

## PRODUCTION OF COALBED METHANE IN MOZAMBICAN COAL BASINS: A VIABLE ALTERNATIVE ENERGY

*PRODUÇÃO DE METANO DE CARVÃO MINERAL EM BACIAS DE CARVÃO  
MOÇAMBICANAS: UMA ENERGIA ALTERNATIVA VIÁVEL*

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**ABSTRACT** – The present study analyzed the potential of coalbed methane (CBM) generation as a viable alternative energy source of production in the Mozambican coal basins considering the geology, the properties of the coal and the respective potentialities. It should be noted that one of the most important coal bearing sedimentary successions in the world occurs in the Moatize-Minjova coal basin, Mozambique. In the analysis of the rank of the types of coal suitable for the production of CBM, the most recommended are the coal or bituminous type that has high levels of CO<sub>2</sub>, high calorific value and higher concentration of gas and, this quality is found in the Moatize-Minjova coal basin. Exploration well drilling data collected by the company ETA STAR Mozambique were analyzed by specific laboratory tests, such as: physical-chemical, mineralogical, geochemical and petrography analyzes. Those analyses facilitated the knowledge of the geology and the economic viability of the reservoir for the determination of the quality and volume of gas contained in the layers of coal as a viable source of energy in the country. Thus, it is anticipated that the result of the pioneer study carried out by the Company ETA STAR Mozambique indicates that this coal basin of Moatize has qualities to generate the coalbed methane. It is also emphasized that the other five coal basins located in the region, due to the geological characteristics, probably have an economically feasible potential for production. In this way, the exploration of the CBM would be a preponderant solution to answer the problematic of the energy demand for the national consumption. However, in order to exploit the CBM's potential in the country, the Government of Mozambique could introduce a specific CBM policy to legally guide the research, exploration, production and consumption of methane gas contained in the coal layers Mozambican.

**Keywords:** Coalbed; Coalbed Methane; Energy; Moatize-Minjova coal basin; Mozambique

**RESUMO** - O presente estudo analisou o potencial de geração de metano a partir de carvão mineral (coalbed methane - CBM) como fonte alternativa energética viável de produção nas bacias carboníferas moçambicanas considerando a geologia, as propriedades do carvão e as respectivas potencialidades. Destaca-se que uma das mais importantes sucessões sedimentares portadoras de carvão no mundo ocorre na bacia carbonífera de Moatize-Minjova, Moçambique. Na análise do *rank* dos tipos de carvão adequados para a produção do CBM, os mais recomendados são do tipo hulha ou betuminoso que possuem elevados teores de CO<sub>2</sub>, elevado poder calorífico, maior concentração do gás e essa qualidade é encontrada na bacia carbonífera de Moatize-Minjova. Os dados de perfuração de poços de exploração coletados pela Empresa ETA STAR Moçambique foram analisados por meio de ensaios laboratoriais específicos, como: análises físico-químicas, mineralógicas, geoquímicas e petrográficas. Tais análises facilitaram o conhecimento da geologia e da viabilidade econômica da jazida com vistas à determinação da qualidade e volume de gás contido nas camadas de carvão como fonte energética viável de produção no país. O resultado do estudo pioneiro realizado pela Empresa ETA STAR Moçambique indica que a bacia carbonífera de Moatize possui qualidades para gerar o CBM. Acentua-se que outras cinco bacias carboníferas presentes na região, pelas suas características geológicas, provavelmente possuem potencial economicamente viável para a produção. Desta forma, a exploração do CBM seria uma solução preponderante para responder a problemática da demanda energética para o consumo nacional. Não obstante, a fim de se aproveitar o potencial do CBM no país, o Governo de Moçambique poderia introduzir uma política específica do CBM para nortear legalmente as atividades de pesquisa e prospecção, exploração, produção e consumo do gás de metano contido nas camadas de carvão moçambicanas.

**Palavras-chaves:** Carvão mineral, Metano de carvão mineral, Energia, Bacia carbonífera de Moatize-Minjova, Moçambique.

