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Lithostratigraphic characterization of the Turonian in the San-Pedro Margin (Côte D'ivoire)

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Abstract

The lithostratigraphic characterization consisted to highlighting, the lithologic, the thickness, mineralogical and petrographic nature of the different formations encountered during drilling in the Turonian stage of the wells in the study area. The data used consist of geological reports of five boreholes and LAS (Log Ascii Standard). This characterization reveals that the Turonian range consists of three major formations, namely claystones, of siltstones and sandstones interbedded with calcareous, dolomitic and silty formations. The clays are gray to black, tender to firm, subfissile and moderately hard to hard. Sandstones are very fine to very coarse, subangular to subarronded, well to poorly sorted, with silty, calcareous and often dolomitic matrix. Note the presence of pyrite, glauconite and carbonaceous debris. A lithostratigraphic correlation shows an increase in thickness of the sediments from east to west and from north to south. In the northeast clayey and silty sediments are dominant interbedded with rare limestone and scarce sandstone , while further west and south we notice a strong presence of sandstone, loose sand interbedded with claystone, siltstone and limestone. These characteristics are typical of deep and turbiditic environments.

Keywords: Lithostratigraphic; Lithologic; Mineralogical; Turonian; San-pedro margin.

1. Introduction

The San-Pedro margin is one of the two margins of the Ivorian sedimentary basin with an area of 41,000 km^2 out of a total of 87,000 km^2. The continental shelf is not very wide with a sediment thickness of less than 500 m according to seismic data. In addition, beyond the edge of the continental slope, significant sedimentation is observed, a very steep slope and a shearing type basin which distinguishes this margin from that of Abidjan. As drilling is rare, the lithostratigraphic characteristics remain little known to this day. In order to promote this area, several investigations are undertaken by the State of Côte d'Ivoire in collaboration with private companies to understand the petroleum system. In this context, the present study aims to establish a local lithostratigraphic column of the Turonian interval which presents geological anomalies. The aim is to highlight the nature of the formations crossed by recent drilling based on the petrographic analysis of the cuttings and log recordings. The study area covers the eastern part of the San-Pedro margin, precisely in deep water between latitudes 4°12'30''N and 4°50'00''N and longitudes - 6°05' 00''W and - 4°53'00''W (Fig. 1).

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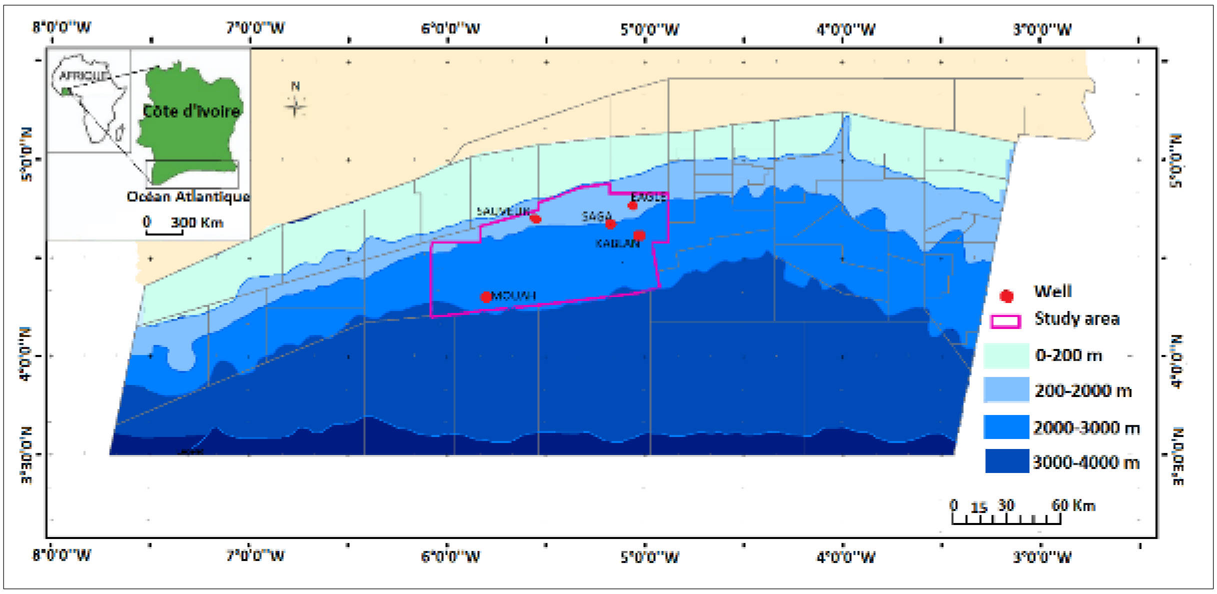

Figure 1 Study area presentation

2. Material and Methods

The lithological and mineralogical descriptions are made from the logs edited via the LAS and the analyzes of cuttings from five (5) boreholes (Mouah, Saumon, Kablan, Eagle and Saga) contained in the reports. Once the logs were edited, the top of each stage were adjusted based on biostratigraphic and seismic data and the readjustment of the vertical deflections of the log signatures. Then a lithological and mineralogical restitution is generated at every 0.3048 meter based on the dry percentage data of each mineralogical constituent and descriptions of the drilling cuttings. We deduce and quantify the different (net) volumes of the formations as well as their thicknesses.

