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Sedimentological Analysis of Core Samples to Decipher Depositional Environments: A Case Study of 'Valz-01' Well Niger-Delta Basin, Nigeria

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Authors' contributions

This work was carried out in collaboration between both authors. Author GEMO designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors GEMO and FAL managed the analyses of the study. Author FAL managed the literature searches. Both authors read and approved the final manuscript.

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ABSTRACT

Sedimentological studies of ninety-seven feet (97ft) of core, covering 1643 -1797.74 m from 'Valz-01' well Offshore Eastern Niger Delta was carried out using twenty-four (24) core slabbed samples with the aim of identifying the textural characterization of sediments from the various sectors of the lithologic unit and to determine the environment of deposition. Six lithofacies units were identified within the cored interval. They include: Muddy heterolith, laminated fine sandstone/siltstone, Fine sandstone/siltstone, Hummocky fine sandstone/siltstone, laminated shale sandy, and shale. Three depositional environments identified include marine environment, transitional and continental environment. The marine environment is characterized by the deposits of shale (1644.27 - 1709) m, while the continental environment is characterized by sandstone (1779 - 1781) m. The transitional environment is characterized by alternation of siltstone and shale (1643 – 1644.22 and 1781 – 1797.74) m. From the studies most of the analyzed samples are deposited in the delta influenced by fluvial and waves actions revealing beach sediments and turbidites.

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Keywords: Depositional environments; subsurface; sedimentological analysis; Valz-01; Niger Delta.

1. INTRODUCTION

The study area is situated in 'Valz' Field, in the western part of the Niger Delta Basin. 'Valz' as well as 'Valz-01' is a fictitious name given to the name of the field and well respectively for obvious proprietary reasons. 'Valz-01' well is one of the wells drilled in 'Valz' Field located offshore in the Niger Delta Basin, Nigeria. The block where the well is located covers an area 916.6 km^2 in water depths ranging from 150m to 1000m (more than 98% in deep waters). Covered by 3D seismic mapping, this block has proven oil and gas in the shallow (Pliocene) part of the 'Valz' Field [1]. The Field was discovered in 1995 [1]. This was followed by 3 additional wells in the appraisal phase. The field contains more than 50 million barrels recoverable reserves of light 34.5 degree crude oil, and significant volumes of natural gas reserves. Identified crude oil reserves potentials for the adjoining blocks are estimated at some 2 billion barrels. Some exciting prospects have been identified in the deeper Miocene interval, and are aggressively being matured. 'Valz' Field is currently being developed, with first oil achieved in 2009, as reported by Wood [1] asset report. Detailed core description and analysis were carried out on 29.59 m (97 ft) of core samples from 'Valz-01' located in 'Valz' Field, in the western part of the Niger Delta basin. Basic sedimentological description was conducted in the core shed. The objective of the study is to carry out sedimentological description of the cores to provide interpretation of the depositional environments through a systematic classification into lithofacies, lithofacies associations / genetic units. The lithofacies present in these cores have been identified on the basis of lithology, texture and sedimentary structures. These have been described and classified using standard SPDC reservoir lithofacies scheme as published in the SIEP (Davies et al., 1997) Lithofacies Scheme *In* SPDC Reservoir Geology Atlas [2].

1.1 Geology of the Niger Delta Basin

The Niger Delta is situated in the Gulf of Guinea and extends throughout the Niger Delta province as defined by Klett et al. [3]. From the Eocene to the present, the delta has prograded southwestward, forming depobelt that represent the most active portion of the delta at each stage of its development [4]. These Depobelts form one of the largest regressive deltas in the world with an area of some 3,000 km^2 [5], a sediment volume of 500,000 km^3 [6], and a sediment thickness of over 10 km in the basin depocenter

