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General Chemostratigraphy of the Formations in Well M, Offshore Senegal.

[1]Selegha Abrakasa [2]Nnodi Okechukwuand [3]Sam Edikan.
[1]selegha.abrakasa@uniport.edu.ng
[2]okeynnodi12@gmail.com
Geology Department,
University of Port Harcourt,
Port Harcourt. Nigeria.

Abstract.

The general chemostratigraphy of formations in well M, offshore Senegal was evaluated. Data used for this study wasobtained from a Spectro XEPOS, manufactured by AMETEK with an X–LabPro 5.1. software for data processing.Results showed that V/Ni ratio indicated that the sandstone series of 1850m to 2120m and 2350m to 2450mwere deposited in oxygen rich nearshore or shallow marine environment. The Fe_2O_3+MgO parameter showthat the sandstones of 1850m to 2120m have very low Fe_2O_3+MgO value, implying their source to becontinental crust, while the deeper series of 2120m to 3200m have very high values indicating their source tobe oceanic crust. The TiO_2–Zr binary diagram show that majority of the samples were derived from sourcewith lithology, which corresponds to continental crust and continental arcs.

Keywords: Chemostratigraphy, Senegal, Mafic, Felsic, Paleoweathering, Paleoclimate, Provenance, Reservoir Efficiency

. 1.Introduction.

Senegal is a country located in West African, ithas an open coast to the Atlantic Ocean. It is within the Sahel region.Senegal lies between 12ºN to 16ºN and 18ºW to 12ºW. Senegal sits as part of the Senegal Basin. It has a country area of 196, 722km^2. Senegal is entirely underlain by Cenozoic rocks of alluvial, fluvial marine and coastal beach sediments [2].

Chemostratigraphy is a trending aspect of Geochemistry which became more frequent in the 1980s, with the oldest publication in 1986 [13]. It deals with the fact that sediments are the custodian of records of changes in physical, chemical, biological conditions and events which take place before, during and after their depositions to express paleoclimatic variations, tectonic settings, provenance, reservoir characteristics, paleoenvironments; relating to their source and mechanism associated with their origin in stratigraphic context [13]. The basic concept is that the sediment consists of minerals and elements, the compositional distribution of the elements and minerals expressed as ratios bears some trends with geological events that could be interpreted in the context of stratigraphy.
The hypothesis of this study is that, the compositional distribution of these elements and minerals that consist the different formation could delineate their provenance, tectonic settings, paleoclimate and paleoenvironment of deposition of the formations. Potential changes that the sediments have undergone could be unraveled.

2. Geology of Senegal.

The geology of Senegal is based on the lithological and stratigraphic description of the formation transversed by Well M [2]. The shallowest formation is comprised of tertiary sediments, which is underlain by Senonian–Maastrichtian sandstones that stretches into a slope. This is in–turn underlain by the Cenomanian–Turonian Shales. Underlying,is the Albian clastic rocks which is underlain by the Aptian Shale, this is underlain by the

Neocomian– Jurassic Carbonates and finally the Triassic anhydrite, sandstone and cobbled clastics. The geomorphology is almost like that of the Niger Delta (figure 1) [2].

Well M is located within the Senegal basin, the Senegal basin was formed during the opening of the Central Atlantic, when North America separated from North West Africa during the Permian –Triassic rifting. The Senegal basin is the largest in the North West Africa among the North West African Atlantic basins. The depositions after the rift consist of Late Jurassic to Holocene in age. The basal unit which was deposited during the rifting is coarse sandstone,overlying is fine sandstone and evaporites, then the series after the rift were thick carbonate formation which range from the Middle to Upper Jurassic, the unit continued to the Aptian and Albian, particularly in the Central offshore area. By the Cenomanian, thick marine shales were deposited with intercalations of marginal marine sandstones. In the Turonian, widespread deposition of black bituminous shale occurred during a marine transgression, while in the Senonian there was a major marine regression leading to the extensive deposition of sandstones [2], [7], [10], [11], [16].

The regional structural style is characterized by gravitational features such as faulting and slumping, which reflects a slope environment being influenced by the opening of the Central Atlantic. Figure 2, shows a fair reflection of the lithology on the shale volume which is modelled from the gamma ray data of Well M using Techlog version 2015.

The separation/ rifting was initiated by basement uplifts (figure 3), during the rifting and after the rifting, coastal (Offshore) basins subsided and received sediments from the interior (Onshore) basins which did not subside. The North West Africa consists of Precambrian granitized basement which forms the West African Craton. The granitic basement is exposed in the Eastern Senegal. During the Permian,at about the commencement of rifting, sediments were very scarce, and were of the form of red sandstones and conglomerates. Thereafter, extensive outpour of basaltic lava occurred during the Triassic. During the Jurassic, sedimentation occurred in the continental shelf area and coastal basins including Senegal, these were continuous continental margin zones of subsidence and deposition. Marine transgression began in Early Jurassic covering about 5% of the continents, at the Late Jurassic, it covered 25% of the continent resulting in increase of calcareous deposits in expense of the clastics [7], [10], [11], [16].

3. Location of Study Site.

Well M is a deepwater exploration well located Offshore The Gambia (figure 4). Senegal is part of the MSGBC (Mauritania, Senegal, The Gambia, Guinea Bissau and Guinea Conakry) hydrocarbon basin, where there has been proven hydrocarbon successes.

4. Sampling and Analysis

Samples were collected from the shale shaker; the samples were sieved to get rid of the cavings (3mm), only the 0.063mm size samples were used. The samples were washed and dried. The washed samples were powdered, by introduction into the crusher cell and the vibrating crusher was used to powder the samples using a ball grinder (MM400). 5grms of the crushed powder was used to produce the pellets, since the equipment uses pellets for analysis. Pellets were produce manually using 25 tons hydraulic jack.

