



UNIVERSIDADE D
COIMBRA

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**ORGANIC GEOCHEMISTRY AND ORGANIC
PETROLOGY OF CARBON RICH ROCKS FROM
LAGA, BAUCAU MUNICIPALITY
(TIMOR LESTE)**

Dissertation in the scope of Master in Geosciences, Specialization in Geological Resources supervised by Professor Joana Paula Machado Ribeiro from University of Coimbra, submitted to Department of Earth Science, Faculty of Science and Technology, University of Coimbra

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Abstract

The main objective of this work is to assess the potential as source rock for hydrocarbon generation of organic rich rocks from Timor Leste in Laga (Baucau Municipality). It is expected that the results will contribute to knowledge that might be useful for hydrocarbons exploration in the onshore of Timor.

Petrographic and geochemical analysis were conducted for the identification and characterization of the kerogen and determination of the thermal maturation. Samples of organic rich rocks from Cenozoic formations were investigated through petrographic (identification of organic matter, determination of vitrinite reflectance, determination of thermal alteration index) and geochemical methodologies (TOC, Rock-Eval pyrolysis).

The results demonstrate that the organic matter occurs in the form of vitrinite and inertinite in all samples and bituminite in samples from Viqueque formation. Particles of zooclasts were also found in all samples. Geochemical analysis reveals that the organic matter in the study samples is classified as type I and II kerogen in Viqueque Formation, type II/III and III kerogen in Barique Formation and type IV in Cablac Limestone.

The maturity stage of the organic matter was evaluated through vitrinite reflectance, TAI and Rock-Eval pyrolysis. Generally, the results of all techniques evidence the immature stage of the organic matter. However, some parameters point the potential in samples Viqueque Formation. Further investigations should be developed in order to properly evaluate the potential for hydrocarbons generation in Viqueque Formation.

Keywords: Timor Leste, Cenozoic, source rocks, total organic carbon, maturation.

Resumo

O principal objetivo deste trabalho é avaliar o potencial de geração de hidrocarbonetos de rochas ricas em matéria orgânica de Timor Leste em Laga (Baucau). Espera-se que os resultados contribuam para o conhecimento sobre a prospeção de hidrocarbonetos em Timor.

Análises petrográficas e geoquímicas foram realizadas para identificação e caracterização do cerogénio e determinação da maturação térmica. Amostras de rochas ricas em carbono da Cenozóico formações foram investigadas através de metodologias petrográficas (identificação da matéria orgânica, determinação de refletância da vitrinite, determinação do índice de alteração térmica) e geoquímicas (TOC, pirólise Rock-Eval).

Os resultados demonstram que a matéria orgânica ocorre na forma de vitrinite e inertinite em todas as amostras e também betuminite nas amostras da Formação de Viqueque. Também foram encontradas partículas de zooclastos em todas as amostras. A análise geoquímica revela que a matéria orgânica nas amostras estudadas é classificada como cerogénio tipo I e II na Formação Viqueque e cerogénio tipo II/III e III na Formação Barique e tipo IV na Cablac Limestone.

A maturação da matéria orgânica foi avaliada através da refletância da vitrinite, índice de alteração térmica e pirólise Rock-Eval. Os resultados de todas as técnicas evidenciam o estágio imaturo da matéria orgânica. No entanto, alguns parâmetros apontam o potencial nas amostras da Formação Viqueque. Estudos futuros devem ser desenvolvidas para avaliar adequadamente o potencial de geração de hidrocarbonetos na Formação Viqueque.

Palavras-chave: Timor Leste, Cenozóico, rochas geradoras, carbono orgânico total, maturação.

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CHAPTER 1 INTRODUCTION

1.1 Justification of the work

Timor-Leste is a mountainous country, located between Indonesia and Australia, with a tropical climate and an area of around 15 000 km² (fig. 1.1). The country has a population of approximately 1.5 million people based on the 2017 population census. Timor-Leste became independent in 2002 and current government income primarily comes from petroleum resources.

Oil and gas exploration in Timor-Leste has been ongoing since Portuguese times (Audley-Charles, 1968; Castelo Branco, 1915; Grunau, 1957) and Timor-Leste and Australia have recently agreed on a new maritime boundary between the two countries extending Timor-Leste's offshore territory, until 2018 Timor Leste became the official owner of Maritime boundary (Joint Petroleum Development Area). Discovering new hydrocarbon reserves onshore and offshore is a high priority for the government.

Exploration of the oil reserves onshore Eastern part of Indonesia (including Timor Island) has been carried out since the 20th century (Livsey et al, 1992; Ware & Ichram 1997; Peter et al, 1999). In the process of oil and gas exploration, petrographic and geochemical studies are needed to determine, among others, the occurrence, age, depositional environment, thermal maturity of source rocks. Such data provided by petrographic and geochemical studies play an important role in the understanding of petroleum systems (Tissot and Welte 1984).

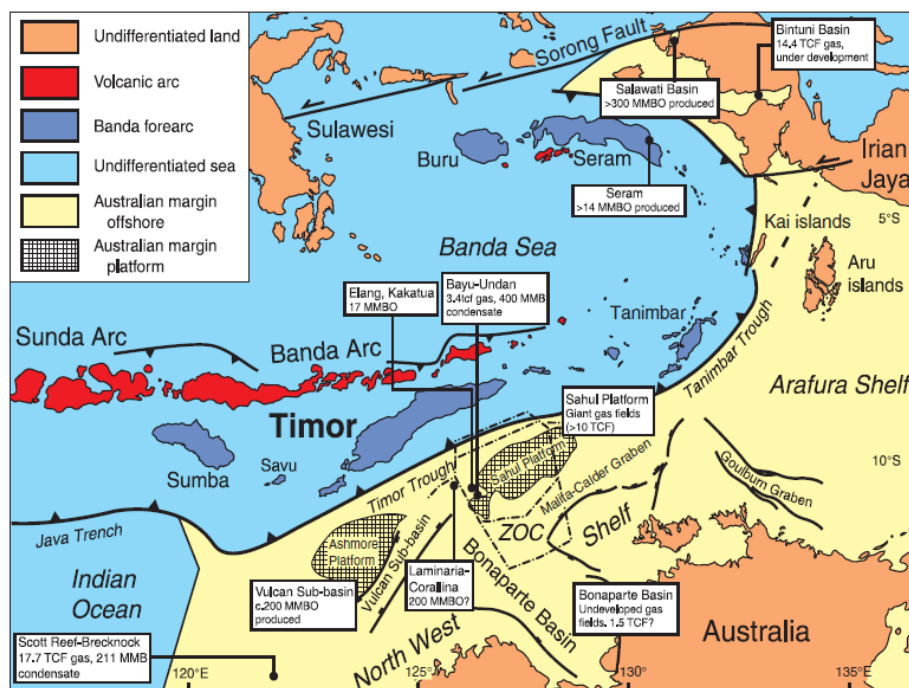


Figure 1.1 - Timor structural setting and regional oil and gas occurrences (Charlton, 2002).

1.2 Objectives of the study

The purpose of this thesis is the petrographic and geochemical study of organic rich rocks from Timor (Laga, Baucau Municipality) to assess their potential as source rock for hydrocarbon generation.

The specific objectives of the study, which included field work for samples collection and laboratorial analysis, are the identification and characterization of the kerogen and determination of the thermal maturation.

To achieve the objectives of this study, petrographic analysis for identification of organic matter, determination of vitrinite reflectance, determination of thermal alteration index (TAI), and Rock-Eval pyrolysis analysis were conducted in samples of organic rich rocks outcropping from the studied area.

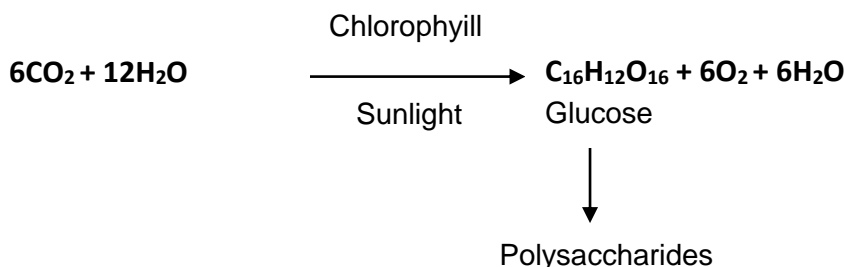
It is expected that the results will contribute to knowledge that might be useful for hydrocarbons exploration in the onshore of Timor.

1.3 Literature Review

The literature review intends to provide some description and explanation about the occurrence of organic matter in rocks. It is expected that this information might be helpful to understand the contents of the research work and the interpretation of the results.

1.3.1 General occurrences of organic matter

The organic matter associated with potential source rock is related with photosynthesis process. This process converts light energy into chemical energy; photosynthesis is basically the transfer of hydrogen from water to carbon dioxide to produce organic material in the form of glucose and oxygen (Tissot and Welte 1984); oxygen is present in water molecules and not in carbon dioxide. In photosynthesis, plants that contain chlorophyll convert water into glucose (carbohydrate) needed for biological energy, releasing oxygen as follows:



By this process every autotrophic organism can synthesize polysaccharides such as cellulose and starch and all other necessary constituents.

Organic matter is composed of organic compounds that have come from the remains of organisms such as plants and animal and their products, which can be found in association with terrestrial and marine environments. Basic structures are produced from cellulose, tannins, cutin and lignin, along with other various proteins, lipids and carbohydrate.

The principal chemical composition in organic matter comprises carbon (C), hydrogen (H), oxygen (O), nitrogen (N) and sulfur (S), with these elements forming organic molecules in form of monomers and polymers (Tissot and Welte, 1984). The presence of organic matter in sedimentary rocks depends on the depositional environments.

The terrestrial environments consist of primary biomass (algae, bacteria and plants) and marine environments formed by (1) dissolved matter is abundant in marine and freshwater systems and is one of the cycled reservoir of organic matter on earth, accounting for the same amount carbon as the atmosphere and up to 20% of all organic carbon; (2) particulate matter are pollutants that not dissolve in water as their molecules could no reaction with water molecules as well as anaerobic microorganisms (biodegradable); (3) colloidal matter are dissolved substance in seawater categorized as protein, polysaccharides and lipids as well as plankton organism (fig. 1.2) (Mark & Goldberg, 1991). These types of matter are deposited to sediments and forming the organic matter from marine environments.

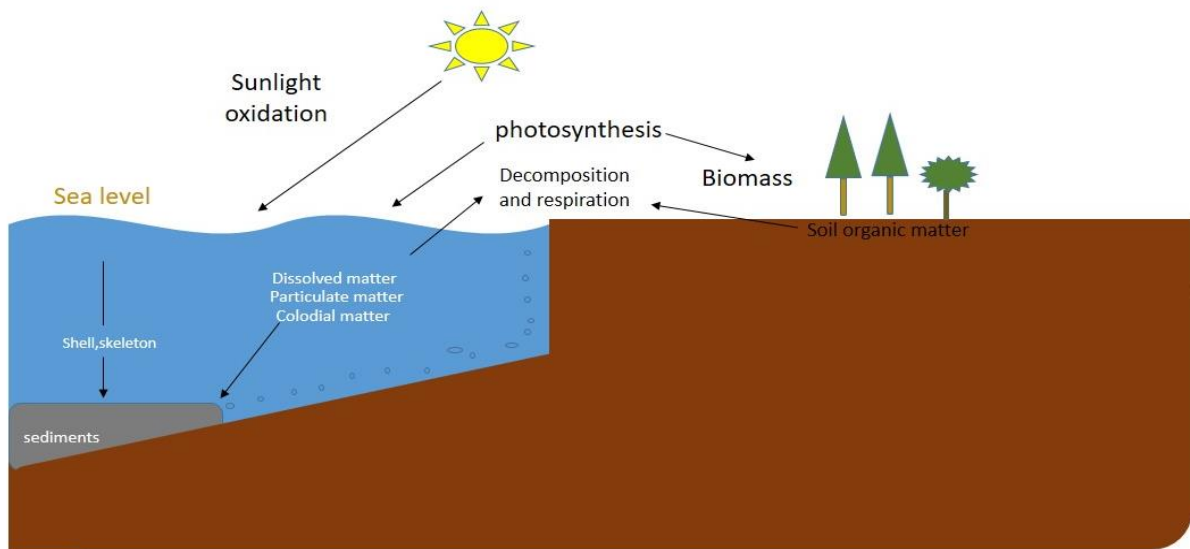


Figure 1.2 - General process and occurrences of organic matter in terrestrial environments and marine environments (McCarthy et al, 2011).

1.3.2 Classification of organic matter

The organic matter in sedimentary sequences ranges from finely disseminated occurrences of organic particles to concentrated organic matter in coals. The characteristics of organic matter in rocks depend on the origin (type) and nature of the precursor organic material (planktonic and bacterial biomass, land plants, and reworked material), organic productivity, inputs to the sedimentary environment, physico-chemical conditions existing in that environment, diagenesis and thermal evolution (Taylor et al, 1998; Suárez-Ruiz et al, 2012)

The organic matter observed under incident light are described as macerals (usually identified and described in coals). In addition to some main maceral groups, secondary products, other components associated with the organic facies such as zooclasts can be observed in sedimentary rocks.

Macerals are identified on the basis of their physico-optical properties and are microscopic organic material derived from terrestrial, lacustrine and/or marine plant remains, modified by deposition processes, diagenesis and thermal evolution.

There are three maceral groups: huminite/vitrinite, liptinite and inertinite. In addition to main maceral, in sedimentary rocks with dispersed organic matter zooclasts and microfossils of various compositions may be found. The zooclasts group includes: scolecodonts, chitinozoans, graptolites and conodonts, and other organic remains such as fish scales. Dinoflagellates and acritarchs are other forms of algal-derived materials in rocks. Non-structured organic matter (amorphous organic matter) or organo-mineral groundmass is commonly identified in oil shales and source rocks (Suárez-Ruiz et al, 2012). Table 1.1 systematizes the classification of organic matter.

The huminite/vitrinite group derives from botanical tissues mainly composed of lignin and cellulose, are found in highest concentration in sediments of terrestrial origin (coals and carbonaceous shales) and are almost absent in most carbonate rocks. The group of huminite/vitrinite includes maceral within gray color with reflectance between liptinite and inertinite. The sub groups of macerals are: telovitrinite (telinite, colotelinite), detrovitrinite (vitrodetrinite, colodetrinite) and gelovitrinite (corpogelinite, gelinite) (ICCP, 1998).

The inertinite maceral group derives from plant material that has been affected by pre- or syn-sedimentary alteration processes such as oxidation and fungal attack. The group of inertinite present high reflectance than vitrinite and liptinite groups. This group is relatively rich in carbon and lower in hydrogen and oxygen. The macerals are divided in structure vegetation ligno-cellulosic, detritic fine fragments, gels. The macerals are fusinite, semifusinite, micrinite, funginite, secretinite and inertodetrinite (ICCP, 2001).

The liptinite maceral group is derived from the resistant lipids constituents of the organisms such as spore and pollen, cuticles, and various types of vegetal secretions (plant waxes, fats, oils and resins), algal-derived materials, and some degradation products and products of secondary generation during the maturation processes. The reflectance of this group is lower than vitrinite and inertinite groups. Macerals in this group are sporinite, cutinite, suberinite, resinite, liptodetrinite, alginite, bituminite (Pickel et al, 2017).

Table 1.1 - Classification for organic components in sedimentary rocks (in Mendonça Filho & Borrego, 2017).

MACERAL GROUP	MACERAL SUBGROUP	MACERAL Medium to high maturity	MACERAL Low maturity	MACERAL TYPE
VITRINITE/ HUMINITE	TELOVITRINITE	TELINITE	TEXTINITE (TEXTO-ULMINITE)	TEXTINITE A (dark) & B (light)
		COLLOTELINITE	ULMINITE	
	DETROVITRINITE	VITRODETRINITE	ATTRINITE	
		COLLODETRINITE	DENSINITE	
	GELOVITRINITE	CORPOGELINITE	CORPOHUMINITE	PHLOBAPHINITE
		GELINITE	GELINITE	LEVIGELINITE/PORIGELINITE
INERTINITE	Macerals with plant cell structures	FUSINITE		
		SEMIFUSINITE		
		FUNGINITE		
	Macerals lacking plant cell structures	SECRETINITE		
		MACRINITE		
		MICRINITE		
	Fragmental inertinite	INERTODETRINITE		
LIPTINITE	*In coals, exudatinite (a bitumen) belongs to liptinite group	SPORINITE		
		CUTINITE		
		SUBERINITE		
		RESINITE		FLUORINITE
				CHLOROPHYLLINITE
		LIPTODETRINITE		
		ALGINITE		TELALGINITE
				LAMALGINITE
ZOOCLASTS	Undifferentiated spines and scales are also part of zooclasts	FORAMINIFERA SCOLECODONTS GRAPHTOLITE CHITINOZOA		
SECONDARY PRODUCTS		BITUMEN PYROBITUMEN OIL		

1.3.3 Kerogen

The organic matter is composed by two fractions: kerogen (fraction of the organic matter insoluble in organic solvents), and bitumen (fraction of the organic matter soluble in organic solvents). In the absence of migrant hydrocarbons, kerogen is usually 95% or more of total organic matter in sedimentary rocks (Tyson, 1995).

The classification of the organic matter based on H/C and O/C atomic ratios (van Krevelen, 1993) distinguishes the three main types of kerogens (Type I, Type II and Type III) in the order of decreasing H/C and O/C ratios. Figure 1.3 shows the van Krevelen diagram used to classify kerogen types based on H/C and O/C atomic ratios and to characterize the kerogen maturation considering metagenesis, catagenesis and diagenesis processes.

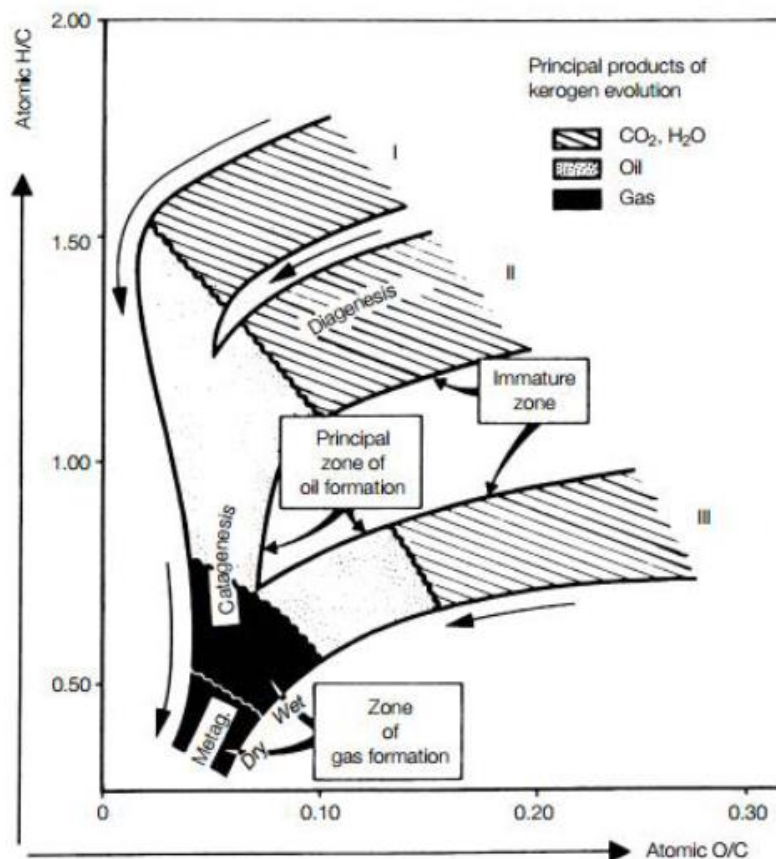


Figure 1.3 - Van Krevelen diagram (Tissot & Welte, 1984).