Fig. 1. Map extract from Microsoft Encarta, 2007 showing study location

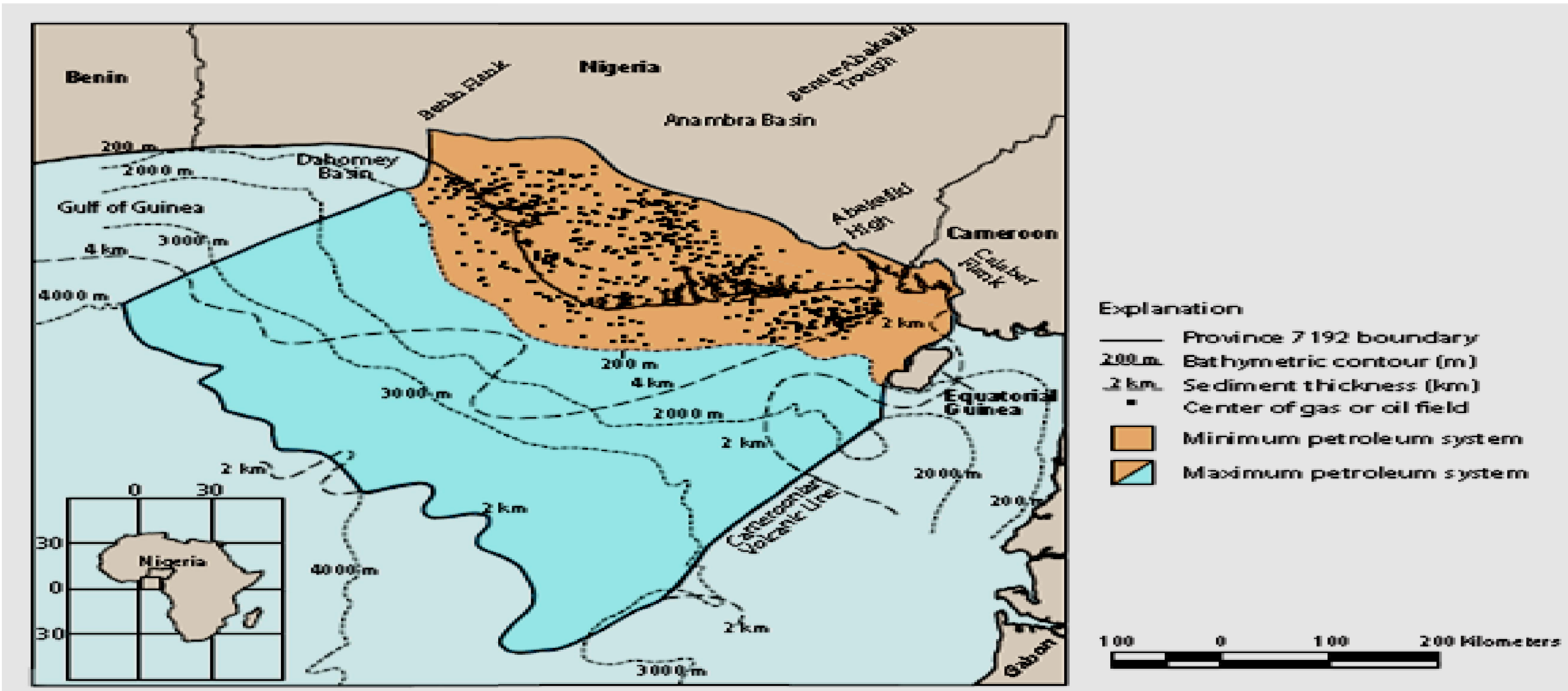


Fig. 2. Index map of Nigeria and Cameroon. Map of the Niger Delta showing Province outline (maximum petroleum system); bounding structural features; minimum petroleum system as defined by oil and gas field centre points (data from Petroconsultants,1996a) [19]; 200, 2000, 3000, and 4000 m bathymetric contours; and 2 and 4 km sediment thickness

[7]. The Niger Delta province contain only one identified petroleum system [5,8]. This system is referred to as the Tertiary Niger Delta (Akata-Agbada) petroleum system. The maximum extent of the petroleum system coincides with the boundaries of the province. The delta formed at the site of a rift-triple junction related to the opening of the southern Atlantic starting in the late Jurassic and continuing into the Cretaceous. The delta proper began developing in the Eocene accumulating sediments that are now 10 km thick. The primary source rock is the upper Akata Formation, the marine shale facies of the delta, with possible contribution from interbedded marine shale of the lowermost Agbada Formation, turbidite sand in the upper Akata Formation is a potential target on deep water offshore and possibly beneath currently producing interval onshore. The information on geology, tectonic sedimentary structures and paleogeography of the basin are adequately covered by previous workers [9,10,11,12,13,14,15,16,4,17]. The Niger Delta Basin is part of the sedimentary basin of southern Nigeria whose depositional history began in the early Cretaceous. The sediment fill of the basin was controlled by three main tectonic phases and by epirogenic movement which resulted in major transgressive and regressive circles [18], as a result of these tectonic events, the axis of the main basin was displaced giving rise to three successive bases. Abakaliki Benue Trough (Albian- Lower Santonian), Anambra Basin (Upper -Lower Santonian) and the Niger Delta Basin (Lower Eocene-Recent). The Niger Delta basin contains Cenozoic to Recent deposits emplaced in high energy constructive deltaic environments.