3. Lithostratigraphic characterization

3.1. Eagle Well

In the Eagle well, the Turonian is located between 3332-3352 m, with a thickness of 20 m (Fig. 2).

Turonian stage is made up of claystone, light medium grayish brown to medium brownish gray in color, it is firm, massive-flattened, commonly in fragments generating a subfissile and smooth texture. It is slightly silty to calcareous, sometimes slightly to medium dolomitic. The presence of silt, limestone and dolomite in trace suggests a less calm and shallow environment.

Sandstone is composed of very fine to fine and moderately sorted quartz grains, subangular to occasionally subrounded, white to off-white, pale brown and translucent. It is tender to locally firm and sometimes very crumbly. The silty matrix is scarce, while the white kaolinite cement is abundant, resulting in low porosity. Note rare traces of glauconite and an absence of hydrocarbon evidence. The grading grain size and the presence of glauconite suggest a shallow environment (SELLEY, 1978).

The limestone is mudstone off white, light gray and firm to moderate hard.

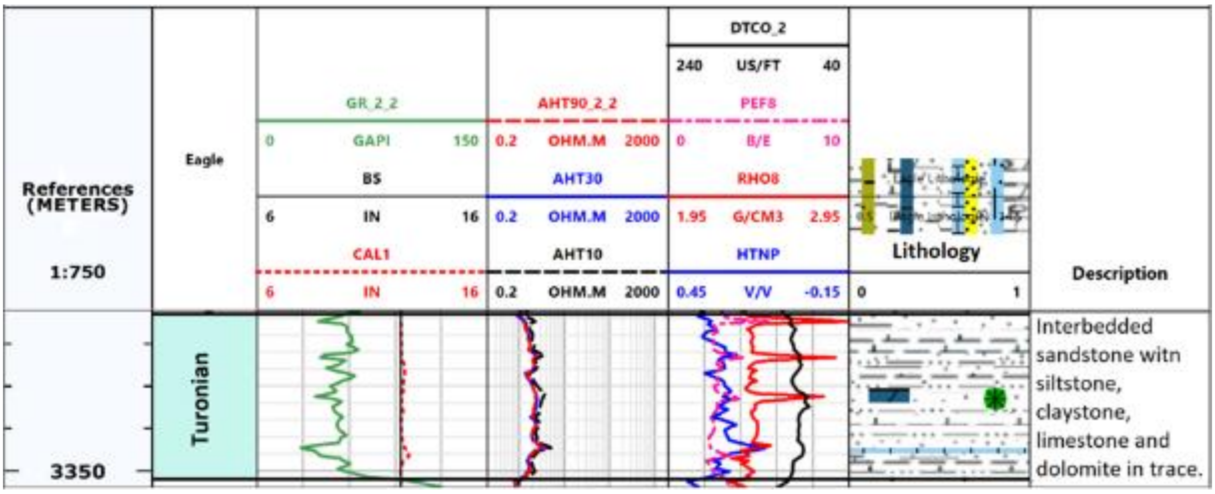

Figure 2 Turonian lithostratigraphic Column of Eagle well

3.2. Saga WELL

This Turonian section located between 4373-4386 m is mainly clayey (Fig. 3).

The claystone is dark gray, sometimes dark gray-brown with traces of very dark gray to black claystone, massive in appearance, soft to firm. It is in places moderately hard and fragile (brittle or friable), not silty, not calcareous.

This essentially clayey interval suggests a calm environment during this period. The appearance of siltstones and sands in the Turonian shows an evolution of the grain size and therefore a supply of increasingly coarse sediment. The presence of glauconite suggests a shallow environment, but could also be due to set up during Turonian-Santonian uplift (Pickett et al., 1998).

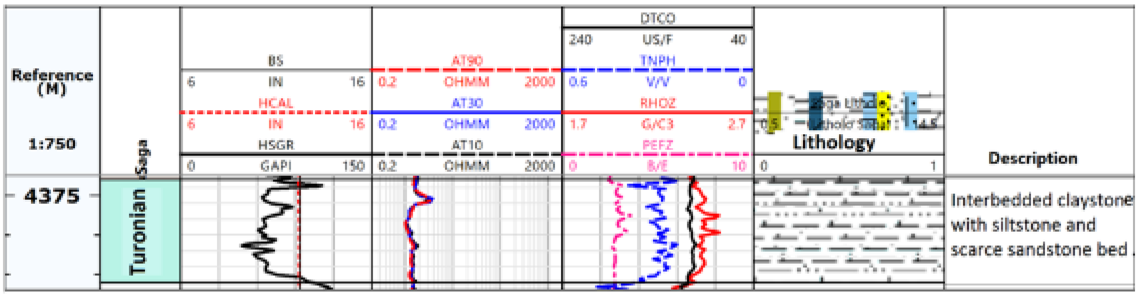

Figure 3 Turonian lithostratigraphic Column of Saga well

3.3. Kablan WELL

This Turonian stage located between 4747-4977 m is made up of claystone, sandstone, loose sand and rare limestone and siltstone (Fig. 4).