Type I kerogen originates mainly from lacustrine environments, where selective accumulation of algal material or severe biodegradation of the organic matter took place. It can also be originated from marine environments. It is composed of algae, plankton and other organic matter which were reworked by bacteria and microorganisms. It shows high H/C atomic ratio and low O/C atomic ratio (Tissot & Welte, 1984). It is oil-prone, but depending on the thermal maturation phase can also generate gas.

Type II kerogen originates in reducing environments from deep marine settings. Type II kerogen is related to open marine sediments where autochthonous organic matter derived from a mixture of phytoplankton and zooplankton was deposited in a reducing environment. Remains of plankton, higher plants, reworked by bacteria compose this kind of kerogen. It shows high H/C and low O/C ratios (Tissot & Welte, 1984). Type II kerogen can generate mainly oil, but also gas, providing enough heating and maturation (Peter & Cassa, 1995).

Type III kerogen derives from continental plants, contains vegetal debris and was deposited in proximal environments. It has been deposited in shallow to deep marine or non-marine environments. It shows low initial H/C ratio and high initial O/C ratio (Tissot & Welte, 1984). This type can produce mixed oil and gas (Peter & Cassa, 1995).

Type IV kerogen shows very low H/C ratio and a relatively high O/C ratio. This kind of kerogen is composed of aromatic carbonized organic matter (pre-deposition, during deposition, or during oil cracking) with no potential for hydrocarbon generation (Tissot & Welte, 1984; Peter & Cassa, 1995).

CHAPTER 2 GEOGRAPHIC AND GEOLOGICAL SETTING

2.1 Location of the study area

This study was developed in the eastern part of Timor Leste which coincides with the Municipality of Baucau, Post Administration of Laga (fig. 2.1). There are several villages in the Laga area that comprises, among others, Soba, Samalari, Sagadate and Atelari, from which the studied samples were collected. These areas include various lithologies such as claystone, siltstone, shale and limestone (Audley-Charles, 1968).

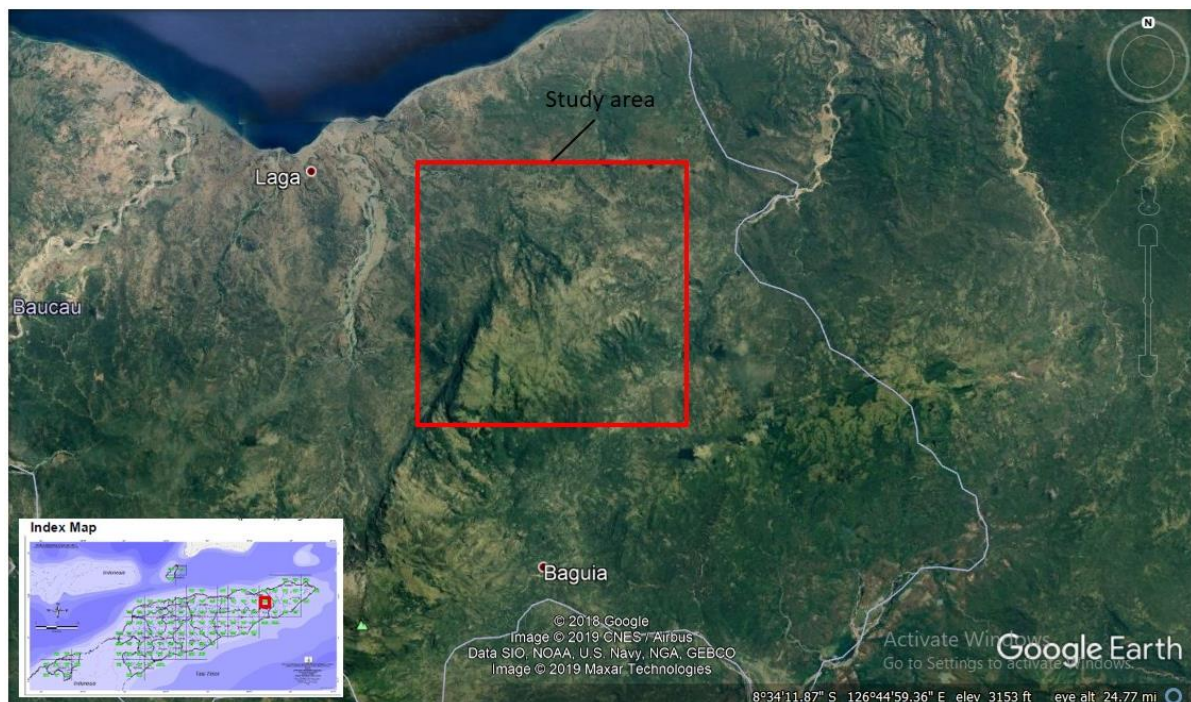


Figure 2.1 - Location of study area in Laga, Baucau Municipality (visualization using Google Earth 2019).

2.2 Geological setting

2.2.1 Tectonic setting of Timor Island

Geologically, Timor is an uplift due to a collision between the Banda arc and the Australian plate (Hall & Wilson 2000; Milsom, 2000; Audley-Charles, 2004; Charlton 2004). This collision occurred around 4 Ma years ago, resulting in a complex fold and thrust belt comprising the Australian continental margin, but also incorporating the remnants of the pre-collisional arc and more recent synorogenic deposits (Audley-Charles, 2004; Charlton, 2004). Banda Arc is dissociated into two chain islands consisting of front arc basin: Arc Banda Timor (inactive volcanic rock) is the largest island of the non-volcanic Inner Banda Arc and Outer Banda Arc (Timor Island) (fig. 2.2).

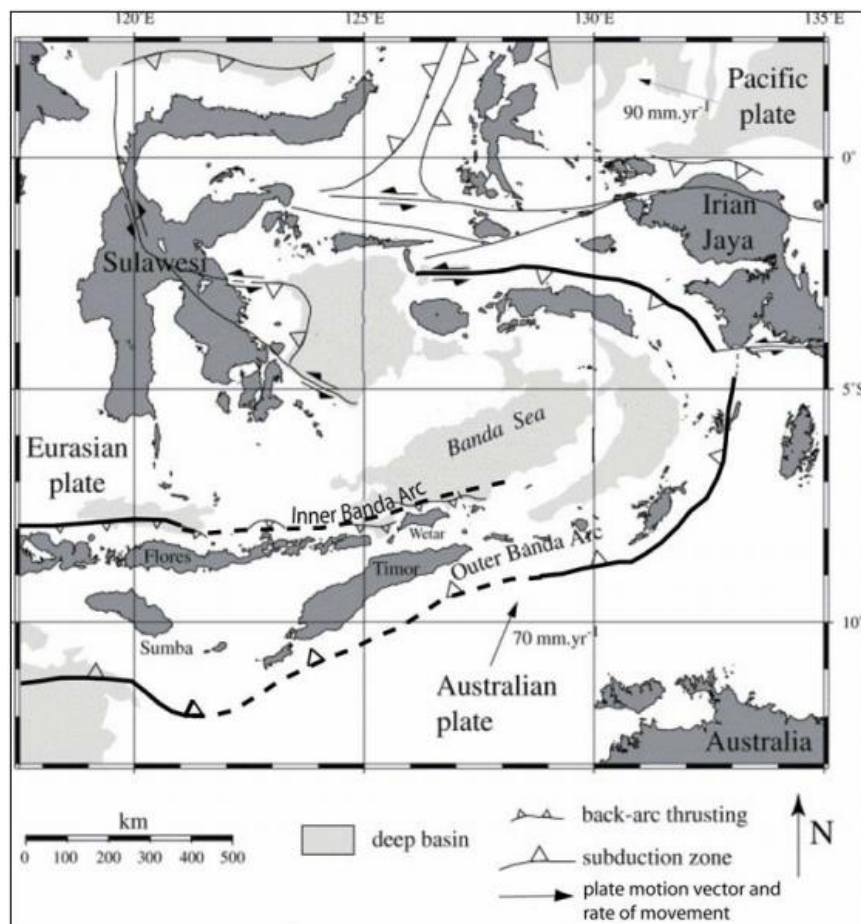


Figure 2.2 - Map of tectonic setting of Timor illustrating the position of the inner and Banda Arcs, the Pacific and Australian plates and their motion relative to the Eurasian plate (adapted from Hinschberger et al, 2001).

Based on previous research, several tectonic models explaining the origin of Timor Island exist.

The Overthrust Model (Audley-Charles, 1968; Audley-Charles & Carter, 1972; Carter et al, 1976; Barber et al, 1977) interpreted that this model is conducted due to the allochthonous strata derived from Eurasian plate to the north were thrust onto the Australian margin during the collision process (fig. 2.3).

Rebound Model (Chamalaun & Grady, 1979) interpreted that the Rebound model dragged by Australian shelf with the oceanic plate to Wetar strait. Then the component of buoyancy force on the continental rapidly equal to the downward, directly slab (fig. 2.3). During the initial down warp this sediment accumulation which can now be identified with Bobonaro Scaly Clay basin on that has occurred some shale diapirism in East Timor and some fault zones are also composed of Bobonaro Scaly Clay (Audley-Charles, 1968).

Imbricate Model (Hamilton, 1979) interpreted that Timor as large accretionary prism, comprising imbricate blocks of Australian margin and Banda arc material of all ages from Permian to Quaternary, metamorphic rocks including high pressure types, ophiolites, continental crystalline rocks, and others jumbled together in melange and imbricate terrain (fig. 2.3). These tectonic models of Timor Island conducted by collision between northward-moving Australian plate with Banda Volcanic arc Asian plate which affected the sedimentary rocks obducted over the Timor Island very complex structure .

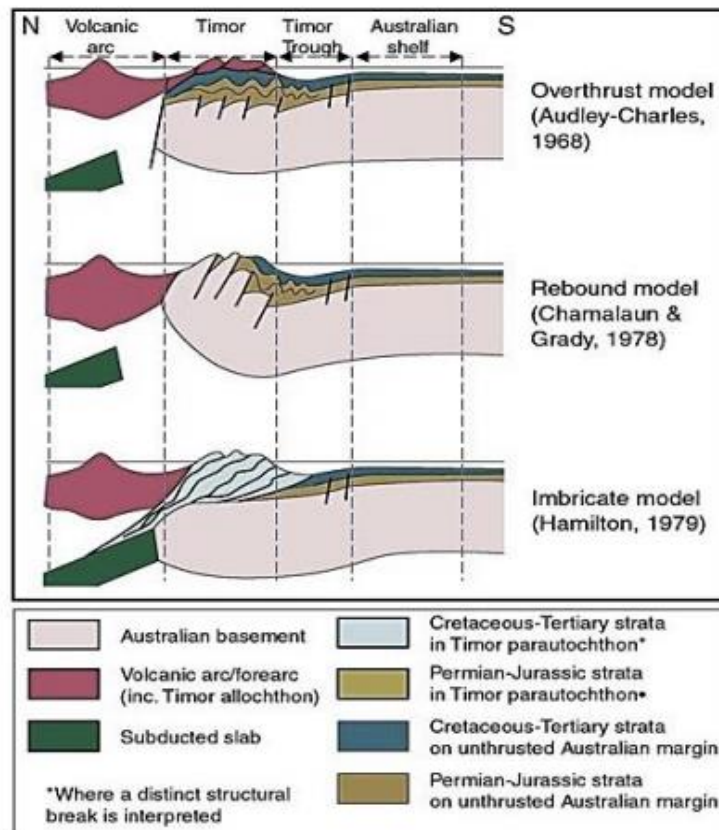


Figure 2.3 - Proposed Tectonic Models of Timor Island (Audley-Charles, 1968; Chamalaun & Grady, 1978; Hamilton, 1979).

2.2.2 The Regional stratigraphy of Timor Island

Stratigraphically, Timor Leste is made up of four main sequence stratigraphy units: Australian terrain sequences, Banda terrain sequences, syn-orogenic melange, and syn-orogenic sedimentary cover. Based on the classification of tectonostratigraphy, Timor Leste is comprised of Australian continental margin unit part of the parautochthon, Asian margin material part of allochthonous and autochthonous units comprised the youngest rocks on Timor (fig. 2.4) (Audley-Charles, 2011).

Autochthonous is tectonically the rock that formed in Timor Island and never moved somewhere. The allochthonous is the rock that formed Timor island the material comes for far places considered as foreign sediments which deposited and mix together in Timor Island. Para-autochthonous material is the youngest material that comes from Australian margin.

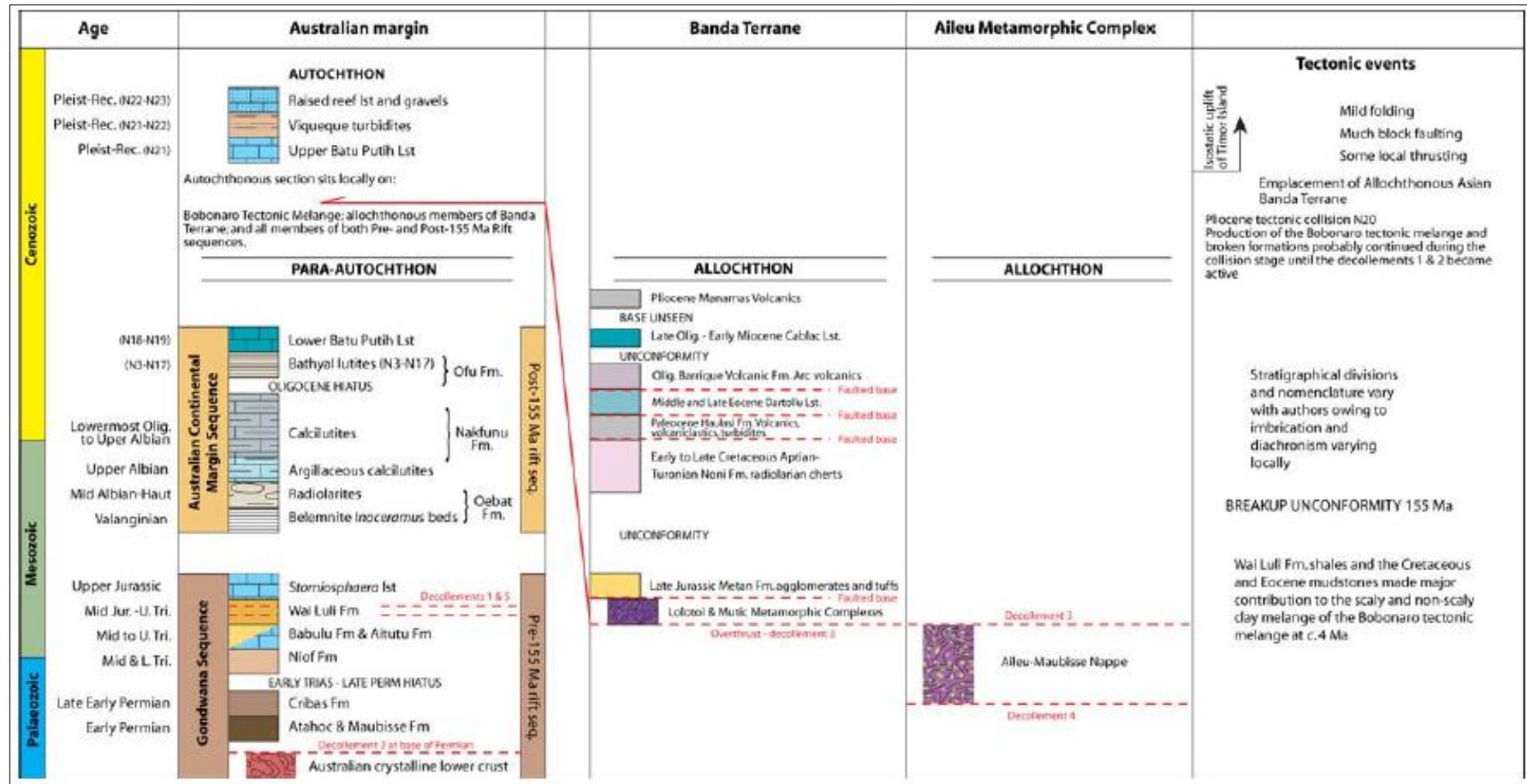


Figure 2.4 - Summary of Timor autochthonous, para-autochthonous and allochthonous stratigraphy (Audley – Charles, 2011).

2.2.3 Regional geology of the study area

Timor Island uncertainly was formed from the Australian mega sequences and Banda terrain this collision presented various rock surface territory of Timor Island. In 1968, Audley-Charles described a map with a scale of 1:250000 with various formations. The geological map become primary reference to geologists. The study area is formed by several formations: (1) Viqueque Formation, (2) Cablac limestone Formation, (3) Barique Formation, and (4) Bobonaro Scaly clay. Figure 2.5 and Table 2.1 present information about the stratigraphy based on Audley-Charles (1968, 2011).

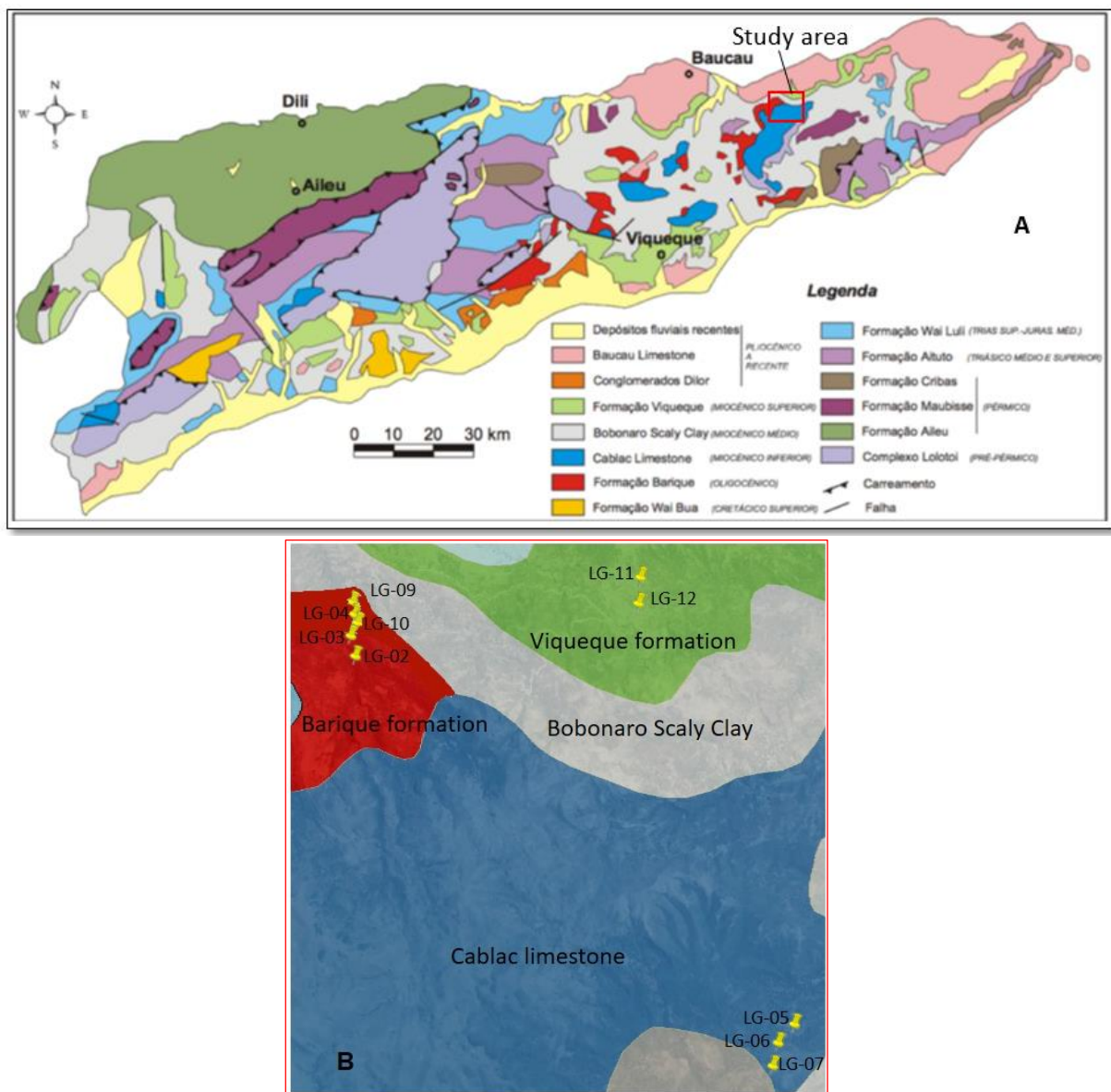


Figure 2.5 - [A] Regional geological map (Audley-Charles, 1968 *in* Carvalho & Lisboa, 2003). [B] Geological simplified map of the study area and samples location.

