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(RESEARCH ARTICLE)

Geochemistry of the Albian to Upper Maastrichtian formations of the K1 oil well (East of the Côte d'Ivoire offshore basin): Depositional environment and implication of provenance

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Abstract

The studies were carried out on 93 samples of cuttings from the K1 oil well. These samples were processed using the Fluorescence Spectrometer (XRF) method. Chemical analyses contributed to the determination of depositional environments and origin of the sediments. Albian sediments deposited in an environment proximal to the continental characterize the MS1 mega-sequence. In contrast, the MS2 mega-sequence (Cenomanian to Maastrichtian) was deposited in a shallow to deep marine environment marked by a decrease in detrital flow. The ratio Ti/Y, with values below 0.017 in the MS1, means that the sediment source of the mega-sequence MS1would therefore be richer in phosphates, with a contribution from mafic volcanic rocks (rich in illite, iron and magnesium). In contrast to MS1, MS2 is characterized by ratio Ti/Y values above 0.017. This decrease in Yttrium content in this mega-sequence is consistent with Th/Al values below 1.588. This would suggest a richer source of titanium oxides, which could be rutile, sphene or anatase.

Keywords: Geochemistry; Minor elements; Offshore basin; Upper Albian-Maastrichtian; Depositional environment; Source/provenance

1. Introduction

The sedimentary basin of Côte d'Ivoire has been the subject of several studies for the oil exploration and knowledge of the basin (Yao, 2012). This is how, the Ivorian Cretaceous, a period of interest for Ivorian oilmen, has been the subject of many studies in Côte d'Ivoire. These include the work of (Toé-Bi *et al.,* 2016; Guéde *et al.,* 2019; Ouattara *et al.,* 2021). These studies concern lithology, biostratigraphy, geochemistry and petrography. Although geochemistry is applied to these sediments, chemostratigraphy remains somewhat of a new method that has not been used enough in this basin. Chemostratigraphy can be defined as the application of sedimentary geochemistry to stratigraphy. It allows to refine lithostratigraphy. Thus chemostratigraphy helps to determine the characteristics of the differents variations of major and trace elements. These variations are sensitive to changes in facies, variations in chemical and mineralogical composition, and weathering and diagenesis phenomena (Soua, 2011). The present study aims to identify the differents chemical elements in order to determine the different sources of provenace and the depositional environment of basin sediments during the Cretaceous of well K1. This well is located in the eastern part of the Abidjan margin (Figure 1).

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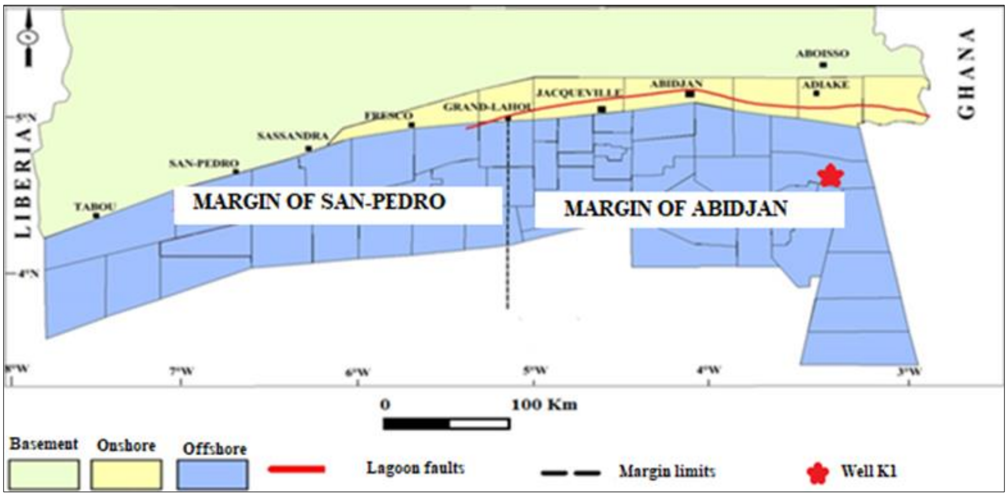