### INTRODUCTION

Currently, due to energy needs and even will continue to be one of the main inputs for with the inclusion of new energy sources, coal electricity generation, especially in developing

countries. This is due to the abundance and geographic distribution of reserves coupled with low cost and price stability when compared to other conventional fuels (Ministry of Mines and Energy, 2013). It is noteworthy, however, that more than 90% of the world's coal reserves are located in the Northern Hemisphere, and the United States holds 70% of the world's Coalbed Methane (CBM) production to date (Levandowski, 2009).

Coalbed Methane or methane gas has in recent years represented a major source of alternative energy due to the decline in the global conventional oil and natural gas resources recorded at present. Therefore, before the 1970s, CBM production worldwide was considered a risk factor for safety in the coal mining process, but with the development of new technologies, companies began capturing and recovering methane (CH<sub>4</sub>) found in the deeper layers of coal. However, considering the local geology of its sedimentary basins, several countries such as the United States, Australia and Canada have proven to be economically viable the production of methane absorbed in the coal. The example is set by the production of about 61 billion m<sup>3</sup> in 2006 from CBM in the United States, 4 billion m<sup>3</sup> in 2008 in Australia, 1.4 million m<sup>3</sup> in 2007 in China (USGS Energy, 2017). In the last two decades, African countries such as Zimbabwe, Botswana and South Africa are betting their energy investments on prospecting and research activities to effectively produce CBM in their coal-mining basins as an alternative energy source (BP Statistical Review, 2017).

In Mozambique, the basins of Maniamba-Lunho, Mucanha - Vuzi, Sanagoê - M'Fidezi, Moatize - Minjova and Mepotepote are the six main coal - producing basins with probable potential for CBM production, given their geological characteristics. These basins are

still unexplored, with exception of the coal basin of Moatize - Minjova. The province of Tete has one of the largest unexploited coal basins in the world, whose characteristics denote the existence of CH<sub>4</sub> in its layers. The Moatize-Minjova coal basin is the most studied in Mozambique, has estimated reserves of more than 2.5 billion tons of coal, whose exploitation is done in the open using the classic strip-mining method given the geological and geomorphologic conditions of the terrain (José & Sampaio, 2012). In this basin, three main mining companies stand out: the Brazilian company Vale S.A; the Indian Consortium International - Indian Coal Ventures Limited (ICVL) and the South African - Minas Moatize Ltda., which produce thermal coal and metallurgical (Selemane, 2010). Therefore, the implantation of these companies is part of the process of internationalization of large companies in the countries known as BRICS (Brazil, Russia, India, China and South Africa) intensified in the last two decades (Coelho, 2015).

Studies carried out in coal basins around the world indicate that the coal layers are good accumulators of CH<sub>4</sub>, as they act as both a generator rock and fuel gas reservoir, storing large amounts of methane gas due to the microporosity of the material and can have six times greater gas production capacity than a conventional reserve (WCI, 2017). Current coal mining in the Moatize - Minjova coal basin, as well as in other Mozambican basins, does not take advantage of the methane gas contained in the coal layers, that is, it is emitted into the atmosphere contributing to intensify environmental problems.

In this way, the present research intends to analyze the exploration and production activities of the Coalbed Methane (CBM) in the Mozambican coal basins focusing on its use as a possible energy alternative.