Table 2.1 - Stratigraphy of Timor (Audley-Charles, 1968; Audley-Charles, 2011).

Autochthonous Units			
Age	Formation	Facies	Petroleum Prospects
Holocene and Pleistocene	Suai Formation Poros Limestone Baucau Limestone	Litoral epineritic Lacustrine Litoral	Possible source and reservoir
Pleiocene- Holocene	Ainaro Gravels	Alluvial mollase	
Upper Pliocene to Upper Miocene	Seketo Block Clay Dilor Conglomerate Viqueque Formation	Neritic submarine slumps, Epineritic marine data	Oil seeps, Source beds and reservoirs. Possible anticlinal traps.
Lower Miocene	Cablac Limestone	Bahamite	
Oligocene	Barique Formation	Marine neritic	
Middle and upper Eocene	Dartollu limestone	Off-reef	
Middle to Upper Jurassic	Waibua Formation	Infraneritic	Oil seeps
Middle Jurassic to Upper Triassic	Wai luli Formation	Neritic	Oil and Gas seeps, Bituminous shale and porous arenites
Middle to Upper Triassic	Aitutu Formation	Neritic	Oil and gas seeps Bituminous limestone and Shales Dolomitization, possible arenites reservoirs
Upper Permian	Cribas Formation	Neritic Flysch	Oil and gas seeps, Bituminous shale and porous arenites
Lower permiam	Atahoc Formation	Neritic Flysch	
Allochthonous Units			
Middle Miocene	Bobonaro Scaly Clay	Wildflysch	
Permian (Middle Miocene)	Maubisse Formation	Litoral and Epineritic	
Probably Permian (Middle Miocene)	Aileu Formation	Infraneritic and Bathyal	
Probably pre- Permian (Middle Miocene)	Lolotoi Formation	Metamorphic complex	

Viqueque Formation

The formation part of synorogenic sequences derived in Upper Miocene. The deposit of deep marine limestone and turbidites that grade upward into more clastic-rich and higher energy deposits. This formation have four members:

- Batu Putih - massive, white calcilutite / chalk (planktonic foraminiferal wackestones with abundant *Globigerina*), light grey marls, vitric tuff and rare graded arenite. Accessory components: thin shelled bivalves, plant debris, benthonic foraminifera, mollusc debris, ostracods, phosphatic fish debris, pyritized organic matter, glauconite & monocrystalline quartz.
- Noele Marl - Laterally discontinuous, bedded, brown, dark grey to tan arenite with intervening units of *Globigerina* marl, tuffaceous marl and calcilutite, white to yellow vitric tuff, bioclacarenite, silty and sandy limestone and interbedded siltstone and sandstone. Massive Nuamain facies silt and sandstone is discontinuous and found above N20 hiatus. Bioclasts are very common in sandstones and grainstones, and include planktonic and benthonic foraminifera, mollusc and echinoderm debris, and red algae. Episodic horizons of coarsening upward clastic material. Graded beds and numerous soft-sediment slump structures. Extreme lenticularity.
- Coral Terrace - Hard, vuggy cavernous massive white and red-stained crystalline limestone. Forms terraces with karst topography and dark reddish soil. Other lithologies include calcirudite, which form massive conglomerate composed of reef debris cemented in carbonate, calcarenite, calcilutite, marl, sandstone and fresh water deposits, including lacustrine limestone.
- Alluvial Terrace and Fan - poorly sorted boulder and pebble conglomerate, coarse sandstone and rare shale and coal deposits. Layers are lenticular and commonly cross cross-stratified (Audley-Charles, 1968).

Cablac Limestone

Grouped to the Lower Miocene limestones within Eocene and Cretaceous age under Fatu Limestone (Grunau, 1953; Gageonnet & Lemoine, 1958; Audley-Charles, 1968). The Cablac Limestone is composed entirely of hard, massive limestone with few bedding-planes. There five types of limestones have been recognized: calcilutites, oolitic limestones, calcarenites and intraformational conglomerates of two very different kinds. The weathered appearance of most of the limestone is a distinctive soft grey colour with spiky surface. The freshly broken surface is usually white, pale yellow or pink (Audley-Charles, 1968).

Barique Formation

The formation grouped in Oligocene age. Generally, this formation is composed of a series of tuffs with an occasional lava. Basic tuffs predominate and consist largely of fragments of basalts and serpentinites, zeolitites are common. Some tuffs contain Foraminifera, and some contain large rounded quartz grain probably derived from sedimentary non-volcanic rocks (Audley-Charles, 1968).

CHAPTER 3 SAMPLING AND METHODS

This chapter describes the methods that were used for this study including sampling, samples preparation and petrographic and geochemical analysis.

3.1 Sampling

The field work for sampling was conducted during one week in Laga, Baucau Municipality. The samples were collected in three villages: Soba, Samalari and Atelari. A total of 10 samples of organic rich rocks were collected for petrographic and geochemical analysis. Figure 3.1 and Table 3.1 present the location of the study area and the location of sampled outcrops.

Some information about the study area is based on occurrences of oil and gas seeps, remote sensing data and also previous studies from Gas and Petroleum Unit of Institute Petroleum and Geology (IPG). In addition, more information about the description of outcrops from Barique Formation, Viqueque Formation and Cablac Limestone was obtained from (Audley-Charles, 1968).

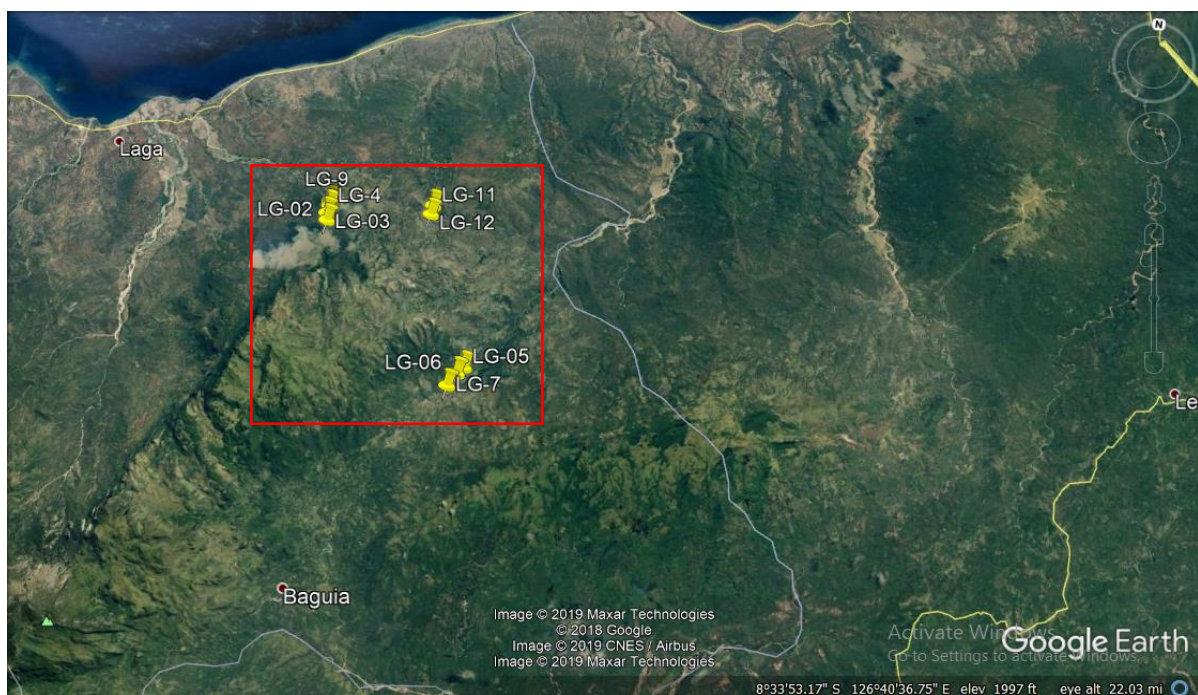


Figure 3.1 - Location of study area and points of samples collection (visualization through Google Earth image 2019).

Table 3.1 - Data base of the samples collected for this study.

Sample	Location	Coordinates	
LGIPG-02	Asanunu river, Boleha, Soba, Laga Baucau Municipality	08° 30' 44.5"	126° 38' 46.4"
LGIPG-03	Nokowai river, Boleha, Soba, Laga Baucau Municipality	08° 30' 35.8"	126° 38' 44.3"
LGIPG-04	Nokowai river, Boleha, Soba, Laga Baucau Municipality	08° 30' 26.6"	126° 38' 45.7"
LGIPG-05	Samaliu river, Samagata, Atelari, Laga, Baucau Municipality	08° 33' 18.8"	126° 41' 52.2"
LGIPG-06	Lalukau river, Lauadae, Atelari, Laga Baucau Municipality	08° 30' 26.6"	126° 41' 45.3"
LGIPG-07	Darliu river, Lauadae, Atelari, Laga Baucau Municipality	08° 33' 41.5"	126° 41' 36.6"
LGIPG-09	Nokowai river, Boleha, Soba, Laga Baucau Municipality	08° 30' 21.3"	126° 38' 44.9"
LGIPG-10	Nokowai river, Boleha, Laga Baucau Municipality	08° 30' 30.2"	126° 38' 47.0"
LGIPG-11	Tirloidae, Samalari, Laga Baucau Municipality	08° 30' 12.8"	126° 40' 47.0"
LGIPG-12	Lalulai, Samalari, Laga Baucau Municipality	08° 30' 23.7"	126° 40' 46.2"

In the field, outcrops were selected and a fresh (as much as possible) portion of each sample was collected and conditioned in bags. The sampling point's location were registered with a GPS (Geography Positioning System). Figure 3.2 shows materials and equipment's used for field work and sampling.



Figure 3.2 - Materials and equipment used during the field work.

3.2 Methods

The petrographic and geochemical methods used for the analysis of the organic rich rock samples included: optical microscopy (transmitted and reflected light) for identification and characterization of kerogen, vitrinite reflectance and thermal alteration index (TAI) for the investigation of thermal maturation; Rock-Eval Pyrolysis, and determination of total organic carbon for evaluation of source potential.

The laboratorial procedures were carried out at the LEMIGAS laboratory (Research and Development Center of Oil and Gas, Jakarta, Indonesia), in Department of Earth Sciences from Faculty of Sciences and Technology from University of Coimbra (Portugal), and in Institute of Earth Sciences – University of Porto Pole (Portugal).

3.2.1 Samples preparation

The samples preparation process carried out at the LEMIGAS laboratory, in Jakarta, (Indonesia) included number assignment, cleaning, air drying and samples detailed description. Samples were crushed to approximately 80 mesh fragments to obtain kerogen concentrates and finely milled for geochemical analysis. The grounded sample were treated successively with hydrochloric and hydrofluoric acids to concentrate the kerogen.

For petrographic analysis of whole rock samples through reflected light microscopic observations, polished blocks were prepared in accordance with standard procedures (ISO 7404-2, 2009). This preparation process was carried out at Department of Earth Sciences from Faculty of Sciences and Technology from University of Coimbra and in Institute of Earth Sciences – University of Porto Pole.

After cleaning and air drying, the samples were crushed to 1mm using an agate mortar (fig. 3.3). The grinding material had been carefully washed after use for each sample to avoid the contamination between samples.

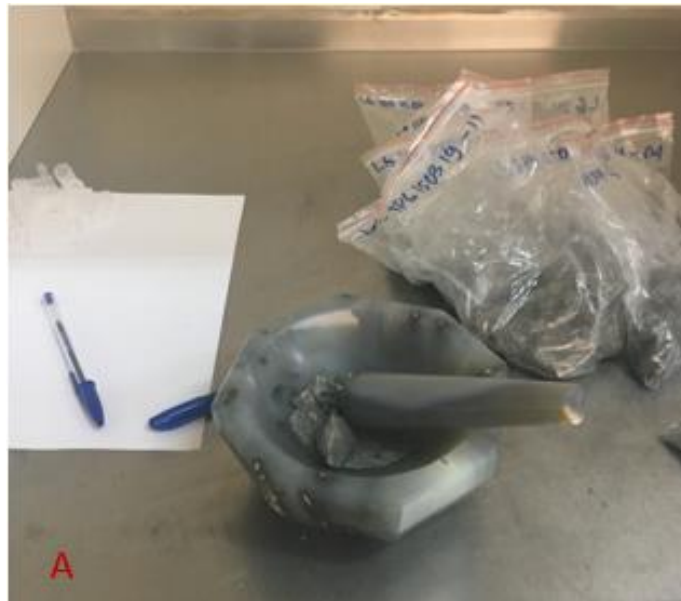


Figure 3.3 - Grinding of samples to 1 mm.

The samples were then placed in appropriate moulds and a mixture of resin and hardener was added; for solidification of the blocks, the moulds were air dried for 24h. Subsequently, the blocks were polished using 4 silicon carbide papers with decreasing grain size (pre-polishing) and 2 lap cloths, made of cotton and synthetic fabric for the final polishing of the surfaces.

The preparation of the polished surface consists of pre-polishing and final polishing using water, alumina and colloidal silica as abrasives in the polishing equipment's showed in figure 3.4. The pre-polishing serves to obtain uniform flat surface using four type of silicon carbide papers with progressively finer grain size (240, 500, 1200 and 4000 mesh) seated on a rotary plate and using water as lubricant (Table 3.2).



Figure 3.4 - [A] Pre-polishing equipment. [B] Final polishing equipment.

Table 3.2 - Pre-polishing and polishing processes.

Step	Silicon carbide	Abrasive	Rotation (rpm)
1	240 mesh	Water	300
2	500 mesh	Water	300
3	1200 mesh	Water	300
4	4000 mesh	Water	300
5	Texmet	Alumina, 0.3 μ m	300
6	Mastertex	Colloidal silica 0,1 μ m	300

After the final polishing, the blocks were keep inside a desiccator during 24 hours to eliminate water used during polishing process. Figure 3.5 shows the polished blocks.



Figure 3.5 - Polished blocks.

3.2.2 Total organic carbon

The total organic carbon (TOC) was determined in pulverized depicted samples dried in the oven for 24 h with a temperature of 40 °C, using a LECO Carbon Analyzer (SC-114) (fig. 3.6), after eliminating the carbonate fraction by acidification with HCl.

It is generally accepted (Peter & Cassa, 1994) that samples with less than about 0.5 wt. % TOC cannot yield sufficient hydrocarbons to form commercial deposits and are therefore considered non-sources; samples with between 0.5 and 1.0 wt. % TOC are rated as marginal in source quality; samples with between 1.0 and 2.0 wt. % TOC are rates as average (good) in source quality and samples with more than 2.0 wt. % percent TOC are considered to be above average (rich) in source quality.



Figure 3.6 -The LECO SC-144DR equipment for analysis of TOC.

3.2.3 Rock-Eval pyrolysis

Pyrolysis data was obtained using the Source Rock Analyzer apparatus (fig. 3.7), where 100 mg of crushed samples accurately weighed was placed into a crucible and introduced into a furnace at 250°C. Free hydrocarbons (roughly equivalent to solvent extractable hydrocarbons) are volatilised and quantified by flame ionisation

detector (FID) to give Peak 1 (S_1 , mg/g). The furnace temperature is increased to 550°C at 25°C/minute and within this range, kerogen cracks to give hydrocarbons, measured by FID to give Peak 2 (S_2 , mg/g), and carbon dioxide, measured by thermal conductivity detector (TCD) to give Peak 3 (S_3 , mg/g) (Peters, 1986; Lafargue et al,1998; Behar et al, 2001).



Figure 3.7 - Source Rock Analyser equipment.

The temperature at the maximum rate of evolution of cracked volatiles (T_{max}) was measured automatically but can also be monitored visually. The instrument was calibrated using standards both at the beginning of the work period and at regular intervals thereafter and crucible blanks are run as routine (Behar et al, 2001). The data given in the analyses comprise the following parameters (Peter & Cassa, 1994):

- T_{max} (°C): Temperature of maximum rate of Peak S_2 hydrocarbon evolution.
- Hydrogen Index (HI): S_2/TOC (mg/g) or ratio of released hydrocarbon to organic carbon content. This is a measure of the hydrocarbon generating potential remaining in the kerogen as opposed to that of the whole rock.
- Oxygen Index (OI): S_3/TOC (mg/g) or ratio of released carbon dioxide to organic carbon content.

- Production Index (PI): S_1/S_1+S_2 , or ratio of the amount of hydrocarbons released in the first stage of heating to the total amount of hydrocarbons released and cracked during pyrolysis.
- Potential Yield (PY): S_2 or total of hydrocarbons released during cracking of kerogen compared to original weight of rock.

The Tmax, HI and OI are each functions of both maturity and kerogen type. Using published and empirical data, it has been possible to assemble a model to show the relationships of these parameters to maturity as measured by spore colouration and vitrinite reflectance (Peter & Cassa, 1994).

The HI is a measure of the hydrocarbon generating potential of the kerogen and is analogous to the atomic H/C ratio. Immature, organically rich source rocks and oil shales give values above 500, mature oil source rocks give values between 200 and 550. For a given kerogen type, these values progressively diminish with increasing maturity (Peters, 1986; Peters & Cassa, 1994).

The temperature of maximum rate of pyrolysis depends partly on kerogen type but the transition from immature to mature organic matter is marked by temperatures between 415°C and 435°C. The maturity transition from oil and wet gas generation to dry gas generation is marked by temperature between 455° and 460°C. In practice, greater variation than these ideal temperature ranges may be seen, but they are nevertheless useful, as general guides to the level of maturity attained by the sediment. The PI increased with maturity from values near zero for immature organic matter to maximum values of 0.15 during the late stages of oil generation. Anomalously high values indicate the presence of oil or contaminants (Peter, 1986).

Pyrolysis techniques have in recent years provided a major advance in the assessment of source rock quality and generating potential. Hydrocarbon yields from immature source beds examined on-structure may be translated into actual oil productivity from the same beds in mature basinal, off-structure situations. Models relating maturity and kerogen type may be used to define original source rock quality grades which are of great value in mapping organic facies. Amorphous kerogen

types, indistinguishable in microscopic preparations over a wide range of chemical properties, may be readily differentiated by pyrolysis (Peters, 1986; Lafargue et al, 1998; Peter & Cassa, 1994; Behar et al, 2001).

The problem of analysing bulk samples containing mixed kerogens has been largely overcome by the kerogen type/maturity model and anomalous results arising from the presence of casing contamination and drilling mud additives can usually be explained by inspection. High OI sometimes occur as a result of the presence of metastable carbonates and in such cases the sample is acid decarbonated and rerun (Peter & Cassa, 1994).

3.2.4 Petrographic analysis

The petrographic analysis of whole rock polished blocks using white and blue reflected light were done using a microscope Leica DM4000, equipped with Discus-Fossil system (fig. 3.8) using a 50x oil immersion objective.