Figure 1 Study area showing the location of the K1 study well

2. Material and methods

Ninety-three (93) cuttings from well K1 were used as support for this geochemical study. Before the actual analysis, the samples have undergone physical treatment. 4 g of each sample was taken and placed in a beaker, whose number corresponds to a rating of the survey in order to avoid identification errors. The samples were washed in dichloromethane (DCM) to remove soluble pollutants (drilling mud and any traces of oil). After washing and drying, the samples were sorted or picked under a binocular magnifying glass to separate the different formations observed in the cuttings. Only clayey lithologies are recovered by chemostratigraphic analysis. Several sediments of different lithologies may be found in the same sample.In this case, picking will be carried out on each lithology of the same sample. We then proceed to grind the samples using a vibratory ball mill to obtain very fine fractions (less than 63 µm). Four grams (4g) of the powder obtained is then combined with one gram (1g) of binder (cereox type). This mixture is then pressed to the press to make the pellet 33 millimeters in diameter. It is these pellets that are analyzed using an X-ray fluorescence spectrometer, in order to determine the differents concentrations of trace, major and minor elements within the limits detectable by XRF. Before any XRF analysis, the instrument is calibrated using an international reference standard. This calibration allows the device to give good results according to international standards. Elements such as Zr, Nb, Ti, Rb, Th and Y have been used to determine the source/provenance of the sediment (Pearce *et al.,* 2005). Rb and the major minerals are used to determine the depositional environment. These elements are greatly influenced by weathering and diagenesis. The major elements used are K, Al and Mg. Ratios such as Ti/Al have been used to determine the depositional environment and sea level variation during sediment deposition (Ratcliffe and Wright, 2012).

3. Results

The increase in the values of the ratios K/Al; Mg/Al; Ti/Al; Fe/Al; and Mn/Al, as well as theirs falls in the sediments, made it possible to highlight two sequences: Mega-sequence 1 (MS1) and Mega-sequence 2 (MS2) (Figure 2).

3.1. Determination of deposition environments:

The MS1 in this well is characterised by K/Al, Fe/Al and Mg/Al ratios higher than 0,152, 0,712 and 0,162 respectively, and Ga/Rb ratios lower than 0,19 (Fig. 2). The evolution of these ratios in the MS1 bears witness to the high detrital contributions, with a richness of illite (materialized by the high values of the K/Al ratio) and minerals carrying Fe and Mg which could be chlorite, vermiculite. Moreover, these important terrigenous fluxes revealed by these important values of the K/Al, Fe/Al and Mg/Al ratios would be explained by the proximity of the depositional environment to the continent. This analysis agrees with the low Ga/Rb values, which indicate a richness of illite relative to the proportion of kaolinite in the depositional environment. This poverty in kaolinite would come from the fact that the envrironnment is not submerged, or not sufficiently submerged, to leach the labile elements such as K and Rb in the sediments during their transport before the deposit. Chlorite and biotite are therefore absent from this sequence, since Fe is an element, which enters part into the composition of these minerals. The same is true between Ca and Mg, which indicates that carbonate minerals are absent in the clays of MS1. The proportion of Mg in this sequence would therefore linked to the presence of detritus from basic and ultrabasic igneous rocks.Unlike MS1, MS2 is characterised by values of the K/Al, Fe/Al and Mg/Al ratios respectively lower than 0,152, 0,712 and 0,162. The Ga/Rb ratio also shows an opposite evolution in this mega-sequence compared to MS1, with values above 0,19. This information suggests that a marine transgression was responsible for moving the depositional environment away from the continent and caused the drop in terrigenous flows. Because marine arrivals would have inhibited detrital contributions because of the action of the waves, which would have opposed continental flows; this would therefore justify the reduction of Fe/Al and Mg/Al ratios. In addition, this significant presence of water would even have led to the leaching of labile elements (K and Rb) from the sediments, which are carried to the depositional environment, hence the drop in values of K/Al ratio. This drop in the ratio reflects the reduction in the proportion of illite in the depositional environment in favour of an enrichment in kaolinite. In fact, illite loses its chemical elements (K, Rb) and is transformed into kaolinite under the effect of intense alteration supported by important drainage of the sediments. The richness of kaolinite in this mega-sequence is shown by the high values of the Ga/Rb ratio. This mega-sequence is therefore enriched in kaolinite and depleted in illite.

