LITHO-STRUCTURAL AND PALEOGEOGRAPHIC ANALYSIS OF THE SEDIMENTARY FORMATIONS THE SAKAMENA SERIES OF THE KARROO SYSTEM IN MORONDAVA AND MAJUNGA-DIEGO BASINS

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ABSTRACT

The Sakamena series is composed of conglomerates, of deltaic continental sandstone of dating,
Upper Permian and continental sandstones and marine marls of Lower Triassic dating. Apparently; it represents good prospects in petroleum systems, especially in the deep marine sedimentary part, onshore or offshore.
To this end, our reseach based on the analyzes of the formations (lithological sequence, facies), linked with different structures or tectonic deformations, while taking into account their lithological compositions and their stratigraphies and especially of their paléogéographic conditions during accumulation of the deposits, the dating of formations, of the presence of the organic, microbiological and biochemical substances and the possibility of petroleum systems, can better justify and support the distribution of the structural areas and formations susceptible to deposits or oil traps and some gas.
The method known as" litho-structural and paléogéographic analyzes of formations" is a recent method, developed in the field of oil and gas prospecting, particularly in Russia. It is used above all during regional investigations and allows better orientation of the detailed work, it consists of clearing horizontally and vertically all formations or sub-formations accumulated in the structural geological elements or well defined structural.

Keyword: *Formation, sub-formation, Litho-structural, Litho-paléogéographic, Tectono-stratigraphic, Structural area, Petroleum system, Lithological bevels, Diapiric folds.*

1. INTRODUCTION

As if the Malagasy State still has an aspiration to also discover oil or gas or condensate gas deposits, it encourages oil exploration in the Sakamena sedimentary basin of Morondava, Majunga and Diego (onshore and offshore) .

This article is effectively part of the prospecting and the investigation of oil and gas deposits in the Malagasy sedimentary basins [1]. In this article, a less expensive and rarely used but efficient method is proposed for the regional investigation of oil and gas deposit in Madagascar. It makes it possible to identify the formations or sub-formations in vertically and the structural areas horizontally, the shapes of geological bodies such as tabular layers, the reefs, diapiric folds, the mouths bars, lithological bevels with their respective lithological compositions, to identify their paleogeographic conditions during the accumulation of the deposits, their dating of formations, the subsistence of the organic, microbiological and biochemical substances and to release the possibility of the petroleum systems or even probable natural reservoirs with tectonic, stratigraphic and lithological barriers likely to trap oil and gas.