The identification and characterization of the organic matter followed the ICCP nomenclature (ICCP, 1998, 2001; Pickel et al, 2017) and vitrinite random reflectance was measured according to standard ASTM D7708-14 (2014).

Vitrinite reflectance measured in incident white light under oil immersion is the most robust parameter used in organic petrology to define the level of maturity of sedimentary rocks containing dispersed organic matter (Taylor et al, 1998). Vitrinite reflectance in combination with other geochemical parameters, such as Rock-Eval pyrolysis, has been used extensively used to assess rock thermal maturity stages.

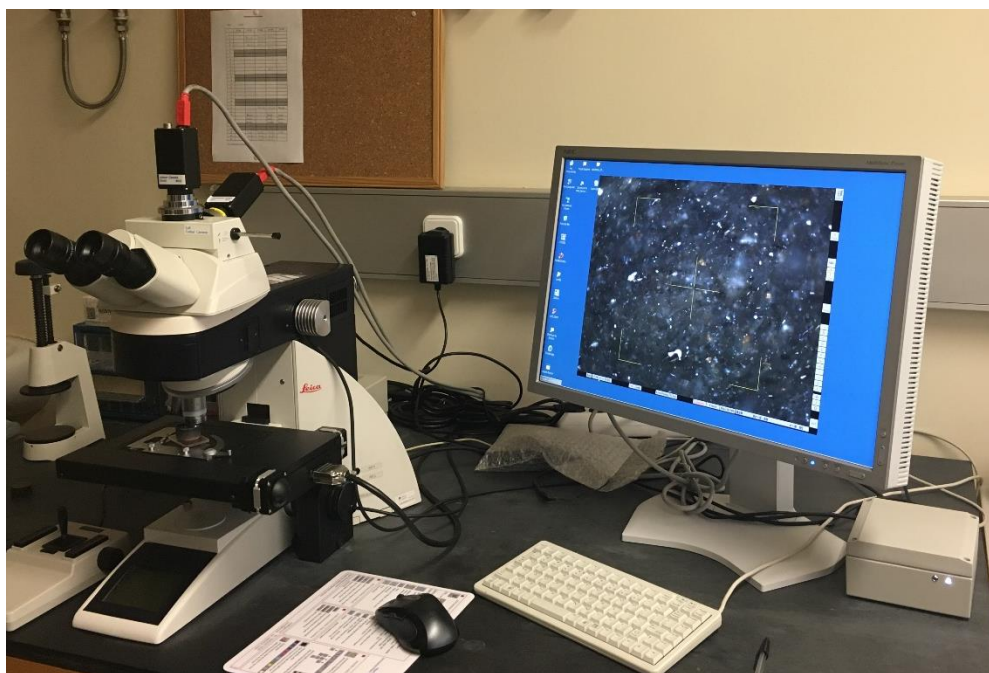


Figure 3.8 - Optical microscope Leica DM4000 from Laboratory of Institute of Earth Science – University of Porto Pole.

3.2.5 Thermal alteration index

The study of organic matter by transmitted light is applied to isolated organic material after acid treatment. These observation of kerogen concentrates by transmitted light allows the identification of organic components color, transparency or morphology to evaluate changes in thermal maturation (Yule et al, 2000).

Thermal evolution of sedimentary rocks causes many physical and chemical changes in the properties of the organic matter that may be used as indicators for maturation. The palynomorphic coloration changes produced as increasing maturation (burial and temperature) can be used to evaluate the state of thermal alteration on a scale. With increase in thermal maturation of organic matter a gradual change in color is observed in transmitted light, from yellow in immature samples through orange, brown, black, and opaque organic debris. Pollen and spores are the organic-walled microfossils most commonly used to estimate maturation.

The thermal alteration index (TAI) is based on color changes of one variety of pollen or spore (Staplin, 1969) and can range from a value of 1 for strictly immature spores

and pollen (pale-yellow in color) to a value of 5 for strong thermal evolution corresponding to the dry-gas zone or above (dark-brown color).

The determination of TAI is a subjective visual color estimation of palynomorphs using a transmitted white light microscopy. However, the TAI scale have been standardized to the vitrinite reflectance maturity scale. The TAI is therefore related to vitrinite reflectance and has been used as a thermal maturity parameter to assess the hydrocarbon potential of rocks containing organic matter.

The TAI have been systematically used to measure organic maturity in sedimentary rocks, especially in petroleum source rocks, since it allows the estimation of maturity levels within the range of oil generation, and is considered a complement to petrographic techniques such as determination of vitrinite reflectance.

Figure 3.9 illustrates the correlation of maturity of organic matter, thermal alteration index and phases of oil and gas generation (Taylor et al, 1998).

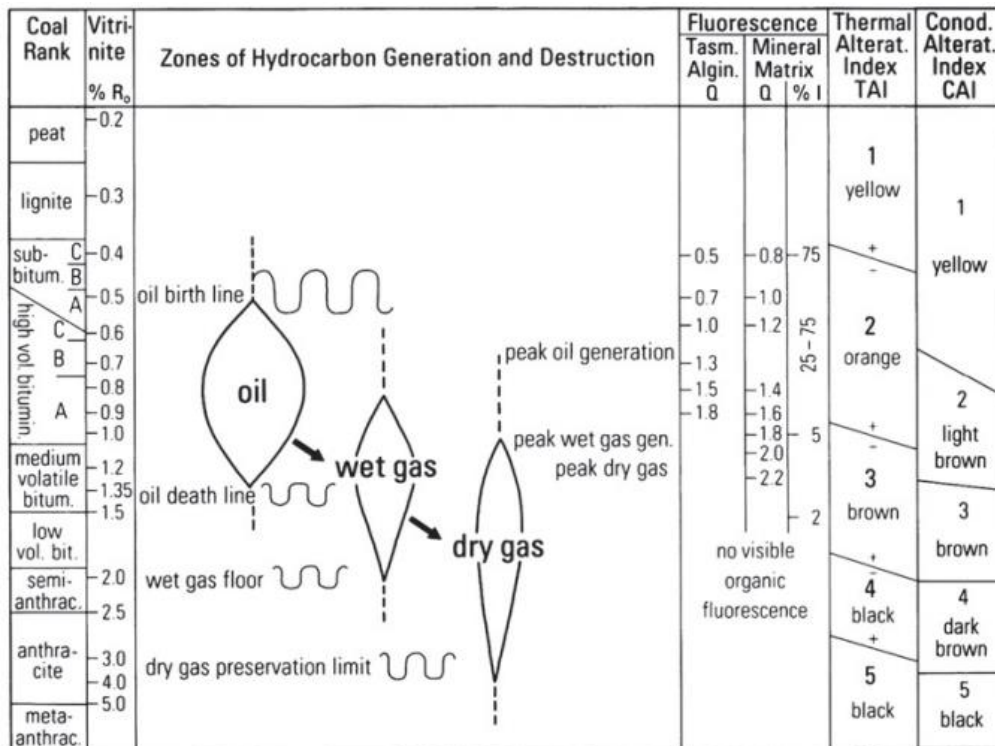


Figure 3.9 - Correlation of maturity of organic matter, thermal alteration index and phases of oil and gas generation (Taylor et al, 1998).

CHAPTER 4 RESULTS AND DISCUSSION

4.1 Outcrops description

The field work was conducted based on some geological data provided by Audley-Charles (1968) which includes information about hydrocarbon occurrences. In the field several outcrops with organic rich rocks were found. From these outcrops, the Formations that were identified and sampled were: Viqueque Formation, Barique Formation and Cablac Limestone Formation.

A total of 10 samples were collected in different outcrops (figs. 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 4.9, 4.10, and 4.11). Samples LGIPG-02, LGIPG-03, LGIPG-04, LGIPG-09, LGIPG-10 are included in the Barique Formation; samples LGIPG-05, LGIPG-06 and LGIPG-07 are included in the Cablac Limestone Formation; samples LGIPG-11 and LGIPG-12 are included in the Viqueque Formation. The observation and description of the different outcrops is systematized in Table 4.1 and detailed below.

Table 4.1 - Description of samples.

Sample	Color	Grain size	Structure	Formation
LGIPG-02	Dark grey black	Fine	Laminated	Barique Formation
LGIPG-03	Dark grey black	Fine	Laminated	Barique Formation
LGIPG-04	Dark grey	Fine	Laminated	Barique Formation
LGIPG-05	Med. Grey dark	Fine	-	Cablac Limestone
LGIPG-06	Dark grey	Fine	-	Cablac Limestone
LGIPG-07	Dark grey black	Fine	Laminated	Cablac Limestone
LGIPG-09	Dark grey	Fine	Laminated	Barique formation
LGIPG-10	Dark grey	Fine	Laminated	Barique formation
LGIPG-11	Dark grey black	Fine	Laminated	Viqueque formation
LGIPG-12	Dark grey black	Fine	Laminated	Viqueque formation

4.1.1 Viqueque Formation

The Viqueque Formation outcrops were found in the locality of Lalulai near a road (fig. 4.1 and 4.2) southeast of Samalari village. In the type-section, the succession is composed of: laminated black shale bedding with mudstone and intercalating with chert, some fragment of sulfur cover the black shale, pink soft to brown mud, grey to dark shale, and grey to green mud. Bedding mudstone are rare towards the base of the section but in the upper part of the section bedded mudstone and chert become more common. Towards the top of the type-section mudstone become less common and the chert rare. The samples that were collected in the Viqueque Formation include: LGIPG-11 and LGIPG-12. The general succession is similar along the road of the Samalari village within the elevation ranged from 400-500 m. The succession probably derived from deep marine environment (Audley-Charles, 1968).



Figure 4.1 - Image showing the outcrop of sample LGIPG-11 from Viqueque Formation, located in Tirloidae, Samalari village, Laga post administrative, Baucau Municipality.



Figure 4.2 Image showing the outcrop of sample LGIPG-12 from Viqueque Formation, located in Lalulai, Samalari village, Laga post administrative, Baucau Municipality.

4.1.2 Barique Formation

The Barique Formation occurs in the river Asanunu bank, in Soba village northwest of Soba Village. The lithology in the type-section includes fine grain limestone interbedded with grey to dark shale. Laminated limestone is thicker than shale. The structure of black shale is laminated. Bedded limestone occurs in the bottom and shale in the middle and in the upper part limestone is less common. The general succession is similar along the river estimated 2 km toward new succession within the elevation ranged 225-300 m. The samples collected in Barique Formation included: LGIPG-02, LGIPG-03, LGIPG-04, LGIPG-9 and LGIPG-10 (figs. 4.3; 4.4; 4.5; 4.6; 4.7).



Figure 4.3 - Image showing the outcrop of sample LGIPG-02 from Barique Formation at Asanunu river, Boleha, Soba village, Laga post administrative Baucau Municipality.

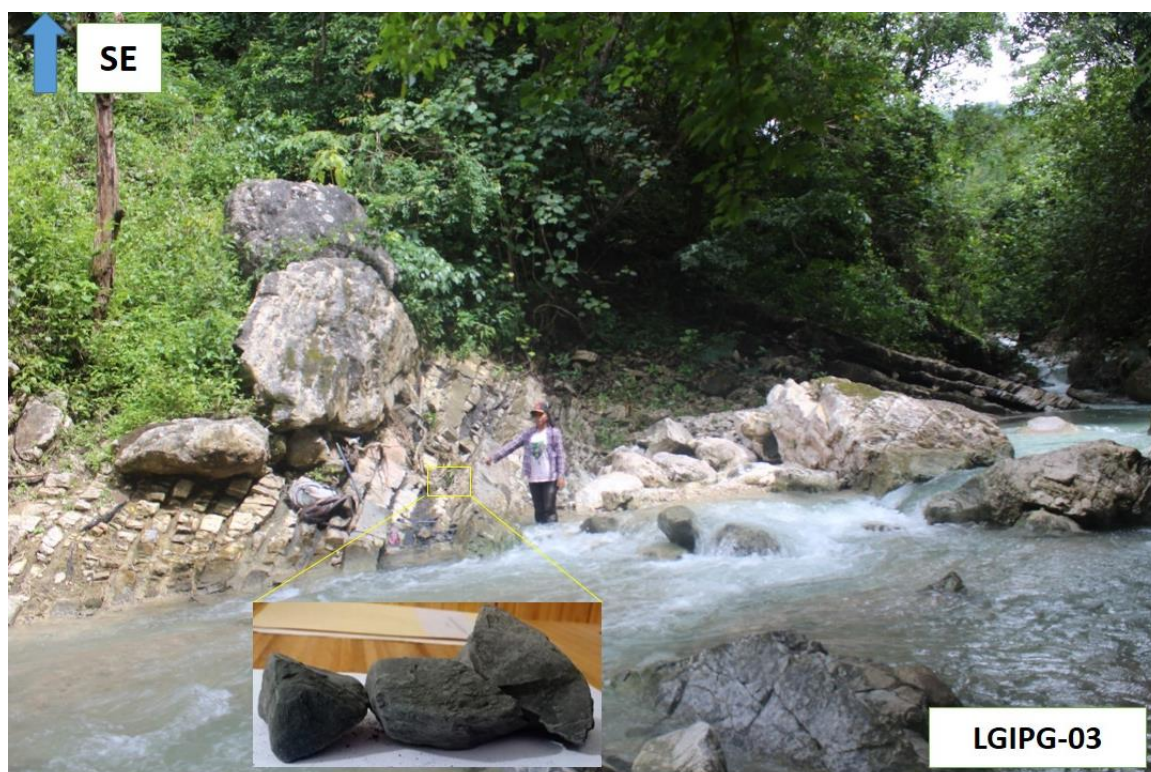


Figure 4.4 – Image showing the outcrop of sample LGIPG-03 from Barique Formation at Asanunu river, Boleha, Soba, Laga post administrative, Baucau Municipality.



Figure 4.5 - Image showing the outcrop of samples LGIPG-04 from Barique Formation at Nokowai river, Boleha, Soba, Laga post administrative, Baucau municipality.



Figure 4.6 Images showing the outcrop of samples LGIPG-09 from Barique Formation at Nokowai river, Boleha, Soba, Laga post administrative, Baucau municipality.



Figure 4. 7 Images showing the outcrops of samples LGIPG-10 from Barique Formation at Nokowai river, Boleha, Soba, Laga post administrative, Baucau municipality

4.1.3 Cablac Limestone

The Cablac Limestone outcrops were found in the banks of the river Lalukau, southeast of the Atelari village. The litology in the type-section is composed of grey to dark shales, red shales, claystone, siltstone, limestone, sandstone and mudstone, and some fragments of mud. Bedded limestones are rare toward the base of the unit but in the upper part of the type-section bedded limestone, mudstone and calcilutites become common. Toward the top of the upper part of the type section, limestone become less and shales are rare (fig. 4.8;4.9 and 4.10). The thickness in the type section and other inliers is estimated to be about 500 m. The samples that were collected in the Cablac Limestone include: LGIPG-05, LGIPG-06 and LGIPG-07. The general succession is similar along the river estimated 500 m toward other succession, within the elevation around 380 m.



Figure 4. 8 Images showing the outcrops of samples LGIPG-05 from Cablac Limestone Samaliu river, Samagata, Atelari, Laga post administrative, Baucau municipality

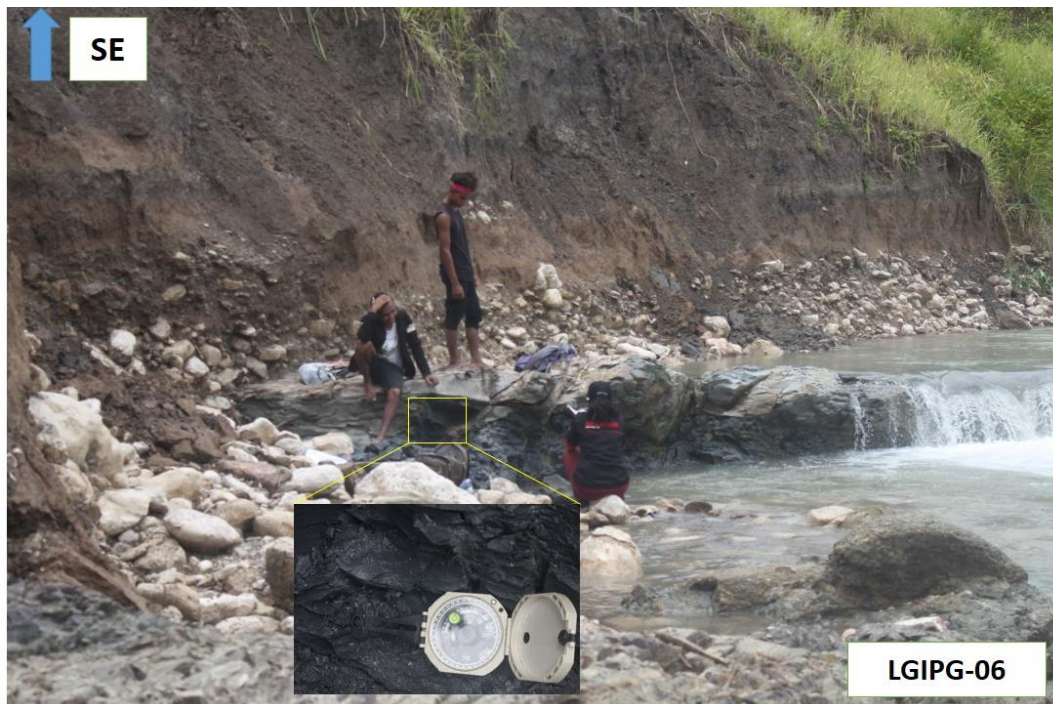


Figure 4. 9 Images showing the outcrops of samples LGIPG-06 from Cablac Limestone Lalukau river, Lauadae , Atelari village, Laga post administrative, Baucau Municipality.



Figure 4. 10 Images showing the outcrops of samples LGIPG-07 from Cablac Limestone, Darliu river, Lauadae, Atelari village, Laga post administrative, Baucau Municipality

4.2 Organic Geochemistry

The identification of potential source rocks, their organic content, maturity and their regional distribution are best accomplished by screening of rock samples using the Rock-Eval pyrolysis. This technique has been routinely used for about fifteen years and has become a standard for hydrocarbon analysis (Lafargue et al, 1998). The source rock potential may be evaluated through the analysis of TOC and Rock-Eval Pyrolysis analysis, and results for the studied samples are expressed in Table 4.2.

Table 4.2 - TOC and Rock-Eval pyrolysis results.

Sample	TOC (%)	S1	S2	S3	Tmax °C	PI	HI mgHC/g TOC	OI mgCO ₂ /g TOC
		mg/g						
LGIPG-02	0.36	0.06	0.44	0.13	405	0.12	123	36
LGIPG-03	0.91	0.07	1.63	0.23	408	0.04	179	25
LGIPG-04	0.78	0.05	0.50	0.26	412	0.09	64	33
LGIPG-09								
LGIPG-10								
LGIPG-05	0.43	0.03	0.10	0.11	452	0.23	24	26
LGIPG-06	0.50	0.03	0.13	0.07	431	0.19	26	14
LGIPG-07								
LGIPG-11	4.53	0.92	45.06	0.67	407	0.02	995	15
LGIPG-12	11.44	0.52	44.60	2.08	416	0.01	390	18

TOC: Total Organic Carbon; Tmax: maximum temperature; PI: Production Index HI: Hydrogen Index; OI: oxygen Index.