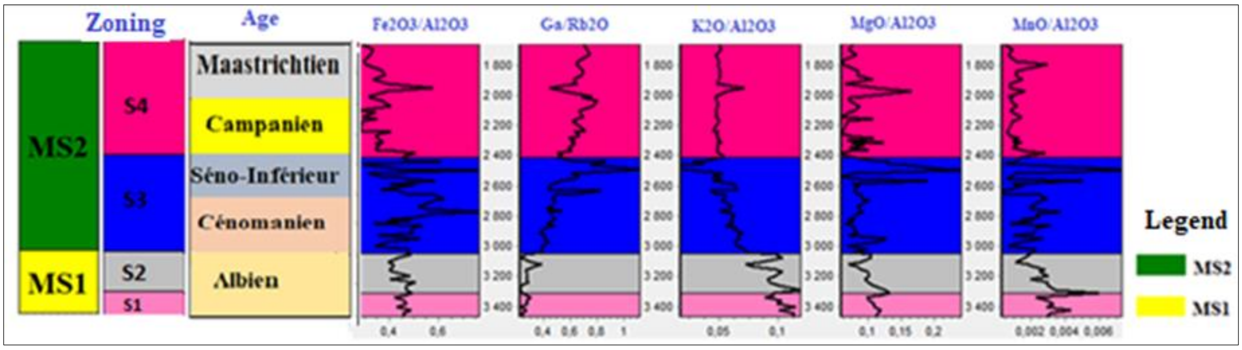

Figure 2 Chemostratigraphic profile of depositional environment of the K1 Well

3.2. Source of sediments

The threshold values of the Ti/Y and Th/Al ratios indicate the same limits between MS1 and MS2 defined by those of the ratios of elements indicating the environment of deposition (Figure. 47). Ti/Y values are below 0.017 in MS1, meaning that the source of sediment in this mega-sequence is poorer in Ti-bearing minerals compared to phosphates, the yttrium-bearing minerals. The richness of yttrium-bearing mineral phase in this mega-sequence is confirmed by the high values of the Th/Al ratio above 1.588 since these two elements (Th and Y) have a high correlation coefficient. This high concentration of Th and Y could be explained by the presence of apatite and/or monazite. The sediment source of the MS1 mega-sequence deposits would therefore be richer in phosphates and have a low concentration of titanium-bearing minerals. The richness of illite, iron and magnesium in MS1 suggests some contribution of mafic volcanic rocks in the source zone, which is obviously in the Ivoirien crystalline basement.In contrast, MS2 is characterised by Ti/Y values greater than 0,017, a sign of the richness of Ti in relation to Y (Figure 47). This decrease in Y content in this mega-sequence is consistent with Th/Al values below 1,588. These changes indicate a change in the source of the sediments. The marine transgression, identified as responsible for the changes in the depositional environment between MS1 and MS2, would clearly be the cause of the change in the sedimentary zone. In fact, with the marine arrivals, the depositional environment is submerged and probably distanced from the source of the sediments. New sedimentary provinces will therefore bring the detritus into the depositional environment. Also, the hydrodynamics caused by the force of the waves with the arrival of marine waters will control the transport and deposition of sediments in the depositional environment. It would then be a source richer in titanium oxides, which could be rutile, sphene or anatase.