The claystone between 4747-4870 m is olive black to grayish black or brownish black, submassive to subflattened in appearance, firm to fragile, with a matte texture. It is non-calcareous, rarely silty with occasional sand inclusions. While between 4870-4976 m, it is olive black to grayish black, submassive to subflattened, occasionally massive, firm, fragile with a dull texture. The black color would reflect the presence of organic matter. This claystone is sandy or silty, sometimes slightly or not calcareous with scattered traces of pyrite. This type of deposit would be characteristic of a confined deep marine environment and/or above the CCD.

Sandstone formations vary petrographically with depth. Thus four types of sandstone are distinguished from the top to the base. Sandstone 4 located between 4760 to 4780 m is made up of clear, opaque, translucent to transparent quartz grains. These sandstones are light gray to yellowish gray, generally fine to coarse grained, sometimes very coarse subspherical, subrounded to subangular, sometimes angular and poorly sorted causing low porosity. Between 4780-4800 m: the grains are very fine associated with a matrix of calcareous mud, unconsolidated, sometimes well hardened with traces of siliceous cement. These poorly classified grained sandstones suggest a turbulent environment, furthermore the presence of calcareous matrix suggests a deposition in a marine environment above the CCD. No oil show was detected. Sandstone 3 located between 4820-4875 m with a thickness of 31 meters has clear, opaque, translucent, light gray, very fine, to occasionally fine, subrounded to subangular, subspherical and well sorted quartz grains. These unconsolidated sandstones are associated with a matrix of calcareous mud, sometimes clayey. The good sorting associated with the limestone matrix would suggest an environment with a low deposition energy but above the CCD. They are in places, fine to coarse, occasionally very coarse, angular to sub-rounded, poorly sorted, unconsolidated. Which reflects past strong energy deposition. The sandstone is friable, sometimes hard and occasionally well cemented by a weak siliceous cement making the intergranular porosity low. Note traces of magmatic rock powder and a fairly good hydrocarbon index. Between 4890-4904 m Sandstone 2 with a thickness of 14 meters at the base is light gray, pink with unconsolidated quartz grains, clear, opaque, translucent, fine to very coarse, angular to sub-rounded and is poorly sorted. This poor classification suggests a strong depositional energy (authors to be added). In places the grains are very fine to occasionally fine, well sorted, subrounded to subangular, subspherical associated with a frequent calcareous and sometimes clayey mud matrix. The rock is friable, commonly unconsolidated, and rarely consolidated by siliceous cement. In places well cemented and hard, the deduced intergranular porosity is low. Note traces of rock powder and signs of trace or absent hydrocarbon. Sandstone 1 located at the base between 4912-4977 m is generally very fine grained to pebble and well sorted. Subrounded to subangular, or even subspherical, quartz grains are associated with an abundant calcareous mud matrix. It is commonly unconsolidated, friable, occasionally well cemented and hard resulting in low intergranular porosity. This sandstone would have been deposited in a deep environment (channel) above the CCD with low energy. Note rock powder occasionally associated with fine to coarse quartz grains and in places coarse, transparent to translucent or opaque, light gray and pink. These grains are angular to sub-rounded, poorly sorted, loose with low intergranular porosity. Hydrocarbon indices are low to medium.

The Siltstones located between 4878 and 4884 m are olive black, submassive, firm, non-calcareous, clayey and do not contain any hydrocarbon show.

The limestone is mudstone, pale orange, olive grey, off white to medium grey, sub blocky, firm, crumbly, micro-cripto blocky, firm, crystalline and argillaceous with dark grey micro laminations. The porosity is no visual.

