GEOPHYSICS

Original article
EDN: TIYEQF
DOI: 10.21285/2686-9993-2025-48-2-185-203

Structural mapping and prospects identification in Otio oil field, Niger Delta

Mohammed A. Mohammed[a]

[a]*Irkutsk National Research Technical University, Irkutsk, Russia*

Abstract. This research presents a detailed structural mapping and prospects identification study of the Otio Field located in the Niger Delta. The study integrates 3D seismic data and well logs to delineate subsurface structures and assess the hydrocarbon potential of the field. Five key horizons were evaluated using petrophysical analysis, revealing porosity values ranging from 18 to 27 %, water saturation levels between 20 and 31 %, and Net-To-Gross ratios of 59 to 96 %. Time-depth structure maps were generated for each horizon, allowing for the identification of two prospects, namely the North-Eastern and South-Eastern prospects. The North-Eastern prospect was ranked higher due to its larger estimated hydrocarbon volume, with Sand E2 identified as the most promising reservoir based on volumetric analysis. This study underscores the importance of integrating seismic and petrophysical data for effective exploration and field development, providing a basis for future drilling decisions in the Otio Field. The research method started with the subsurface evaluation of the "Otio Field" integrating well log data from the field and seismic data spanning the field. The databases used for this project are three Dimensional (3D) seismic cube, base map, six well data in LAS format and check shot data for only one well. The results show the identified hydrocarbon bearing zones are Sands D, E1, E2, H and J as interpreted from gamma-ray and resistivity logs. The sand correlation across the field showed uniform sand development from well to well. The checkshot is interpreted as good because of the absence of outliers or spurious values. The plot is a gentle slope that eventually steepens because of com-paction of the underlying units that causes Two-Way Time to decrease. The results from the structural Interpretation, sixteen faults (F1–F16) were interpreted across the field as seen on seismic section. Faults in the field trend in the East-West direction with majority of them dipping north except for faults F4 F6, F7 and F9 dipping south. In the conclusion, the 3D structural analysis of Otio Field in the Niger Delta enhanced understanding of its structural styles and hydrocarbon traps. Eight reservoirs were identified, with five hydro-carbon-bearing sands (D, E1, E2, H, J) mapped, consisting of sands sealed by shales.

Keywords: Niger Delta, structural mapping, seismic interpretation, petrophysical analysis, hydrocarbon prospects, Otio Field

Acknowledgements: The author is grateful to his Director, A.V. Parshin, his colleagues and associates from the Institute of the Siberian School of Geosciences, Irkutsk National Research Technical University, Irkutsk, Russia, Department of Geology and Mining, University of Abuja, Abuja, Nigeria, and his research team: I.C. Ofia, S.L. Mohammed, M.G. Mohammed and her team and A.M. Abubakar for their undiluted support and assistance during and after carrying out this research.

For citation: Mohammed M.A. Structural mapping and prospects identification in Otio oil field, Niger Delta. *Earth sciences and subsoil use.* 2025;48(2):185-203. https://doi.org/10.21285/2686-9993-2025-48-2-185-203. EDN: TIYEQF.

ГЕОФИЗИКА

Научная статья
УДК 550.3

Структурное картирование и определение перспективных залежей месторождения углеводородов Отио в дельте реки Нигер

М.А. Мохаммед[a]

[a]*Иркутский национальный исследовательский технический университет, Иркутск, Россия*

Резюме. Целью данного исследования являлось детальное структурное картирование и определение перспектив нефтеносного месторождения Отио, расположенного в дельте реки Нигер. В ходе работы использовались 3D-данные сейсморазведки и каротажные диаграммы для выделения подповерхностных структур и оценки углеводородного потенциала месторождения. Пять ключевых горизонтов были оценены с помощью петрофизического анализа, выявившего значения пористости в диапазоне от 18 до 27 %, уровни водонасыщенности от 20 до 31 % и отношение мощности нефтенасыщенного пласта к его эффективной мощности от 59 до 96 %. Для каждого горизонта были построены структурные карты зависимости времени от глубины, что позволило выделить два перспективных участка – Северо-Восточный и Юго-Восточный. Северо-Восточный перспективный участок был оценен выше из-за большего предполагаемого объема углеводородов, а участок Sand E2 был определен как наиболее перспективный резервуар на основе объемного анализа. Данное исследование подчеркивает важность интеграции сейсмических и петрофизических данных для эффективной разведки и разработки месторождений, так как обеспечивает основу для принятия будущих решений по бурению на месторождении Отио. Исследование началось с оценки недр нефтеносного месторождения Отио, интегрирующей данные каротажа скважин и сейсмические данные, охватывающие месторождение. Для проекта использовались трехмерный сейсмический куб, базовая карта, данные по шести скважинам в формате LiDAR Aerial Survey и данные сейсмокаротажа (по одной скважине). Результаты показали, что выявленными углеводородоносными зонами являются пески D, E1, E2, H и J (по данным гамма-каротажа и резистивного каротажа). Корреляция песков по месторождению показала равномерное их развитие от скважины к скважине. Сейсмокаротаж был оценен положительно из-за отсутствия выбросов или ложных значений. Годограф представляет собой пологий наклон, который в конечном итоге становится круче из-за уплотнения нижележащих слоев, что приводит к уменьшению полного времени пробега. В результате структурной интерпретации на месторождении было выявлено шестнадцать разломов (F1–F16), как показазно на сейсмическом разрезе. Разломы на месторождении простираются в направлении с востока на запад, причем большинство из них характеризуются падением пласта к северу, за исключением разломов F4 F6, F7 и F9, падающих на юг. Трехмерный структурный анализ месторождения Отио в дельте реки Нигер позволил лучше понять его тектоническую структуру и угдеводородные ловушки. Было выявлено восемь коллекторов, пять нефтегазоносных песков (D, E1, E2, H, J), состоящих из песков, запечатанных сланцами, были нанесены на карту.

Ключевые слова: дельта реки Нигер, структурное картирование, интерпретация данных сейсмической разведки, петрофизический анализ, перспективы месторождения углеводородов, месторождение Отио

Благодарности: Автор выражает благодарность своему директору А.В. Паршину, коллегам и сотрудникам Института «Сибирская школа геонаук» Иркутского национального исследовательского технического университета (г. Иркутск, Россия), кафедры геологии и горного дела Университета Абуджи (г. Абуджа, Нигерия) и исследовательской группе в составе И.Ч. Офиа, С.Л. Мохаммед, М.Г. Мохаммед и ее группе, а также А.М. Абубакару за их всестороннюю поддержку и помощь во время и после проведения данного исследования.

Для цитирования: Мохаммед М.А. Структурное картирование и определение перспективных залежей месторождения углеводородов Отио в дельте реки Нигер // Науки о Земле и недропользование. 2025. Т. 48. № 2. С. 185–203. https://doi.org/10.21285/2686-9993-2025-48-2-185-203. EDN: TIYEQF.

Introduction

Hydrocarbon reservoirs are found in geologic traps, that is, any combination of rock structure that will keep oil and gas from escaping vertically or laterally [1]. Most known traps in Niger Delta fields are structural although stratigraphic traps are not uncommon[1]. The goal of oil and z exploitation is to identify and delineate these traps suitable for profitably exploitable accumulations and delineate the extent of discoveries in field appraisals and development [2]. In this study, three Dimensional (3D) seismic data were integrated with well logs to delineate geologic structures and prospects in "Otio Field" onshore Niger Delta. Majority of traps in the Niger Delta are structural [1]. Examples of these structural traps are rollover anticlines, flanks of shale domes and traps related to faulting. Identification and proper classification of these traps as prospects form the basis of further exploration and economic decisions. Otio Field is located onshore Niger Delta Field (Fig. 1). Due to proprietary reasons and confidentiality agreement with the data, exact location of the field cannot be provided.

The Niger Delta has an aerial extent of 75,000 km^2 (28,957 mi^2) and is located between longitude 3o and 9o E, latitude 4o 30' and 5o 20' N (Fig. 2) [3]. The northern boundary is the Benin Flank (see Fig. 2) – a northeast trending hinge line south of the West Africa Basement Massif. The north-eastern boundary is defined by outcrops of the Cretaceous on the Abakaliki High and further southeast by the Calabar Flank (see Fig. 2) – a hinge line bordering the adjacent Precambrian. The offshore boundary of the province is defined by the Cameroon volcanic line to the east, the eastern boundary of the Dahomey Basin (the eastern-most West African transform-fault passive margin) to the west. During the Tertiary it built out into the Atlantic Ocean at the mouth of the Niger-Benue river system, an area of catchment that encompasses more than a mil-

[1] Tuttle M.L.W., Charpentier R.R., Brownfield M.E. The Niger Delta petroleum system: Niger Delta Province, Nigeria, Cameroon, and Equatorial Guinea, Africa: U.S. Geological Survey Open-File Report 99-50-H // USGS Science for a changing world. 1999. Available from: https://pubs.usgs.gov/of/1999/ofr-99-0050/OF99-50H/OF99-50H.pdf [Accessed 12th March 2025].