4.2.1 Viqueque Formation

The results of the TOC for samples LGIPG-11 and LGIPG-12 from Viqueque Formation showed significant high values of TOC: 4.53% and 11.44% allowing their categorization as source rock with a very good to excellent potential (Peters & Cassa, 1994). The results of Rock-Eval pyrolysis for these samples showed free hydrocarbon (S₁ peak) values of 0.52 mg/g and 0.92 mg/g and the amount of hydrocarbon that are produced during the thermal cracking (Lafargue et al., 1998) (S₂ peak) is 44.60 mg/g and 45.06 mg/g and S₃ peak is 0.67 mg/g and 2.08 mg/g;

considering the high S_2 , samples are considered to have very good to excellent source rocks potential (Peter & Cassa, 1994). The values for HI are 390 and 995 mg HC/g TOC, and therefore the samples can be categorized as oil prone type I and II. The OI is 15 and 18 mg CO_2 /g TOC due to the hydrogen index that make a possibility for generate the hydrocarbon. The PI is 0.01 and 0.02 which means that potential hydrocarbon released are higher and production of hydrocarbon during cracking are lower. The maximum temperature registered was 407°C and 416°C and therefore the samples are categorized as immature source rock. The results of Rock-Eval pyrolysis allows the identification of samples kerogen type and maturation which are represented in diagrams presented in figures to 4.11 to 4.15.

4.2.2 Barique Formation

In the Barique formation (samples LGIPG-02, LGIPG-03, LGIPG-04, LGIPG-09 and LGIPG-10), TOC values range between 0.36% and 0.91%, and therefore present poor to fair and good potential for source rock (Peter & Cassa, 1994). In addition, the results showed a decrease in the value of free hydrocarbons (peak S_1) presenting values from 0.05 mg/g to 0.07 mg/g; S_2 ranges between 0.44 mg/g and 1.63 mg/g; these results indicate that samples from Barique formation are categorized as poor to generate hydrocarbon. The HI values ranges from 64 to 179 mgHC/g TOC indicating a type IV kerogen (Peter & Cassa, 1994). The OI values varies between 25 and 58 mg CO_2 /g TOC. The PI shown values ranging from 0.04 to 0.18 which means that cannot generate hydrocarbons. Similarly to Viqueque Formation, maximum temperature values indicate immature stage (values between 405°C and 412°C). The results of Rock-Eval pyrolysis allows the identification of samples kerogen type which are represented in diagrams presented in figures to 4.11 to 4.15.

4.2.3 Cablac Limestone

The samples LGIPG-05, LGIPG-06 and LGIPG-07 belonging to the Cablac Limestone, show poor TOC values ranging between are 0.45% and 0.50%, indicating no potential source rocks (Peters & Cassa, 1994). Furthermore, the results

of Rock-Eval pyrolysis also show lower S_1 values (0.3 mg/g for all samples), S_2 values between 0.10 and 0.13 mg/g, and S_3 values between 0.07 and 0.11 mg/g. These result indicate that the free hydrocarbon and hydrocarbon composition is very low (Peter & Cassa, 1994). The HI of 24 and 26 mg HC/g TOC indicates a type IV kerogen (Peter & Cassa, 1994). The PI of samples from Cablac Limestone varies between 0.19 and 0.23 and the maximum temperature between 423 °C and 452 °C. The results of Rock-Eval pyrolysis allows the identification of samples kerogen type and maturation which are represented in diagrams presented in figures to 4.11 4.15.

The diagram plotting TOC vs S_2 (fig 4.11) shows that the Viqueque Formation (green color) is categorized as very good to excellent source rock while the Barique formation (yellow color) and Cablac Limestone (red color) are categorized as poor to fair.



Figure 4.11 - Source rock potential shown by diagram TOC vs S_2 (modified after Langford & Blanc Vallenons, 1990).

The diagram TOC vs HI (fig. 4.12) indicates poor to excellent potential for source rocks, where Viqueque Formation (green color) is categorized as very good to excellent source rocks, and Barique Formation (yellow color) and Cablac Limestone (red color) categorized as poor to fair.

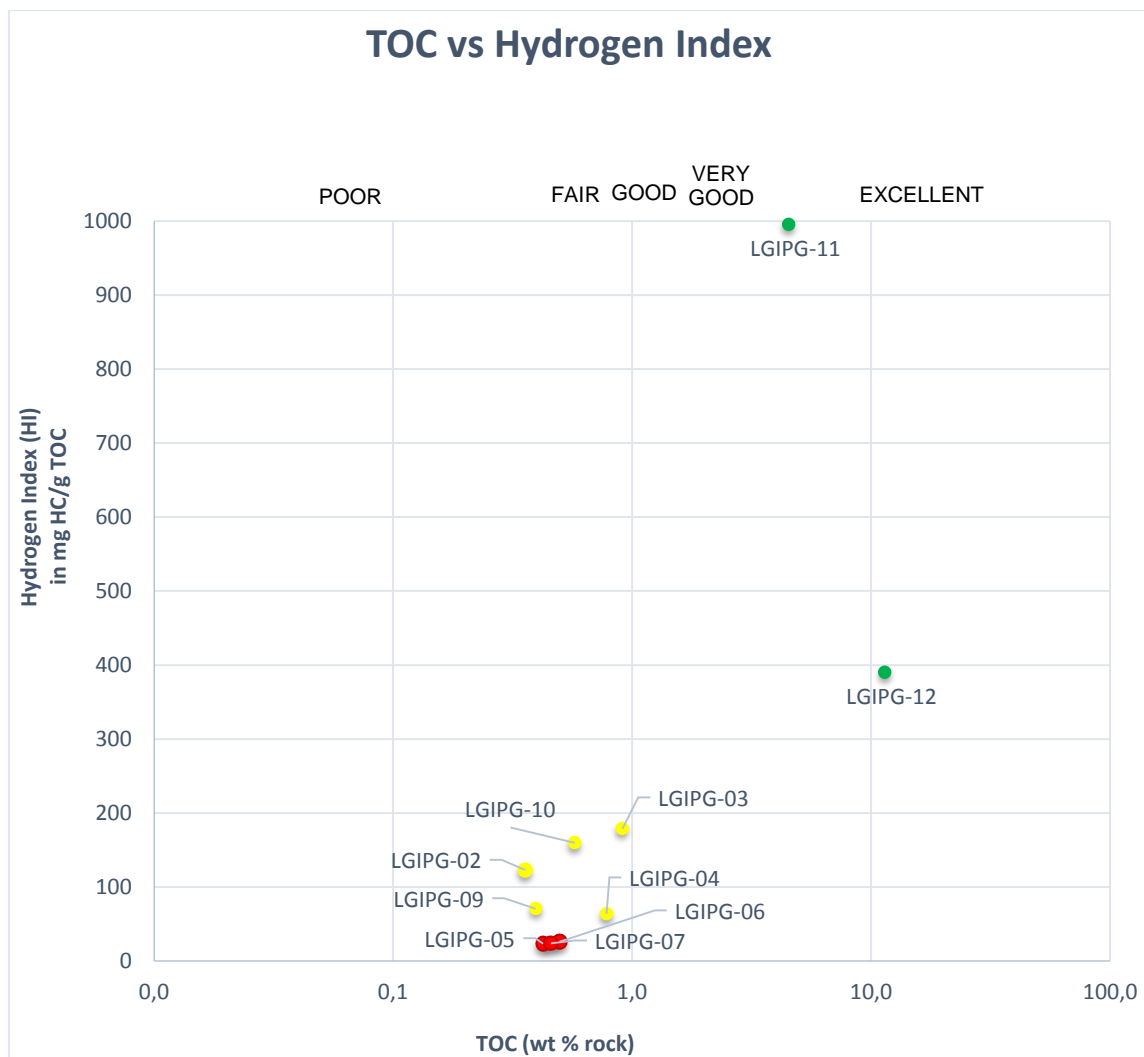


Figure 4.12 - The potential source rock shown in diagram TOC vs Hydrogen Index (modified after Langford & Blanc Vallenons, 1990).

The identification of kerogen type can be represented in the diagram plotting S_2 vs TOC. Figure 4.13 shows that Viqueque formation (green color) has type II kerogen, Barique Formation (yellow color) has type II and III, and Cablac Limestone (red color) has type IV kerogen. Figure 4.13A shows all the diagram and figure 4.13B shows the magnification of the square drawn in A.

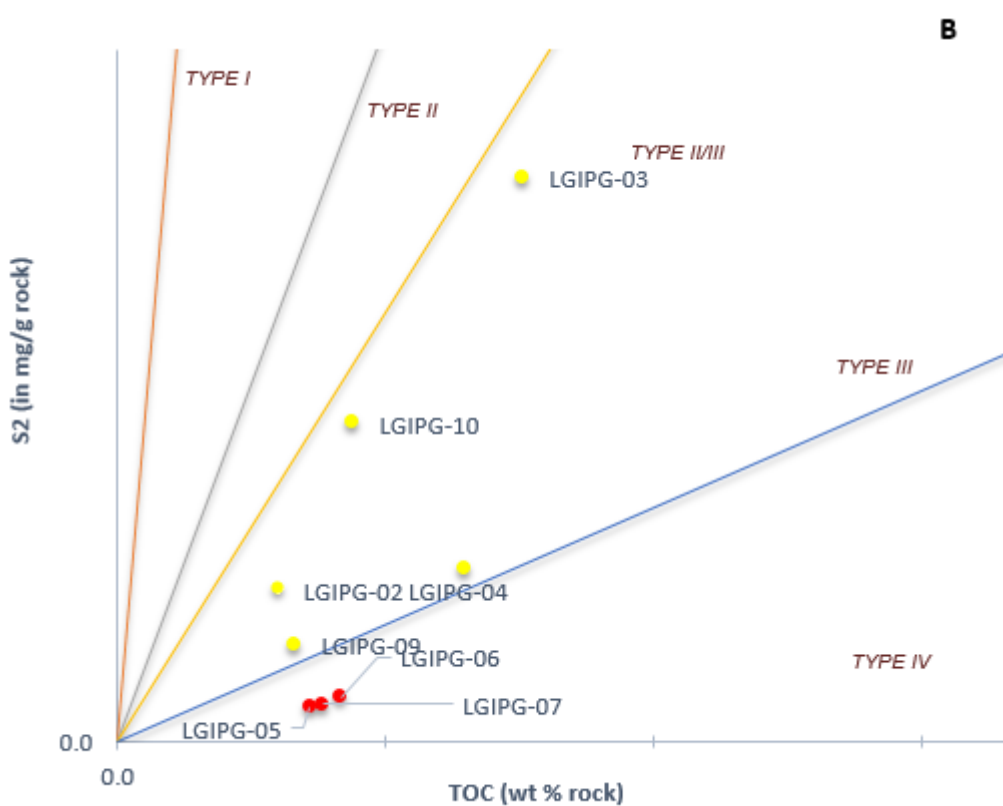
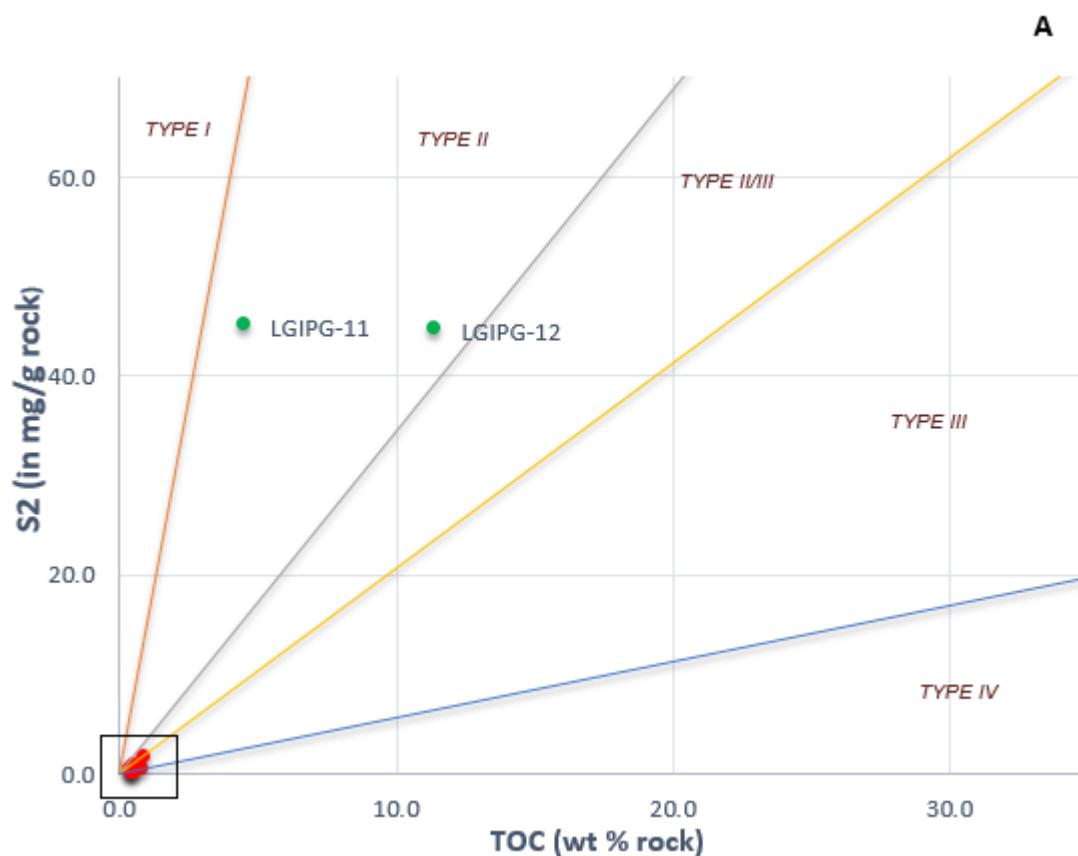


Figure 4.13 - Kerogen type shown by diagram TOC vs S₂ (modified after Jackson et al, 1985); B is the magnification of the square drawn in A.

The diagram plotting HI vs OI, also known and modified van Krevelen diagram, also allows the identification of the kerogen type present in the studied samples. Figure 4.14 shows that Viqueque Formation (green color) contain type I and II kerogen, Barique Formation (yellow color) contains type II/III and III kerogen and Cablac Limestone (red color) contain type IV kerogen. The results for the different diagram for kerogen type identification are consistent.

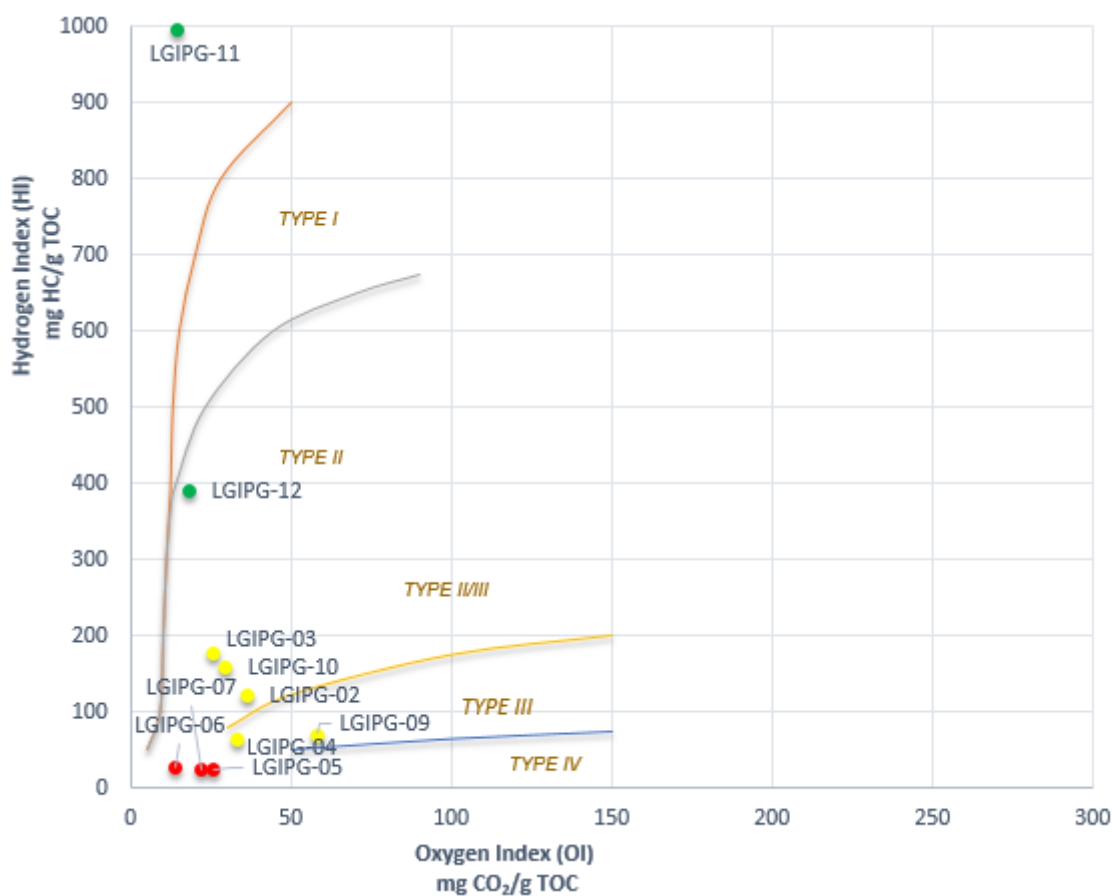


Figure 4.14 - Modified van Krevelen diagram showing the relationship between HI and OI.

The diagram plotting Tmax vs HI also allows the identification of kerogen type. Figure 4.15 corroborates the diagrams in figures 4.13 and 4.14.

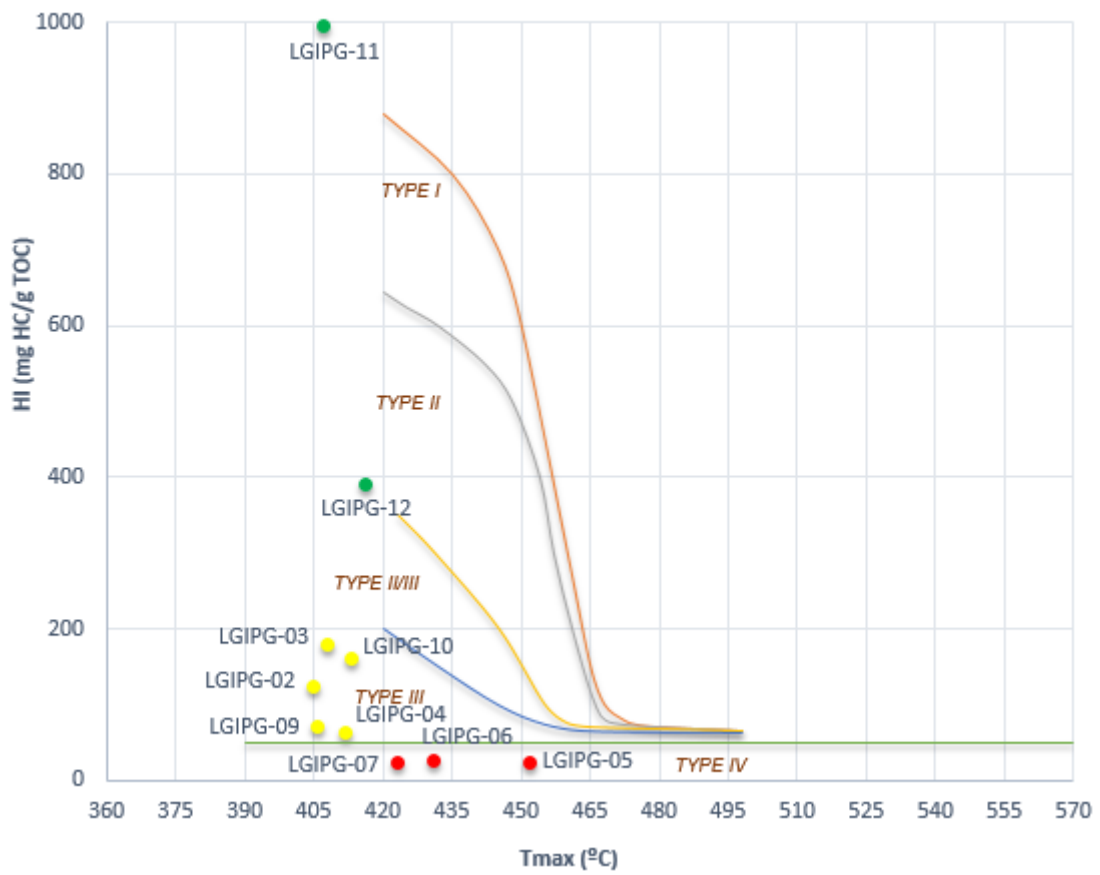


Figure 4.15 - Diagram plotting Tmax vs HI for kerogen type identification (modified after Van Krevelen, 1961).