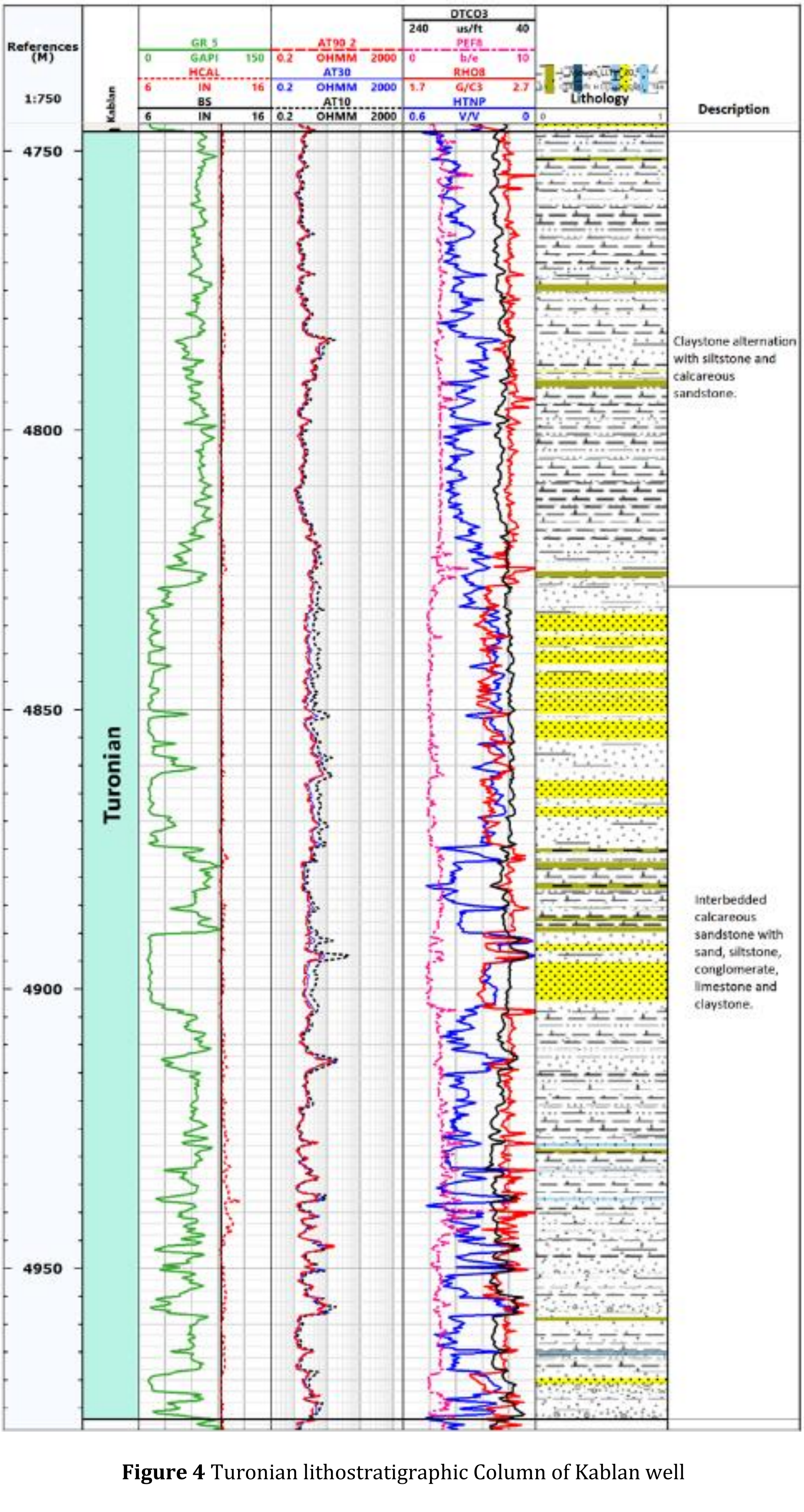

Figure 4 Turonian lithostratigraphic Column of Kablan well

3.4. Mouah well

These Turonian formations located between 5602-5947.5 m with a thickness of 345.5 m (Fig. 5) is made up of four formations which are:

The claystone located between 5602-5712 m is dark gray to very dark gray sometimes blackish, moderately hard to firm, sometimes hard, moderately to well compacted, sometimes fissile and very well compacted. It is non-calcareous with a submassive to massive aspect with traces of disseminated pyrite and the silty matrix evolves into siltstones. Which suggests that the depositional environment is confined deep marine. Furthermore, the absence of limestone shows that the deposition took place below the CCD. At 5747 m it is olive black, very hard, subfissile to fissile, well compacted and not calcareous. Between 5750-5802 m the clay at the top is dark gray to very dark gray, sometimes blackish, moderately hard to firm, sometimes very hard, moderately to well compacted, sometimes fissile and locally very well compacted. Submassive to massive in aspect with a matte sheen, it is silty locally evolving into siltstones. It is non-calcareous with disseminated traces of pyrite within it. At the base the clay is olive black with in places very fine, silty grains of sand, evolving into siltstones. The olive-black indurated clay evolves into siltstones between 5828-5840 m. It is non-calcareous, hard, very compact, submassive to subfissile, sometimes micro micaceous and hygroscopic. Between 5847-5880 m the clay is dark gray to olive black, firm to moderately hard, massive to subfissile, waxy, hygroscopic, non-calcareous, well compacted. These clayey intercalations between the clastic sediments reflect a variation in depositional energies. At 5884 m it is slightly calcareous, silty in places evolving into siltstones. The presence of limestone shows that the depositional environment is deep marine above the CCD.