## MATERIALS AND METHODS

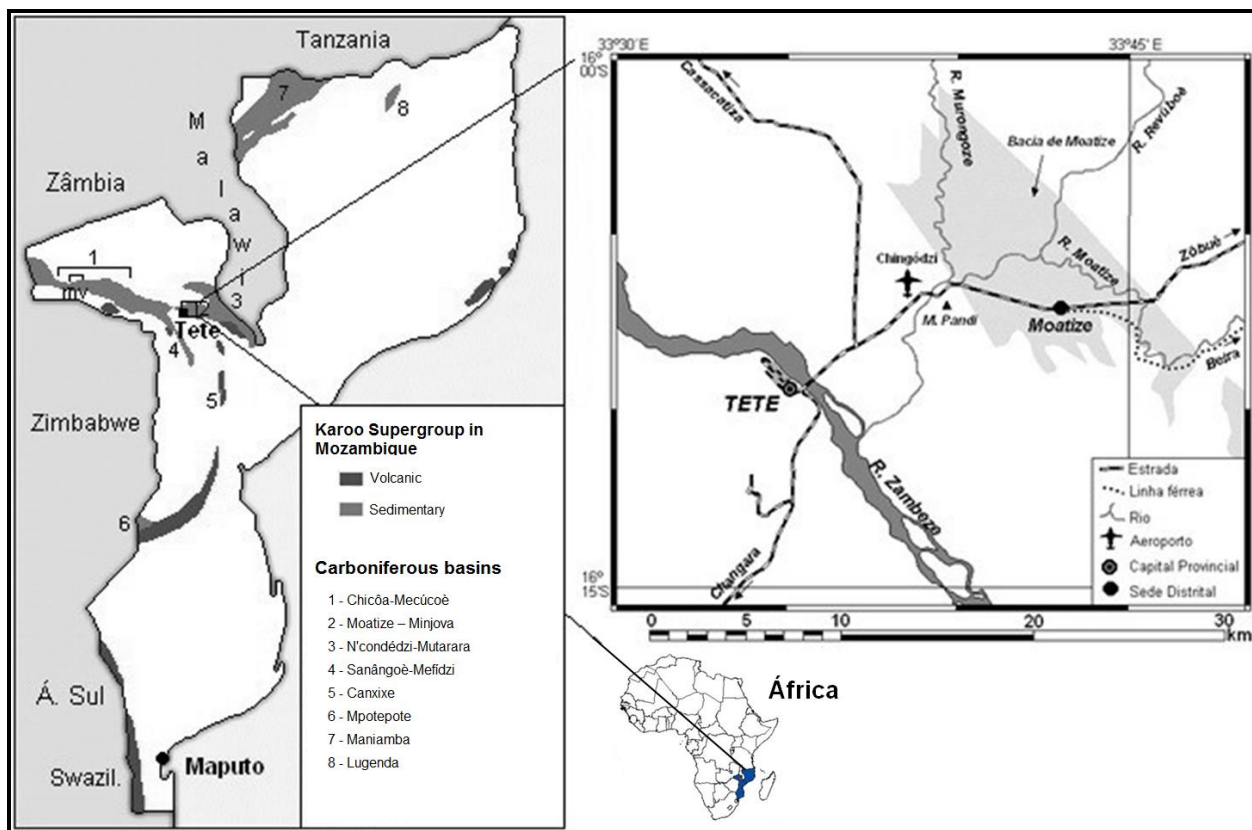
The methodology used was the bibliographical research that consisted in the data collection and analysis and related to the characterization of the coal mining in the Moatize district; regional and local geological context of the region; and evaluation of the CBM production potential in the Moatize - Minjova coal basin.

The results on petrography (analysis of macerals and vitrinite reflectance), chemical analyzes (immediate analysis, sulfur content, calorific value, diffraction and X-ray fluorescence), absorption tests (CH<sub>4</sub> and CO<sub>2</sub>) and isotope analysis (C and H), the gas composition of the coal layers used in this article were carried out by the Company ETA STAR Mozambique.

## The Moatize - Minjova coal basin in Mozambique

Mozambique is a country that is located in East Africa, has about 780,000 km<sup>2</sup> of surface and 2,500 km of coastline (Muchangos, 1999).

The Moatize-Minjova coal basin is about 8,455 km<sup>2</sup>, and is located in the district of Moatize, Tete Province, northwest of Mozambique (Figure 1), being cut by three main rivers called: Zambeze, Revúbuè and Moatize, as well as tributaries.



**Figure 1** - Geographical location of the Moatize coal basin (Source: Modified the Vasconcelos, Muchangos & Siquela, 2009).