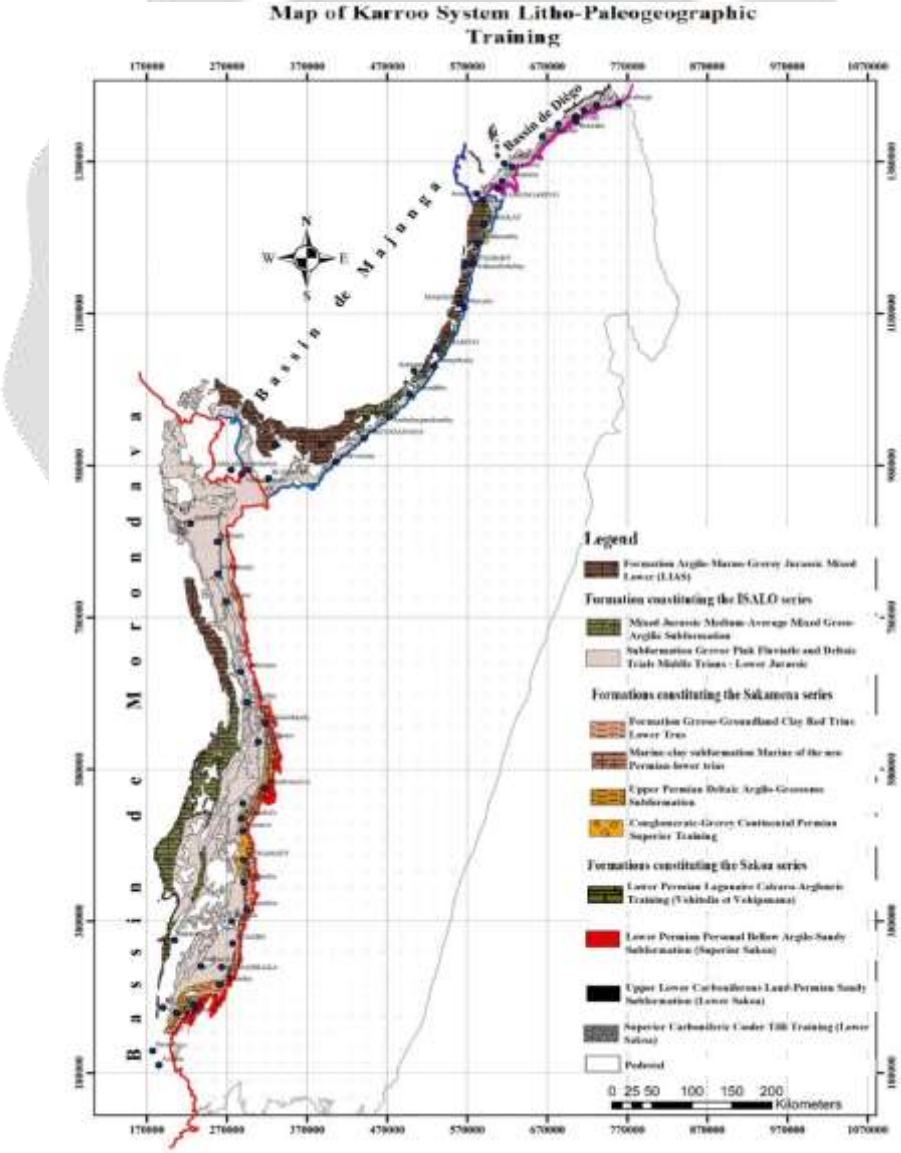
2. MATERIAL AND METHODS

2. 1. Materials

The lithological section obtained gotten from the drilling are used to be correlated when determining the shape of the body of the formations or sub - formations and of the establishing of the natural reservoirs or the petroleum system. The formations in the Karoo system which date from Upper Carboniferous to the Lower Jurassic were identified from data from 55 boreholes drilled by SPM, CHEVRON, CONACO, COPETMA, MOBIL, AGIP,OCCIDENTAL, AMOCO, OMNIS and other companies,located in the three large Malagasy sedimentary basins. The term Karroo encompasses sedimentary and intrusive formations, deposited or emplaced in Africa, in intra and peri- continental basins located South of the Equator [2].

They are: the Karroo basin (South Africa), the Etjo basin (Botswana), the Limpopo and Zambèze basins (Zimbabwe, Mozambique), the Congo basin (Zaire), the Rovuma valley (Tanzania), the Mombasa basin (Kenya), the Morondava and Majunga-Diego basins (Madagascar) [3].

In particular in Madagascar, the « Malagasy Karroo »has been recognized from the oldest to most recent having as series: Sakoa (Upper Carboniferous - Lower Permian), Sakamena (Upper Permian - Lower Triassic) and Isalo (Upper Trias –Lower Jurassic). Each series is formed by specific geological bodies.



Map-1: Karroo system litho-paleogeographic of Madagascar

Drilling BW1, carried out by the Société Pétrolière de Madagascar (S.P.M.) in 1952 in Bezaha, with a final depth of 2713,6 m, having as geological objective: Lower Sakamena (Upper Permian) [2].

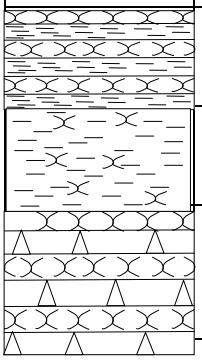
Lithological section	Interval (m)	Thickness (m)	Characteristc	Geological set	Dating
	2206-2348	142	Alternation sandstone and clays	Lower Sakamena	Upper Permian
	2348-2630	282	Arkozics and stonewith clayey's predominance	Lower Sakamena	Upper Permian
	2630-2713,6	83,6	Arkozic sandstone with middle grain of enough angular and compact quartz	Lower Sakamena	Upper Permian

Fig -1: Geological section n°1

Drilling AW1, carried out by the Société Pétrolière de Madagascar (S.P.M.) in 1953 in Antsokaky, with a final depth of 1138,5 m, having as geological objective: Lower Sakamena (Upper Permian) [2].