The sandstone levels with a thickness of 84 meters intercalated between the clays are distributed as follows: Unit 4 between 5660-5668 m is olive gray, very hard, submassive and brittle. Bound grains of quartz are very fine to very coarse, subrounded to subangular, subspherical, transparent to translucent, and poorly sorted. The poor classification suggests a high depositional energy, furthermore the calcareous and dolomitic matrix shows that the depositional environment is deep marine above the CCD. This sandstone is well cemented, well compacted with zero porosity and no hydrocarbon evidence. Unit 3 located between 5740-5784 m is medium light olive gray, brownish yellow, very hard, submassive and friable. Its poorly sorted bound grains are fine to very coarse, transparent to translucent, subangular to subrounded, subspherical. Poor sorting stipulates a turbulent deposition environment. This slightly calcareous, dolomitic sandstone suggests a marine depositional environment above the CCD. It is well cemented and well compacted with low to no porosity. Unit 2 located between 5801-5820 m is olive gray, very hard, submassive. Bound quartz grains are fine to coarse, transparent to translucent, subangular to subrounded, subspherical. Slightly calcareous, well cemented and well compacted dolomitic, this poorly sorted sandstone would have been deposited above the CCD in a high energy environment. We note zero porosity and no index. Unit 1 located between 5836-5847 m is olive gray, very hard, submassive, friable to brittle with fine to coarse, transparent to translucent, subangular to subrounded, subspherical bound grains. This poorly sorted, well-cemented, well-compacted sandstone generating zero porosity suggests a turbulent environment, furthermore the slightly calcareous, dolomitic matrix shows that the depositional environment is deep marine above the CCD. Note the presence of common metallic mineralizations. From 5850 to 5947 m the black sandstone, with a massive aspect, is very fine to medium grained, transparent to translucent, subangular to subrounded, subspherical. It is well cemented and well sorted calcareous with common mafic minerals and carbonaceous debris. Between 5858-5947 m the off-white to olive gray calcareous sandstone is made up of fine to medium quartz grains, sometimes granular, clear to translucent, subrounded to subangular, subspherical. It is submassive to firm, brittle, in places friable moderately well sorted. The porosity is medium with a small, calcareous material matrix. The hydrocarbon index is zero. The good grain classification suggests a deep environment with low depositional energy.

Siltstones are dark gray to brownish black, sometimes olive black, very hard, brittle to fissile, very compact, well cemented, slightly calcareous to non-calcareous. The traces of pyrite disseminated in the summit part (5602-5742 m) show that the depositional environment becomes deep reducing. At the base it is slightly calcareous and dolomitic.

The Limestone located between 5890-5940 m has a mudstone to wackestone texture. It is pale gray or light gray, off-white, creamy, clayey, intercalated with very fine laminations of dark gray clay. It is locally silty and sandy in places. It is firm to moderately hard, in places soft, submassive to massive, microcrystalline, compact with absent porosity. Note an absence of hydrocarbon evidence. The sandy dolomite to the base, with fine to very fine quartz grains shows that the depositional environment is marine above the CCD.

The Turonian can be subdivided into two parts:

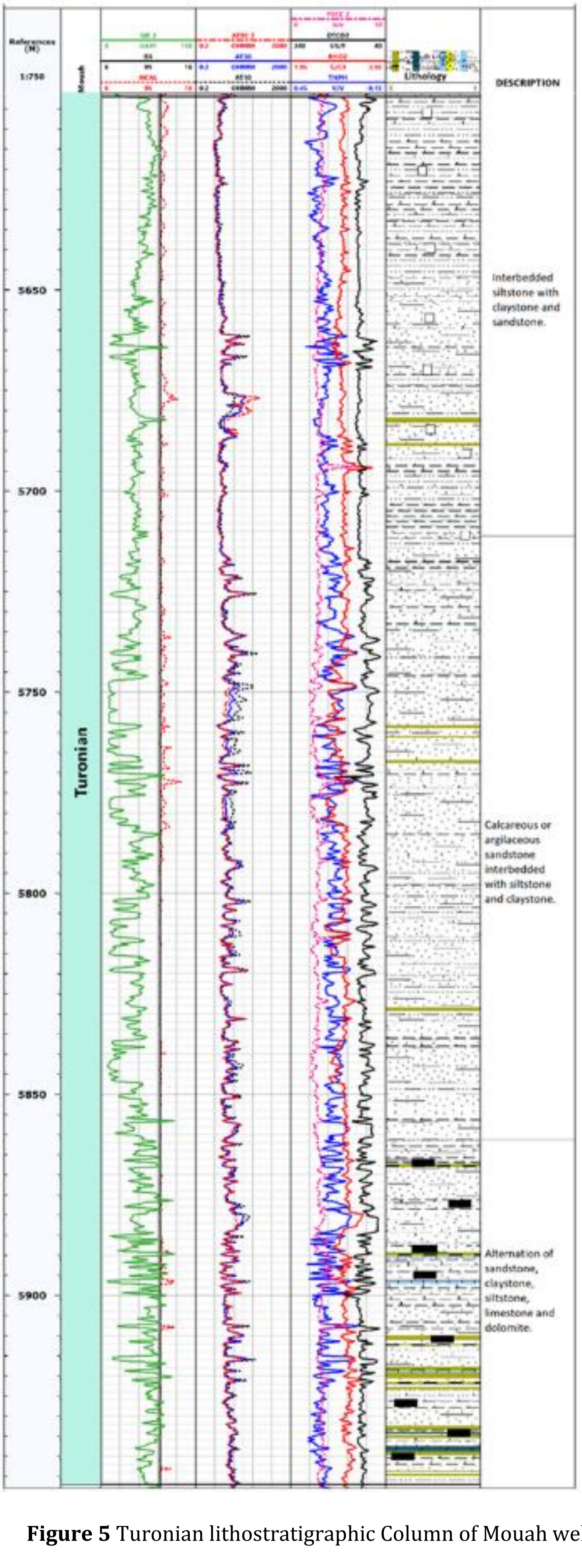

Figure 5 Turonian lithostratigraphic Column of Mouah well

At the top a silty interval interbedded with claystone, sandy limestone and silty sandstone with pyrite presence. Those units (4 and 3) of sandstone is very fine to very coarse grained associated with a calcareous matrix.