In relation to geology, Mozambique is divided into a crystalline basement with Archean-Cambrian age and a cover of rocks with Phanerozoic age. The crystalline basement consists of metamorphic supracrustal paragneisses, granulites and migmatites, orthogneisses and igneous rocks (CUMBE, 2007). According to the GTK Consortium (2006b), Tete Province has a complex crystalline basement divided by three different terrains: South Gondwana, East Gondwana and West Gondwana which collided and amalgamated during the Pan-African Orogenic Cycle (COPA). Therefore, the study area is entirely embedded in the South Gondwana Terrain which contemplates the Zimbabwe Craton and a set of tectonic units in the Proterozoic folded belts which were carried and deposited on the northern and eastern shores of Mozambique characterized by Phanerozoic rocks, mafic and felsic intrusions, and the Archaic belt of Manica (GTK Consortium, 2006a).

Moatize mineral coal frequently occurs in the

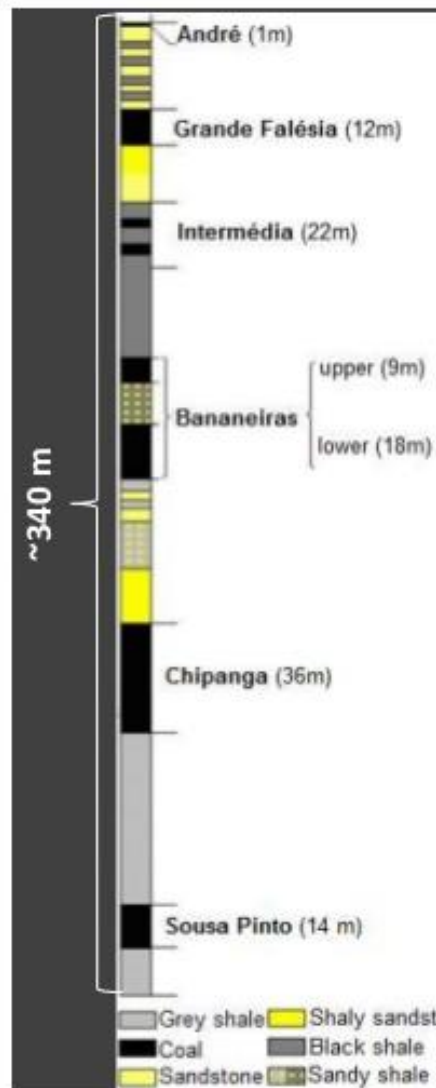
Lower Karoo sediments, mostly deposited in the Moatize-Minjova Formation, whose depositional history began with the Upper Carboniferous age glaciation and ended with the deposition of mixed, granular clastic deposits coarse to fine during the Permian (GTK Consortium, 2006a after Macie, 2015).

According to Afonso (1976, after Amissone, 2009), in tectonic terms, the Moatize-Minjova Formation fills a graben that occupies an area of approximately 300 Km<sup>2</sup> between the rivers Moatize, Revúbuè and Murungodzi to the northeast of the Zambezi river, orientated NW-SE and is surrounded by gabbros and anorthosites of the Suite Tete, of Mesoproterozoic age (1600-1000 Ma). The boundary NE of the basin is conditioned by a normal fault of about 30 km of length-oriented NW-SE. The SW limit is due to nonconformity, as well as to normal fault contact, as is the case of Monte M'pandi fault. These faults define several sections and cut vertically the basin reaching up to 100 meters, originated by the

extensive tectonics associated with the East African Rift, which began to form during the Lower Jurassic (Afonso, 1976 apud Aminosse, 2009).

The coal deposits are of the lower Permian with discordant layers on Precambrian rocks. The lithologies corresponding to the sterile rock, such as siltstones, clays, white to ash sandstone, with fossil flora of *Glossopteris* and *Gangamopteris*, among others, and black clay with layers of coal (Vasconcelos, Muchangos & Siquela, 2009).