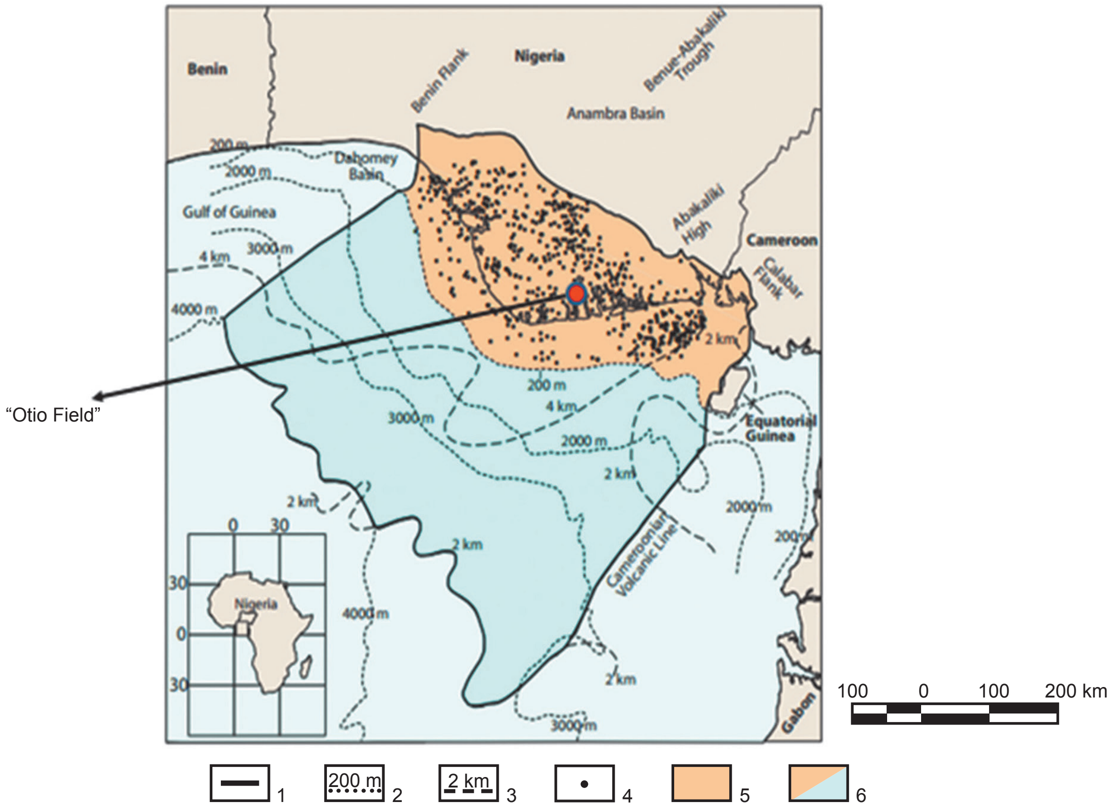


Fig. 1. Location of Otio field location onshore Niger Delta[1]:
1 – province 7192 boundary; 2 – bathymetric contour, m; 3 – sediment thickness, km; 4 – center of gas or oil field; 5 – minimum petroleum system; 6 – maximum petroleum system
Рис. 1. Расположение месторождения Отио на побережье дельты реки Нигер[1]:
1 – граница провинции 7192; 2 – батиметрический контур, м; 3 – мощность отложений, км; 4 – центр газового или нефтяного месторождения; 5 – минимальная нефтегазоносная система; 6 – максимальная нефтегазоносная система

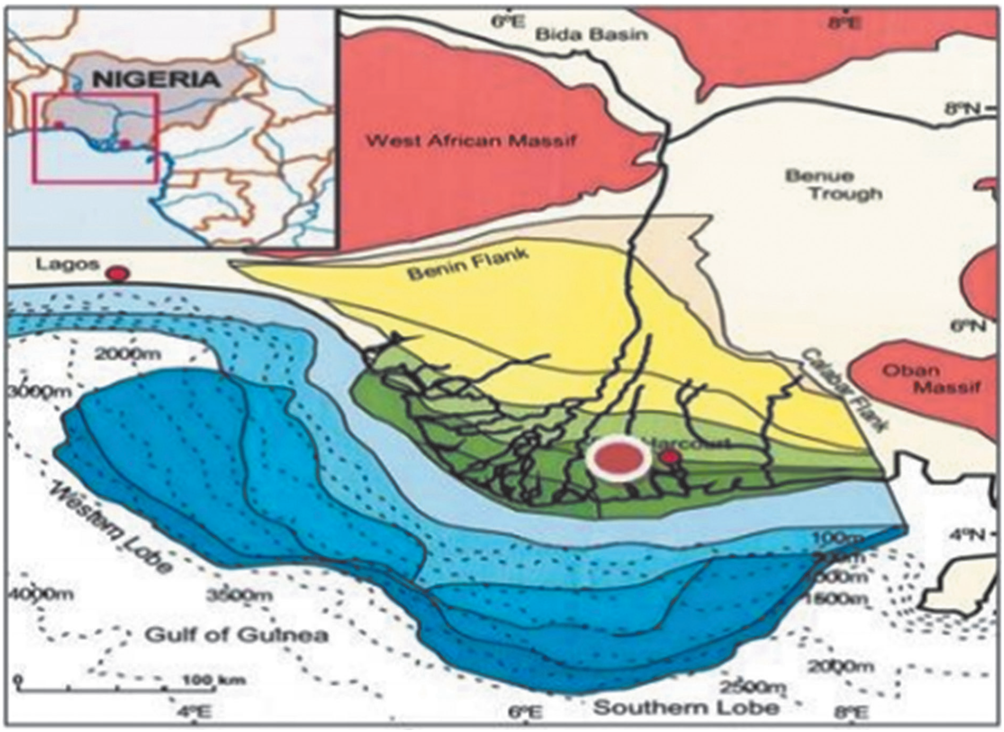


Fig. 2. Location of the Niger Delta [7]
Рис. 2. Расположение дельты реки Нигер [7]

lion square Kilometres of predominantly savannah covered lowlands [4]. The Cenozoic Niger Delta is situated at the intersection of the Benue Trough and the South Atlantic Ocean where a triple junction developed during the separation of the continents of South America and Africa in the late Jurassic[2]. The two arms that followed the southwestern and southeastern coast of Nigeria and Cameroon developed into the passive continental margin of West Africa, whereas the failed arm formed the Benue Trough. Other depocenters along the African Atlantic coast also contributed to deltaic build-ups [5]. After an early history of rift filling in the late Mesozoic, the clastic wedge steadily prograded into the Gulf of Guinea during the Tertiary as drainage expanded into the African Craton with consequent subsidence of the passive margin [6].

Syn-rift sediments accumulated during the Cretaceous to Tertiary, with the oldest dated sediments of Albian age. Thickest successions of syn-rift marine and marginal marine clastics and carbonates were deposited in a series of transgressive and regressive phases [8]. The Syn-rift phase ended with basin inversion in the Santonian (Late Cretaceous). Renewed subsidence occurred as the continents separated and the sea transgressed the Benue Trough. The Niger Delta clastic wedge continued to prograde during Middle Cretaceous time into a depocenter located above the collapsed continental margin at the site of the triple junction. Sediment supply was mainly along drainage systems that followed two failed rift arms, the Benue and Bida Basins. Sediment progradation was interrupted by episodic transgressions during Late Cretaceous time.

During the Tertiary, sediment supply was mainly from the north and east through the Niger, Benue and Cross Rivers. Cross River and Benue River provided substantial amounts of volcanic detritus from the Cameroon volcanic zone beginning in the Miocene. The Niger Delta clastic wedge prograded into the Gulf of Guinea at a steadily increasing rate in response to the evolution of these drainage areas and continued basement subsidence. Regression rates increased in the Eocene, with an increasing volume of sediments accumulated since the Oligocene [4]. Delta progradation occurred along two major axes, the first paralleled the Niger River, where sediment supply exceeded subsidence rate. The Second, smaller than the first, became active during Eocene to early Oligocene basinward of the Cross River where shorelines advanced into the Olumbe-1 area [9]. This axis of deposition was separated from the main Niger Delta deposits by the Ihuo Embayment, which was later rapidly filled by advancing deposits of the Cross River and other local rivers [9]. Late stages of deposition began in the early to middle Miocene, as these separate eastern and western depocenters merged. In Late Miocene the delta prograded far enough that shorelines became broadly concave into the basin. Accelerated loading by this rapid delta progradation mobilized underlying unstable shales. These shales rose into diapiric walls and swells, deforming overlying strata. The resulting complex deformation structures caused local uplift, which resulted in major erosion events into the leading progradational edge of the Niger Delta. Several deep canyons, now clay filled, cut into the shelf and are commonly interpreted to have formed during sea level lowstands. The best known are the Afam, Opuama, and Qua Iboe Canyon fills.

Three major depositional cycles have been identified within Tertiary Niger Delta deposits [9, 4]. The first two, involving mainly marine deposition, began with a middle Cretaceous marine incursion and ended in a major Paleocene marine transgression. The second of these two cycles, starting in late Paleocene to Eocene time, reflects the progradation of a “true” delta, with an arcuate, wave- and tide-dominated coastline. These sediments range in age from Eocene in the north to Quaternary in the south [4]. Deposits of the last depositional cycle have be divided into a series of six depobelts separated by major syn-sedimentary fault zones [4]. These depobelts formed when paths of sediment supply were restricted by patterns of structural deformation, focusing sediment accumulation into restricted areas on the delta. Such depobelts changed position over time as local accommodation was filled and the locus of deposition shifted basinward (Fig. 3) [4].

Normal faults triggered by the movement of deep-seated, overpressured, ductile, marine shale have deformed much of the Niger Delta clastic wedge [8]. Many of these faults formed during delta progradation and were syn-depositional, affecting sediment dispersal. Fault growth was also accompanied by slope instability along the continental margin. Faults flatten with depth, known as growth faults, onto a master detachment plane near the top of the overpressured

[2] Obaje N.G. Geology and mineral resources of Nigeria. Berlin: Springer, 2009. 221 p.