The basal part is made up of alternating indurated clays, sandstones and rare limestones. The sandstones (unit 2) are fine to coarse well sorted associated with a slightly calcareous or dolomitic matrix. While the calcareous sandstones (unit 1) are fine to coarse with a material matrix (charcoal).

3.5. Sauveur WELL

Four formations located between 3549-3716 m with a thickness of 167 m are differentiated within the Turonian: sandstone, siltstone, claystone and limestone (Fig. 6).

These sandstone formations are divided into two units. Unit 2 is formed of transparent to translucent, subangular to subrounded, subspherical grains. The fine to very coarse grains are linked, evolving into conglomerate, with rock powder. It is submassive to massive, very hard to hard, very compact. Poor sorting and good cementation by limestone suggests a marine turbulent environment above the CCD. Between 3548-3590 m, it is greenish gray to dark greenish gray, olive gray to light olive gray, off-white to grayish white, and made up of fine granular quartz, with the presence of glauconite, chlorite and pyrite mineralized confirming the deep environment. While between 3590-3619 m the sandstone is off-white, to yellow-white, greenish gray to greenish white with fine to very coarse bound grains, granular to pebble size in places. The grains, in addition to the morphoscopy mentioned above, are subelongated, rarely angular. We did not note the presence of any indication of hydrocarbon.

Unit 1 generally off-white to pale greenish gray, medium gray to light gray, greenish gray to light olive gray is made up of subangular to subrounded, subspherical bound grains. It is submassive, firm, poorly sorted, calcareous with the presence of rock powder due to the action of the bit, and an absence of evidence. The sandstones located between 3619-3650 m are made up of fine to granular quartz (quartz fractured in places), spotted and detached (due to the drill bit). The grains are clear to translucent, greenish translucent. Between 3650-3716 m the grains are fine to very coarse, in places granular to the size of small pebbles and evolving into conglomerates. They are fractured and angular in places, friable and pyritic in places. Note the absence of hydrocarbon evidence, and the presence of rock powder due to the action of the bit. This unit would have been deposited in a deep turbulent environment.

The Siltstone is located between 3550-3690 m. They are grayish black, very compact, calcareous, massive, hard and brittle with a silty texture. Note the presence of very fine lithic fragments and pyrite. This presence would suggest a deep reducing environment below the CCD. Indurated clay: Between 3695-3716 m is olive black, massive, hard, well compacted, calcareous, silty.

The limestone with a mudstone texture and cryptocrystalline appearance is off-white to light olive gray in color. It is firm to moderately hard and brittle.

The claystone located to the base is olive black, blocky, hard. It’s well compacted, calcareous and silty.

The Turonian is essentially made up of alternating sandstone and siltstone.

At the top the sandstone has a uniform thickness with fine to poorly sorted granular grains, associated with pebbles evolving into conglomerates in places. Whereas at the base they are fine to very coarse, evolving into granules or even pebbles and they are poorly sorted.