The coal deposits are coal-like to bituminous and present a stratigraphic sequence consisting of six main layers of coal, approximately 340m thick designated from the bottom up: André's Layer, the Grande Falésia Layer, the Intermediate Layer, the Banana Layer, Layer Chipanga, and the Layer Sousa Pinto (GTK Consortium, 2006d). Among these layers, the Chipanga Layer is considered the most important productive series with 36 meters of thickness (Figure 2).



**Figure 2** - Stratigraphic sequence of the Moatize-Minjova basin (Source: Vasconcelos, 2005 apud José & Sampaio, 2012).

## RESULTS AND DISCUSSION

### Coalbed Methane Storage, Generation and Production Technologies

The Coalbed Methane is a gas that we may find adsorbed on the inner structures of the layers of coal. The charcoal layers to be considered as the generating rock and CH<sub>4</sub> reservoir must have the following characteristics: rank, petrographic composition (analysis of macerals and vitrinite

reflectance), mineral content, water absorbing capacity and fractures (physical properties, such as permeability, macro and microporosity) as Lourenzi (2013) pointed out.

According to Levandowski (2009) the composition of the natural gas reservoir associated with layers of coal contains 70-100% of methane, a small amount of hydrocarbons

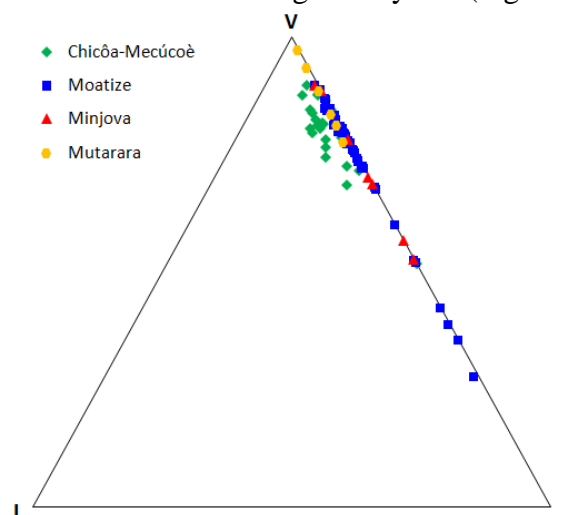
with the greatest number of carbon atoms and low amounts of CO<sub>2</sub>, N<sub>2</sub> and H. Gas storage of CH<sub>4</sub>, is usually found in pores and fractures because of physical absorption, mopping with layers of coal or associated with sediment. However, the gas storage in the coal can be presented in four different mechanisms: free gas in the porous spaces; condensed as a solid or liquid; dissolved in the carbon structure; and adsorbed on the inner surfaces (Crosdale et al., 1988 apud Levandowski, 2009).

According to Lourenzi (2013), the gas generation in the coal layers is controlled through two processes namely: (i). Biogenic generation: result of CH<sub>4</sub> and CO<sub>2</sub> that have been produced by the decomposition of organic matter by microorganisms (peat and turf). Some parameters, such as anoxic environment, low sulfate concentrations, low temperature, and abundance of organic matter, high Ph, adequate pore spaces and fast sedimentation are necessary in this generation; (ii). Thermogenic generation: it forms in high pressures and elevated temperatures associated with the increase of the carbonification. The gases generated mainly CH<sub>4</sub>, come from the cracking of the molecules of the coal by a process called catagenesis (vitrinite reflectance between 0.6 and 2%). Therefore, in the beginning the amount of gas is small and will increase with the thermal evolution. As the maturity increases, the increase of methane (CH<sub>4</sub>), typical of deposits of humic carbons that present greater source of CBM, occurs.

The main technology used for the exploitation of unconventional natural gas such as CBM is hydraulic fracturing, this technique uses high pressure water jets to break off the generating rock and release the gas. Therefore, this method consists of performing vertical drilling until reaching the layer of coal and then drilling horizontally for several kilometers. After drilling, huge amounts of water and chemicals are injected, which cause a network of micro fractures in the formation, thus allowing the trapped gas, to flow into the gas pipe, where it is piped to a compression station and combined with the production (Levandowski, 2009). Therefore, the water injected is most often reinjected into the production or treated wells and discarded at the surface. However, coal layers have six times greater potential for gas production than a conventional well.