Data used for this study was provided as part of the surface logging service, an aspect of surface formation evaluation service using X–Ray Fluorescence analysis. The model of the X-Ray Fluorescence Spectrometer is Spectro XEPOS, manufactured by AMETEK, with an auto sampler with 12 positions for samples and a 50watt end window X–ray tube to excite the samples. The software for data processing is X–LabPro5.1.

The data consist major element in oxide expressed as percentages (%), these oxides are Na_2O, MgO, Al_2O_3, SiO_2, P_2O_5, SO_3, K_2O, CaO, TiO_2, MnO, Fe_2O_3. While minor elements where expressed in parts per million (ppm). These are V, Cr, Co, Ni, Cu, Zn, Ga, As, Rb, Sr, Y, Zr, Nb, Mo, Ba, Hf, W, Pb, Th and U. [13].

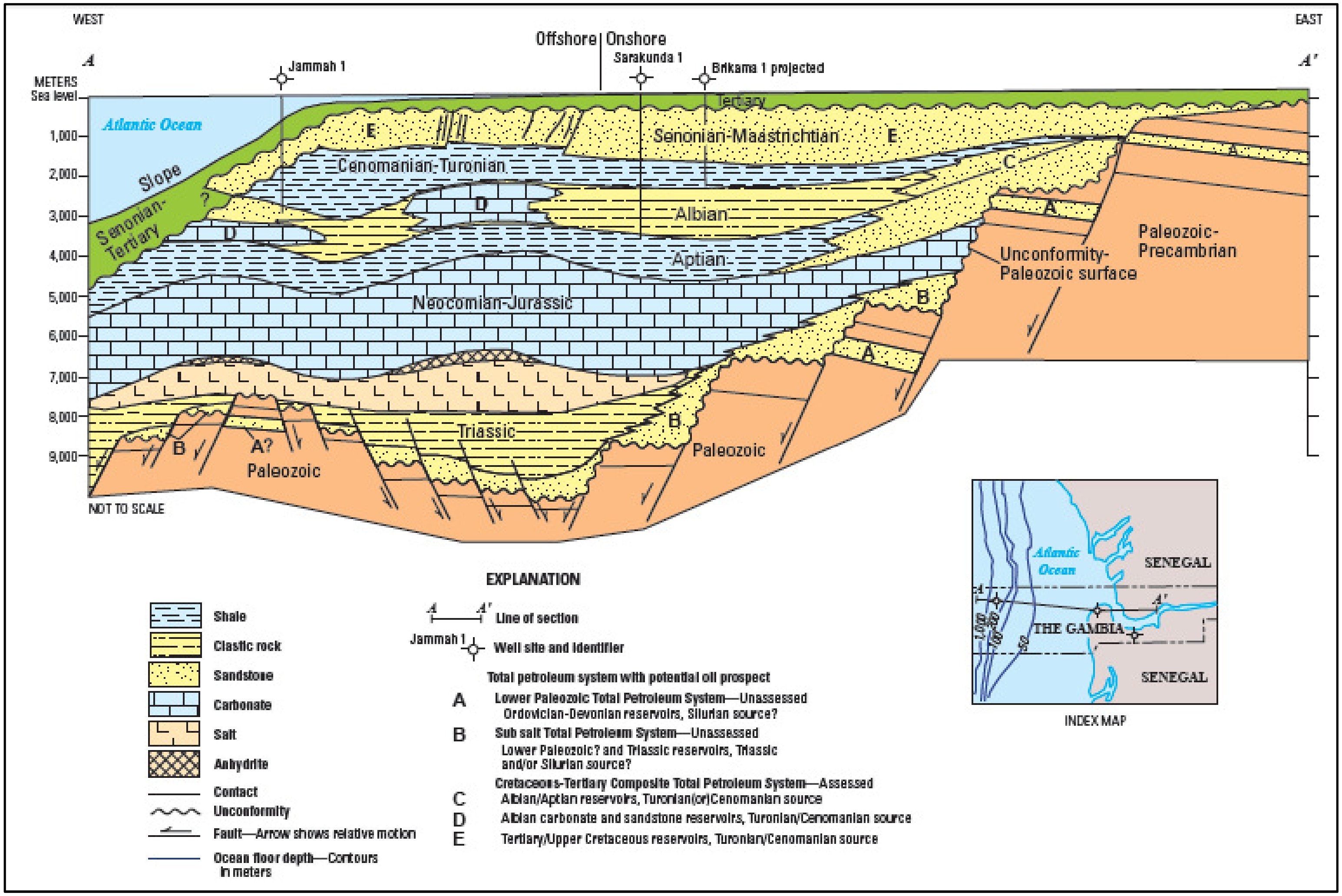

Figure 1, A Litho–Stratigraphic cross section of Sen–Gambia. Insert the A–A' transverse as represented by the cross section.After Bungener (1995)