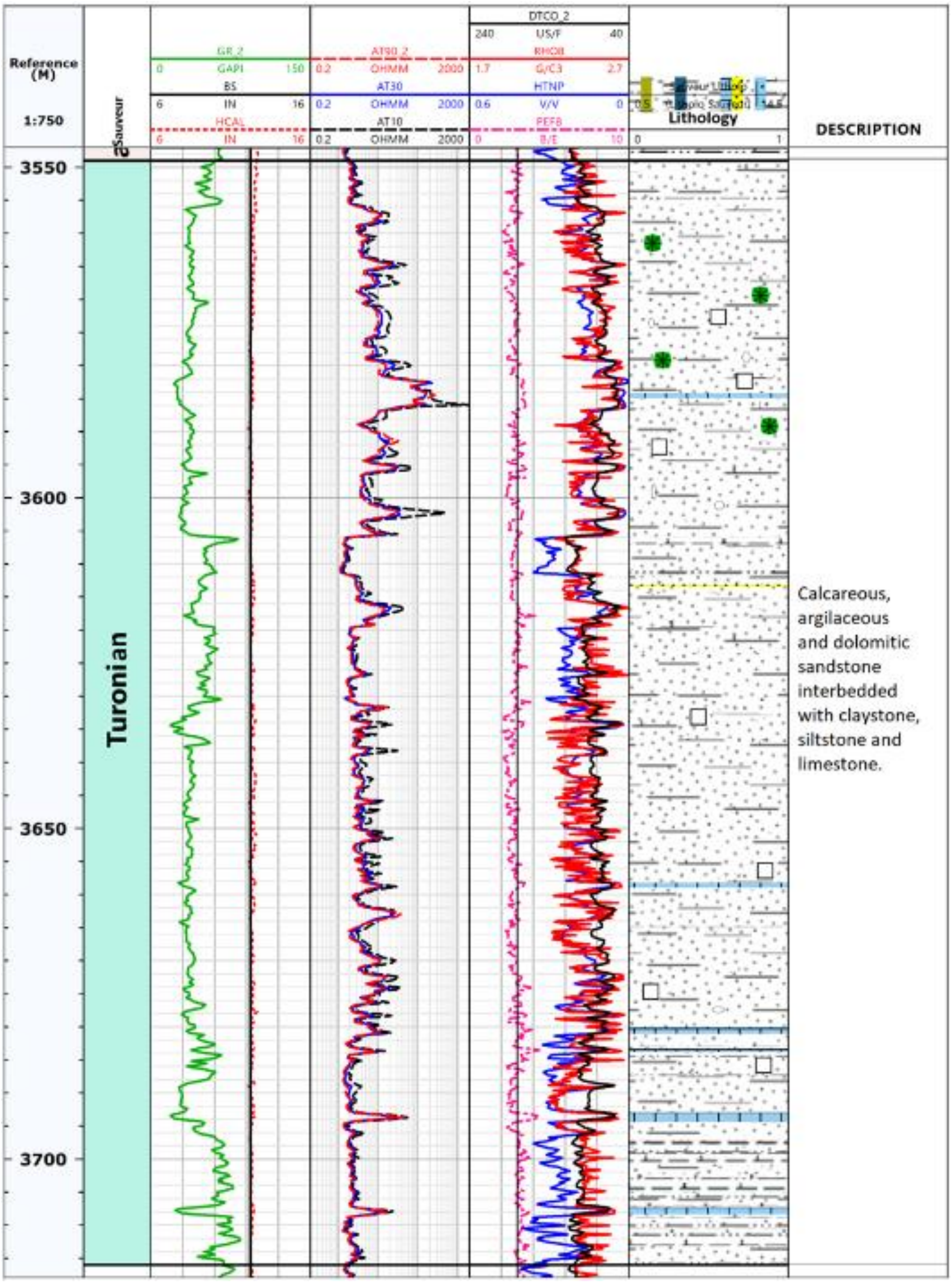

Figure 6 Turonian lithostratigraphic Column of Sauveur well

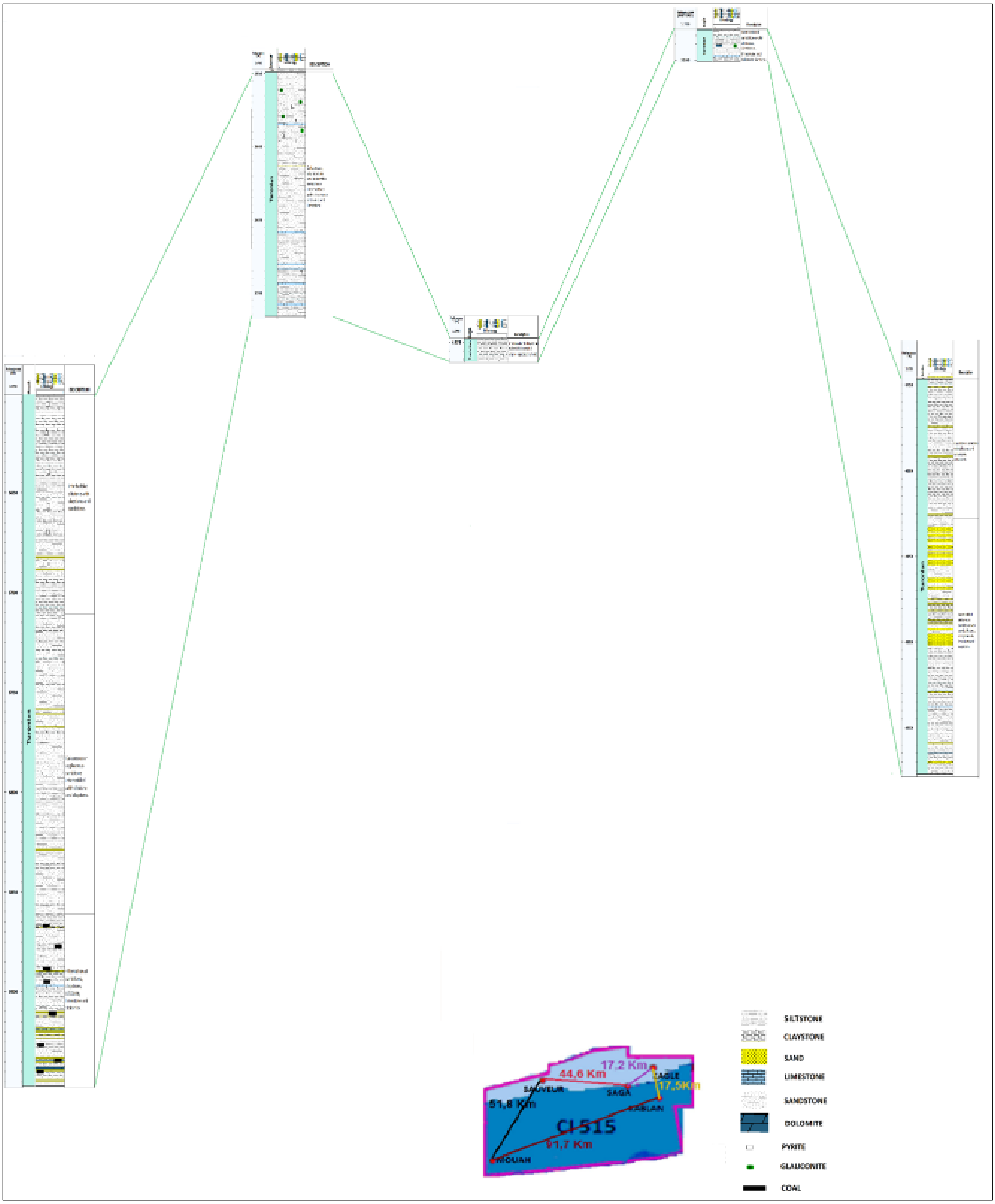

Figure 7 Turonian East-West lithostratigraphic column

4. Discussion

The lithological synthesis of the five characterized boreholes reveals deposits of claystone interbedded with sandstone, sandy, silty and calcareous formations (Wefer and al., 1998). All of these formations were revealed in the deep Ivorian-Ghanaian basin in the Site 959-962 wells (Shipboard Scientific Party, 1996). This lithological variety was described in unit III of well 960C (sandy claystone, siltstone mixed with micrite or sandy, sandstone cemented by calcite, and limestones; Mascle and al., 1996). These formations thicken from East to West and from North to South (Petroci and al., 1990, 2010). To the northeast of the study area, the Turonian is particularly clayey with rare presence of sandstone and dolomites in trace. To the northwest it's typically made up of shaly or calcareous sandstone and limestone at the base of Sauveur. This carbonate and high energy coarse clastic sediments are interpreted to have been set up during Turonian- Santonian uplift (Pickett and al., 1998) associated with the spreading ridge passed by the marginal ridge in late Cretaceous times (Mascle and al., 1987).

Petrographic characterization shows that these formations are made up of very fine particles (clay) evolving from fine to coarse grains or even pebbles and vice versa. This variation in size beyond the slope to the deep basin stipulates very variable depositional energies due to turbidites (Kneller, 2003). These turbiditic currents are fluctuated by major phenomena of transgression and regression. These coarse up and fine up which characterize turbiditic deposits (Allen, 1984) are interpreted as the result of a progressive decrease in the capacity of the energy transporting fractions of different sizes initially suspended in the flow (Hiscott, 1994). This drop in energy occurs at each point along the transport path, and is attributed to the temporal deceleration of a decreasing flow (Kneller, 1995). The black color of clays indicates deposition in calm and reducing or anoxic conditions, it can also indicate its richness in organic matter (Chevillon, 1992; Massala 1993). The sediments contain pyrite, glauconite and rare micas and lithic fragments. The presence of pyrite and micas flakes testifies to the reducing conditions of the sedimentation environment where these deposits accumulated (Taylor et