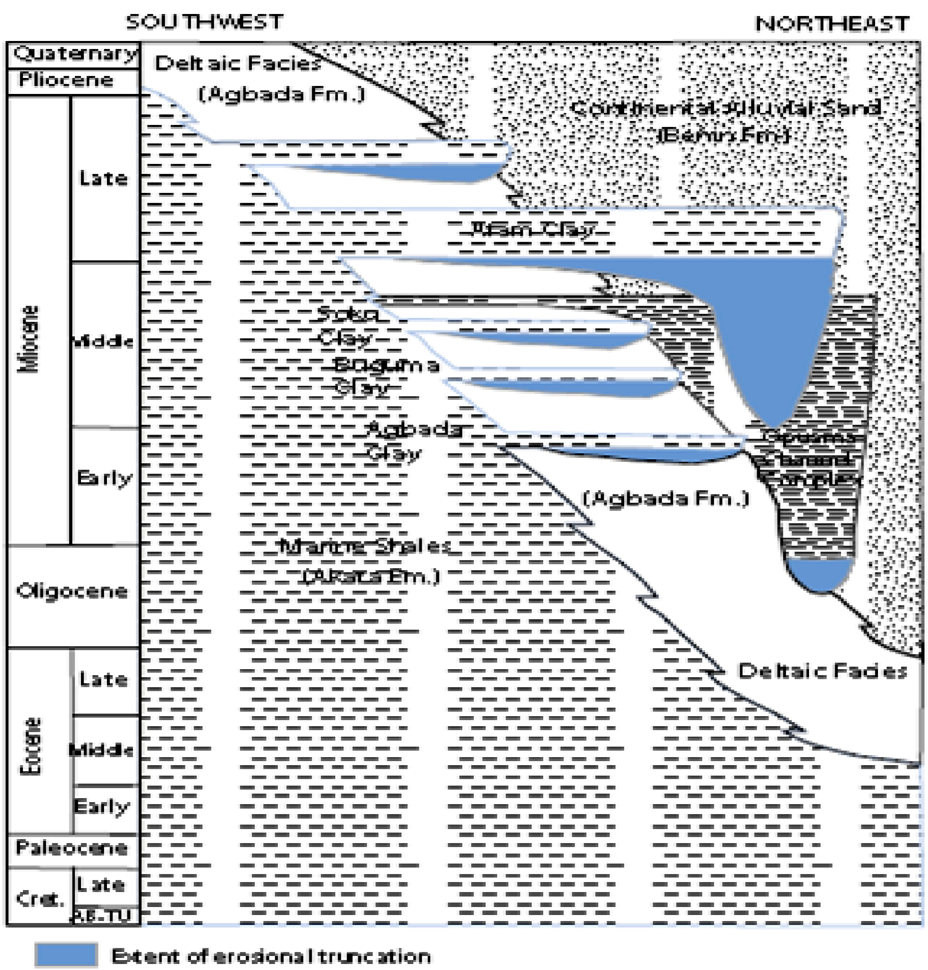


Fig. 3. Stratigraphic column showing the three formations of the Niger Delta. Modified from Shannon and Naylor (1989) [20] and [4]

1.2 Lithostratigraphy of the Niger Delta Basin

The Niger-Delta consists of three broad formations [9]. These are the continental top facies (Benin formation) which is the shallowest part of the sequence and consists predominantly of fresh water bearing continental sands and gravels, Agbada formation which underlies the Benin Formation and consists primarily of sand and shale and it is of fluviomarine origin (it is also the hydrocarbon window) and the Akata formation. The lithofacies of the Akata formation is composed of shales, clays and silts at the base of the known Delta sequence. They contain a few streaks of sand, possibly of turbidite origin.

1.3 Petroleum Occurrence in the Niger Delta Basin

Petroleum occurs throughout the Agbada Formation of the Niger Delta. However, several directional tends form an “oil-rich belt” having the largest field and lowest gas-oil ratio. The belt extends from the northwest offshore area to southeast offshore and along a number of north south trends in the area of Port Harcourt. This hydrocarbon distribution was originally attributed to timing of trap formation relative to petroleum migration (earlier landward structures trapped earlier migrating oil). Evamy [15] however showed that in many rollovers, movement on the structure building fault and result growth continued and was relayed progressively southward into the younger part of the section by successive crustal faults, concluding that there was no relation between growth along a fault and distribution of petroleum. Weber [21] indicates that the oil-rich belt (“golden lane”) coincides with a concentration of roll-over structures across Depobelts having short southern flanks and little paralic sequence to the south. Doust [4] suggest that the distribution of petroleum is likely related to heterogeneity of source rock type (greater contribution from paralic sources in the west) and/or segregation due to re-migration. Haack [22] relate the deposited adjacent to the delta lobes and suggest that the accumulation of these source rocks was controlled by pre-Tertiary structural sub-basins related to basement structures.

1.3.1 Hydrocarbon source rock

There has been much discussion about the source rock for petroleum in the Niger Delta which has reflected in [23,16,24,25,4]. Possibilities include variable contributions from the marine interbedded shale in the Agbada Formation, the marine Akata shale and the Cretaceous shale [4,13,16,22,24,26,27,28]. The Agbada Formation has intervals that contain organic-carbon contents sufficient to be considered good source rocks. The intervals, however, rarely reach thickness sufficient to produce a world-class oil province and are immature in various parts of the Delta [15,27]. The Akata shale is present in large volumes beneath the Agbada Formation and is at least volumetrically sufficient to generate enough oil for a world class oil province such as the Niger Delta. In the case of the Cretaceous shale, it has never been drilled beneath the delta due to its great depth; therefore, no data exist on its source-rock potential [15].

1.3.2 Reservoir rock

Petroleum in the Niger Delta is produced from sandstone and unconsolidated sands predominantly in the Agbada Formation. Characteristics of the reservoirs in the Agbada Formation are controlled by depositional environment and by depth of burial. Known reservoir rocks are Eocene to Pliocene in age, and are often stacked, ranging in thickness from less than 15 meters to 10% having greater than 45 meters [15]. The thicker reservoir represents composite bodies of stacked channels [16]. Based on reservoir geometry and quality, [5] describes the most important reservoir types as point bars of distributary channels and coastal barrier bars intermittently cut by sand-filled channels. The primary Niger Delta reservoir was described in [15] as Miocene paralic sandstones with 40% porosity, 2 Darcys permeability, and a thickness of 100 meters. The lateral variation in reservoir thickness is strongly controlled by growth faults; the reservoir thickens towards the fault within the down-thrown block [24].

1.3.3 Traps and seals

Most known traps in Niger Delta fields are structural although stratigraphic traps are not uncommon. The structural traps developed during synsedimentary deformation of the Agbada paralic sequence [15]. Doust [4] describe a variety of structural trapping elements, including those associated with simple rollover structures clay filled channels, structures with multiple growth faults, structures with antithetic faults, and collapsed crest structures.