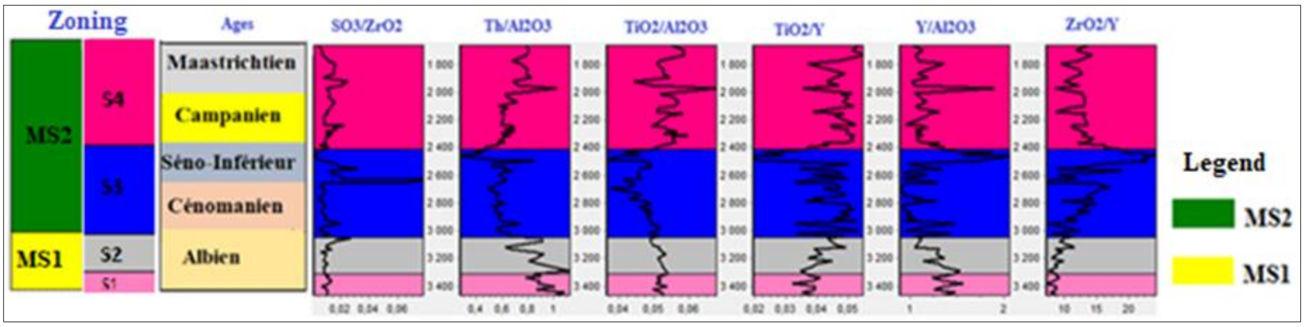

Figure 3 Chemostratigraphic source profile of Well K1

4. Discussion

The sediments of meg-asequences 1 (MS1), which correspond to the Albian, are characterised by a very high aluminium content. Al_2O_3 is a relatively stable element in environments where intense chemical weathering, while MgO, CaO, Na_2O and K_2O are easily leached in similar settings (Ratcliffe *et al.,* 2015). In general, the element Th is considered to be very immobile in aqueous conditions and is exclusively concentrated in detrital heavy minerals (Craigie, 2018), their abundance in our sediment sequences would indicate a proximal environment. These results corroborate those of the work of (Bamba et al., 2011) who maintains that in this interval, the sediments were deposited in an environment of the internal platform type with continental influence. The sediments of megasquence 2 (MS2) correspond to the Cenomanian to Maastrichtian stages. The Lower Senonian is characterised by a relative drop in potassium content, which indicates the alteration of K-rich sediments, and there the dissolution of the latter. We are therefore moving from a proximal environment to a clear marine environment, which corroborates the work of Bamba *et al.,* (2011). They argue that in the Turonian interval, they noted a decrease in the planktonic population and the appearance of benthic forms with elongated tests, which reflects a decrease in oxygen content. However, in the Cenomanian, Campanian and Maastrichtian periods, we observe a progressive increase in the potassium content. We therefore have a slow enrichment in detrital minerals, which would indicate a rapprochement of the coasts. Its high presence in an environment would indicate a depositional environment close to the continent. The sediments of these stages were deposited in an environment close to the continent than those of the Lower Senomanian. These results corroborate those of (Digbehi et al., 2011) who argue that in this interval, the predominance of spores and pollen grains and the rarity of peridinioid cysts reflects an environment relatively closer to the littoral zone. Heavy elements such as Zr, Ti and Al are generally used to interpret the eustatic level (Sageman, 2003), (Travis, 2007), (Ratcliffe and Wright. 2012). Zr is a heavy element that tends to concentrate at the seashore and Ti can be found in sediments by wind and tends to concentrate in deep-water sediments. Variations in Nb/Zr and Ti/Al would indicate a sea-level transgression within MS2.

5. Conclusion

At the end of this geochemical study, we can conclude that the Albian, Cenomanian, Campanian and Maastrichtian sediments in the Ivorian sedimentary basin were deposited in an environment close to the continent. On the other hand, the Lower Senonian sediments were deposited in a marine environment. The source of the Albian sediments would be richer in phosphates, with a contribution of mafic volcanic rocks. All of the deposits in mega-sequence 2 (Cenomanian, Lower Senonian, Campanian and Maastrichtian) would have a source richer in titanium oxides.

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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