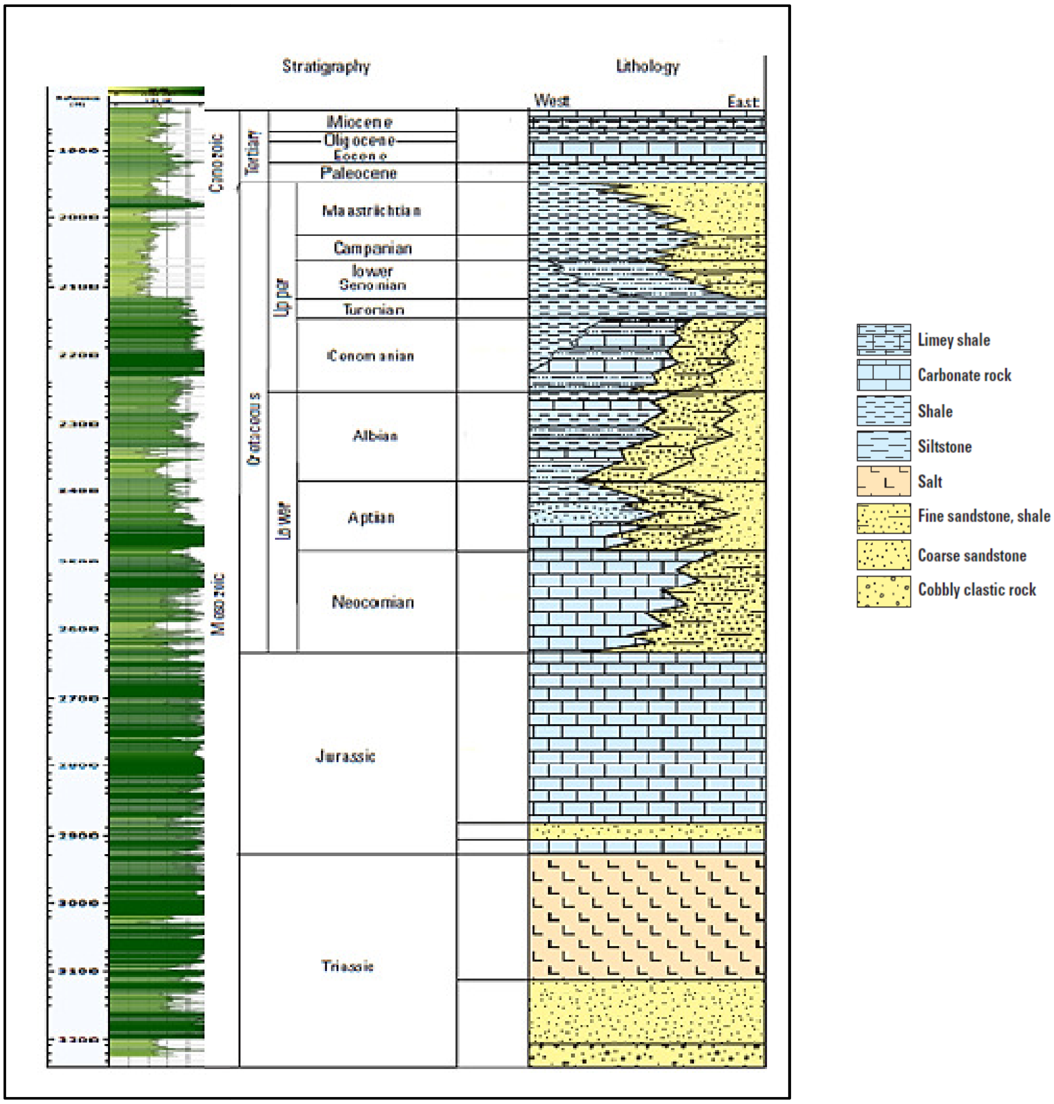

Figure 2. A corroboration of shale volume model from Well M and the general stratigraphy of Senegal basin

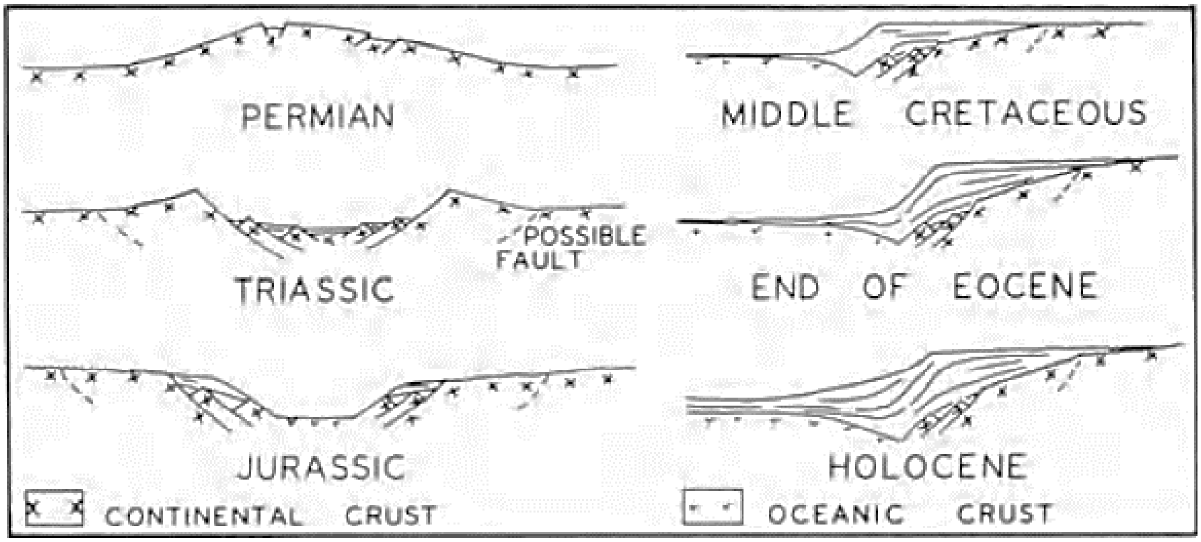

Figure 3. The stages in the development of the present Central Atlantic West African Margins