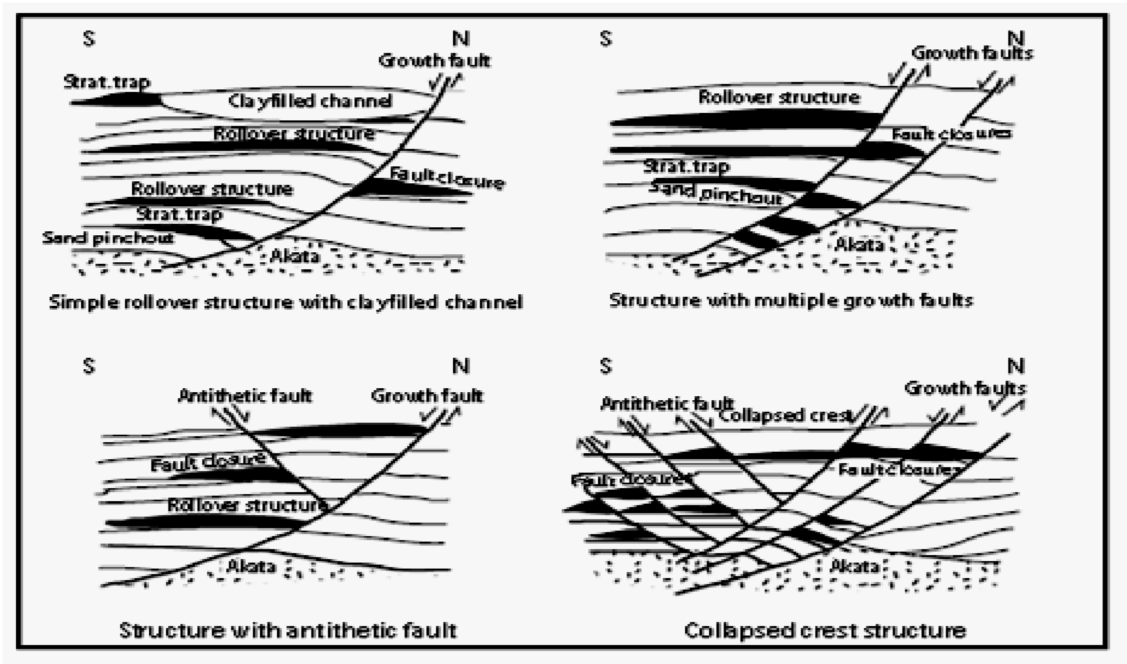


Fig. 4. Examples of Niger Delta oil field structures and associated trap types (Modified from [4] and [27]

2. MATERIALS AND METHODS

This study was carried out on core samples recovered from the 'Valz-01' well. A total of 24 core slabbed samples were selected from between 1643 meters and 1797.74 meters depth for the study.

2.1 Coring and Core Recovery

The coring of 'Valz-01' well was done using a fiber glass inner barrels coring assembly. The core recovery at acquisition was good and cores were generally in good state except for intervals that were unconsolidated resulting in little – moderate resin inversion. Generally, there was a moderate to good recovery (Table 1).

2.2 Sedimentological Studies

Detailed Sedimentological data was used to model the Geology and environments of deposition of the reservoir and include the following as a function of depth:

1) Grain size profile
2) Bioturbation
3) Sand/shale ratio
4) Sedimentary structures
5) Cementation
6) Oil stain
7) Environments of deposition

The sedimentological study entailed a systematic examination and recording of all macroscopic observable features, such as lithology (rock type), textures (color, grain size, sorting, fabric), sedimentary structures (stratification, cross-stratification, deformation structures, bioturbation) and any other striking features along the entire footage. These features were represented in a sedimentary log (Fig. 8). The environment of deposition strongly influences the morphology, trend, and continuity of a reservoir [29]. The standard Shell Petroleum Development Company (SPDC) Lithofacies scheme was used for the study. Details of composition and texture were observed under a hand lens. The standard legend "Tapeworm" of [30] was used as a guide for lithological descriptions. 10% HCL was used to check for presence of carbonate. The KSEPL publication by Flint et al. [31] was used as a comparator to facilitate the identification of genetic units.

2.3 Lithofacies

Lithofacies constitute the smallest building block in reservoir geology because the unique physical characteristics of a particular lithofacies type

Table 1. 'Valz-01' well core recovery

Core run no	Depth (M)	Missing interval
1	1643 -1650	1650 - 1707
2	1707.60 – 1711.85	1718 - 1727
3	1791 - 1797	None
5	1777 - 1791	1734 - 1767

(e.g. planer/parallel-bedded fine-medium sandstone) mean that they possess uniform reservoir properties. The SIEP (Davies *et al*. 1997) Lithofacies Scheme – SPDC Practice) was used for this study. It is based primarily on lithology, dominant grain size, dominant sedimentary structure and diagenetic modifications.

2.4 Lithofacies Associations

Lithofacies Associations represents groups of lithofacies within a Genetic unit with environmental significance, consistent range of reservoir properties, consistent external geometry consistent set of Log properties, and upscaling from micro to meso scale for reservoir modelling purposes. Genetic reservoir units are the result of a practical subdivision of a reservoir into components which have a consistent range of reservoir properties, a consistent external geometry, and a set of log responses (electrofacies) by which they can be consistently recognised. This up-scaling step from lithofacies to genetic reservoir unit (micro- to meso-scale) is a key stage in the reservoir geological modelling process. Electrofacies refers to groups of rocks which have similar physical properties as measured by petrophysical logging tools. The SHELL SIEP'97 Lithofacies Association Scheme using Walther's Law [32] was adopted equally during the grouping/stacking of the lithofacies. This was based largely on vertical stacking and existence of lithofacies having a deeping or shallowing upward pattern, utilizing Walther's Law [32].

3. RESULTS

The core samples used for this study are shown and described in Figs. 5 to 6.