### Coalbed Methane potential generator in the Moatize coal basin - Minjova

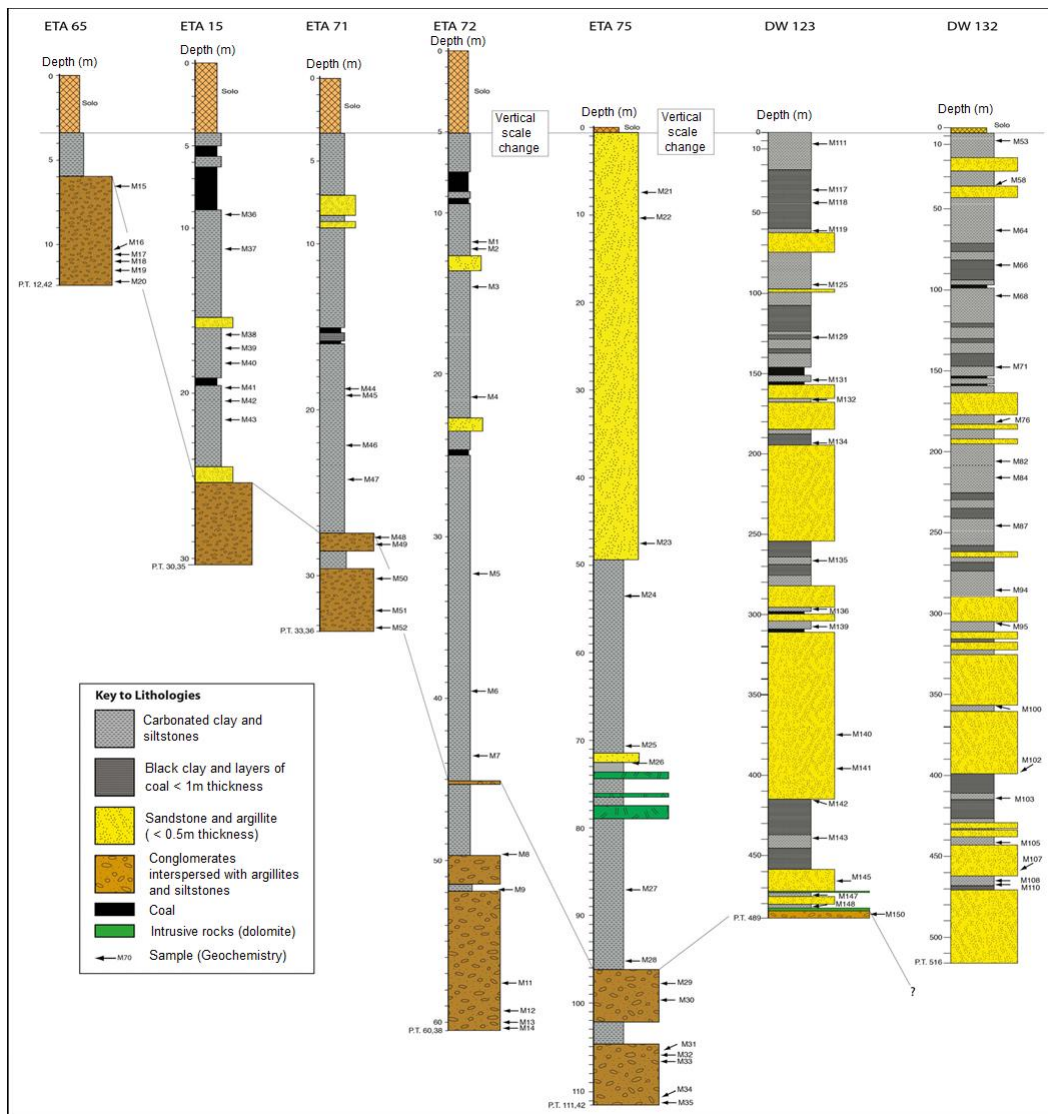
In the Moatize coal basin, some geochemical and petrography studies were carried out by the multinationals such as Vale SA, Rio Tinto, Minas Moatize Ltda and others under the supervision of the National Geological Department of Mozambique, aiming at characterizing the quality of the existing coal. Therefore, the analyzes of the organic and petrography geochemistry performed in the basin indicate that the coal is of the bituminous type, with the volatile content varying from high to low and occasionally anthracitic; are rich in vitrinite than in inertinite, the liptinite content is very low, the ash production is high and the total sulfur content is generally low (Figure 3).