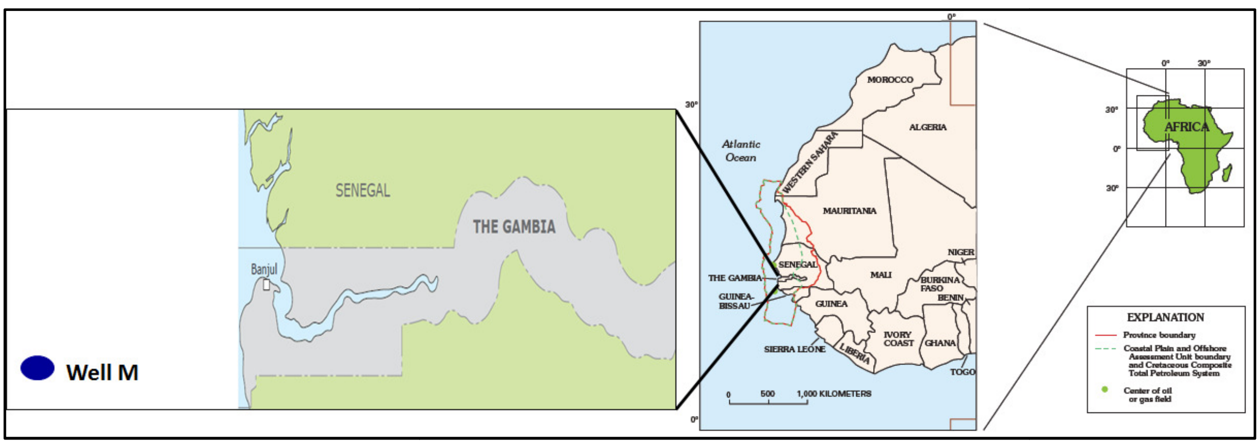

Figure 4. Location of study site, Well M (blue elliptical circle) Offshore Senegal.

5. Results and Discussion

The result of the analysis is summarily presented in figure 5, since it's a large data set. However, the log view profiles are represented in figure 5. The profileconsists of logview throughout the well for V/Ni, Y/Nb, Zr/Cr, Rb/Cs, Cr/Na_2O, Na_2O/Al_2O_3, Ga/Rb, Al_2O_3/Bases and (Fe_2O_3+MgO).

The shale volume indicates a sandstone formation between 1850m to 2120m, then intercalations of shale, sandstone, siltstone and carbonate rocks between 2120m to 2625m. From 2625m to 3025m, mostly carbonate rocks are observed and from 3025m to 3100m salt. While from 3100 to the bottom, intercalation of sandstones and conglomerates.

The V/Ni ratio which had been used as indicator of redox environment show a significant variation, clearly the sandstones intervals such as 1850m to 2120m and 2350m to 2450m show very low values which indicates that the sediments were deposited in shallow marginal marine or coastal near shore environment, while depths that have significantly high V/Ni ratios were deposited in marine environment. The depth range of 2125m to 2350m bear very high V/Ni ratios, this seemingly corresponds to Cenomanian to Turonian, which has been indicated as the best source rocks [13]. The Y/Nb ratio markly discriminates the sandstone rich interval from the shale rich interval, the depth range of 1850m to 2120m indicates high values of Y/Nb ratio, this corresponds to the Senonian to Maastrichtian interval, which was characterized by widespread deposition of sandstones which could have been sourced from continental clastic rocks [1],[3],[5],[12]. This interval is also noted with renowned regression event. The depth range of 2120m to the bottom of the well bear significantly low values, the ratio show indication of reduction with increase in shale volume. The Al_2O_3/Bases ratio, for which the bases (Na_2O, K_2O, MgO and CaO) bear very low ratios within the sandstone interval of 1850m to 2120m, and high values for interval of high shale volume. This implies that most of the feldspars had been preferentially retained in the sandstone interval while clay rich minerals were preferentially retained in the shale and carbonate rich intervals[1],[3],[5],[12],[13].

The Zr/Cr and Rb/Cs ratios bear similar profiles down the wellbore, the Zr/Cr ratio varies with organic content as portrayed by the shale volume which is modelled from gamma ray. The profile show increase in Zr/Cr ratio for interval with high shale volume, while intervals with low shale volume and invariably high sandstone content bears near zero ratios [1],[3],[5]. The Rb/Cs ratio seems more serrated, in intervals close to the bottom of the well (mostly shale), it can be used to determine changing clay mineralogy between intervals. Ga/Rb ratio show a marked distinction between the sandstone rich interval and the clay rich interval. Ga has been associated with kaolinite, while Rb is with illite, therefore the Ga/Rb ratio represents Kaolinite/illite ratios [1],[3],[13]. The Ga/Rb ratio is high within the sandstone interval of 1850m to 2125m, below to the bottom of the wellbore, very low values were encountered. This infers that the sandstones had more kaolinite compare to other intervals, while other narrow sandstone sections bear higher illite content. This implies, in the context of pore morphology that the sandstones may not be an efficient producer since kaolinites are pore filling minerals and will block/prevent production, while illiteare mostly pore lining minerals and will limit/reduce production in reservoirs[1],[3],[13].

The Fe_2O_3+MgO ratio show lower values for sandstones of 1850m to 2120m, relative to deeper series of mainly shale and carbonate rocks which bear higher values.