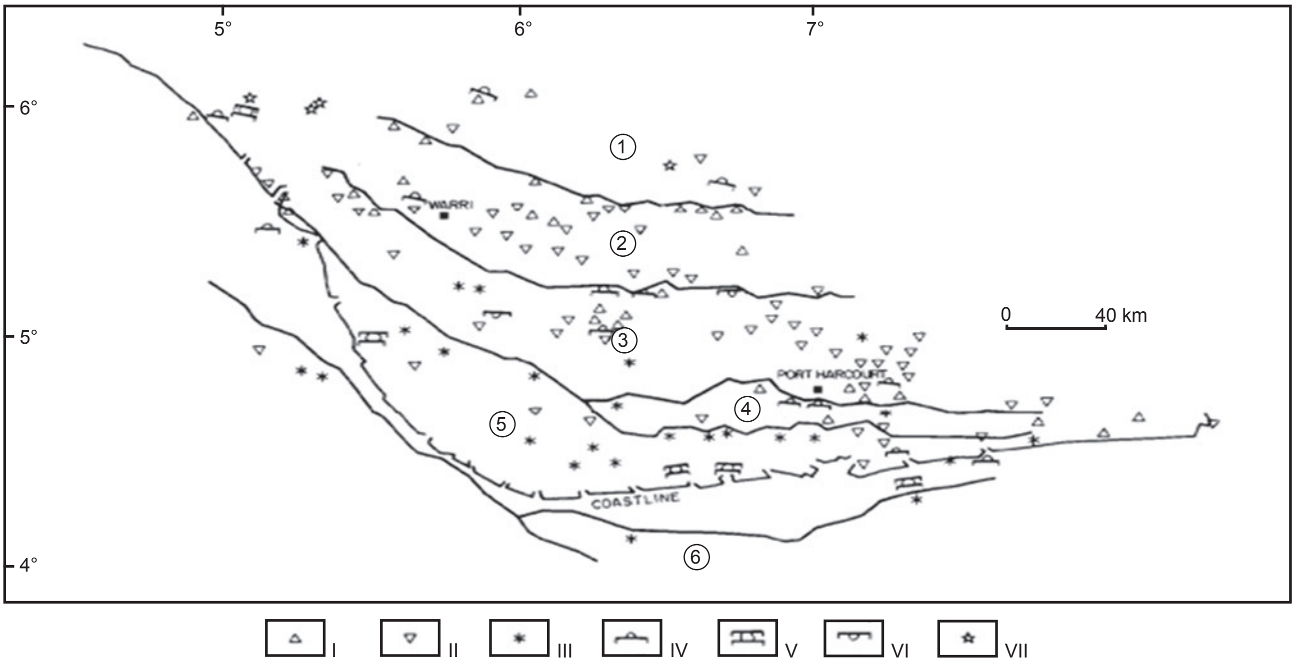


Fig. 3. Structural types of the Niger delta and associated depobelt [4]:
1 – northern delta; 2 – Greater Ughelli; 3 – central swamp 1; 4 – central swamp 2; 5 – coastal swamp; 6 – offshore
I – anticline; II – faulted anticline; III – collapsed crest; IV – footwall closure; V – k-type footwall closure; VI – hanging-wall closure; VII – stratigraphic component
Рис. 3. Структурные типы дельты реки Нигер и связанного с ней пояса залежей [4]:
1 – северная дельта; 2 – Большой Угелли; 3 – центральная заболоченная территория 1; 4 – центральная заболоченная территория 2; 5 – прибрежная заболоченная территория; 6 – шельф
I – антиклиналь; II – нарушенная антиклиналь; III – обрушившийся гребень; IV – замкнутая структура подошвы; V – тип k замкнутой структуры подошвы; VI – структура висячего крыла сброса; VII – стратиграфический компонент

marine shales at the base of the Niger Delta succession. Structural complexity in local areas reflects the density and style of faulting. Simple structures, such as flank and crestal folds, occur along individual faults. Hanging-wall rollover anticlines developed because of listric-fault geometry and differential loading of deltaic sediments above ductile shales. Growth faults and associated anticlinal closures form the primary traps for oil and gas, with major fields often located along faulted rollover structures (Fig. 4) [10]. More complex structures, cut by swarms of faults with varying amounts of thrown, include collapsed crest features with domal shape and strongly antithetic (opposing) fault dips at depth. The interaction between extensional and compressional regimes is particularly evident at the delta's toe, where compressional folds and thrust faults develop in response to gravitational sliding on the continental slope [11].

The thick wedge of the Niger Delta sediments can be considered to consist of three stratigraphic units (Table 1) [9]. The basal unit primarily compose of marine shales [12] is called the Akata Formation with Imo Shale as its surface equivalent. During the Paleocene and earliest Eocene times, marine shales were deposited (Fig. 5) [13]. This unit also comprises some sand beds, which are thought to be continental slope channel fills and turbidites. The Akata Formation ranges in thickness from 600 to probably over 6000 meters. The overlying paralic sequence, forming the Agbada Formation consists of interbeded sands and shales with a thickness of 300 up to about 4500 meters. The Agbada Formation consists of alternating sandstones and shales deposited at the interface between the lower deltaic plain and the marine sediments of the continental shelf fronting the delta [12]. The Agbada Formation is built up of numerous offlaps cycles of which the sandy parts constitute the main hydrocarbon reservoirs and the shales the caprock, the topmost unit. The Benin Formation is composed of fluviatile gravels and sands. The sandstone is coarse grained, commonly very granular and pebbly to very fine grained with few shale intercalations [9]. This unit has a maximum thickness of about 2100 m [14] where there is maximum subsidence of the basement. Advanced seismic imaging

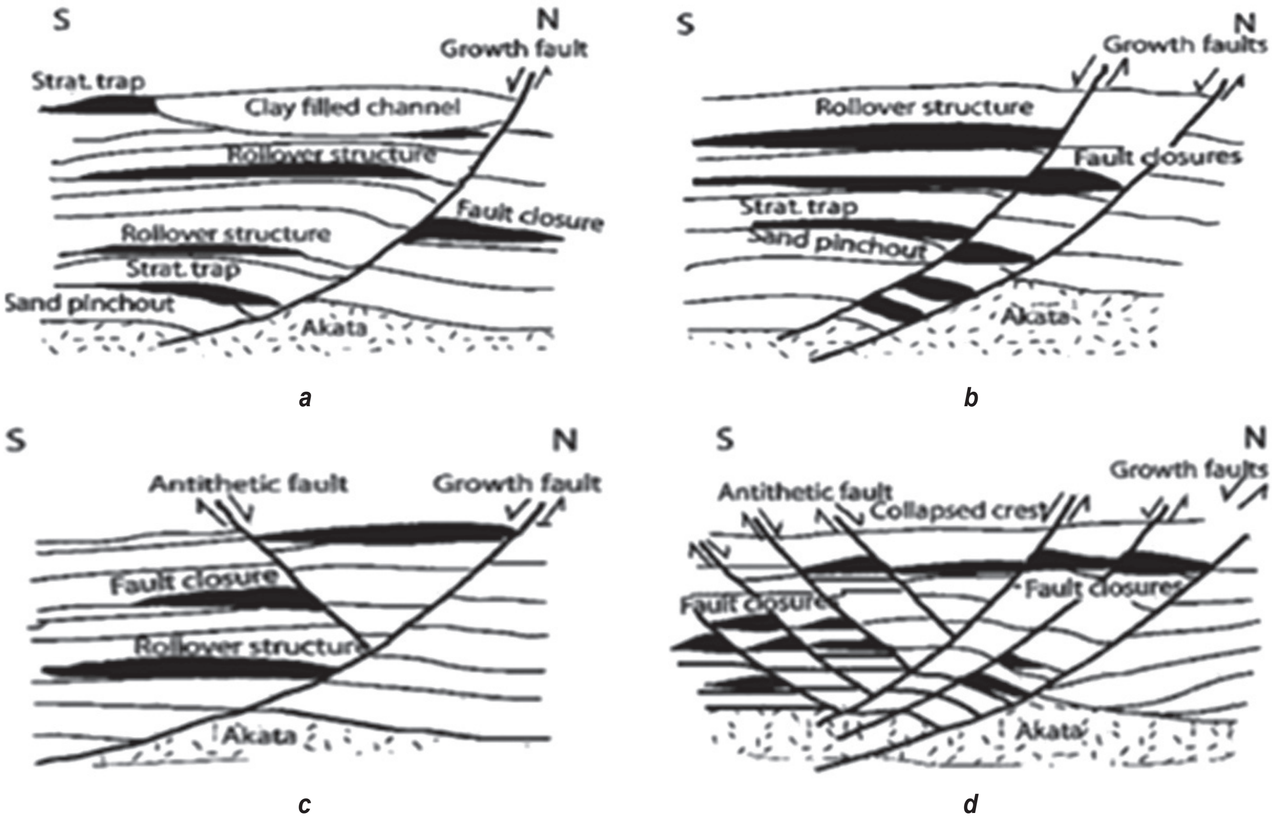


Fig. 4. Typical Niger delta structures [4]:
a – simple rollover; b – growth faults; c – antithetic fault; d – colapsed crest
Рис. 4. Типичные структуры дельты реки Нигер [4]:
a – простой сброс; b – разломы роста; c – антитетический сброс; d – обрушившийся гребень

and structural modeling have become essential tools for mapping these complex features, enabling better prediction of reservoir distribution and trap integrity [15].