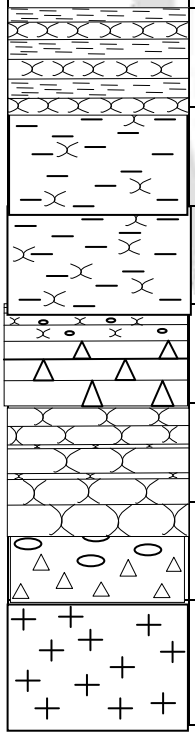
Lithological section	Interval (m)	Thickness (m)	Characteristc	Geological set	Dating
	166-323	157	Sandstone in alternation with pelitic cleyey shales	Lower Sakamena	Upper Permian
	323-538	215	Faciès compact, schisteux et grès argileux	Lower Sakamena	Upper Permian
	538-714	176	Grès fin et pélitique , argiles schisteuses	Lower Sakamena	Upper Permian
	714-905	191	Conglomérats et grès fins à petits galets	Lower Sakamena	Upper Permian
	905-1106	201	Grès grossiers, Grès moyen, avec passage de grès fins	Lower Sakamena	Upper Permian
	1106-1132	26	Conglomérats à galets de roches cristallines	Lower Sakamena	Upper Permian
	1132-1138	6	Crystalline base	Basement	Precambrian

Fig -2: Geological section n°2

Drilling AB-1, carried out by the Société Pétrolière de Madagascar (S.P.M.) in 1955 in Ambalabe, with a final depth of 2190 m, having as geological objective: Middle Sakamena (Permian - Triassic) [2].

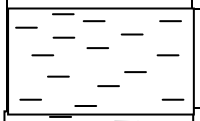
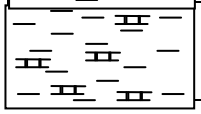
Lithological section	Interval (m)	Thickness (m)	Characteristc	Geological series	Dating
	1725-1844	119	Layer of clays	Middle Sakamena	Permo-triassic
	1844-2180,90	336,9	Compact clays	Middle Sakamena	Permo-triassic

Fig -3: Geological section n°3

Drilling carried out by the Société Pétrolière de Madagascar (S.P.M.) in 1958 in Vohidolo, with a final depth of 2733 m, with the geological objective: Basement[2].

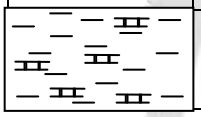
Lithological section	Interval (m)	Thickness (m)	Characteristc	Geological series	Dating
	2570-2708	138	Clays with benches of limestones	Middle Sakamena	Permo-Triassic

Fig -4: Geological section n°4

Drilling BW1, carried out by the Société Pétrolière de Madagascar (S.P.M.) in 1952 in Bezaha, with a final depth of 2713,6 m, having as geological objective: Lower Sakamena (Upper Permian) [2].

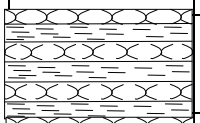
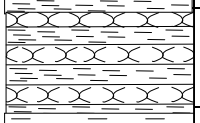
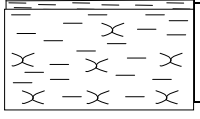
Lithological section	Interval (m)	Thickness (m)	Characteristc	Geological series	Dating
	317-990	66	Alternation sandstone and clays in passage	Upper Sakamena	Lower trias
	990-1457	467	Alternation sandstone and clays in passage	Upper Sakamena	Lower trias
	1457-1810	353	Clays and arkozic sandstone	Upper Sakamena	Lower trias

Fig -5: Geological section n°5

Drilling AB-1, carried out by the Société Pétrolière de Madagascar (S.P.M.) in 1955 in Ambalabe, with a final depth of 2180,90 m, having as geological objective: Lower Sakamena (Permian - Triassic) [2].

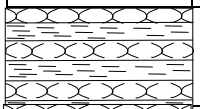
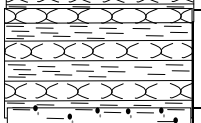
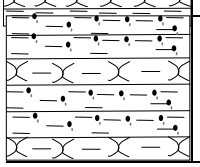
Lithological section	Interval (m)	Thickness (m)	Characteristc	Geological series	Dating
	1205-1463	258	Alternation of clays and sandstone	Upper Sakamena	Lower trias
	1463-1590	127	Alternation clay and the hardy sandstone	Upper Sakamena	Lower trias
	1590-1725	135	Passage of sandy clays or clayey sandstone	Upper Sakamena	Lower trias

Fig -6: Geological section n°6

2. 2. Methods.