4.3 Organic Petrology

The petrographic analysis in this study was performed through transmitted light and reflected light microscopy observations.

4.3.1 Viqueque formation

The petrographic observation of samples LGIPG-11 and LGIPG-12 allows the identification of rare and small in size organic particles interbedded with mineral matter (figs. 4.16 to 4.21). Particles of vitrinite and inertinite were identified along with bituminite and zooclasts. Different forms of vitrinite were identified with variable size (fig. 4.16).

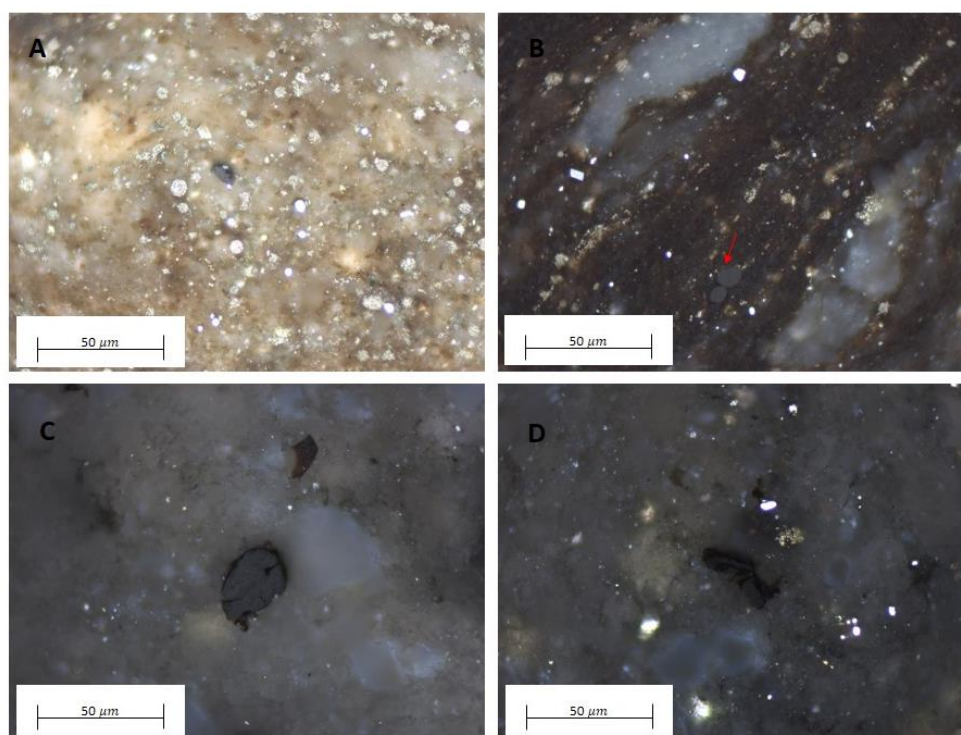


Figure 4.16 - Photomicrographs exhibiting vitrinite particles in samples LGIPG-11 (A, B) and LGIPG-12 (C, D) from Viqueque Formation.

Inertinite generally occur in small particles (fig. 4.17) with reflectance values higher than those measured in vitrinite ($> 1\%$). The occurrence of bituminite was also noted in samples from Viqueque Formation, principally associated with siliceous material and pyrite (fig. 4.18).

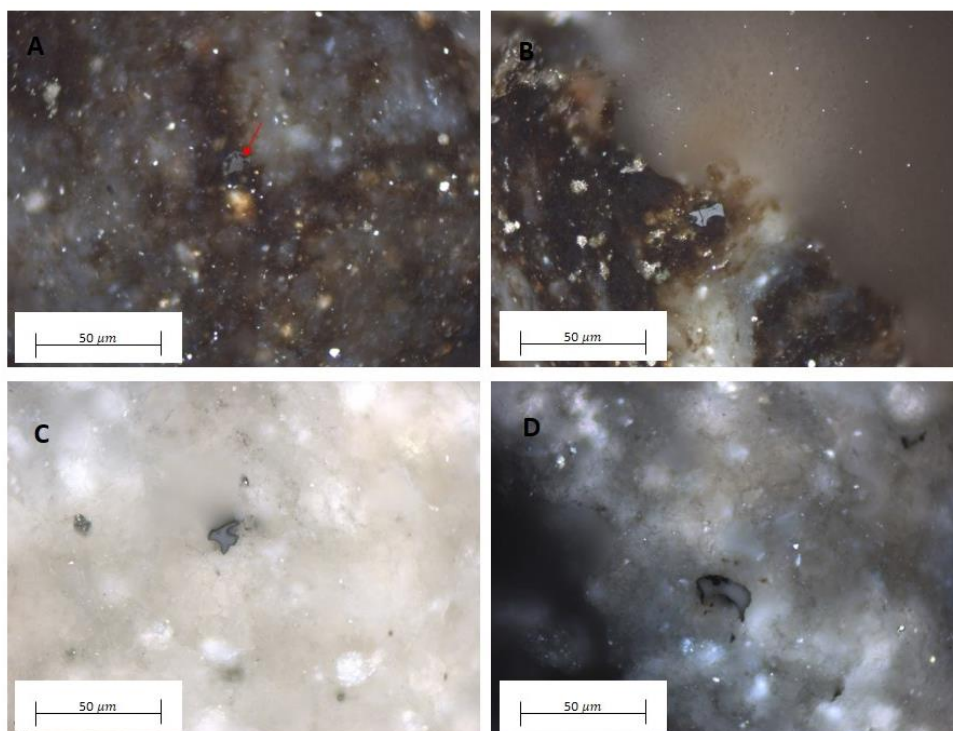


Figure 4.17 - Photomicrographs exhibiting inertinite particles in samples LGIPG-11 (A, B) and LGIPG-12 (C, D) from Viqueque Formation.

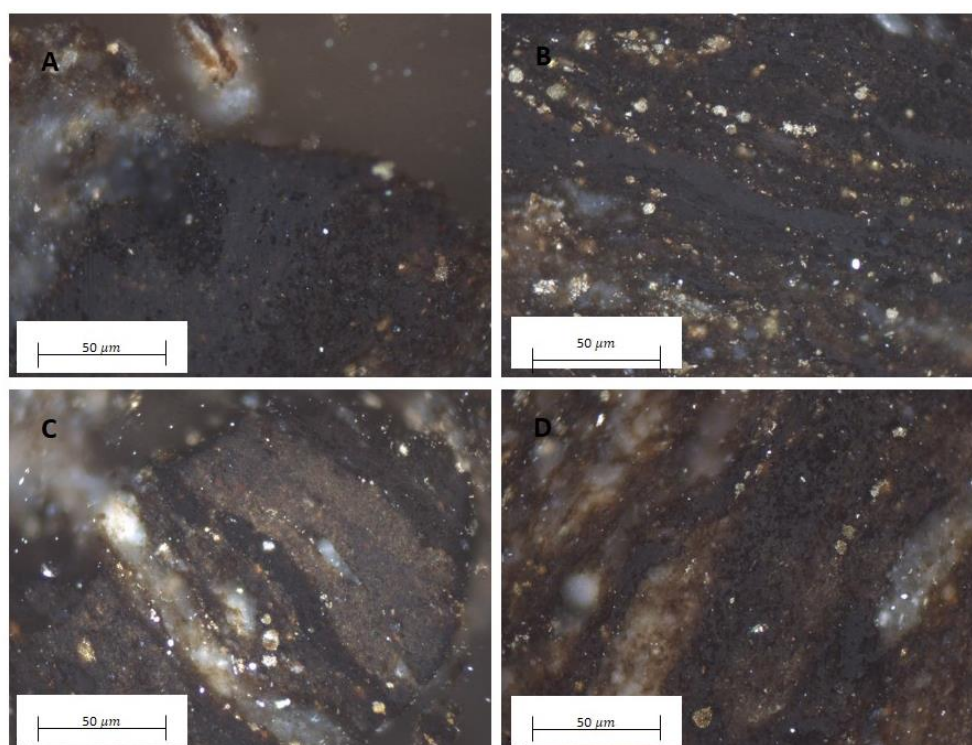


Figure 4.18 - Photomicrographs exhibiting bituminite in samples LGIPG-11 (A, B) and LGIPG-12 (C, D) from Viqueque Formation.

Some remnants of animals were also found in samples LGIPG-11 and LGIPG-12. Figure 4.19 shows some examples of the animal-derived organic particles, the so-called zooclasts, in samples from Viqueque Formation.

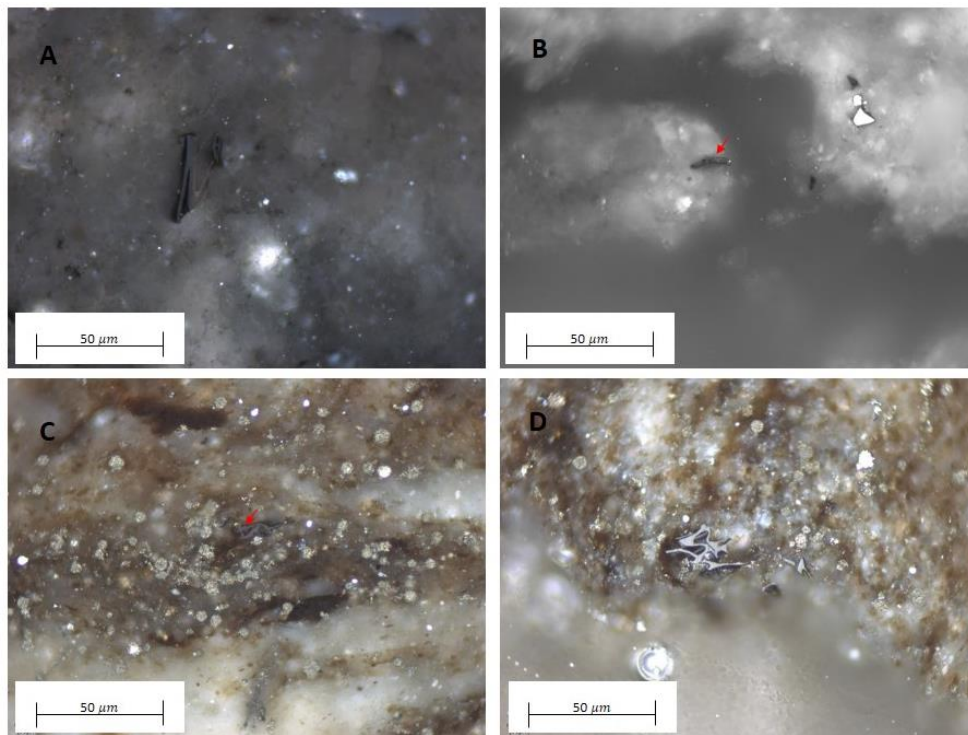


Figure 4.19 - Photomicrographs exhibiting zooclast particles in samples LGIPG-12 (A, B) and LGIPG-11 (C, D) from Viqueque Formation.

The mineral matter present in sedimentary rock samples from Viqueque Formation includes siliceous and carbonates materials (fig. 4.119). As already outlined in outcrops description, and as it can be observed in figs. 4.16 to 4.21, sample LGIPG-11 has a siliceous character while sample LGIPG-12 presents abundant carbonates. The occurrence of pyrite was also observed in these samples (fig. 4.21).

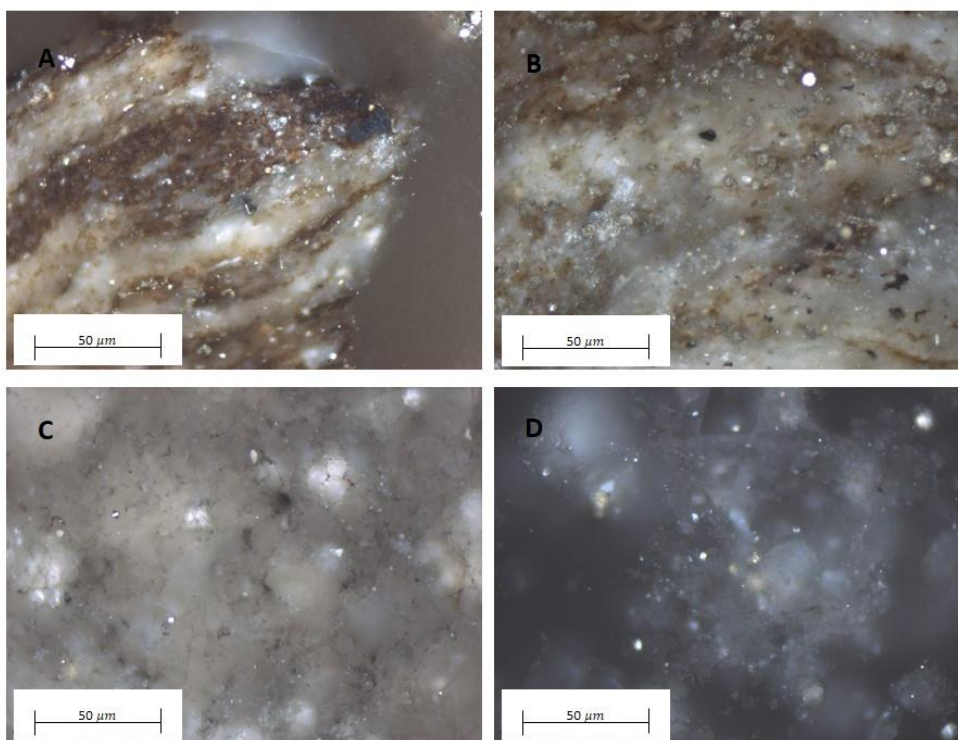


Figure 4.20 - Photomicrographs exhibiting siliceous and carbonates particles in samples LGIPG-11 (A, B) and LGIPG-12 (C, D), respectively, from Viqueque Formation.

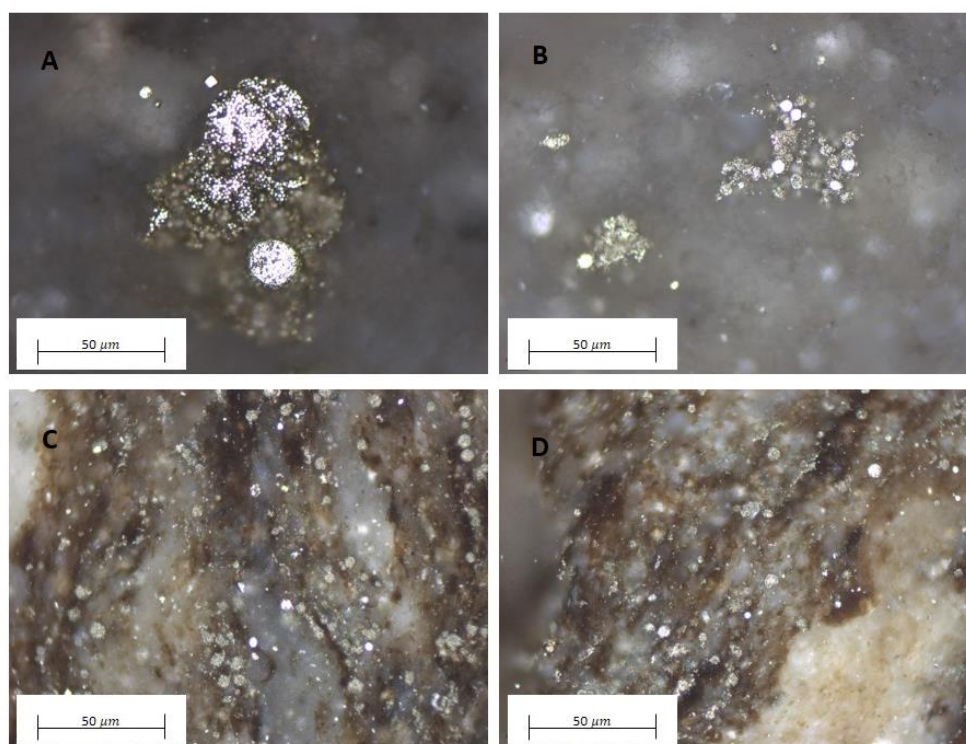


Figure 4.21 - Photomicrographs exhibiting pyrite minerals in samples LGIPG-12 (A, B) and LGIPG-11 (C, D) from Viqueque Formation.

4.3.2 Barique formation

The petrographic observation of samples from Barique Formation reveals the occurrence of organic particles in the form of vitrinite, inertinite and zooclasts along with calcareous mineral matter and pyrite (figs. 4.22 to 4.26).

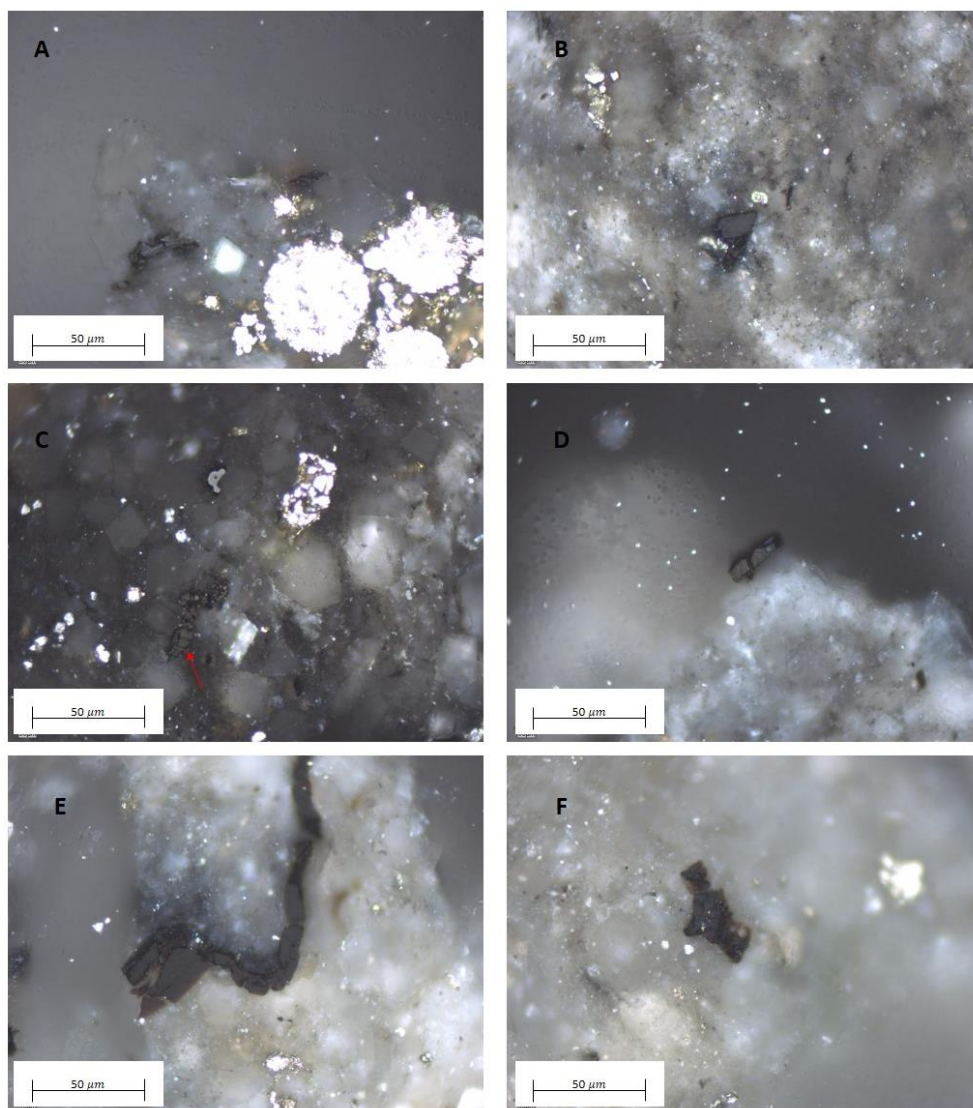


Figure 4.22 - Photomicrographs exhibiting vitrinite particles in samples LGIPG-02 (A), LGIPG-03 (B), LGIPG-04 (C), LGIPG-09 (D) and LGIPG-10 (E,F) from Barique Formation.