In the building of the Akata Formation, rapid sand deposition along the delta edge on top of the undercompacted clay has resulted in the development of large number of syn-sedimen-

Table 1. Showing formations of Niger Delta area, Nigeria (adapted from [9])
Таблица 1. Формации района дельты реки Нигер (Нигерия) (согласно источнику [9])

Subsurface			Surface outcrops		
Youngest known age	–	Oldest known age	Youngest known age	–	Oldest known age
Recent	Benin formation (Afam shale member)	Oligocene	Plio/ Pleistocene	Benin formation	Miocene
Recent	Agbada formation	Eocene	Miocene	Ogwashi-Asaba formation	Oligocene
			Eocene	Ameki formation	Eocene
Recent	Akata formation	Eocene	L. Eocene	Imo Shale formation	Paleocene
			Paleocene	Nsukka formation	Maestrichtian
			Maestrichtian	Ajali formation	Maestrichtian
			Campanian	Mamu formation	Campanian
			Camp/Maest	Nkporo shale	Santonian
Eqiuvalents not known			Coniacian/ Santonian	Awgu shale	Turonian
			Turonian	Eze aku shale	Turonian
			Albian	Asu river group	Albian

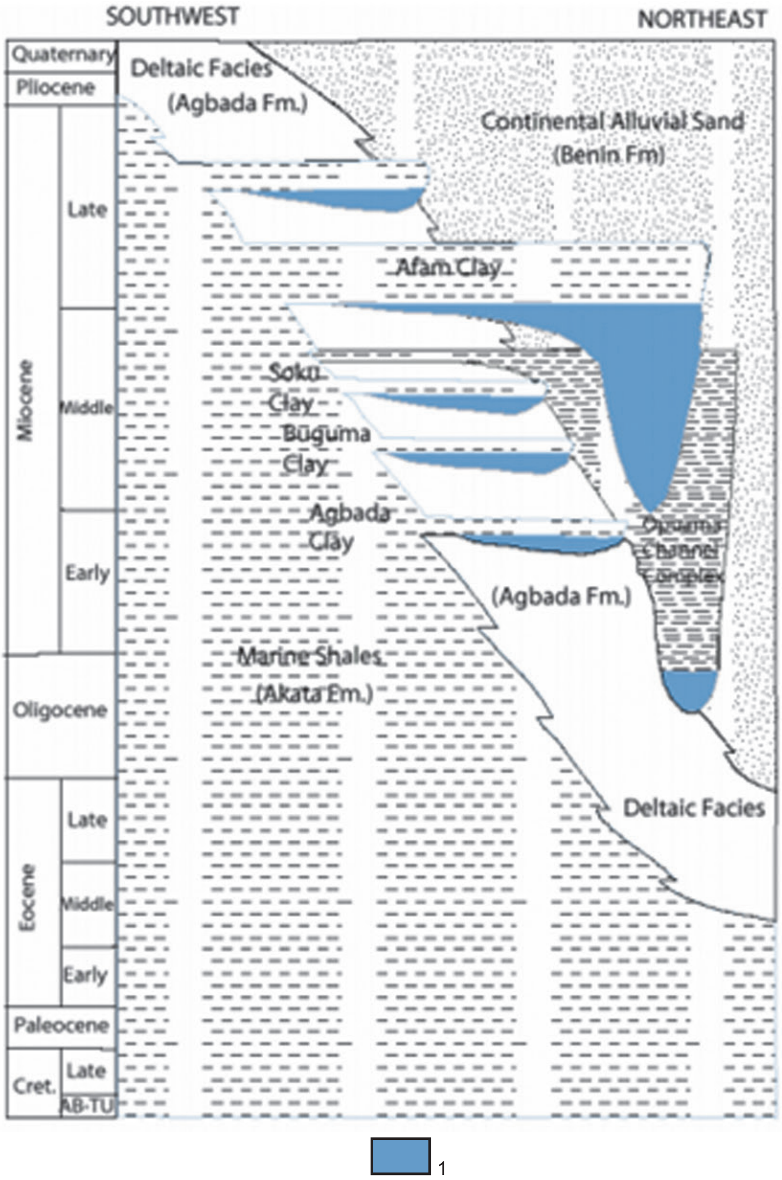


Fig. 5. Schematic representation of the diachronous nature of major lithofacies units, and the stratigraphic relationships of clay filled channels on the delta flanks [4]:
1 – extent of erosional truncation
Рис. 5. Схематическое изображение диахронной природы основных литофаций и стратиграфических взаимоотношений заполненных глиной каналов на склонах дельты [4]:
1 – степень эрозионного среза

tary gravitational faults. These so-called “growth faults” are also well known from the US Gulf coast. The spacing between successive growth fault decreases with an increase in the rate of depositional slope or an increase in the rate of deposition over the rate of subsidence.

The main control on the depositional system in the Niger Delta Clastic wedge is enforced by the continental margin collapse structures. These structures extends laterally along depositional strike across nearly the entire Niger Delta group up to hundreds of Kilometres and are thus defined as mega structures [13], and the associated depobelts which are perpendicular to the shorelines, ranging tens of Kilometres [4]. From early Miocene to present, six depobelts have been deposited, namely; Northern delta, Ughelli, Central, Coastal 1, Coastal 2 and Offshore. The depobelt tend to be fine grained laterally away from areas of most deltas progradation and basinward away from most rapid growth faults developments [4]. They are defined by syn-sedimentary faulting formed as a result of variable rate of subsidence and supply and correspond to break in regional dip of the delta, bounded landward by growth faults and seaward by large counter-regional faults (Fig. 6) [13, 4].

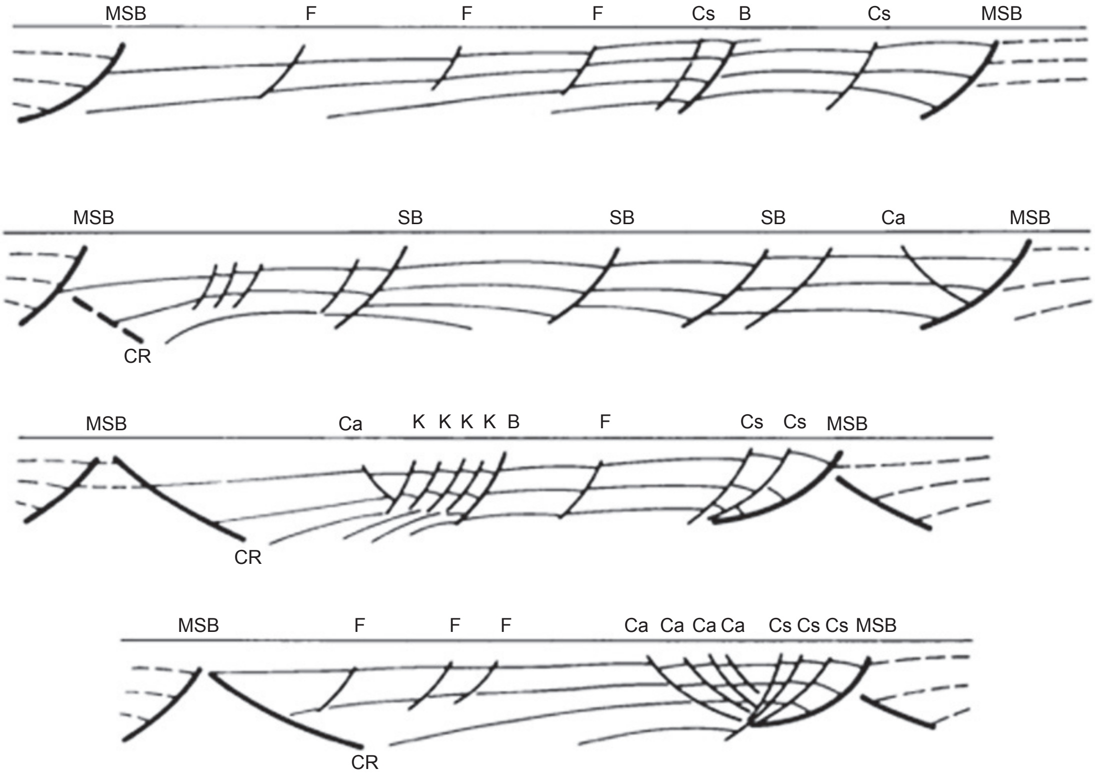


Fig. 6. Syn-sedimentary structures of the Niger delta [13]:
MSB – major structure – building fault separating megaunits; SB – structure – building fault separating macrounits; Cs – crestal fault (synthetic); Ca – crestal fault (antithetic); F – flank faults; K – closely spaced flank faults typified by offshore K block; CR – counter-regional fault
Рис. 6. Синседиментационные структуры дельты реки Нигер [13]:
MSB – основная структура – строительный разлом, разделяющий мегаединицы; SB – структура – строительный разлом, разделяющий макроединицы; Cs – гребневой разлом (синтетический); Ca – гребневый разлом (антитетический); F – фланговые разломы; K – близко расположенные фланговые разломы, типичные для шельфового блока K; CR – секущий разлом

These syn-sedimentary structures include simple non faulted anticline roll over structures, faulted roll over anticline with multiple growth faults, complicated collapse crest structures, sub-parallel growth fault and structural closures along back of major faults [13, 6]. Small scale faults and associated structural deformation tends to be more complex near the progradation axis of the delta than at its margin. Armentrout et al. [16] and Hooper et al. [17] stated that this pattern of deposition with extensional development of growth faults on the modern shelf and slope, and compressional uplift near the toe of the slope of the Niger delta still continues today. As sediment supply filled available accommodation space, new depobelts formed seaward, separated by major fault zones that accommodated differential subsidence [18].

Materials and methods

The principal databases used for this project are three Dimensional (3D) seismic cube, base map (see Fig. 1), six well data (Table 2) in LAS format and check shot data for only one well, Otio-2, that was shared for the rest of the wells in the Field. The 3D seismic data is a high-resolution Post-Stack Time Migration (PSTM) in SEG-Y format. The base map covers an approximate area of 55 square kilometres with Inlines range of 5800–6200 and Crosslines range of 1480–1700.The six wells used for the project are named Otio-1, Otio-2, Otio-3ST, Otio-4, Otio-5 and Otio-6. Otio-3ST and Otio-6 are deviated wells and their deviation data were available. They wells were drilled to depth of 13020 ft, 11669.10 ft, 12090 ft, 11440 ft, 11700 ft, and 13310 ft respectively. The main software packages used for this project are the Openwork Suites with applications such as Siesworks and Zmap used for structural, stratigraphic interpretation and map generation. Powerlog software was used for well correlation and petrophysical analysis.