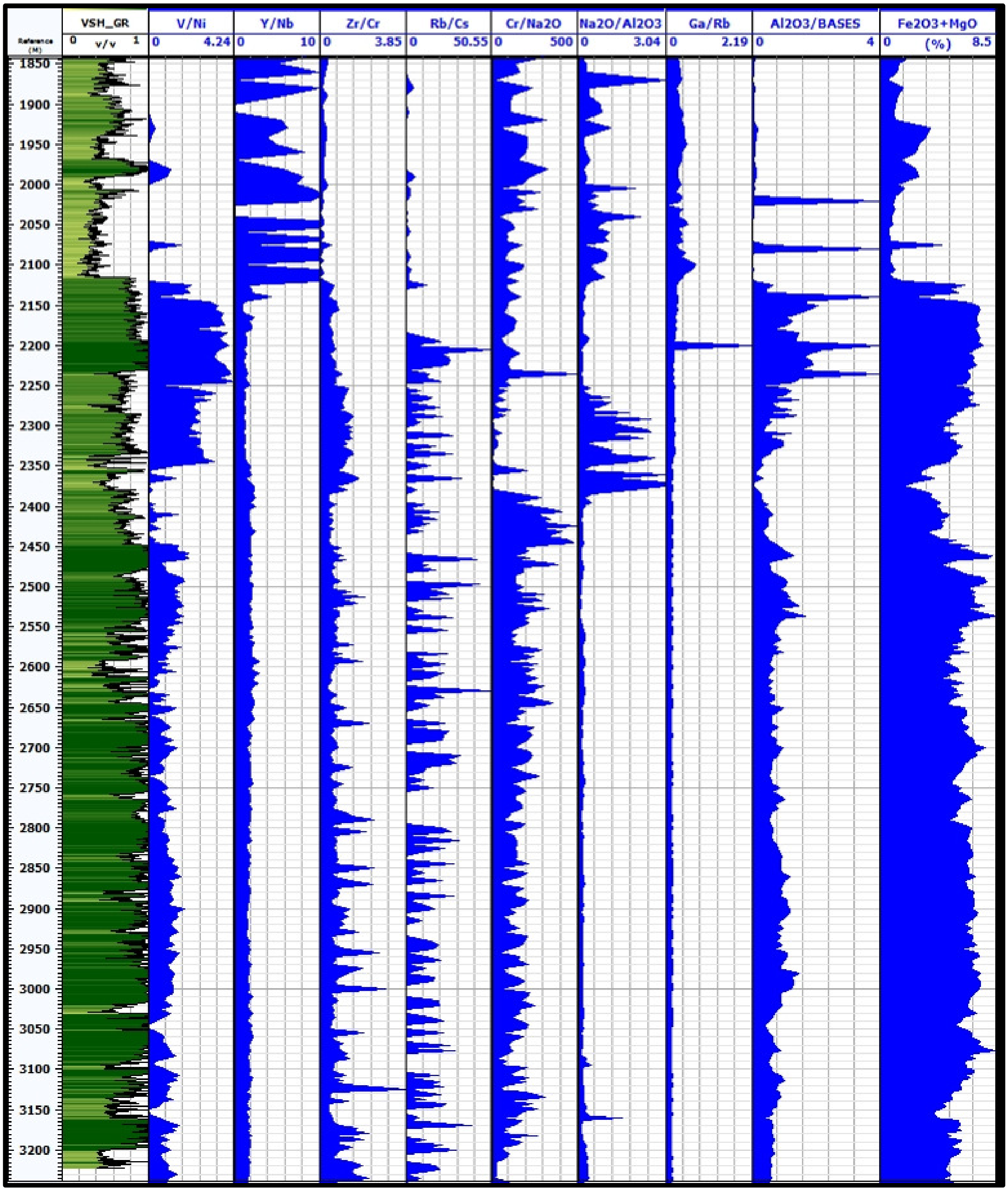

Figure 5. Logview of some ratios

Chemical Weathering and Paleoclimate.

Weathering expresses the wearing away of hydroxides and oxides of Alkaline Earth relative to the Aluminum oxides.It can also be regarded as the alteration of feldspar and subsequent formation of clay related minerals. The concept is that Ca, Na, K, Mg are released from feldspar hosting minerals, causing preferential increase in Al, implying that the larger cations such as Al are preserved in the weathering residue in contrast to the smaller cations such as Na, and Ca.The weathering index in this context is represented as WI = Al / $CaO+MgO+Na_2O+K_2O$ [13]. In figure 5, the Al/Bases ratio is a track in the figure 5. The Al/bases ratio track indicate extremely low values with some spikes within the sandstone formation of 1850m to 2125m. This invariably means that sandstone interval of 1850m to 2125m is richer in feldspar minerals relative to the Al minerals. It has been proposed that Al is mostly hosted by slow–settling fine grained sediment decreasing in abundance with increasing grainsize and suspension. While, Na and Ca occur mainly in faster-settling sediment. Mechanical weathering is dominant in cool and temperate regions while chemical weathering dominates in warm and humid area [4],[5],[13].

In respect of paleoclimate, the Ga/Rb ratio which represent the kaolinite/illite ratio may give an insight, correlating it with Al/bases ratio (figure 5). In this study the Ga/Rb ratio has positive correlation with the Al/bases ratio (figure 5), this implies that the formation of kaolinite increases with hydrolytic weathering, and kaolinite are formed in hot humid climates while illites are formed in drier cooler climates [4],[13]. In the context of reservoir pore morphology, the preferential formation of kaolinite should indicate the occurrence of pore filling minerals in the reservoir sandstones. This should imply that the sandstone formation of 1850m to 2125m bear poor sweep/production efficiency. While, the thin sandstone formation in the deeper series bear lesser kaolinite and less pore filling minerals corresponding to better production efficiency comparatively.