The occurrence of inertinite in the Barique Formation is rare and the particles are small in size (fig. 4.23). Zooclast particles, small in size and with have different physical shapes and nature, were also identified in samples from Barique Formation (fig. 4.24).

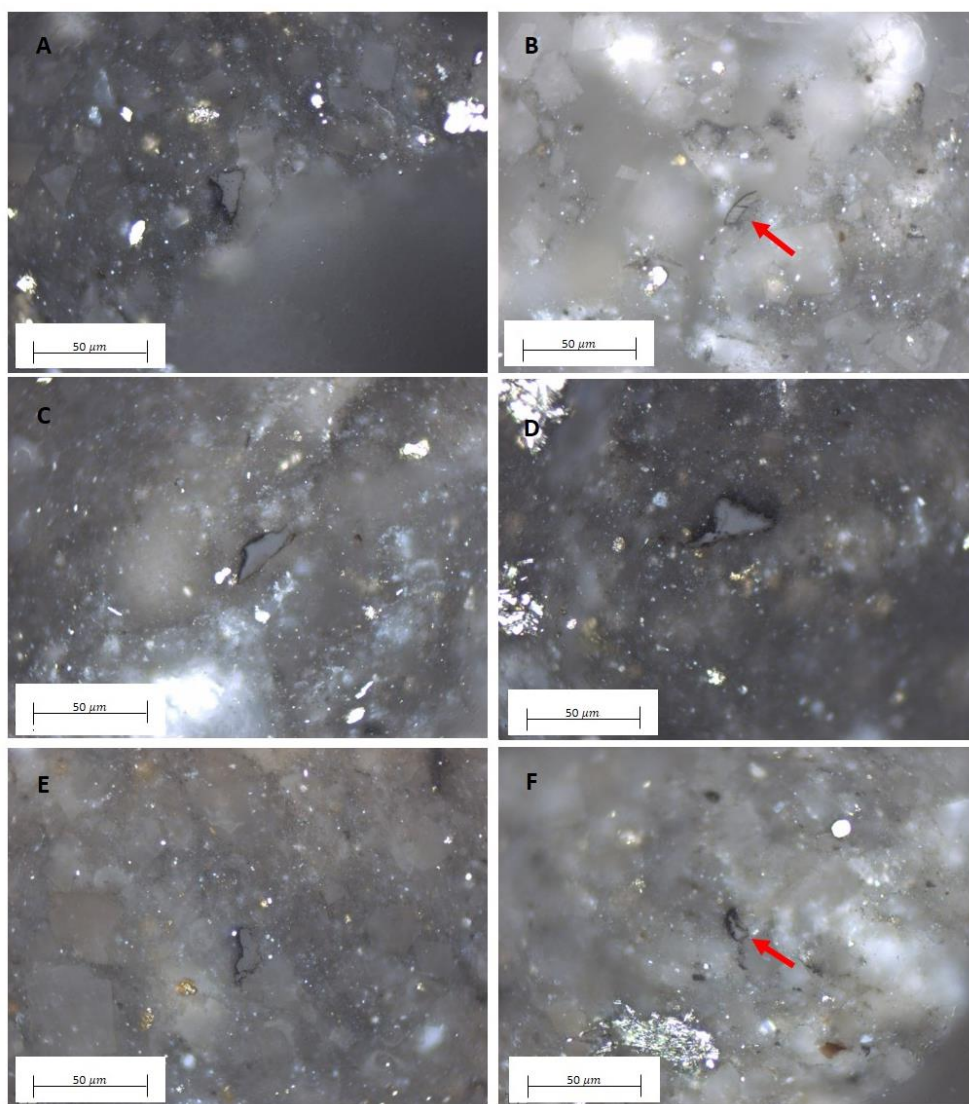


Figure 4.23- Photomicrographs exhibiting inertinite particles in samples LGIPG-02 (A), LGIPG-03 (B), LGIPG-04 (C), LGIPG-09 (D) and LGIPG-10 (E,F) from Barique Formation.

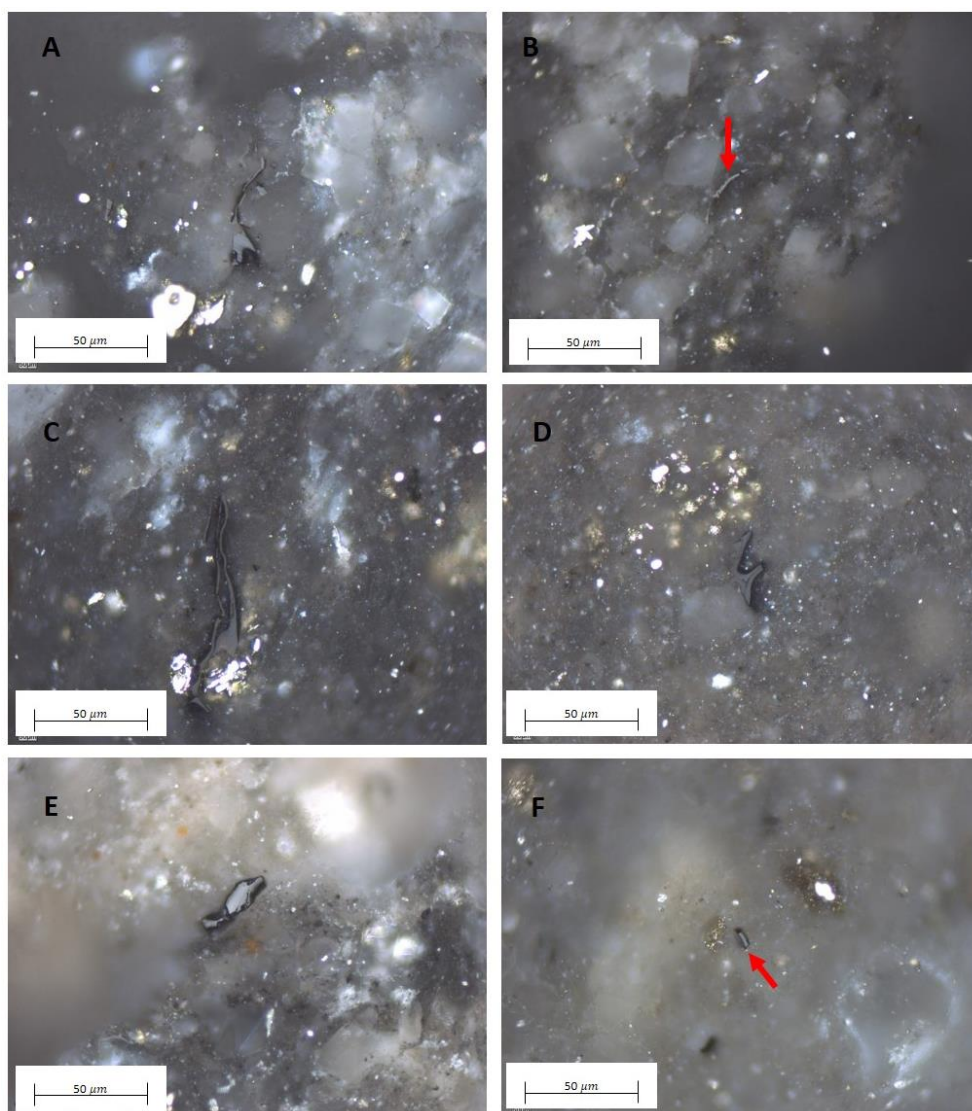


Figure 4.24 - Photomicrographs exhibiting zooclast particles in samples LGIPG-02 (A), LGIPG-03 (B), LGIPG-04 (C), LGIPG-09 (D) and LGIPG-10 (E,F) from Barique Formation.

The mineral matter present in samples from Barique Formation is mainly composed by carbonates (4.25). In addition, all of the samples contained pyrite with variable size and form (4.26). In sample LGIPG-02 the occurrence of pyrite is rare compared to the other samples.

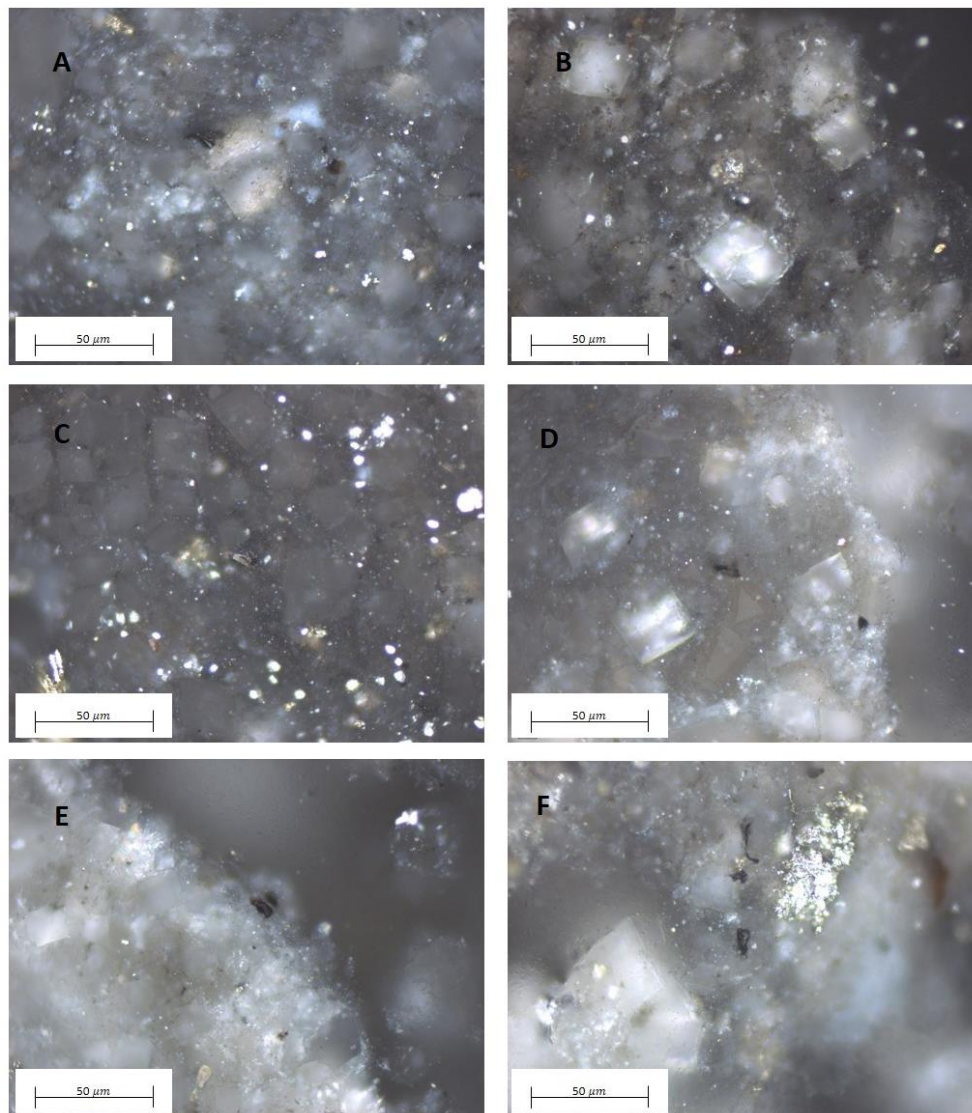


Figure 4.25 - Photomicrographs exhibiting carbonates minerals in samples LGIPG-02 (A), LGIPG-03 (B), LGIPG-04 (C), LGIPG-09 (D) and LGIPG-10 (E, F) from Barique Formation.

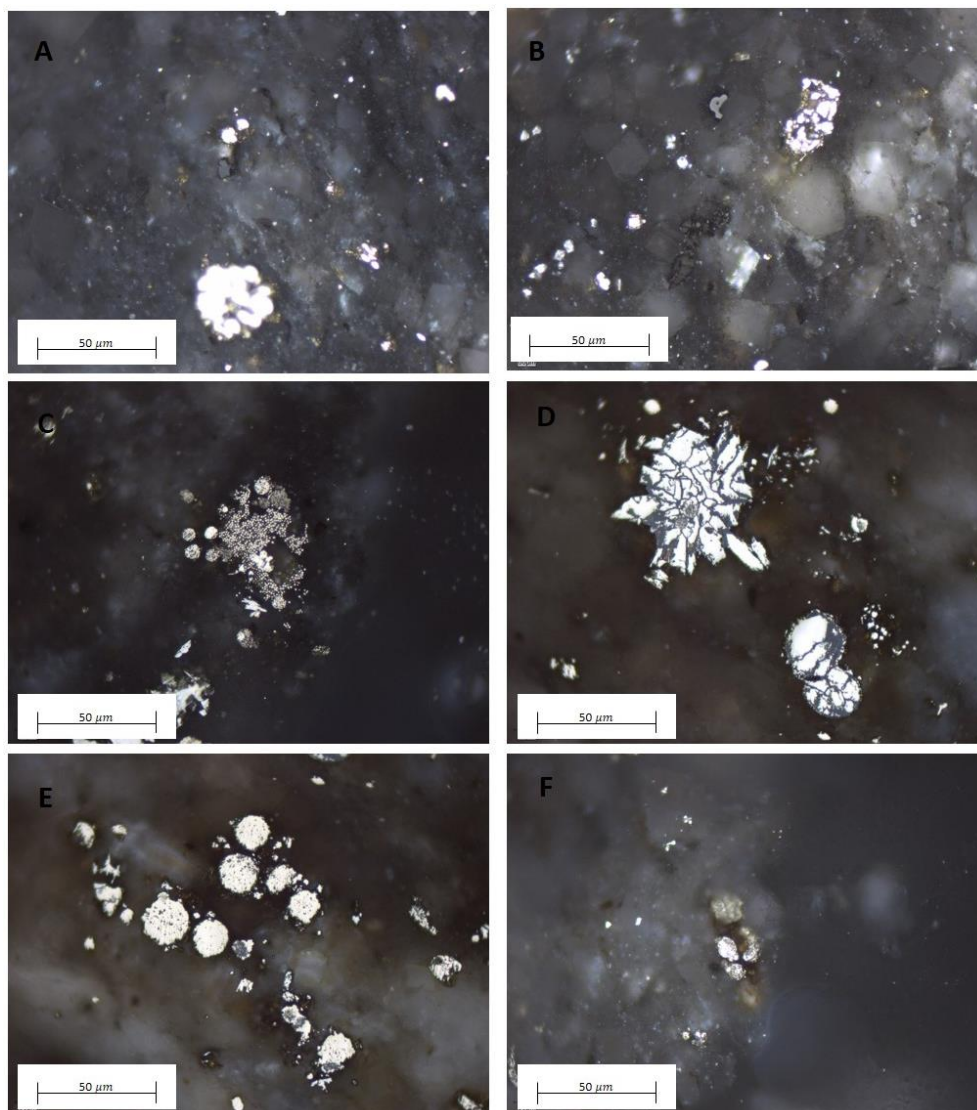


Figure 4.26 - Photomicrographs exhibiting pyrite minerals in samples LGIPG-02 (A), LGIPG-03 (B), LGIPG-04 (C), LGIPG-09 (D) and LGIPG-10 (E, F) from Barique Formation.

4.3.3 Cablac Limestone

The petrographic observation of samples from Cablac Limestone reveals the occurrence of organic particles in the form of vitrinite, inertinite, bituminite and zooclasts along with calcareous mineral matter (figs. 4.27 to 4.30).

Vitrinite particles occurs in significant amounts, with different sizes and shapes, except in samples LGIPG-07, where its occurrence is rare (fig. 4.27).

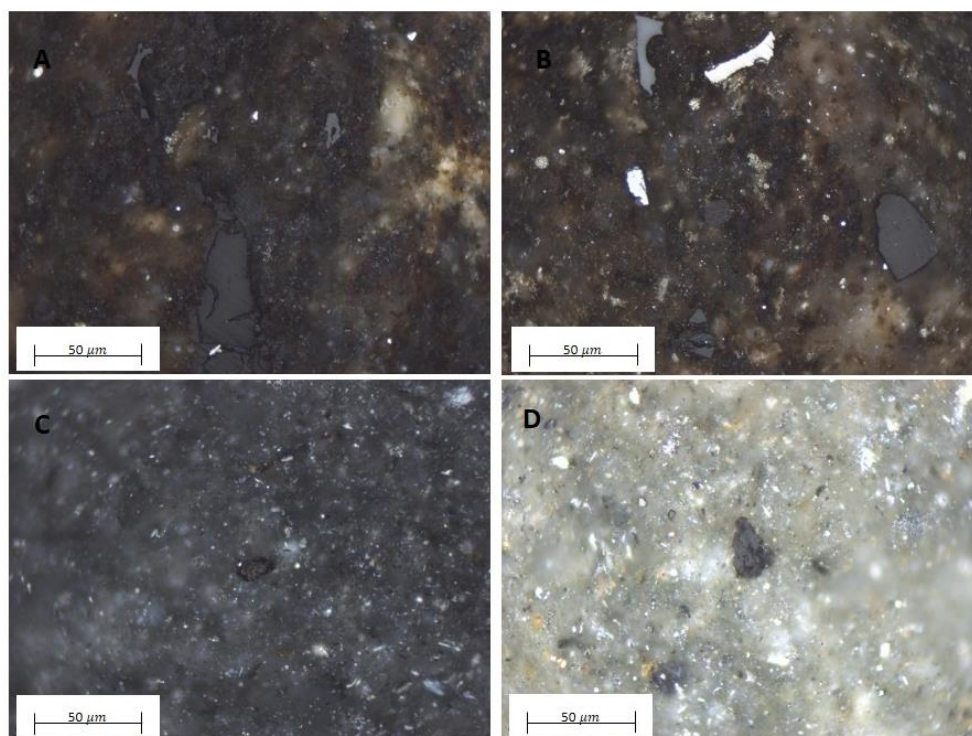


Figure 4.27 - Photomicrographs exhibiting vitrinite particles in samples LGIPG-05 (A, B), LGIPG-06 (C) and LGIPG-07 (D) from Cablac Limestone.

Figure 4.28 shows some examples of inertinite particles found in samples from Cablac limestone, occurring in small amount and particles with variable size.