Table 2. Showing available wells and logs
Таблица 2. Отображение доступных скважин и каротажей

Log data	Otio-1	Otio-2	Otio-3ST	Otio-4	Otio-5	Otio-6
Gamma ray	✓	✓	✓	✓	✓	✓
Resistivity	✓	✓	✓	✓	✓	✓
Neutron	X	✓	X	✓	✓	✓
Density	X	X	X	✓	✓	✓
Sonic	X	✓	X	✓	✓	X
Caliper	✓	X	✓	✓	✓	✓
Checkshot	✓	X	X	X	X	X

Note. ✓ – available; X – unavailable.

The project reported here started off with the subsurface evaluation of the "Otio Field" integrating well log data from the Field and seismic data spanning the field. The following method and workflow were adopted for the evaluation phase (Fig. 7):

– loading of well log data and seismic data;
– QA/QC of loaded data;
– hydrocarbon bearing zones identification;
– sand to sand well log correlation;
– petrophysical analysis;
– integration of correlation with seismic data (well-to-seismic tie);
– structural and stratigraphic interpretation;
– time and depth map generation;
– volumetric estimation.

The seismic data was loaded into Openwork software, while the log data were loaded into the Powerlog software. Benin base of Niger Delta was first established using the first thick shale as marker corresponding to the first major drop in resistivity interpreted as the change from the Benin fresh water to salt water of Agbada were loop tied to assure consistency across the wells.

Geological interpretation was done every 5th Inline and Crossline. Arbitrary lines were taken

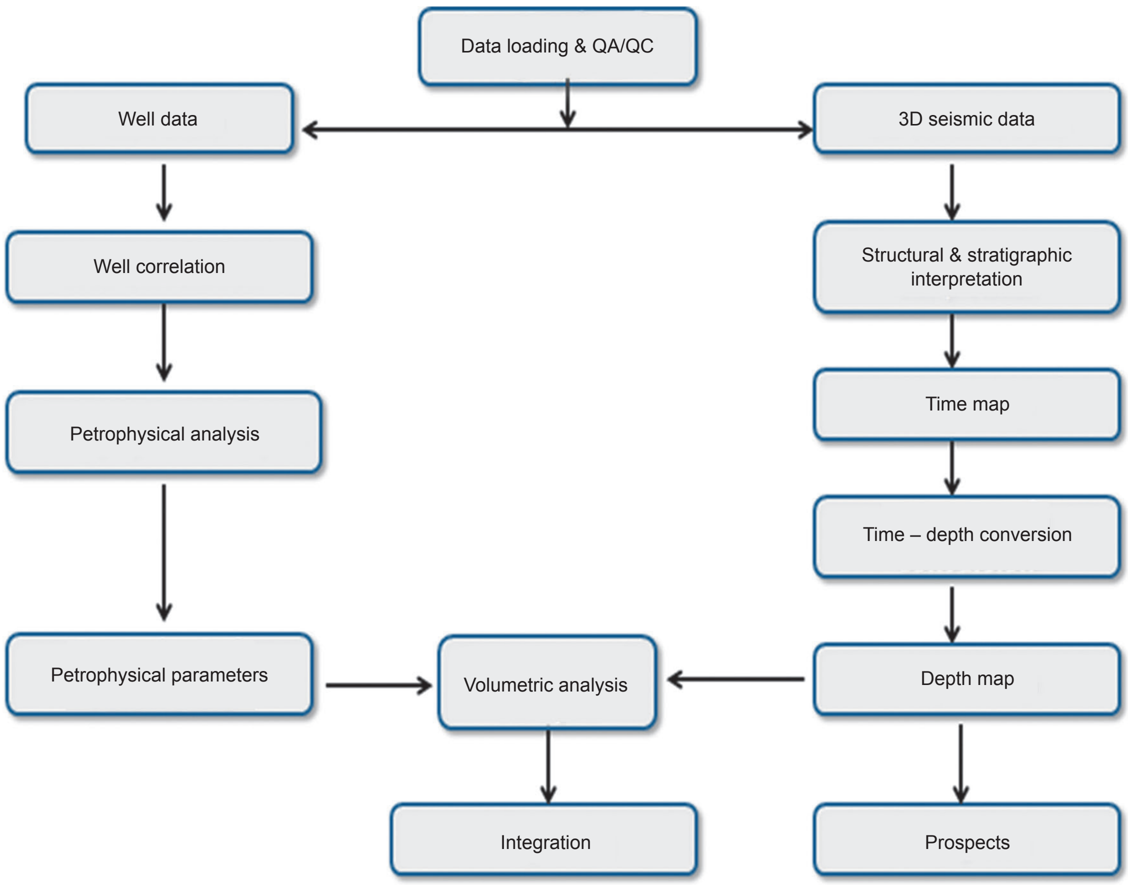


Fig. 7. Workflow for evaluation phase
Рис. 7. Последовательность рабочего процесса на этапе оценки

where necessary to overcome interpretation challenges such as interpretation across fault planes. The faults as seen on the seismic Inline section were interpreted using consistent abrupt terminations of reflection across Inlines first. This is necessary to fully understand the structural style and setting of the Field. The consistency of the faults was viewed in Coherence time display (Fig. 8). The faults were interpreted as normal faults showing varying degree of throw as would be expected in onshore Niger Delta. The faults were mapped based on the following criteria:

– abrupt termination and discontinuity of events across fault planes;

– vertical displacement of reflections;

– change in pattern of events across fault planes.

After mapping the faults, the fault heaves were traced out on the basemap to establish the fault polygons (Fig. 9). Posting the faults on the basemap also helped in identifying and correlating the faults on the seismic sections (Fig. 10). The heaves were observed to be directly related to the throw of the faults. The dip direction was indicated.

There are six steps involved seismic horizon interpretation adopted in this project:

– horizon picking;
– timing;
– time maps generation;
– time-depth conversion;
– contour;
– depth maps generation.

Horizon picking: A horizon is a mappable reflection representing a geologic event on a seismic section. It is the interface between two different rock layers with different density and velocity (Fig. 11). Five horizons were picked which marked the tops of five hydrocarbon bearing sands:

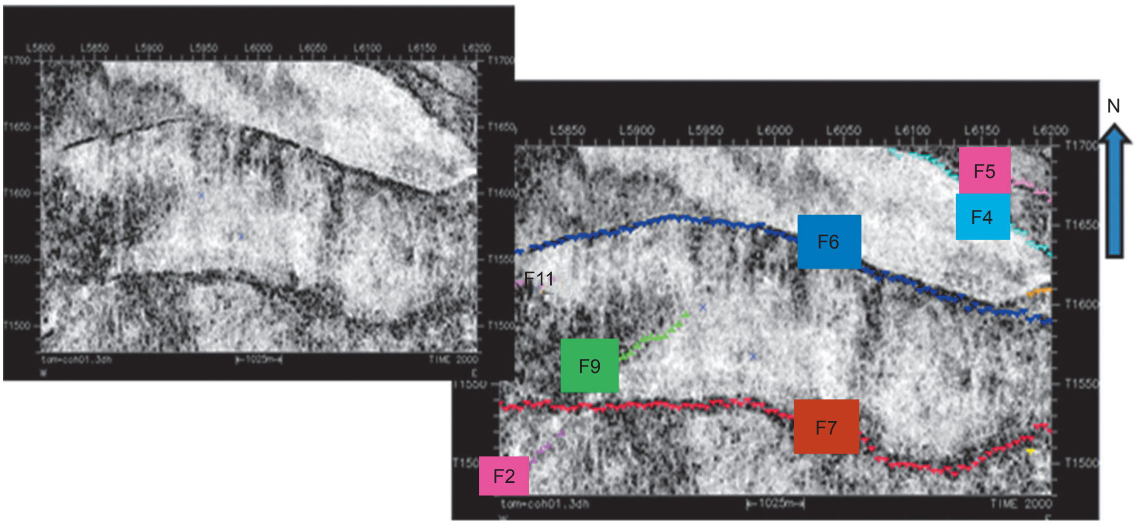


Fig. 8. Coherence time slice showing interpreted fault trend (Openworks, 2011)
Рис. 8. Временной срез когерентности, показывающий интерпретированную тенденцию разлома (Openworks, 2011)

Fig. 9. Interpreted faults polygons on base map (Openworks, 2011)
Рис. 9. Интерпретированные полигоны разломов на базовой карте (Openworks, 2011)

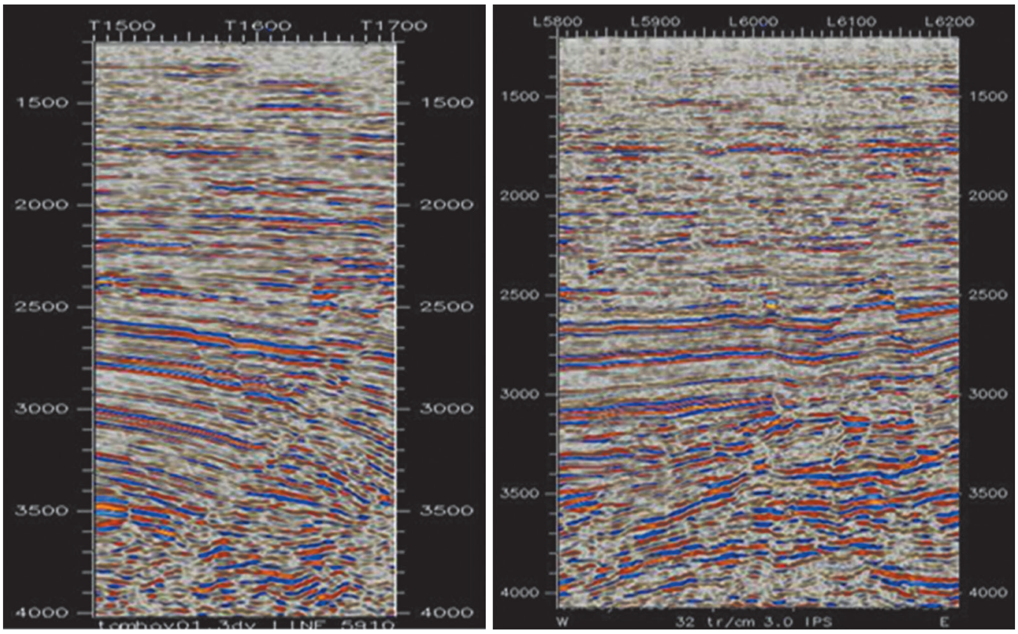


Fig. 10. Post-stack time migration seismic section along inline 5910 (a) and crossline 1580 (b) (Openworks, 2011)
Рис. 10. Сейсмический разрез миграции во временной области после суммирования вдоль линии 5910 (a) и поперечной линии 1580 (b) (Openworks, 2011)