Provenance and Tectonic Setting

Provenance entails the relation of deposited sediments to the source area, this could be achieved via compositional distribution of element and oxide, lithology and age[4],[13]. Sediments are primarily sourced from its original source by weathering which could be mechanical or chemical, and the weathered sediments are then transported to the site of deposition. Regular sources of sediments are normally the passive continental margins or active continental margins. They may also be classified as mafic (Magnesium and Iron rich) or felsic (Feldspar and Silicon rich), the former consist mostly oceanic crust while the later is consist of mostly continental crust. Figure 6 a plot of TiO_2 and (Fe_2O_3+MgO) for the sandstones from of 1770m to 2125m indicate that the Upper series (B) have high (Fe_2O_3+MgO) and TiO2, this might suggest introduction of weathering products from Oceanic Crust, however most of the Lower series (A) have low (Fe_2O_3+MgO) and TiO_2 indicating contributions from Continental Crust. This may imply that during the deposition of the upper series (B) there could have been a tectonic event that lead to the production of basaltic lava which later weathered into heavy sandstone which were deposited as the upper series.[17] recorded extrusions from the volcanics around the area of Dakar within the Senegal basin, this could be the source of the heavy sands. Figure 7 which is a plot of TiO_2 and (Fe_2O_3+MgO) for the formations transversed by the wellbore, also shows that most of the formation are consisted of high values of TiO_2 and (Fe_2O_3+MgO) which indicated that they were sourced from basaltic rocks from Oceanic Crust [9],[10],[11],[17].The tectonic setting for the upper series (B) in figure 6 is that of the Continental Island and for the lower series (A) Passive Continental margin 10],[11],[17].

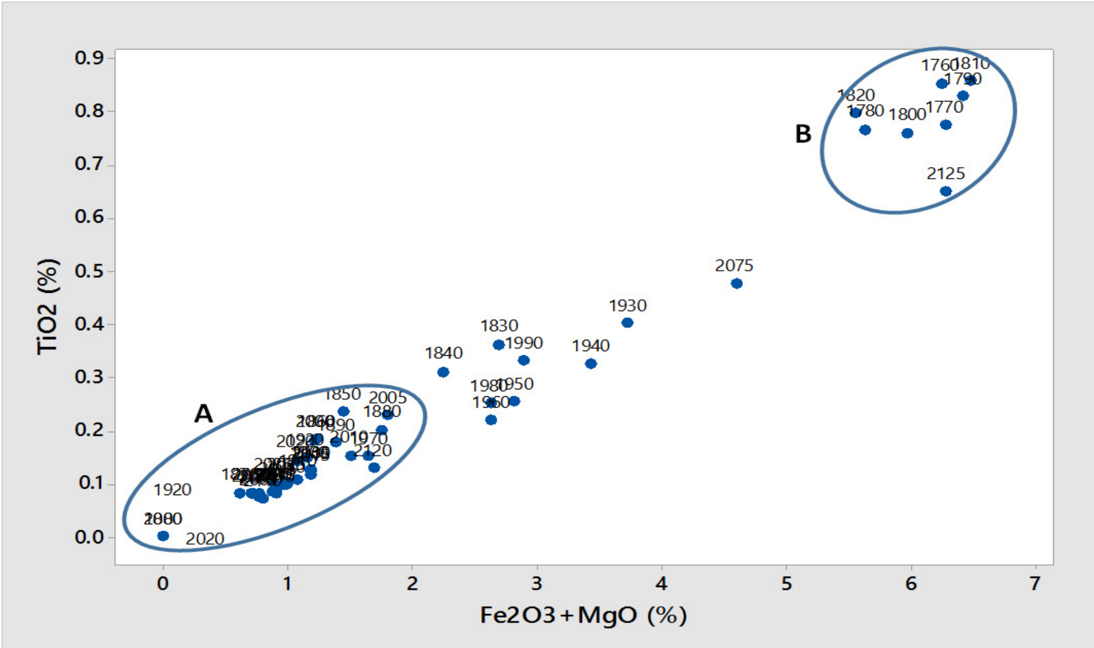

Figure 6 Plot of TiO2 and (Fe_2O_3+MgO) for delineating tectonic setting for sandstone of 1850m to 2120m