4. DISCUSSION

4.1 Lithofacies Description

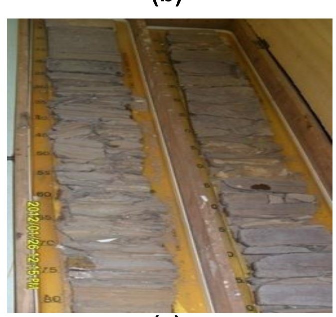
A detailed description of the intervals in the entire length of core used for this study is given in Table 6. The following lithofacies units were identified and described using the SIEP (Davies *et al*. 1997) Lithofacies Scheme – SPDC Practice).

(a)

(b)

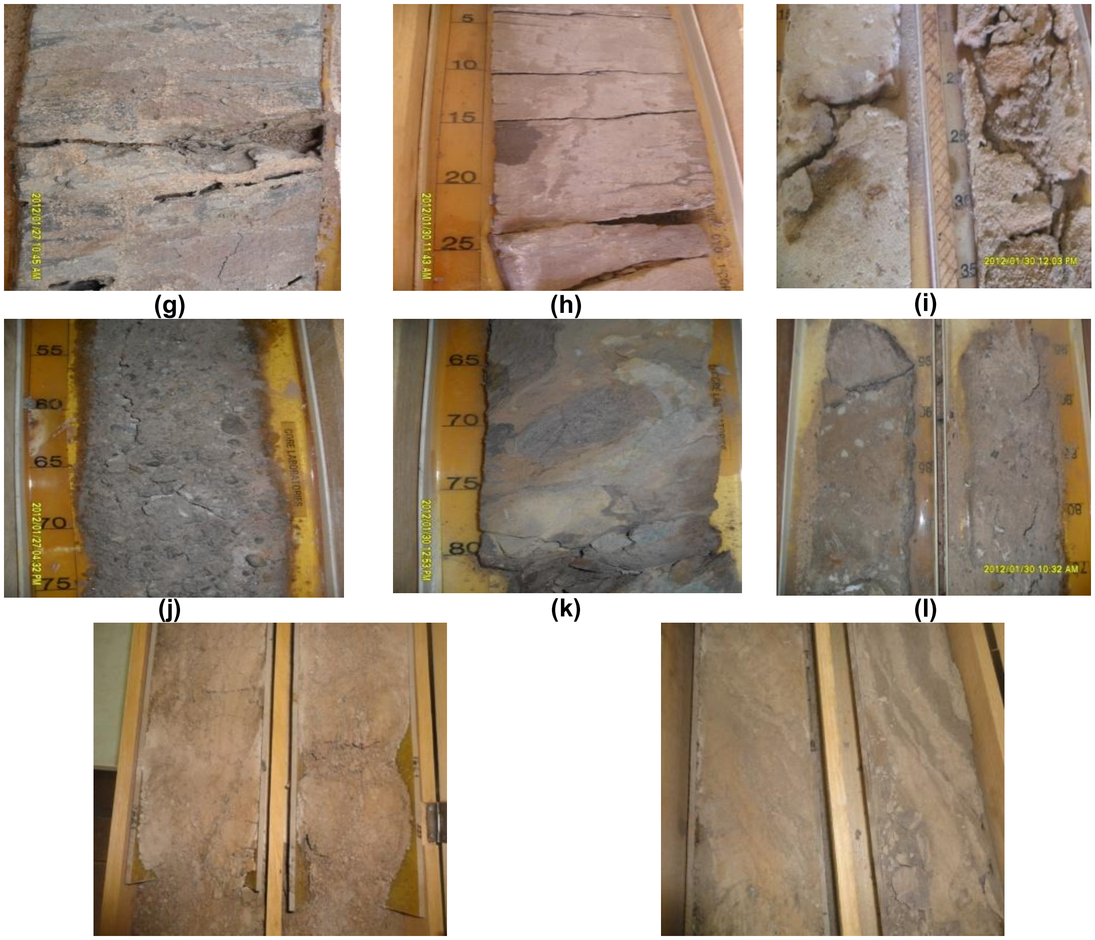
(C)

(d)



(e)

(f)



(g) (h) (i)

(j) (k) (l)

(m) (n)

Fig. 5a – 5n

(a) Shale (1643 – 1643.65) m; (b) Fine-Sands/Silts (1643.65 –1643.67) m; (c) Shale (1643.67 – 1644.18) m; (d) Laminated fine sands/Silts (1644.18 – 1644.27) m; (e) Shale (1644.27 – 1645.15) m; (f) Laminated Shale (1645.15 – 1645.22) m; (g) Shale (1645.22 – 1646) m; (h) Laminated Shale (1646 – 1648) m; (i) Laminated Shale (1648 – 1650) m; (j) Shale (1707.60 – 1708.30) m; (k) Laminated fine sands/Silts (1708.30 – 1708.75) m; (l) Laminated Shale (1708.75 – 1709) m; (m) Fine-Sands/Silts (1711.40 – 1711.85) m; (n) Muddy Heterolith (1778 – 1779) m

(a) (b) (c)

(d)

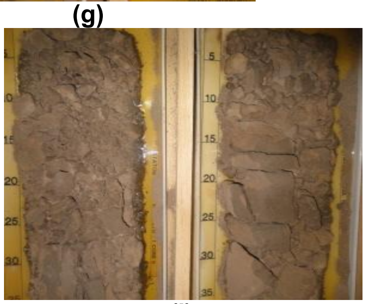
(e)

(f)

(g)

(h)

(i)



(j)

(k)