Sand D, Sand E1, Sand E2, Sand H and Sand J. The horizons were picked using the time equivalent of the sand tops on the wells displayed on seismic using check shot data. Checkshots were used to convert depth to two-way time (Fig. 12). The events corresponding to these sand tops were mapped based on reflection continuity on Inlines and Crosslines honouring terminations due to fault planes already interpreted. Corresponding events were mapped across the faults using the “cor-

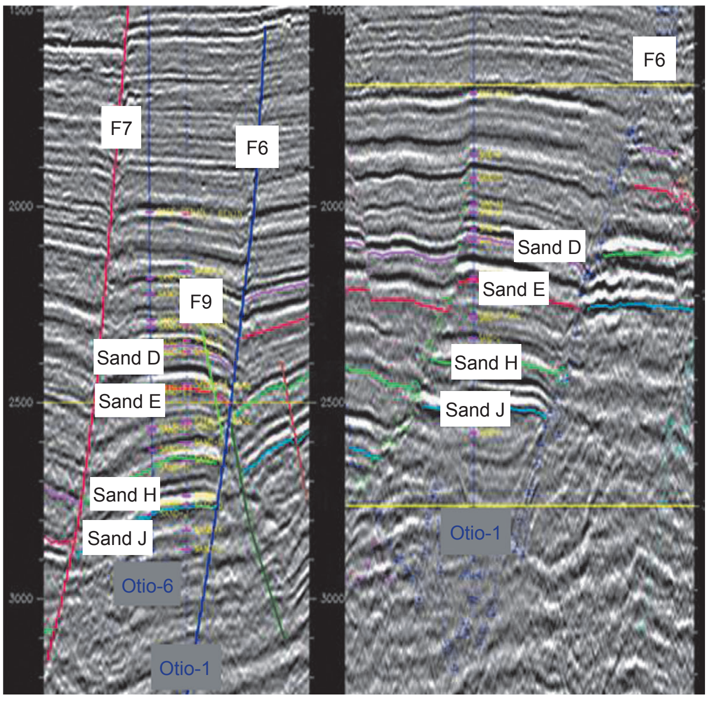
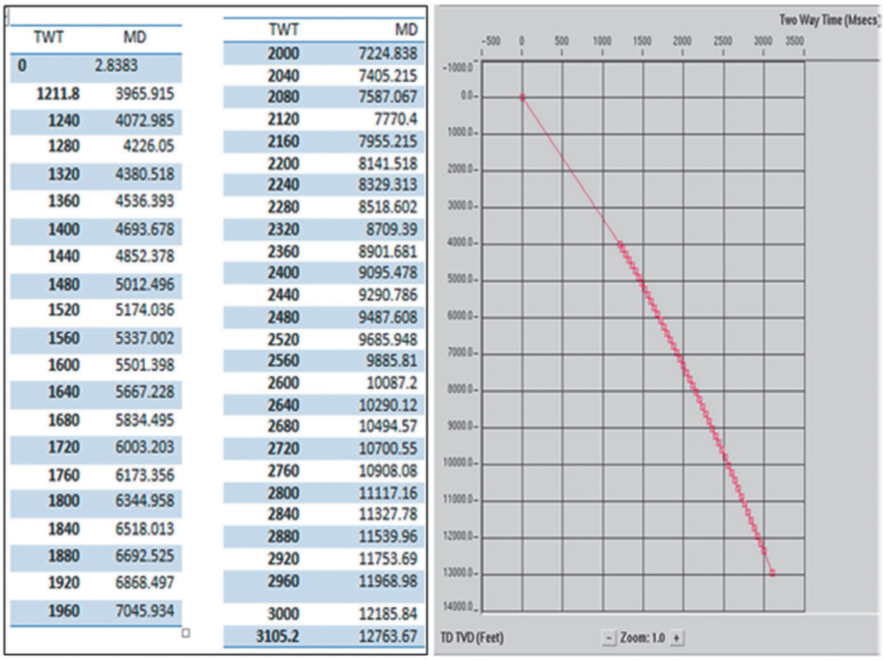


Fig. 11. Interpreted faults and identified horizons of interest on seismic Inline 5910 (Openworks, 2011)
Рис. 11. Интерпретированные изучаемые разломы и выявленные горизонты на сейсмической линии 5910 (Openworks, 2011)



TWT	MD
0	2.8383
1211.8	3965.915
1240	4072.985
1280	4226.05
1320	4380.518
1360	4536.393
1400	4693.678
1440	4852.378
1480	5012.496
1520	5174.036
1560	5337.002
1600	5501.398
1640	5667.228
1680	5834.495
1720	6003.203
1760	6173.356
1800	6344.958
1840	6518.013
1880	6692.525
1920	6868.497
1960	7045.934

TWT	MD
2000	7224.838
2040	7405.215
2080	7587.067
2120	7770.4
2160	7955.215
2200	8141.518
2240	8329.313
2280	8518.602
2320	8709.39
2360	8901.681
2400	9095.478
2440	9290.786
2480	9487.608
2520	9685.948
2560	9885.81
2600	10087.2
2640	10290.12
2680	10494.57
2720	10700.55
2760	10908.08
2800	11117.16
2840	11327.78
2880	11539.96
2920	11753.69
2960	11968.98
3000	12185.84
3105.2	12763.67

a b

Fig. 12. Data (a) and plot (b) of the Otio-2 control image used to tie wells to seismic data (Powerlog, 2014)
Рис. 12. Данные (a) и график (b) контрольного снимка Отио-2, используемые для привязки скважин к сейсмическим данным (Powerlog, 2014)

relation polygon" and reflection count techniques identifying seismic facies in the seismic section.

The horizons were mapped round the whole seismic volume by looping and phantoming. The looped interpretation resulted in seeded maps. Seeded maps have interpreted data gaps that were filled by interpolating.

Results and discussions

Hydrocarbon bearing zones: the identified hydrocarbon bearing zones are Sands D, E1, E2, H and J as interpreted from GR and resistivity logs. These zones are shown in Figures 13–16. These zones are the units of interest for further evaluation.

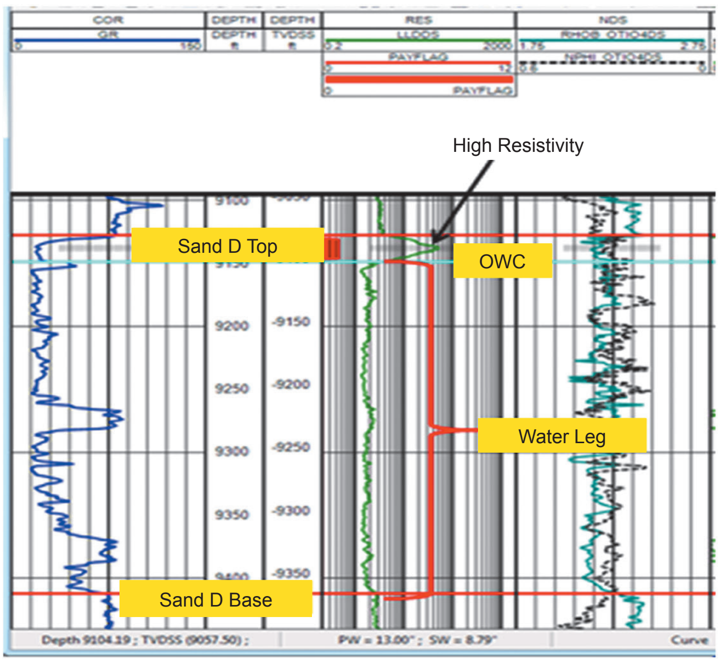


Fig. 13. Sands D in Otio-1 with high resistivity interpreted as hydrocarbon zone (Powerlog, 2014)
Рис. 13. Пески D в Отио-1 с высоким каротажем сопротивления, рассматриваемые как углеводородная зона (Powerlog, 2014)