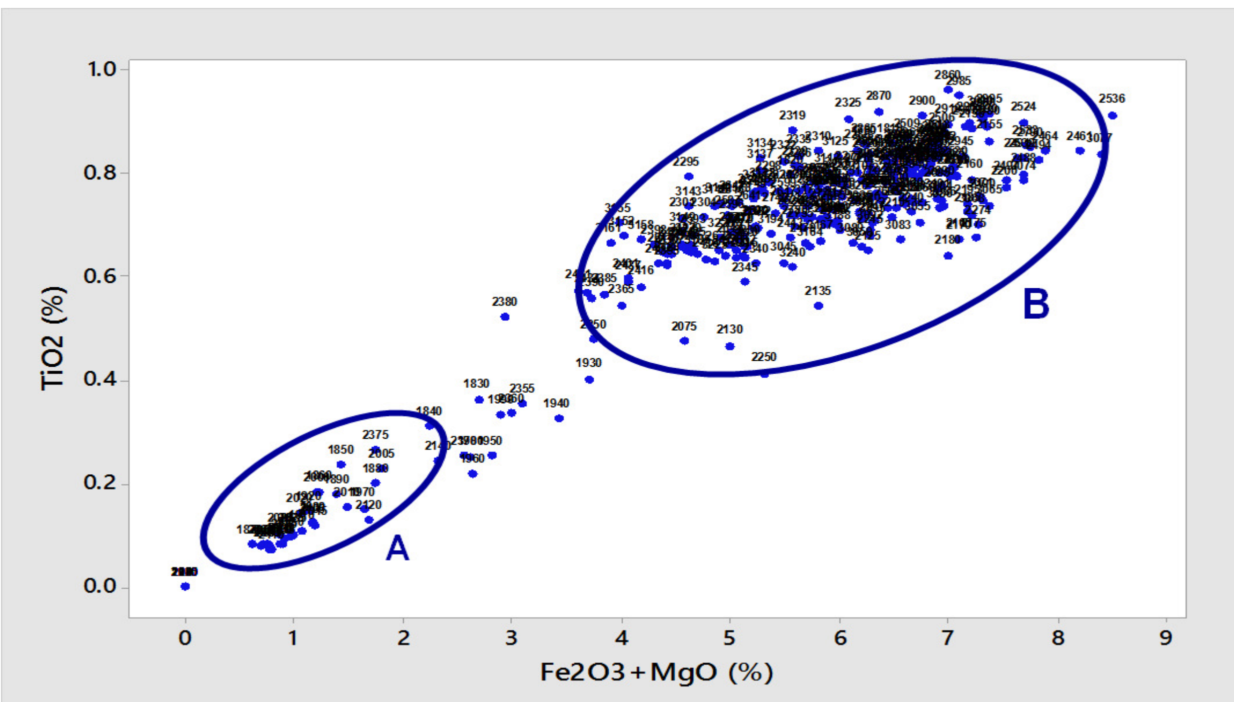

Figure 7. Plot of TiO2 and (Fe_2O_3+MgO) for delineating tectonic setting for the complete well sections

Lithology of Source Rock

The lithology of the source rock entails delineating the lithology from which the sandstone and other sediments were derived. Sediment are normally sourced from older rock due to weathering, most common sources are mafic rocks mostly from Oceanic Crust [10],[11],[17]. While the felsic rocks are mostly sourced from Continental (Land) Crust. Intermediate rock are also found mostly in land crust. Generally, the content of rocks in the context of the silica contents has been used to classify rocks. They are all igneous rocks but can be discriminated by the lava from which they are derived. Rock with 65% silica or higher is considered Felsic, however those with 45% or less is Mafic while those between 45% to 65% are intermediate rock [10],[11],[17. In this study, the TiO_2–Zr binary plot has been used for discriminating potential sources of sandstone and other sediments [4],[13]. Figure 8, a plot of TiO_2 and Zr for discriminating source rock lithology for 1820m–2120m sandstones indicate that the sandstones of the 1750m–2120m are sourced from intermediate rocks which are normally found on Continental Crust or Continental Arcs. Figure 9. Plot of TiO_2 and Zr for the complete well sections, show that all the sediments that consist the formations transverse by the wellbore, are derived from intermediate rock which potentially are sourced from Continental Crust [4],[13]. The SiO_2 and Al_2O_3 has been used to understand the relationship of sandstone and clay in sediments. In this study, figure 9, a binary plot of SiO_2 and Al_2O_3 show a linear relationship for both SiO_2 and Al_2O_3, for all the samples from the wellbore. However, majority of the samples (A) occur between 30% to 60% of silica relatively with high values of Al_2O_3. This observation is indicative of sediments that are derived from intermediate rock which are sourced mostly from Continental Arcs. Some samples (B) bear lower silica values and consequently, lower values of Al_2O_3 these represent mafic sources derived from Oceanic Crust [4],[13].

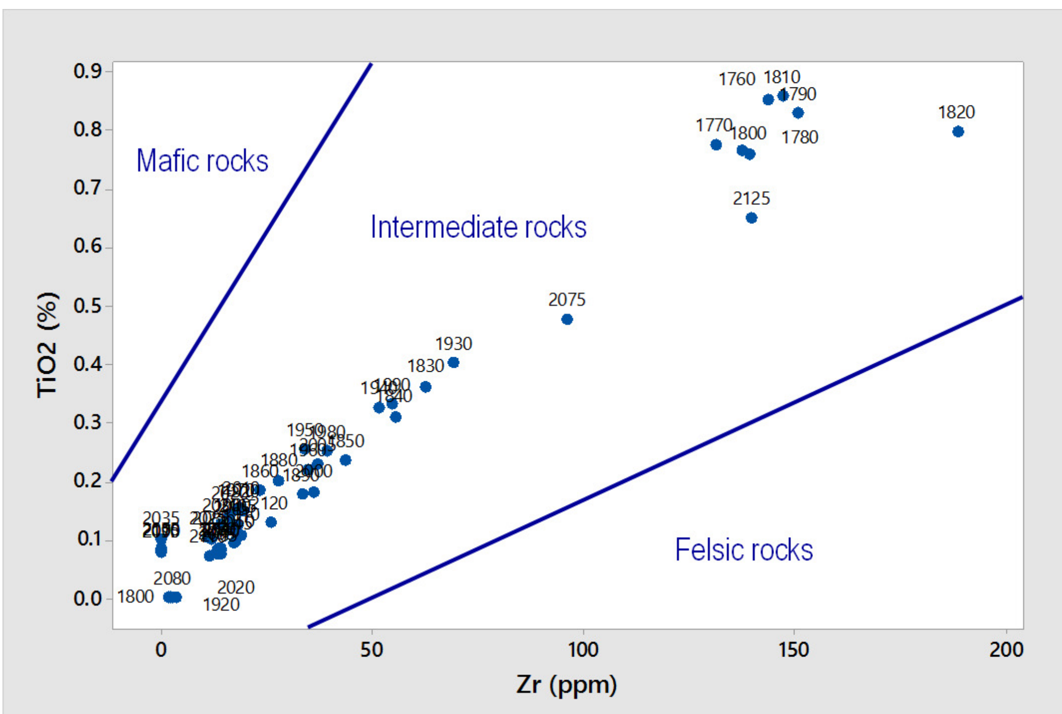

Figure 8. Plot of TiO2 and Zr for discriminating source rock lithology for 1820m–2120m sandstones