**Figure 3** - Ternary diagram representing the content of vitrinite, inertinite and liptinite of Moatize-Minjova Formation (Source: DNG, 2006: 11).

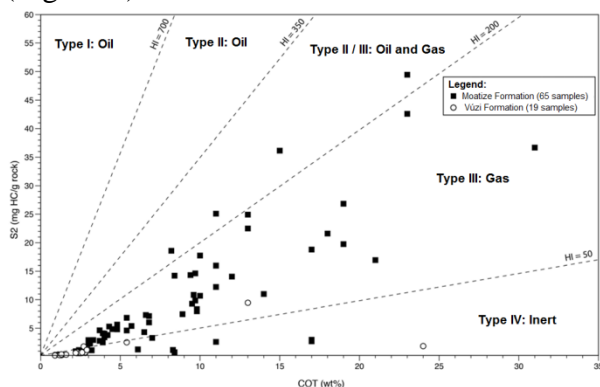
However, one of the pioneer studies for the determination of the CBM generating potential in the Moatize - Minjova coal basin was carried out by the Company ETA STAR Mozambique. Seven surveys were carried out collecting 92 samples from the top of the Vuzi Formation to the Moatize Formation (Figure 4).

The samples were analyzed by means of Geochemistry and Petrography in a laboratory in Germany (GEO - DATA GmbH), whose results were calculated according to Peters & Cassa (1994). The analysis of organic geochemistry - Rock-Eval pyrolysis was used to acquire data on the amount, type and thermal maturation of organic matter in rocks and sediments. The parameters measured by this technique included total organic carbon (TOC), S1, S2, S3 and maximum pyrolysis temperature (Tmax), hydrogen (HI) and oxygen (OI) indexes.



**Figure 4:** Lithological profiles of the polls studied with the position and reference of the samples. The direction line formed by the alignment of the five polls is approximately N-S, with ETA 65 closest to the North and ETA 75 more to the South (Source: Modified from Paulo et al., 2013).

The studies indicated that the Moatize - Minjova Formation is characterized by having type II - III and type III kerogen, with high values of total organic carbon (TOC) and medium to high Hydrogen (HI) values, thus having the capacity to generate methane gas (Figure 5).



**Figure 5:** Chart COT and S<sub>2</sub> with the type of kerogen and its hydrocarbon generating potential (Source: Modified from Paulo et al., 2013).

The data of table 1 present a detailed summary of the geochemical and petrographic results of the surveys conducted in the basin according to the study carried out by Paulo et al. (2013).

Based on the samples studied in the Moatize - Minjova Formation, the majority presented high TOC values (> 8 wt.%) and S<sub>2</sub> values resulting from the pyrolysis above 100 mg HC / g in the rock pointing to a very good to excellent potential for generate methane gas. This Formation presents values of superior S<sub>1</sub>, distributing between the field of moderate potential and good potential. This data indicates that oil was generated during the thermal history of the Moatize Formation, but its potential is moderate. The kerogen type III and IV presented good potential to generate methane gas (Paulo et al., 2013).

However, the above-mentioned pioneering study serves as an obvious example in the coal region, demonstrating the existence of hydro-

Table 1. Geochemical and petrography results of the hydrocarbon generating potential in the Moatize-Minjova coal basin (Source: Paulo et al., 2013).