The method consists in releasing a geological body called" Formation or sub - formation "which is different from the understanding of the" facies ".

Characteristic of the formations and sub - formations.

The « facies » is generally closely linked with paleogeomorphology as for the « formation », in addition to these two (02) aforesaid geological conditions, it is mainly linked with the tectonic movement and was formed in regional geological structure, during a well –defined period.

The meaning of the term "formation" is wide, different and depends on the definition given by researchers.

In this article, a formation is a concrete geological body, delimited by the homogeneity of its lithological composition formed under well-defined paleotectonic and paleogeographic conditions, corresponding to stratigraphic stages or series, rarely to a few series or part of stage[4] [5]...

The analysis of the characteristics of Paleozoic, Mesozoïc, Cenozoïc sedimentary formations of the western coast of Madagascar makes it possible to clarify, each formation released in the structural areas corresponding, the following clauses:

- Determination of the common lithological composition, the shape of the body occupying the surface, the thickness, the types of the main and secondary rocks, the change in their lithological composition and grouping in profile,
- Restoration of the paléotectonic, facial - paléogéographic, géochimical conditions of formations and their evolution.
- Description of contact area characters [4].

3. RESULT

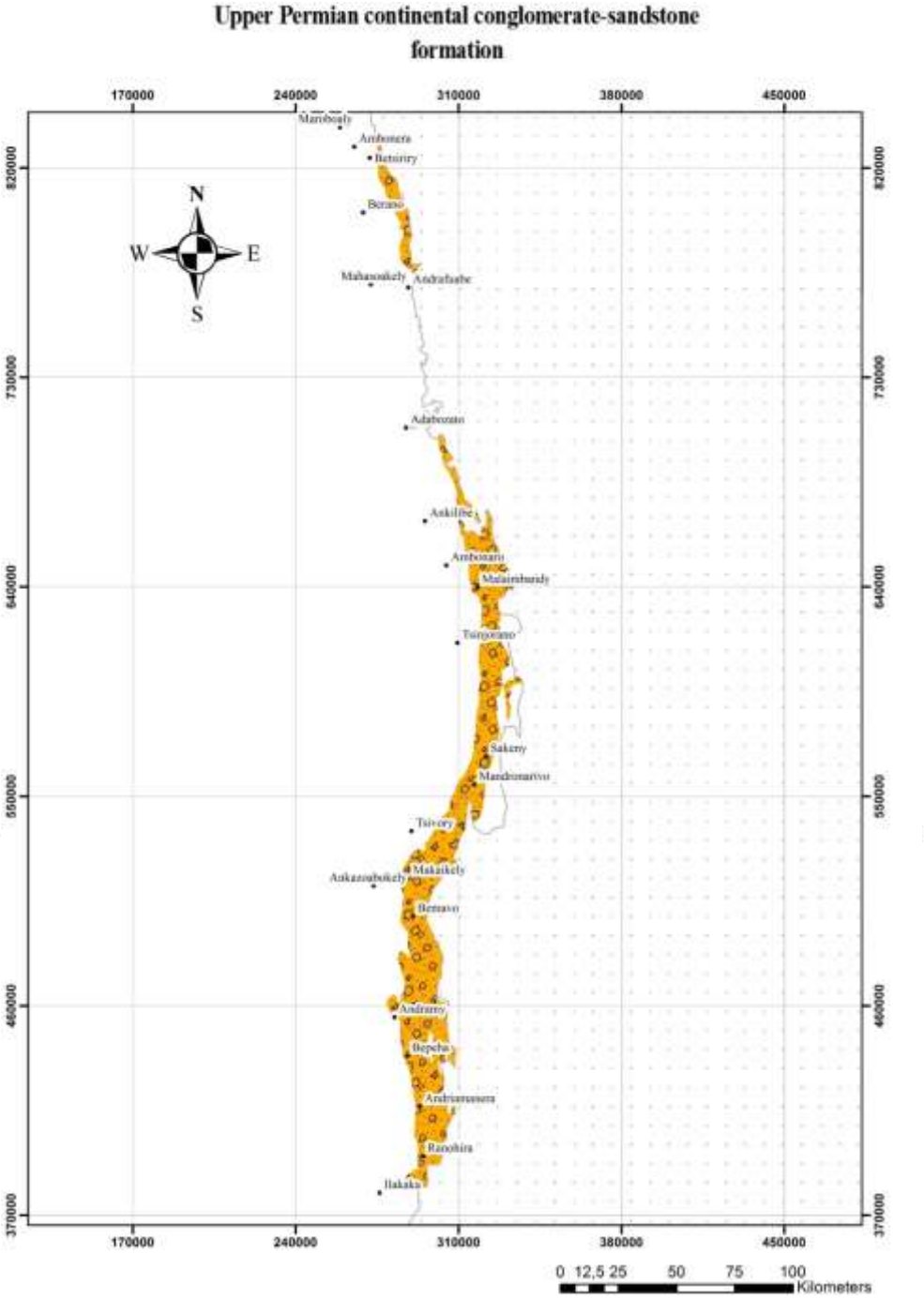
FORMATIONS OR SUB-FORMATIONS RELEASED IN THE SERIES SAKAMENA

Above the Sakoa series is Sakamena series which is also formed by (03) three formations:

1. Upper Permian continental conglomerate-sandstone formation.