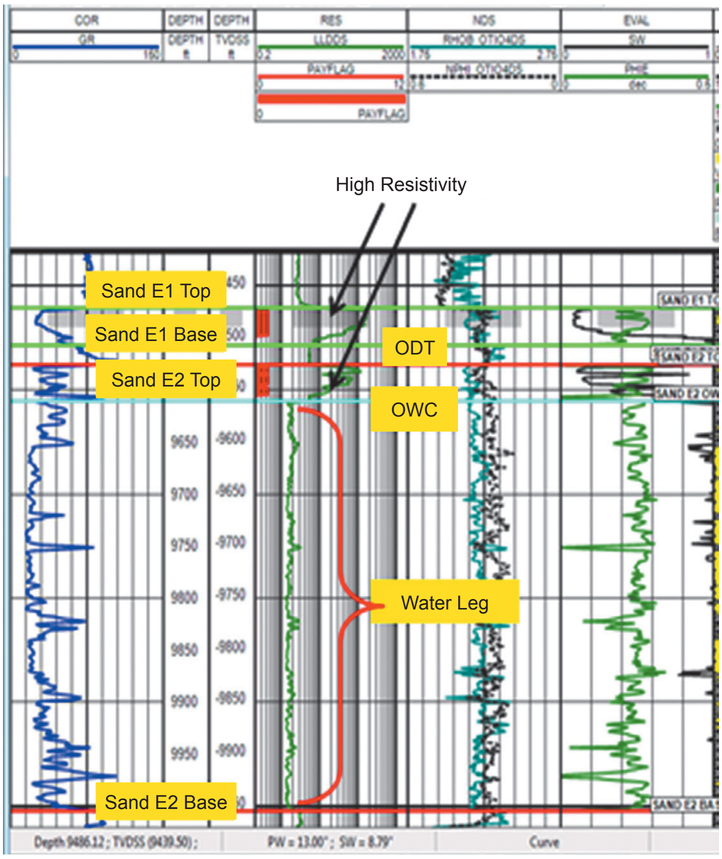


Fig. 14. Sands E1 and E2 in Otio-1 with high resistivity interpreted as hydrocarbon zones (Powerlog, 2014)
Рис. 14. Пески E1 и E2 в Отио-1 с высоким каротажем сопротивления, рассматриваемые как углеводородные зоны (Powerlog, 2014)

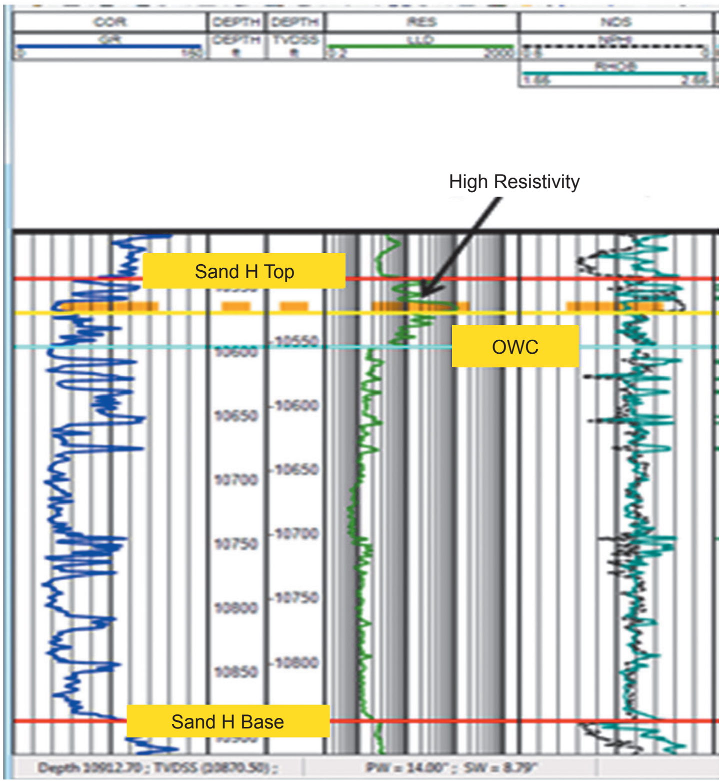


Fig. 15. Sands H in Otio-4 with high resistivity interpreted as hydrocarbon zones (Powerlog, 2014)
Рис. 15. Пески H в Отио-4 с высоким каротажем сопротивления, рассматриваемые как углеводородные зоны (Powerlog, 2014)

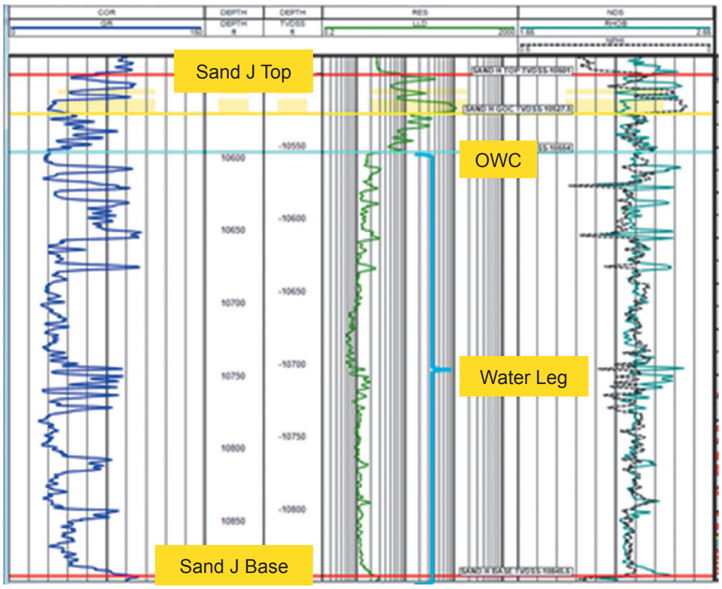


Fig. 16. Sands J in Otio-4 with high resistivity interpreted as hydrocarbon zones (Powerlog, 2014)
Рис. 16. Пески J в Отио-4 с высоким каротажем сопротивления, рассматриваемые как углеводородные зоны (Powerlog, 2014)

Sand to sand correlations: Sand correlation across the field showed uniform sand development from well to well (Fig. 17). Sand H appears missing in Otio-5 due to possible faulting. The sands vary from blocky, progradational and retrogradational depicting variation in environment of deposition. Sands E1 and E2 are separated by a thin shale unit capable of impeding communication between both reservoirs, which necessitated the units to be mapped independently. The correlation shows that the reservoirs is of good continuity as the wells saw all of the reservoirs except sand Otio-5 that has a missing section because it crossed a fault.

Checkshot loading: The result of the third (3rd) order plot of the checkshot data is shown in (see Fig. 9). The checkshot is interpreted as good because of the absence of outliers or spurious values. The plot is a gentle slope that eventually steepens because of compaction of the underlying units that causes Two-Way Time to decrease. Otio-2 checkshot was shared for other wells

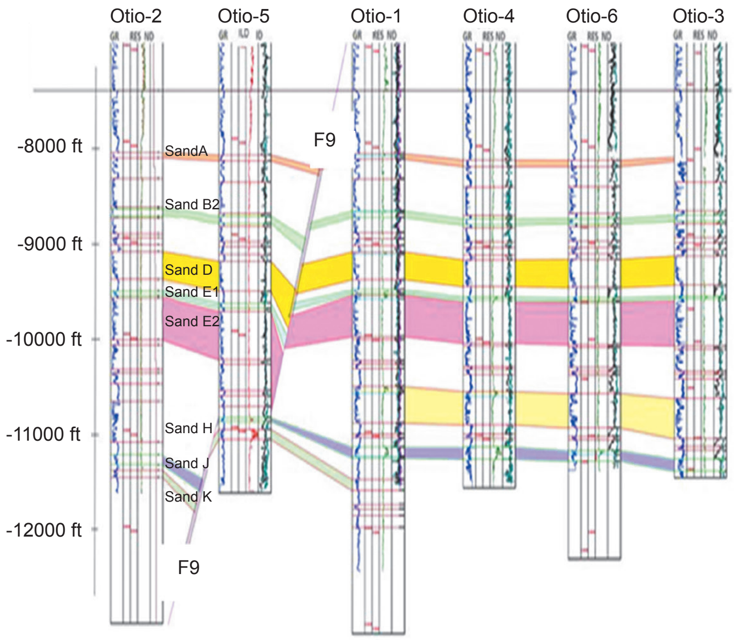


Fig. 17. Sand to sand correlation of the "Otio Field" (Powerlog, 2014)
Рис. 17. Взаимосвязь между песками месторождения Отио (Powerlog, 2014)

(Fig. 18) and a multipanel seismic section (Fig. 19) was taken across the wells to check the consistency of sand top picks across the seismic (see Fig. 10).

Structural Interpretation: Sixteen faults (F1-F16) were interpreted across the field as seen on seismic section. All the faults were interpreted as normal faults with fault F6 and F7 the major faults in the field listric in nature. Coherence Timeslices were used to guide in fault interpretation. Litho-units on the down-thrown block of the major faults appear to be thicker compared to the up-thrown block. F6 and F7 were therefore as listric growth faults which are syn-sedimentary evident in the Niger Delta. Faults in the field trend in the East-West direction with majority of them dipping north except for faults F4 F6, F7 and F9 dipping south. Rollover anticlinal structure (Fig. 20) is seen on the down-thrown block of fault F9.

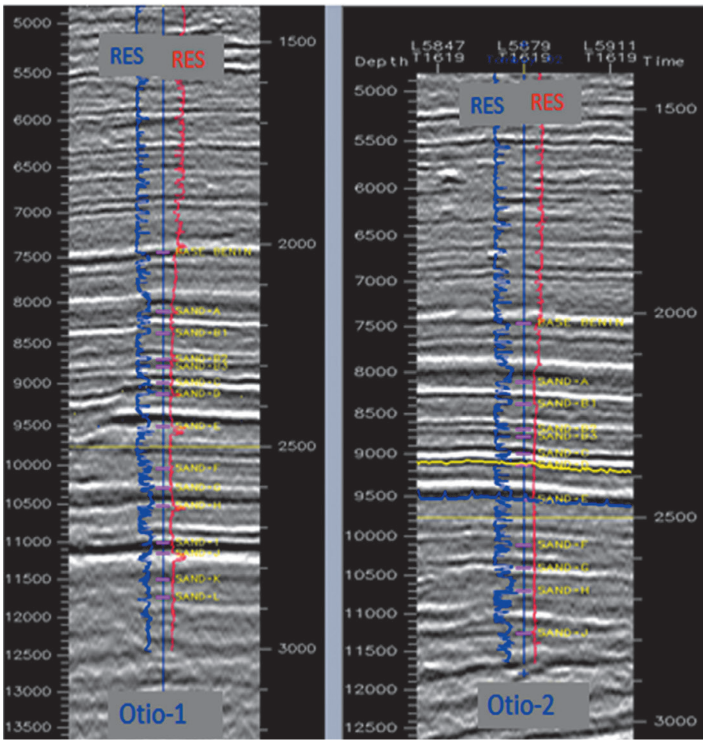


Fig. 18. Otio-1 and Otio-2 well section displayed on seismic section (Openworks, 2011)
Рис. 18. Разрез скважин Отио-1 и Отио-2, отображенный на сейсмическом разрезе (Openworks, 2011)

