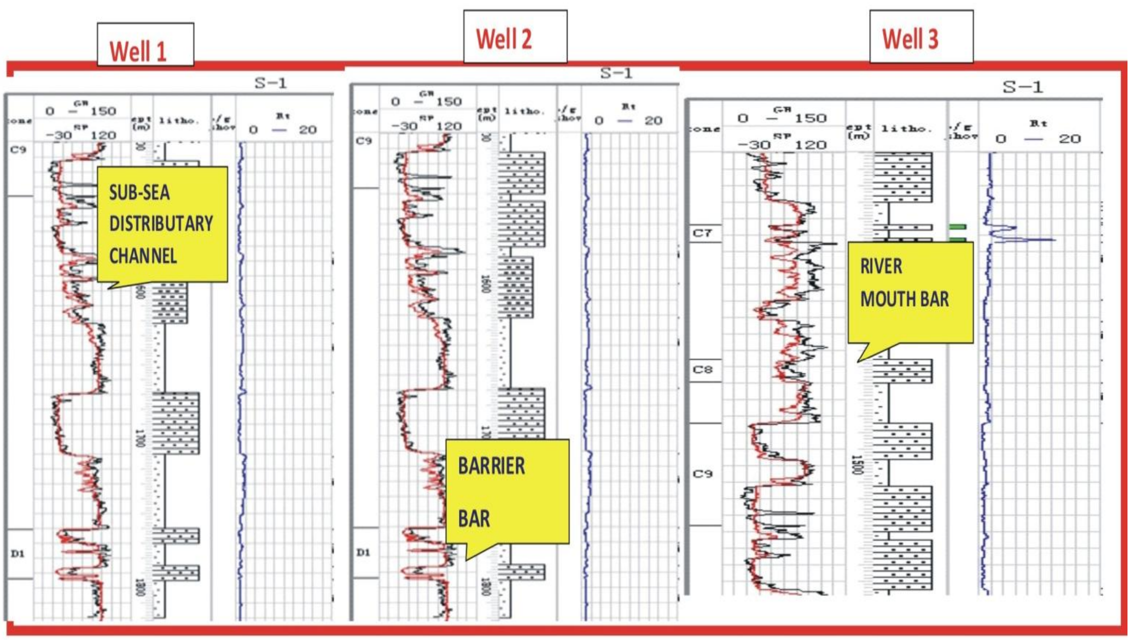


Fig. 3. Seismic attributes correlation with well logs on the reservoir across the field