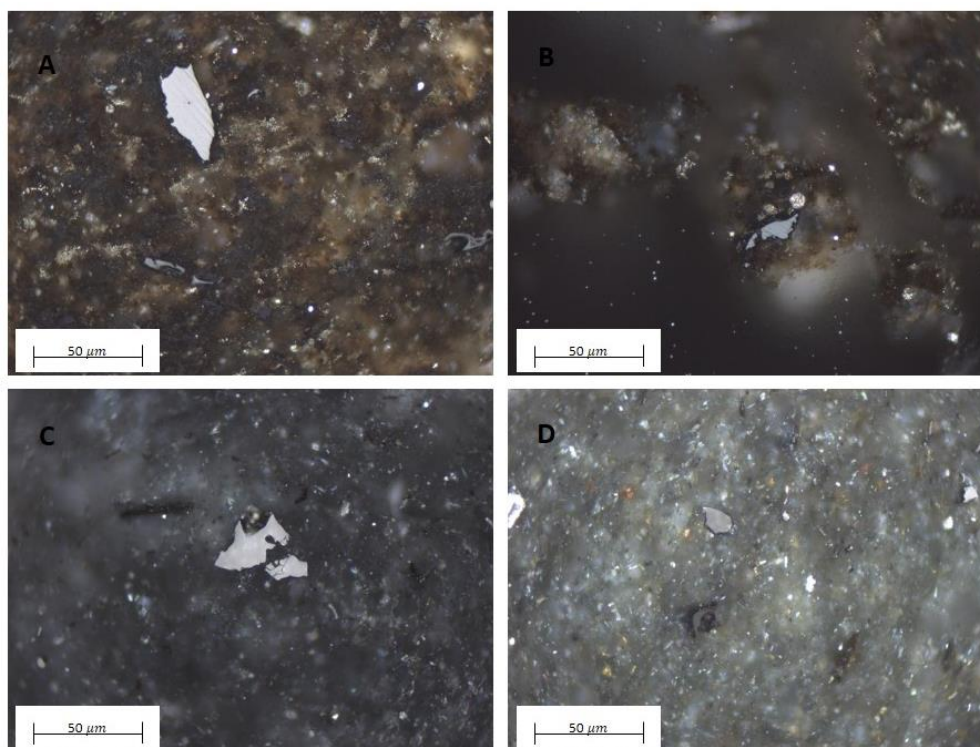


Figure 4.28 - Photomicrographs exhibiting inertinite particles in samples LGIPG-05 (A, B), LGIPG-06 (C) and LGIPG-07 (D) from Cablac Limestone.

Zooecial particles were found in all samples from Cablac Formation (fig. 4.29). However, their occurrence is more abundant in samples LGIPG-05 and rare in sample LGIPG-06 and LGIPG-07.

The mineral matter present in samples Cablac limestone comprises silicates, carbonates, iron oxides, pyrite and clays (fig. 4.30). Samples LGIPG-05 and LGIPG-07 presents more siliceous and clays components, while sample LGIPG-06 has more carbonates. Pyrite also occur in these samples.

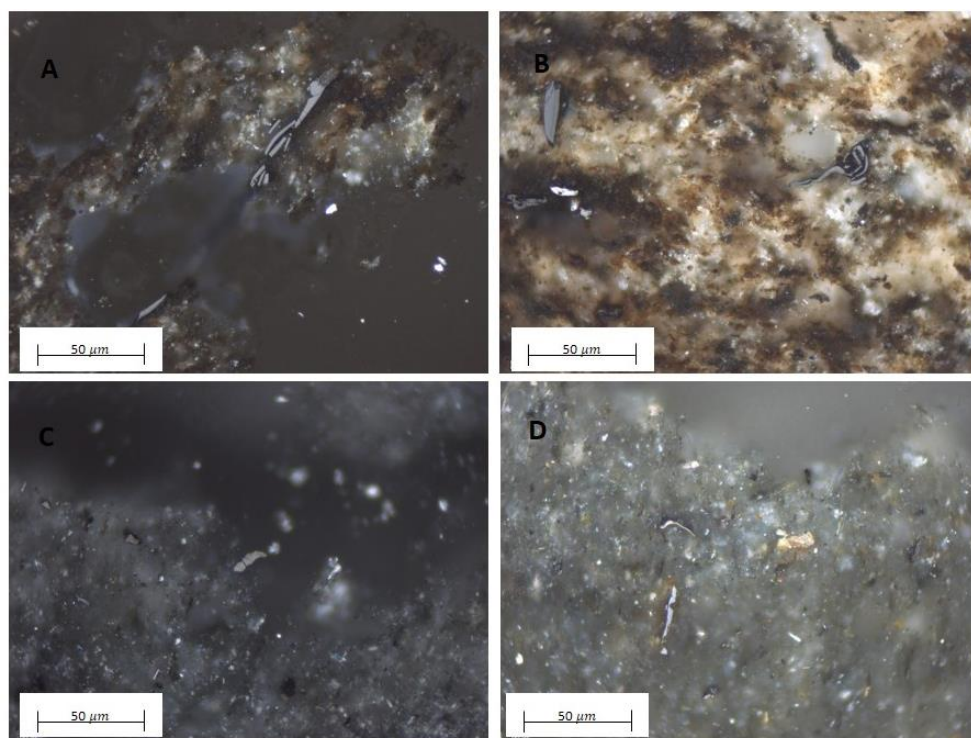


Figure 4.29 - Photomicrographs exhibiting zooclast particles in samples LGIPG-05 (A, B), LGIPG-06 (C) and LGIPG-07 (D) from Cablac Limestone.

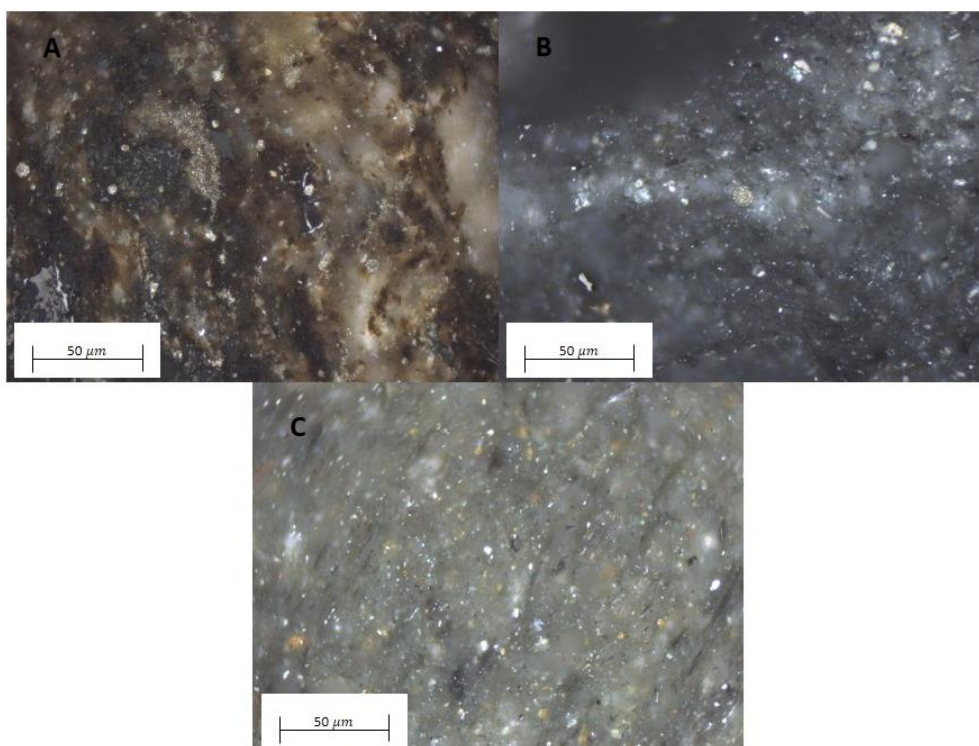


Figure 4.30 - Photomicrographs exhibiting mineral matter in samples LGIPG-05 (A), LGIPG-06 (B) and LGIPG-07 (C) from Cablac Limestone.

4.3.4 Maturation

The observation of kerogen concentrates through transmitted light allowed the visualization and identification of some organic components as well as the determination of the TAI.

The TAI is numerical scale (from 1 to 5) based on color changes induced by maturation of spores or pollens. The TAI has been used as a thermal maturity parameter to assess the hydrocarbon potential of rocks containing organic matter. Considering the determined TAI for the studied samples presented in Table 4.3, ranging between the 1.5 and 3 indicates maturation levels categorized as immature to marginal mature.

Table 4.3 - Thermal alteration index of the studied samples.

Sample	Formation	TAI (scale 1 to 5)
LGIPG-02	Barique Formation	2.5 – 3
LGIPG-03		NDP
LGIPG-04		NDP
LGIPG-09		2 - 2.5
LGIPG-10		2.5 – 3
LGIPG-05	Cablac Limestone	2.5 – 3
LGIPG-06		2.5 – 3
LGIPG-07		1.5 – 3
LGIPG-11	Viqueque Formation	2.5 – 3
LGIPG-12		NDP

NDP - No determination possible.

The observation of whole rock polished block through reflected light microscopy allow the identification of the nature of organic matter, as well as the determination of vitrinite reflectance.

The results of mean vitrinite random reflectance (Ro %) determined in the studied samples is presented in Table 4.4. The values ranges between 0.40 % and 0.68 %, which indicate that the samples are in the immature to early mature (principally in Barique Formation) evolution stages (Tissot & Welte, 1984).

Table 4.4 - Mean vitrinite random reflectance.

Sample	Formation	Mean Vitrinite Random Reflectance (Ro %)	Number of measurements	Standard deviation
LGIPG-02	Barique Formation	0.64	15	0.110
LGIPG-03		0.49	29	0.109
LGIPG-04		0.56	35	0.098
LGIPG-09		0.56	37	0.127
LGIPG-10		0.58	15	0.129
LGIPG-05	Cablac Limestone	0.45	21	0.095
LGIPG-06		0.42	25	0.108
LGIPG-07		0.68	9	0.091
LGIPG-11	Viqueque Formation	0.40	20	0.105
LGIPG-12		0.44	31	0.155

Pyrolysis techniques have in recent years provided a major advance in the assessment of source rock quality and generating potential. The Rock-Eval pyrolysis parameters Tmax indicate that the organic matter in the studied samples is immature (Tmax < 435°C), except sample LGIPG-05 from Cablac limestone that is in the initial mature stage (Table 4.5). Other parameters such as the HI and PI corroborates the immature stage of the organic matter and the poor to fair potential for source rock, except in samples from Viqueque that present higher HI's values (Table 4.5).

Table 4.5 - Rock-Eval pyrolysis parameters.

Sample	Formation	Tmax	HI	PI
LGIPG-02	Barique Formation	405	123	0.12
LGIPG-03		408	179	0.04
LGIPG-04		412	64	0.09
vLGIPG-09		405	71	0.18
LGIPG-10		408	160	0.05
LGIPG-05	Cablac Limestone	452	24	0.23
LGIPG-06		431	26	0.19
LGIPG-07		423	24	0.21
LGIPG-11	Viqueque Formation	407	995	0.02
LGIPG-12		416	390	0.01

CHAPTER 5 CONCLUSIONS

The research on the potential of organic rich rocks as hydrocarbons source rocks was conducted in the Laga area (Baucau Municipality, Timor). Samples of organic rich rocks from Viqueque Formation, Barique Formation and the Cablac Limestone were studied through petrological and geochemical methods.

The identification and characterization of organic matter reveals the presence of organic matter in the form of vitrinite and inertinite in all samples and bituminite in samples from Viqueque formation. Particles of zooclasts were also found in all samples. The mineral matter of the studies samples varies between more siliceous or more carbonaceous features, which is consistent with the description made for samples hand specimens and samples outcrops. The presence of abundant pyrite was also note.

Geochemical analysis reveals that the organic matter in the study samples is classified as type I and II kerogen in Viqueque Formation, type II/III and III kerogen in Barique Formation and type IV kerogen in Cablac Limestone.

The maturity stage of the organic matter was evaluated through vitrinite reflectance, TAI and Rock-Eval pyrolysis. Generally, the results of all techniques evidence the immature stage of the organic matter. However, some parameters point the potential in samples Viqueque Formation.

Generally, the results from both petrographic and geochemical analysis are consistent in the main conclusions regarding identification of organic matter ad its maturation. Some dissimilarities could be due to the limited number of studied samples.

Considering the TOC content, the kerogen type and the maturity stage, of the Viqueque Formation may have potential for hydrocarbons generation. However, the very limited number of studied samples does not allow the achievement of conclusive information. Further investigations should be developed in order to properly evaluate the potential for hydrocarbons generation in Viqueque Formation.

References

- ASTM standart D7708,2014. *Standart Test Methods for Microscopical Determination of Reflectane of Vitrinite Dispersed in Sedimentary Rocks* . West Conshohocken PA.<https://doi.org/10.1520/D7708-14>.: ASTM International.
- Barber, A J, M G Audley Charles, and D J Carter. 1977. "Thrust Tectonics In Timor." *Journal of Geology Society of Australia* 59 - 65.
- Behar, F, V Beaumont, and H L De B Penteadó. 2001. "ROCK-EVAL 6 Technology Performance and Developments." *Oil and Gas Science and Technology* 111-134.
- Carter, D J, M G Audley Charles, and A J Barber. 1976. *Stratigraphical analysis of island arc - continental margin collision in Eastern Indonesia*. London.
- Carvalho, J, and V Lisboa. 2003. "Breve panorâmica sobre os recursos geológicas não metálicos de Timor Leste." *Congresso de Geologia*.
- Castel - Branco, Jose. 1915. *Província de Timor. Informações relativas aos jazigos de petróleo e á agricultura*. Lisboa: Ministério das Colónias.
- Chamalaun, F H, and A E Grady. 1978. "The Tectonic Development of Timor : A new Model and Its Implications for Petroleum Exploration." *The APPEA Journal* 105 - 106.
- Charles, Audley. 1968. *Geology of Portuguese Timor*. London: Geological Society.
- Charles, Audley. 2011. "Tectonic post collision processes in Timor." *The Geological Society of London*.
- Charles, M G Audley, and D J Carter. 1971. *Paleogeographical Significance of Some Aspects of Paleogene and Early Neogene Stratigraphy and Tectonics of Timor sea Region*. London: Elsvier Publishing Company.
- Charlton, T.R. 2002b. "The Petroleum Potential of East Timor." *APPEA Journal 2002* 351-353.
- Charlton, Tim R. 2004. *The Petroleum potential of Inversion Anticlines in the Banda Arc*. United Kingdom: AAPG Bulletin.
- Filho, J G Mendonça, and A G Borrego. 2017. *Dispersed Organic Matter Integrating transmitted light and reflected light microscopy*. Spain: ICCP.
- Gageonnet, Robert, and Marcel Lemoine. 1958. *Contribution to the knowledge of the Geology of Portuguese province of Timor*.
- Grunau, H R. 1953. *The Geology of Eastern Portuguese Timor*.
- Grunau, Hans R. 1957. *Geología da Parte Oriental Timor Português*. Lisboa: Garcia de Orta.
- Hall, R, and M E J Wilson. 2000. "Neogene Sutures in Eastern Indonesia." *Journal Asian of Earth Science* 782-785.
- Hamilton, Warren. 1979. "Tectonic of the Indonesian Region." *Geological survey professional paper* 152-160.
- Hansell, Dennis A., Craig A. Carlson, Daniel J. Repeta, and Reiner Schilter. 2009. *Dissolved Organic Matter in the Ocean: A Controversy Stimulates New Insights*. New york: Oceanography.

- Hinschberger, F, J A Malod, J Dymant, C Honthaas, J P Rehault, and S Burhannudin. 2001. "Magnetic Lineations Constraints for the back arc opening of the Late Neogene South Banda Basin." *Elsvier Science* 48-49.
- Hunt, M. 1979. *Petroleum Geochemistry and Geology*. United States of America: W.H Freeman and Company.
- ICCP, 1998." *The new vitrinite classification (ICCP system 1994)* Fuel 77, 349–358. .
2001. "International Committee for Coal and Organic Petrology." *The new vitrinite Classification (ICPP System 1994)* (The new Vitrinite Classification (ICPP System 1994)) Fuel 80, 459-471.
- ISO 7404-2. 2009." *Methods for the petrographic analysis of Coals – Part 2: Methods of preparing coal samples* 12p.
- Lafargue, E, F Marquis, and D. Pillot. 1998. *Rock-Eval Application in hydrocarbon exploration, and Soil Contamination Studies*. France: Institut Français du pétrole.
- Leme, J C De Azeredo. 1986a. *Breve Ensaio Sobre a Geologia da Provincia de Timor*. Lisboa.
- Livsey, A.R, N. Duxbury, and F. Richards. 1992. "The Geochemistry Tertiary and Pre-Tertiary Source Rocks and Associated Oils in Eastern Indonesia." *Proceedings Indonesia petroleum Association*. IPA,2006. 501 -505.
- McCarthy, K Rojas, K Niemann, M Palmowski, D Peters, and K stankiewicz. 2011. *Basic Petroleum Geochemistry for Source Rock Evaluation*. Oilfield review 23(2), 32-34.
- Mendonça, J G Filho, T R Menezes, O J Mendonça, A D Oliveira, T F Silva, N F Rondon, and F S da Silva. 2012. *organic facies : Palynofacies and Organic Geochemistry Approaches*. Earth System Process.
- Milsom, J. 2000. "Stratigraphic Constraint on suture models for Eastern Indonesia." *Journal of Asian Earth Science* 761 - 779.
- Peters, E., C. Walters, and Moldowan. 2005. *The Biomarker Guide second edition Volume 2*. United Kingdom: Cambridge University Press.
- Peters, K E. 1986. "Guidelines for evaluating petroleum source rock using programmed pyrolysis." *American Association Petroleum Geology Bulletin* 70 318-329.
- Peters, Ken E., Tom H. Fraser, Welly Amris, Budi rustanto, and Eddy Hermanto. 1999. "Geochemistry of Crude Oil from Eastern Indonesia." *AAPG Bulletin* 1929-1935.
- Peters, Kennet E, and Mary Rose Cassa. 1994. *Applied Source Rock Geochemistry*. California: AAPG memoir.
- Pickel, W, J Kus, D Flores, Kalaitzidis, S Christanis, K Cardott, B J Misz Kennan, et al. 1994. "Classification of Liptinite - ICCP System." *International Journal of Coal Geology* 169 40-61.
- Pickel, W, J Kus, D Flores, S Kalaitzidis, K Christanis, B J Cardott, M Misz Kennan, et al. 1994. "Classification of Liptinite - ICCP System." *International Journal Coal Geology* 169 40-61.
- Staplin, F L. 1969. "Sedimentary organic matter, organic metamorphism and oil and gas occurrence." *Bulletin of Canadian Petroleum Geology* 17, 47 - 66.

- Suárez-Ruiz, Isabel. 2012. *Organic Petrology*. Spain: Instituto Nacional del Carbon (INCAR - CSIC). Francisco Pintado Fe 26. 33011- Oviedo.
- Taylor, G H, M Teichmüller, A Davis, C F K Diessel, R Litteka, and P Robert. 1998. *Organic Petrology*.,. Berlin, Stuttgart: Gebrüder Borntraeger.
- Tissot, B., and D. Welte. 1984. *Petroleum formation and Occurrences*. New York Tokyo: Springer Verlag Berlin Heidelberg.
- Tyson, R V. 1995. *Sedimentary Organic Matter : Organic Facies and Palynofacies*. London: Chapman and Hall.
- Ware, Paul, and La Ode Icharm. 1997. "The Role of Mud Volcanoes in Petroleum System, Example from Timor, The South Caspian and Carribean." *International Conference on Petroleum System of SE Asia and Astralasia*. Jakarta: IPA,2006. 956 - 958.
- Wells, Mark L, and Edward D Goldberg. 1991. "Occurance of small colloids in sea watre." *Nature articles* 342-344.
- Wells, Mark L., and Edward D. Goldberg. 1993. *Marine Chemistry*. London: Elsvier.
- Yule, B L, S Roberts, and J E A Marshall. 2000. "The thermal evolution of sporopollenin." *Organic Geochemistry*, 31 859-870.