Fig. 6a – k

(a) Hummocky, Cross bedded, fine sands/silts (1779 – 1780) m; (b) Hummocky, Cross bedded, fine sands/silts (1780 – 1781) m; (c) Fine-Sands/Silts (1781 – 1783) m; (d) Fine-Sands/Silts (1783 – 1785) m; (e) Fine-Sands/Silts (1785 – 1787) m; (f) Fine-Sands/Silts (1787 – 1789) m; (g) Laminated fine sands/Silts (1789 – 1791) m; (h) Fine-Sands/Silts (1791 – 1792) m; (i) Fine-Sands/Silts (1792 – 1794) m; (j) Laminated fine sands/Silts (1794 – 1796) m; (k) Fine-Sands/Silts (1796 – 1797. 74) m

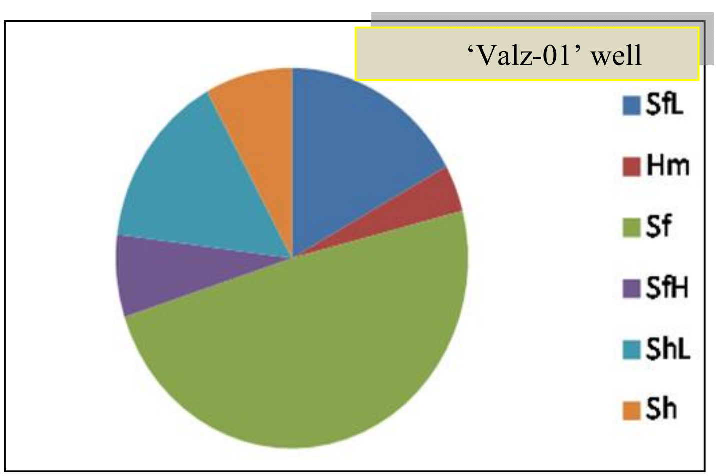
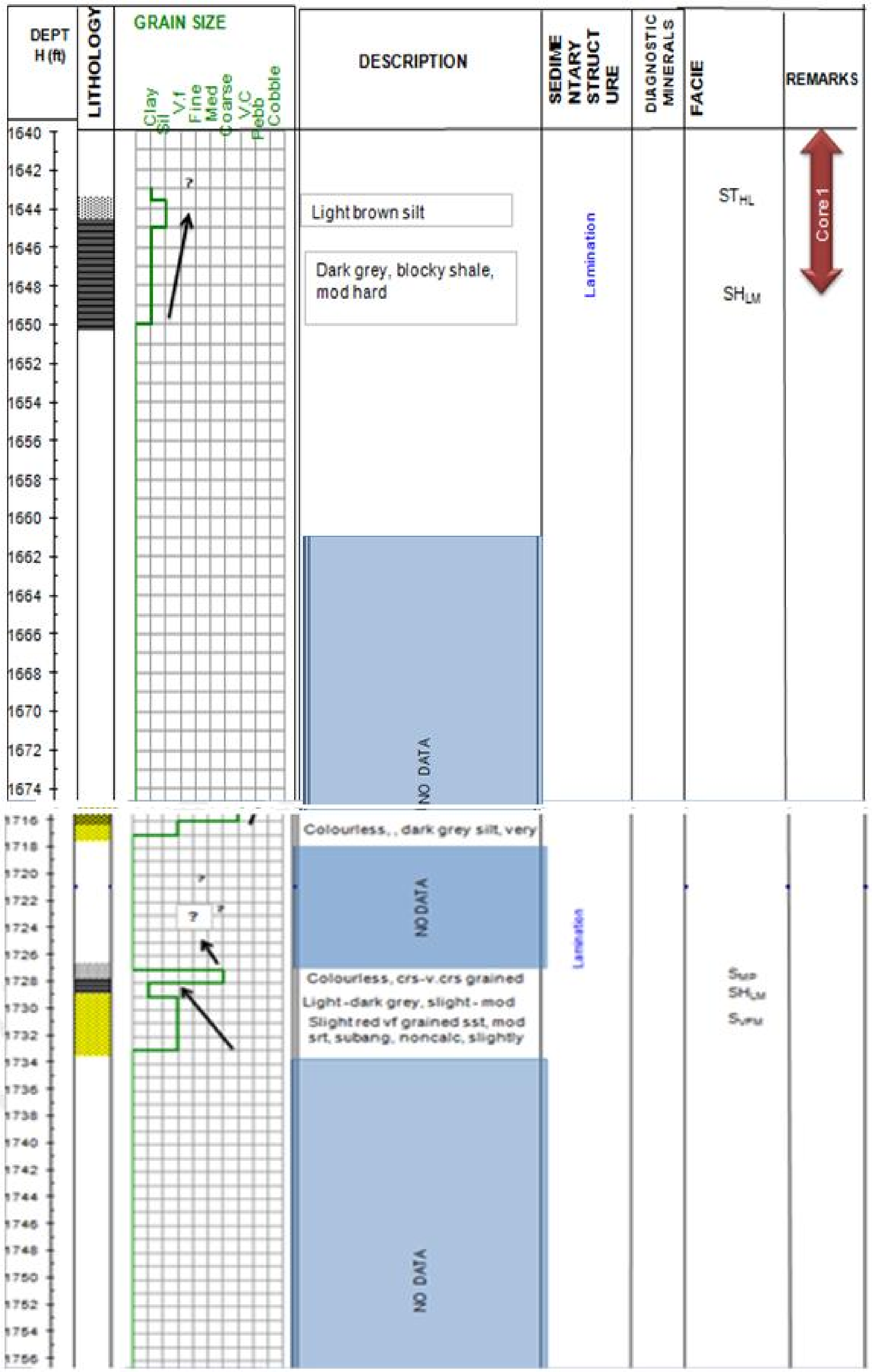