Depositional Environment of the reservoir from Gamma ray logs

Fig. 4. Depositional environment of the reservoir from Gamma ray logs

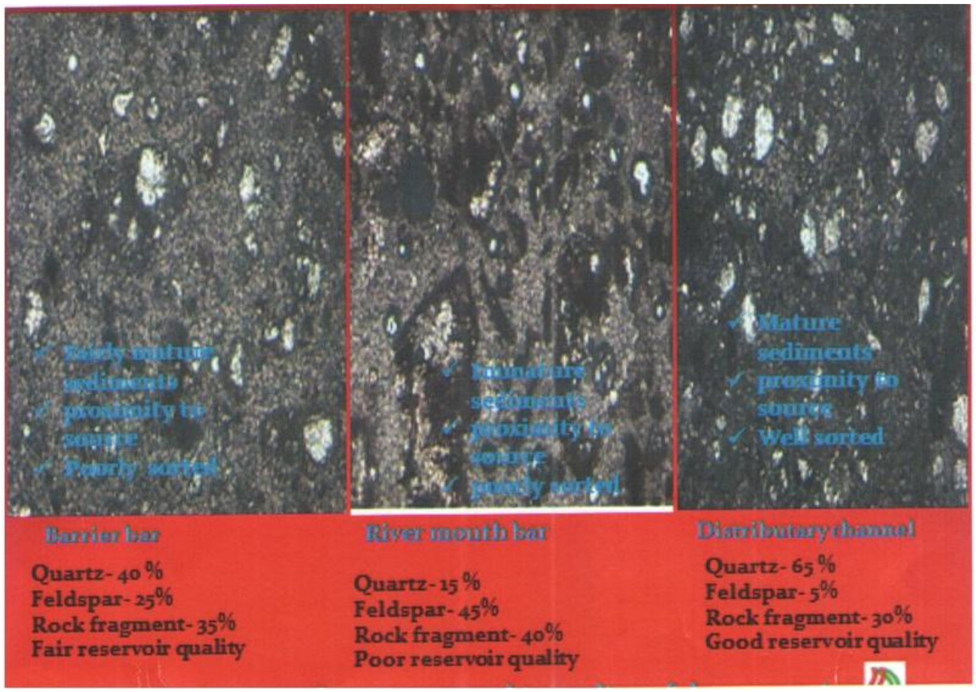


Fig. 5. Petrographic studies from a photomicrograph of the reservoir

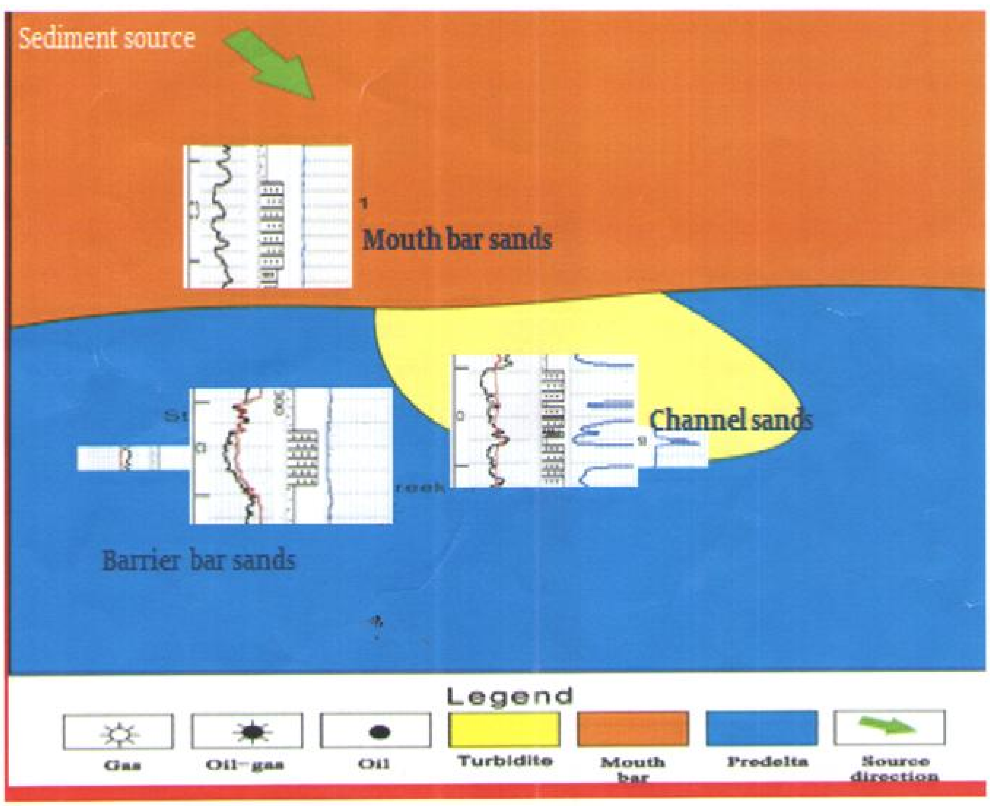


Fig. 6. Seismic time slice displaying depositional environments within the reservoir

Table 5. Historical profile with the study result

Wells	Prod. in 2001(Bbl/d)	Prod. in 2009(Bbl/d)	ERT. Prod.(Bbl/d)	Recovery value(%)	Prod. after study (Bbl/d)	Asset value maximi zed (Bbl/d)	Recovery value (%)
1	3013	233	501	17%	504	3	17%
2	2020	102	203	10%	491	288	24%
3	1010	61	122	12%	490	368	49%
4	1009	64	151	15%	480	329	48%
5	2019	104	214	11%	490	276	25%
6	2021	106	200	10%	512	312	25%
7	2011	62	140	7%	530	390	26%
8	1009	60	1010	10%	470	369	47%
9	2019	115	213	10%	460	247	23%
10	3015	237	508	17%	509	1	17%
Total	**19,146**	**1,144**	**2,353**	**12.3%**	**4,936**	**2,583**	**26%**

It can be derived that poor responses of the general secondary recovery plan for the reservoir were directly contributed by gross heterogeneities of the reservoir.

Studies have shown that the reservoir was deposited under three distinct environment (distributary channels, mouth bar, and barrier bar environment (Fig. 5) in the Late Miocene period (Tortonion-Messinian stages). Different depositional environments of the reservoir were strongly controlled by the subsisting basin architecture in the formative stages of the reservoir .Paleobathmeteric o results show that that reservoir was formed under inner neritic and middle neritic paleoenvironment. These multifarious conditions exhibit a strong influence on the petrophysics of the reservoir which is the direct function of reservoir characterization. This study naturally compartmentalized the reservoir into three distinct environments as seen in Fig. 5 below. Secondary recovery designs were carried out for each compartment differently and utilizing the petrophysical data derived from the study. Compartmentalized secondary recovery plan yielded a positive result compared to a homogeneous secondary recovery plan for the entire reservoir.

4. CONCLUSION

Twelve per cent (12%) production increment was achieved when a general recovery design was developed for the entire field as compared to about twenty-six (26%) production increments recorded from compartmentalized design to maximize crude oil recovery from the reservoir. A general recovery plan does not provide optimum production result from heterogeneous reservoirs rather optimum production yield is achieved with the integration of multi-geosciences studies to compartmentalize the reservoir based on the varied depositional environments of the reservoir. This is a clear case study from the Anda field reservoir.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
https://sdiarticle4.com/review-history/50264