<b>CBM GENERATOR POTENTIAL</b>		
<b>Parameters</b>	<b>Results</b>	<b>Description</b>
<b>Total Organic Carbon (TOC)</b>	It varies between 1.3 and 31 wt. %, but most samples show TOC values higher than 4wt. %.	Typical values of rocks with very good to excellent TOC.
<b>First phase of pyrolysis (S1)</b>	The S1 values are in the majority of the samples, between 0.5 and 2 mg HC/g.	Rock indicating a medium to good potential to generate hydrocarbons.
<b>Second stage of pyrolysis (S2)</b>	Values for most samples range from 5 to 60 mg HC/g.	It has a potential distributed between good, very good and excellent for generating hydrocarbons suggesting an appreciable potential to generate hydrocarbons.
<b>Maximum temperature (T.max)</b>	The values vary between 436 - 531°C	Most of the T.max values of the Moatize Formation samples indicate levels of organic maturation in the oil window and thermogenic gas beginnings.
<b>Vitrinite reflecting power</b>	Indicates high rank of bituminous coals and a position at the end of the oil window and start of the thermogenic gas window.	It has a good potential to generate thermogenic gas.
<b>Type of Kerogen</b>	It has type II and III kerogen, most of which are evident in the type III window, with high TOC (> 4 wt%)	The characteristic of the type of kerogeny the Moatize basin presents capacity to generate gas.

carbons in the coal layers of the Moatize coal basin. Considering the geological characteristics, similar depositional history with other five basins (Maniamba- Lunho, Mucanha - Vuzi, Sanagoê - M'Fidezi, Mepotepote), less studied, probably can possess an economically feasible potential for the production of methane gas since where we have

charcoal we have the CBM trapped in its internal structures, without however import the size of the layer. In this way, it would be a very important solution to respond to the energetic problems of the interior of the provinces of the Midwest and North of the country where the remaining coal basins are located.

### FINAL CONSIDERATIONS

The exploitation of the methane gas contained in the sub - deep and in the deepest coal layer of the Mozambican coal basins is unreal, although there is an enormous potential of high quality coal (bituminous) with a high ranking of the degree of carbonation capable of generating hydrocarbons. Nevertheless, several countries in the world have already demonstrated the viability of production and its importance in the world energy matrix.

In Mozambique there is a significant number of unexplored coal basins that may contain the CBM, such as the basins: Maniamba- Lunho, Mucanha - Vuzi, Sanagoê - M'Fidezi, Mepotepote but which require more detailed studies, with the exception of the Moatize -Minjova basin is the most studied. Most of the reported research on the methane absorption characteristics of the coal layers was concentrated on those that are rich in vitrinite, being of bituminous type. This is the case of Moatize reserves, where coal is rich in vitrinite rather than in inertinite and thus are good methane

gas generators. The results of the surveys carried out by ETA STAR Mozambique point out that the Moatize - Minjova Formation is characterized by having type II to III kerogen, with high TOC values and medium to high HI values, thus possessing capacity to generate MBC. However, because it is one of the first wells drilled to study the potential for hydrocarbon generation in the Moatize-Minjova basin, it is suggested that more detailed studies be carried out with the objective of verifying in the other deposits the CH<sub>4</sub> generation potential contained in the layers of coal.

West and North of the country where the main coal deposits occur, the largest deposit discovered to date is that of the Moatize-Minjova basin with CBM production potential.

It is necessary to invest in activities of exploration of this gas in the various basins of the country and the Mozambican Government should legally regulate the activities of exploration and exploration, exploitation, production and

consumption of the methane gas contained in the Mozambican coal layers, encouraging its partners private investors, international investors in order to make CBM production and consumption a reality. Taking the current example, the United States,

Australia, China, and Canada have proved that CBM is a technically and economically viable alternative for energy production and consumption and can have a major impact on the Mozambican economy and energy scenario.

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