Fig. 7. Pie-chart showing the distribution of 'Valz-01' well Lithofacies

Table 2. Summary of lithofacies and sedimentological description of 'Valz-01' well

Depth	Lithology	Sed. St	Diagnostic	Lithofacies	Facies codes	Description	Depositional environment
Core 1							
1643 – 1643.65	Shale			Shale	Sh	Light brown, blocky shale, mod. Hard	Transitional
1643.65 – 1643.67	Silt			Fine-Sands/Silts	Sf	Light brown silt	
1643.67 – 1644.18	Shale			Shale	Sh	Dark grey, blocky shale, mod hard	
1644.18 – 1644.27	Silt	laminated		Laminated fine sands/Silts	SfL	Very light brown silt	
1644.27 – 1645.15	Shale			Shale	Sh	Brown shale, blocky	Marine
1645.15 – 1645.22	Silt	laminated	Slight mica flakes	Laminated Shale	ShL	Light brown	
1645.22 – 1646	Shale		Presence of slight mica flakes	Shale	Sh	Dark brown, blocky hard shales	
1646 – 1648	Shale	Hummocky, lenticular, laminated		Laminated Shale	ShL	Light brown, blocky shales, mod hard, with silt interbeds	
1648 – 1650	Shale	laminated	Slight mica flakes	Laminated Shale	ShL	Dark brown, blocky shales	
Core 2							
1707.60 – 1708.30	Shale			Shale		Light brown shale, blocky and mod hard	Marine
1708.30 – 1708.75	Silt	laminated		Laminated fine sands/Silts	SfL	Light brown silt	
1708.75 – 1709	Shale	laminated	Slightly ferruginous	Laminated Shale	ShL	Light brown blocky shale, mod hard	
1711.40 – 1711.85	Sandstone			Fine-Sands/Silts	Sf	Fine grained sst, whitish, mod sorted, sub-angular to sub-rounded	Transitional
Core 5							

Depth	Lithology	Sed. St	Diagnostic	Lithofacies	Facies codes	Description	Depositional environment
1778 – 1779	Shaly silt			Muddy Heterolith	Hm	Dark grey shales & silt	Transitional
1779 – 1780	Shale	laminated, cross-bedded, hummocky	Slightly micaceous	Hummocky, Cross bedded, fine sands/silts	SfH	Light brown, blocky shale	Continental
1780 – 1781	Silt	Lam, cross-bedded, hummocky	Slightly micaceous	Hummocky, Cross bedded, fine sands/silts	SfH	Light brown silt	
1781 – 1783	Silt		Slightly micaceous	Fine-Sands/Silts	Sf	Light brown silt	Transitional
1783 – 1785	Silt			Fine-Sands/Silts	Sf	Light brown silt	
1787 – 1789	Silt		Slightly micaceous	Fine-Sands/Silts	Sf	Light brown silt	
1789 – 1791	Silt	beddings		Laminated fine sands/Silts	SfL	Light brown silt	
Core 3							
1791 – 1792	Silt		Slightly micaceous	Fine-Sands/Silts	Sf	Light brown silt	
1792 – 1794	Silt		Slightly micaceous	Fine-Sands/Silts	Sf	Light brown silt	
1794 – 1796	Silt	laminated		Laminated fine sands/Silts	SfL	Light brown silt	
1796 – 1797. 74	Silt			Fine-Sands/Silts	Sf	Light brown silt	


DEPTH (ft)
LITHOLOGY
GRAIN SIZE
Clay Sil V.f Fine Med Coarse V.C Pebb Cobble
DESCRIPTION
SEDIMENTARY STRUCTURE
DIAGNOSTIC MINERALS
FACIE
REMARKS
Light brown silt
Dark grey, blocky shale, mod hard
Lamination
ST_{HL}
SH_{LM}
Core 1
NO DATA
Colourless, , dark grey silt, very
NO DATA
Colourless, crs-v.crs grained
Light-dark grey, slight-mod
Slight red vf grained sst, mod srt, subang, noncalc, slightly
SH_{LM}
NO DATA