al., 1995). This association of pyrite and glauconite shows a shallow but poorly oxygenated marine depositional environment with a slowdown in sedimentation (Odin, 1975; Yao and al., 2011). Glauconite is characteristic of shallow environments of 50 to 500 m (Foucault et al, 2014) and according to the encyclopedia of geology (Selley, 2005), unaltered glauconite has been analyzed in marine sediments deposited under 10 to 30 m of water. These data contrast with the presence of pyrite (FeS; iron sulphide) which is characteristic of deep and confined environments (Nichols, 2009). This presence of glauconium would be due to the transport of these minerals from the continental shelf via channels to the deep environment or to subsidence. Glauconite would have appeared in very deep water (2000-3000 m) on the Scotia Ridge and on the two Japanese coasts. Sediments studied from the Japanese coast reveal an association of faunas indicating deposition in shallow water. This could be due to seaward redeposition (reworking) of sediments or rapid subsidence in this tectonically active area (Huggett, 2005). These hypotheses corroborate with those of Holmes (ODP, 1998) which stipulate a reworked of the formations from the continental shelf to deep water.

5. Conclusion

The Turonian stage is subdivided into three major formations, namely indurated clays, siltstones and sandstones interbedded with calcareous, silty formations, and rare dolomite often in traces.

To the north of the study area, the Turonian is characterized by a predominance of clay interbedded with fine sandstone. These sandstone increase considerably towards the west (Fig. 7: Sauveur well) with poorly sorted fine to very coarse grains, in places granular to the size of small pebbles and evolving into conglomerates. While clays evolve into siltstones.

The North-South transition of the said study area goes from conglomerates and coarse sandstones gradually to coarse to finer sandstones towards the South. Further offshore, the Turonian is dominated by clayey and sandstone intervals, interbedded with calcareous and silty levels. From East to West, the clays evolve into siltstones while the sandstones become thicker with the notable presence of limestone (Fig. 7 Mouah, Kablan wells).

The Turonian is most often a sandy interval, generally more clayey towards the east and with a higher content of sandstone and siltstone towards the west and the south.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

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