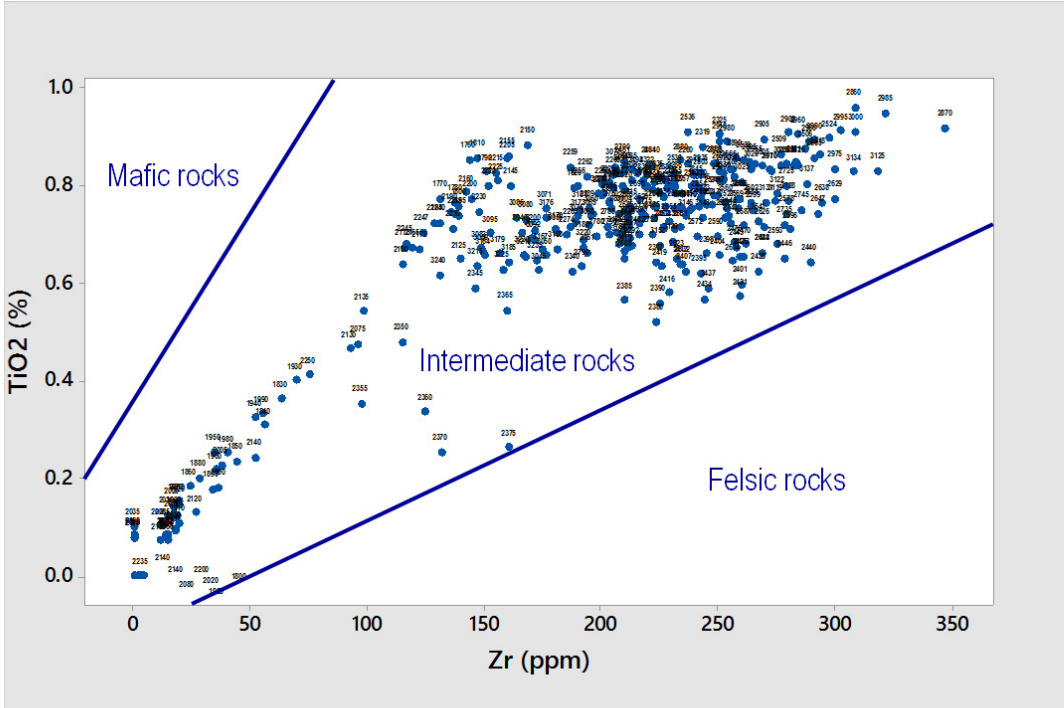

Figure 9. Plot of TiO2 and Zr for discriminating source rock lithology for the complete well sections

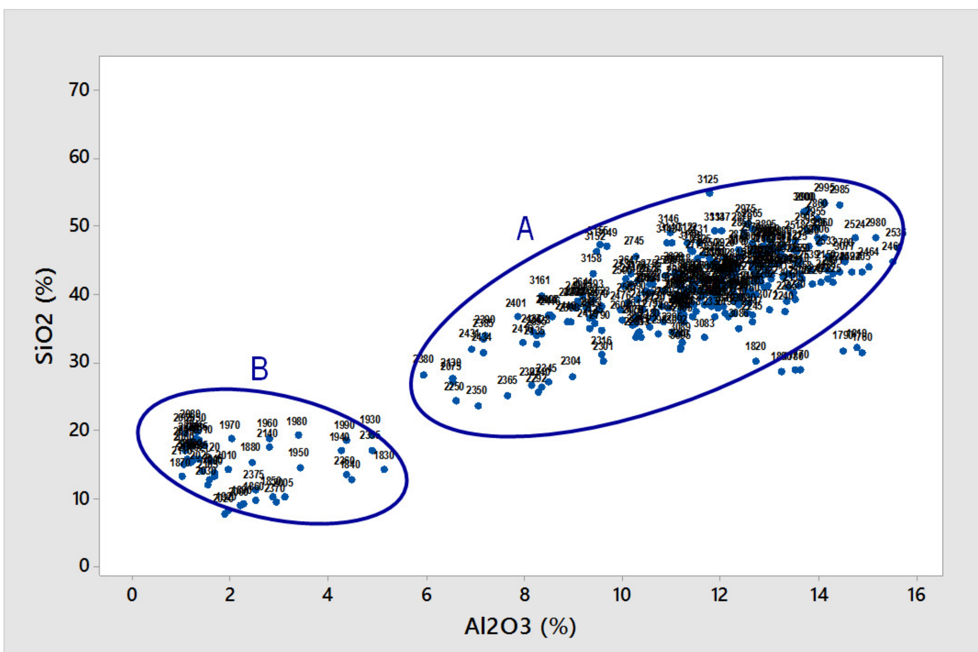

Figure 10. Plot of SiO2 and Al2O3 for the complete well sections

Conclusion.

The V/Ni ratio indicates redox environment, the ratio indicates that the sandstone series of 1850m to 2120m and 2350m to 2450m were deposited in oxygen rich nearshore environment or shallow marine environment. While sediments of 2120m to 2330m and from 2450m to 3200m bear very high values indicating more marine environments. The Fe_2O_3+MgO parameter show that the sandstones of 1850m to 2120m have very low Fe_2O_3+MgO values,implying their source to be from Continental Crust, while the lower series of 2120m to 3200m have very high values indicating their source to be Oceanic Crust. The Al/bases ratio clearly discriminate between 1850m to 2120m sandstones which have low Al/bases ratio, implying pervasive weathering which corresponds to humid and wet climate.The TiO_2–Zr binary diagram shows that majority of the samples were derived from source with lithology which corresponds to Continental Crust and Continental Arcs. The Ga/Rb ratio which represent the kaolinite/illite ratio indicates higher values for the sandbody of 1850–2120 series, implying high pore filling minerals and poor sweep/production efficiency for reservoir functionality

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