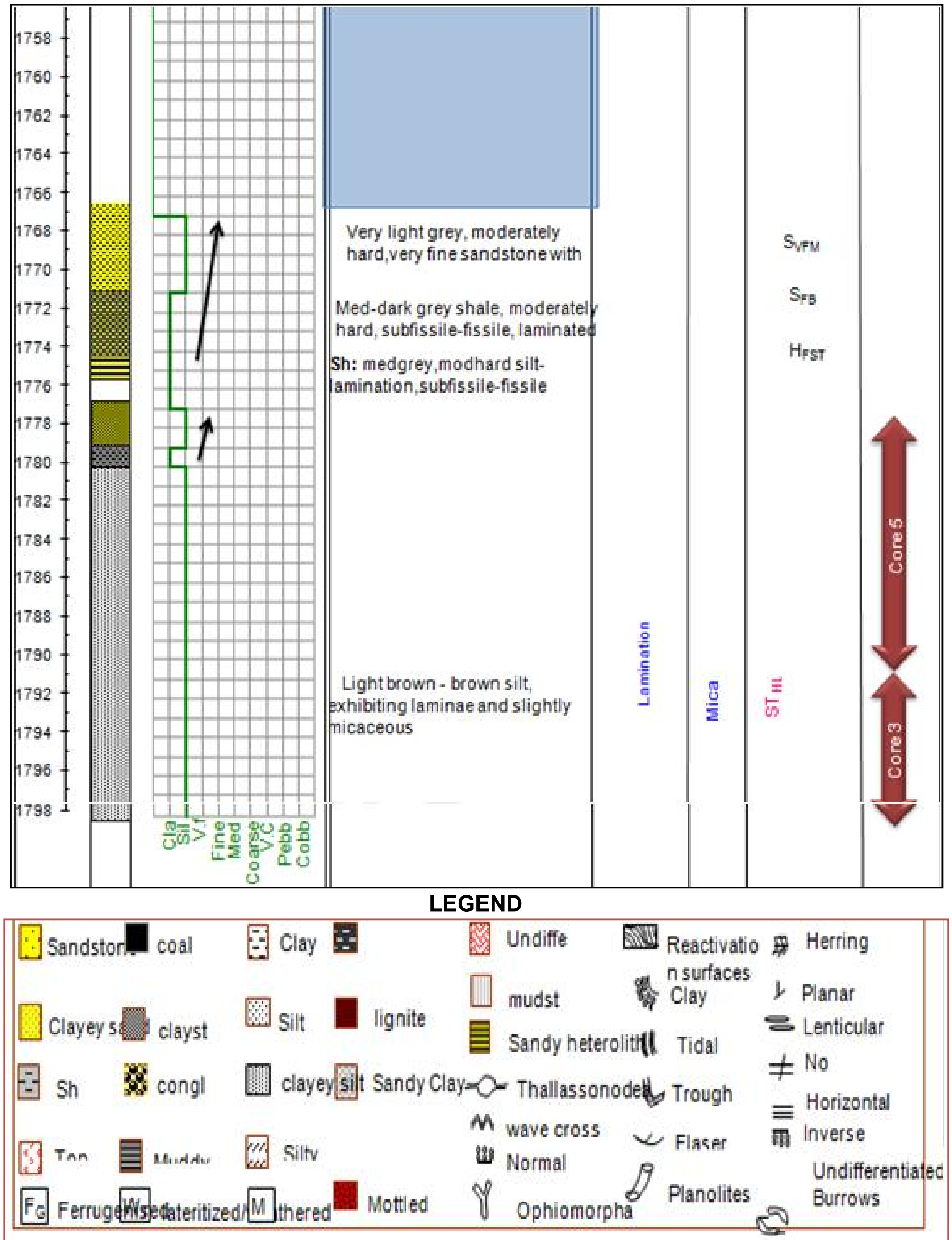


Fig. 8. Lithology Log of 'Valz-01' well

4.1.1 Laminated Fine Sandstone/siltstone (SfL)

This lithofacies unit occurs over the interval range (1644.18 – 1644.27, 1708.30 – 1708.75, 1789 – 1791 and 1794 – 1796) m. This unit is 5m thick. It is made up of laminated fine sands/silts, light brown in color, well sorted, sub-rounded and friable with horizontal laminations. Mica occurs as an accessory mineral. The lithofacies unit inferred a transitional condition of sedimentation.

4.1.2 Muddy Heterolith (Hm)

This lithofacies unit occurs only in one interval (1778 – 1779) m and is about 1 m thick. Grain size ranges from fine to very fine with fine as the dominant grain size. It is well sorted, sub angular to sub-rounded. It is characterized by dark grey shales and silt with no evidence of bioturbation. It inferred a transitional condition of deposition.

4.1.3 Fine Sandstone/Siltstone (Sf)

This unit occurs over the interval range (1645.65 – 1645.67, 1711.40 – 1711.85, 1781 – 1783, 1783 – 1785, 1785 – 1787, 1787 - 1789, 1791 – 1792, 1792 – 1794 and 1796 – 1797.74) m. It is 14.21m thick. Color is white to light brown, fine-grained, sub-angular to sub-rounded, moderately to well sorted, with presence of slight mica flakes. It inferred a transitional condition of deposition.

4.1.4 Hummocky Fine Sandstone/Siltstone (SfH)

This unit occurs over the interval range (1779 – 1780 and 1780 -1781) m. It is 2 m thick. It is characterized by an alternation of light brown silt and blocky shale. Sedimentary structures present are lamination, beddings, cross beddings, and hummocky with the presence of slightly micaceous minerals. It inferred a continental condition of deposition.

4.1.5 Laminated Shale (ShL)

This lithofacies occurs over the interval range (1645.15 – 1645.22, 1646 - 1648, 1648 – 1650 and 1708.75 – 1709) m which is 4.32 m thick. It is light to dark brown in color, blocky shale, fine-grained, moderately hard, laminated beddings, lenticular, hummocky, and presence of slightly ferruginous and mica minerals. It inferred a marine condition of deposition.

4.1.6 Shale (Sh)

This unit occurs over the interval range (1643 - 1643.65, 1643.67- 1644.18, 1644.27 – 1645.15, and 1645.22 – 1646) m. This unit is 2.28 m thick. It is light to dark brown in color, blocky shale, moderately hard with slight amount of mica flakes. It inferred a marine to transitional condition of deposition.

5. CONCLUSION

A section of the cored interval of 'Valz-01' well was studied between (1643 – 1797) m based on virtual observations of the characteristic features of the interval. The section showed a number of heterolithic characteristics, ranging from coarse grained sandstone to mudstone, shales, and siltstone. From the study, most of the analyzed samples were deposited in the delta influenced by fluvial and waves actions, characterized by low wave and tide energy, decrease of velocity at the sea front, mouth bar – distributive pattern, decrease grains side with depth, non prograding channel, sandy coastal bars and well-sorted sand, revealing beach sediments and turbidities which are in line with textural characteristics.

COMPETING INTEREST

Authors have declared that no competing interests exist.

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