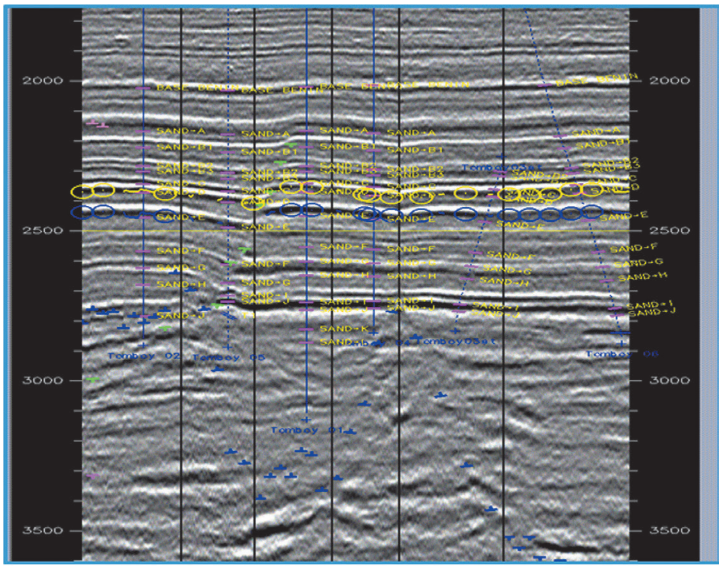


Fig. 19. Multipanel display of all well sections (Openworks, 2011)
Рис. 19. Многопанельное отображение всех разрезов скважин (Openworks, 2011)

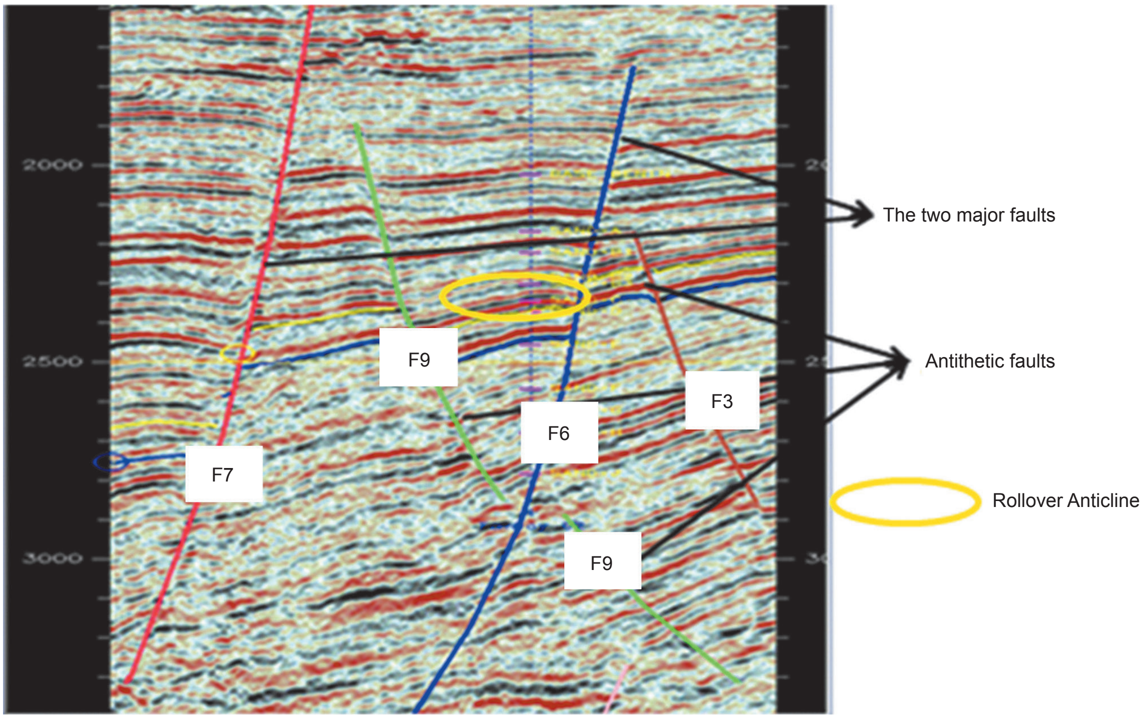


Fig. 20. Seismic section showing the two major faults in the "Otio Field" (Openworks, 2011)
Рис. 20. Сейсмический разрез, показывающий два основных разлома месторогждения Отио (Openworks, 2011)

The structural styles as observed from depth structure map of Sand D (Fig. 21) top show rollover anticlines on fault F9 assisting in hydrocarbon accumulation. This was also observed at deeper levels on Sands E1 and E2 tops. On Sand H top structure map, fault F9 has grown bigger latching on fault F6. This new configuration makes accumulation totally dependent on faults F9 and F6 (see Fig. 20). Appearance of new faults (F15 and F16) is observed on Sand H top and disappearance of fault F11 is noted. The same structural setting is observed on Sand J, however, there is the disappearance of fault F15 on the up-thrown block of fault F6 and the appearance of another small fault F14 which plays no role in hydrocarbon accumulation. From seismic section, Sand H appears missing due to obvious faulting which corroborates the missing unit in Otio-5 as seen in the well correlation panel. Otio-5 encounters pay zone in another fault block after crossing fault F9.

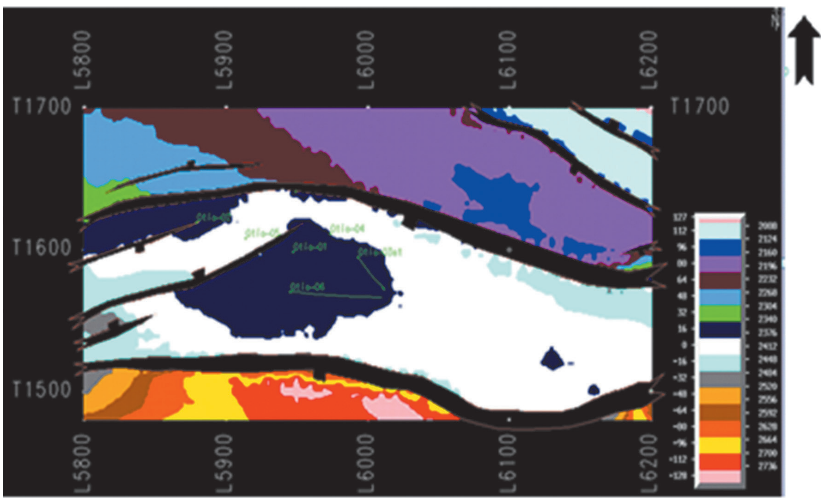


Fig. 21. Interpolated sand D on the base map (Openworks, 2011)
Рис. 21. Интерполированный песок D на базовой карте (Openworks, 2011)

Conclusion

The 3D structural analysis of Otio Field in the Niger Delta enhanced understanding of its structural styles and hydrocarbon traps. Eight reservoirs were identified, with five hydrocarbon-bearing sands (D, E1, E2, H, J) mapped, consisting of sands sealed by shales. Wells Otio-1, Otio-3ST, Otio-4, and Otio-6 hit pay zones, while Otio-2 was wet, and Otio-5 found pay deeper after crossing fault F9. Petrophysical analysis showed porosity of 18–27 %, water saturation of 20–31 %, and Net-To-Gross of 59–96 %. The field features moderate faulting with two major south-dipping, east-west trending growth faults (F6, F7) and a fault-assisted closure (F9) down-thrown of F6, critical for deeper traps. Six wells targeted this closure, with Otio-1, the deepest, testing all reservoirs near the structure's crest. Anticlinal structures and fault-dependent closures are key trapping mechanisms. Volumetric analysis identified Sand E2 as the most prolific (24.72 MMBO) and Sand H the least (3.77 MMBO). Two prospects, North-Eastern (NE) and South-Eastern (SE), were defined, with NE being more economical (STOIIP 49.42 MMBO vs. 37.63 MMBO for SE). Integrating seismic and well log data was vital for mapping and prospect identification, guiding future exploration.

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Information about the author / Информация об авторе

Mohammed Abubakar Mohammed,
Ph.D.,
Research Engineer,
Siberian School of Geosciences,
Irkutsk National Research Technical University,
Irkutsk, Russia,
✉ mmbaama@gmail.com; mmohammed@geo.istu.edu
https://orcid.org/0009-0008-1298-6117
Мохаммед Абубакар Мохаммед,
доктор наук,
инженер-исследователь,
институт «Сибирская школа геонаук»,
Иркутский национальный исследовательский технический университет,
г. Иркутск, Россия,
✉ mmbaama@gmail.com; mmohammed@geo.istu.edu
https://orcid.org/0009-0008-1298-6117

Contribution of the author / Вклад автора

The author performed the research, made a generalization on the basis of the results obtained and prepared the copyright for publication.

Автор выполнил исследовательскую работу, на основании полученных результатов провел обобщение, подготовил рукопись к печати.

Conflict of interests / Конфликт интересов

The author declares no conflict of interests.

Автор заявляет об отсутствии конфликта интересов.

The final manuscript has been read and approved by the author.

Автор прочитал и одобрил окончательный вариант рукописи.

Information about the article / Информация о статье

The article was submitted 28.04.2025; approved after reviewing 12.05.2025; accepted for publication 29.05.2025.

Статья поступила в редакцию 28.04.2025; одобрена после рецензирования 12.05.2025; принята к публикации 29.05.2025.