The Upper Permian continental conglomerate-sandstone formation (Map. 2) is scattered along the contact of the sedimentary rocks with the basement. It found widespread from Ambonera to Mahasoakeky, in the northern part of the Morondava basin. Then, it is present form Andabozato to Ilakaka in southerly direction in the eastern part of the Karroo-Isalo graben and having a lenticular shaped body. The maximal thickness reaches 100 m in the central part of the Karroo pit. The thickness of this formation decrease up to 30 m, towards the South or toward the North. Its upper border is materialized by the sudden change oin the lithological composition, at the level of the wall of the sandstone-clayey series of Upper Permian dating. In this formation, some transgressive overlay has been noticed; and gradually upward to geological section n°1 and n°2, the fragmentary or clastic textures of the materials change pebbles or gravel with clay sandstone filling to finer classified sediments, lœss mud and silt. This formation is of continental origin, constituted of conglomerates, sandstone and clayey rocks with schistosity and the presence of Esthéria fossils. It was formed during the reworking or resedimentation of fragmentarytheterrigenous materials or brought by the rivers with the relatively active water current, from the outcrops areas of the crystalline basement, during the humid climate. Quartz, the feldspar, the plagioclase, and other make up the mineral composition, along with the light fraction and the

accessory minerals like garnet, zircon, tourmaline, magnetite, ilmenite, and other heavy minerals. The main permanent source of contributions of fine and extremely fine-grained detrital material called pelite, is the Precambriancrystalline massif[6].



Map 2*:* Upper Permian continental conglomerate-sandstone formation

2. Upper Permian – Lower Triassic mixed terrigenous formation

The Upper Permian – Lower Triassic mixed terrigenous formationis constituted of two sub- formations:

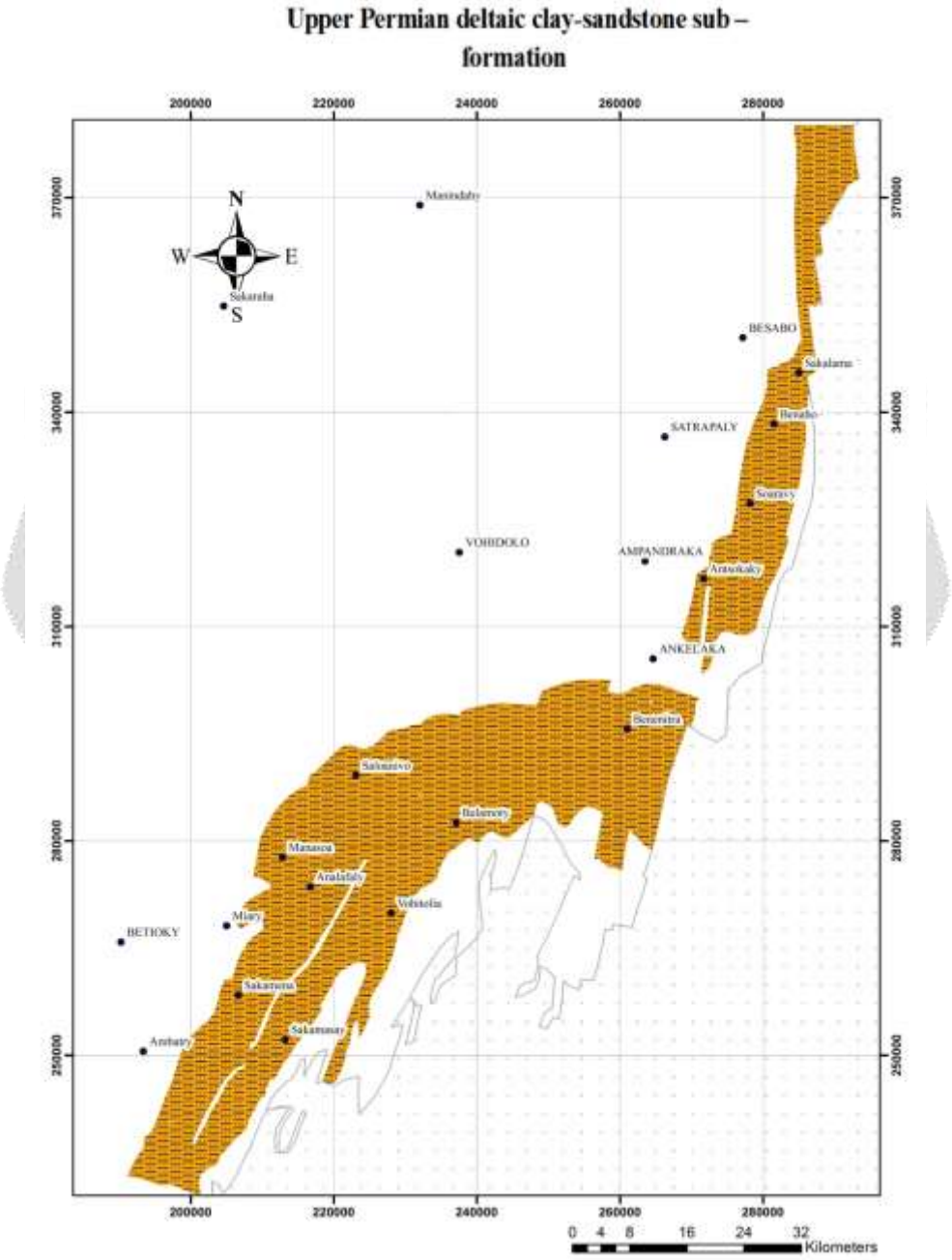
- ***Upper Permian deltaic clay-sandstone sub – formation;***
- ***Neopermian – Lower Triassic marine marl – clay sub- formation***;

- The Upper Permian deltaic clay-sandstone sub – formation (Map 3), the geological body of this sub-formation has a lanticular shape, widespread in the part located a little to the west of the territory of the Karroo pit.

Its roof sinks in an east –west direction from the outcrop on the surface to 6 km deep.

This sub-formation is alternated with terms, layers and and intercalations of sandstone and sand from 15% to 45%, aleurolites and black clays from 55% to 85%. In general, clays predominate in the lithological composition of this

sub-formation because about two third (2/3) of its geological section in the submerged part of the Karroo graben in particular in the Morondava basin are represented by the clays with an average grade by 70%.
The maximum thickness of the sub-formation reaches up to 2500m in the central part of the Karroo pits of the Morondava basin and 1400 m in the northen part of the Morondava basin. The decrease in the thickness is noticed towards the north up to a few tens of meters. Often,brachiopods, remains of Glossopteria and Voltzias plants are found in the clays. These paleontological clues allow us to say that these sandstones have a fluvio-deltaic origin. The superior part of this sub-formation is relatively by multiple sandstone layers compared toits lower part. In these layers, remains of Rinesuchus, Tangasaurus, Hovasuruses reptiles have been observed. The character of the filtration capacity of aleurolites and sands change considerably in surface and depth, generally deteriorating in general downwards of the top and of the zone of border toward the parts power station and immersed deep from the top bottom and the edge zone towards the central and deeply submerged part of the pits of Morondava basin [6].



Map 3: Upper Permian deltaic clay-sandstone sub – formation

Neopermian – Lower Triassic marine marl – clay sub- formation

The - Neopermian – Lower Triassic marine marl – clay sub- formation (Map 4) is arranged from Ambonara to Ilakaka, in eastern part of theMorondava trench system and also in the northern part of the Diego basin, in contact with the basement, especially in the grabens of Ankarana, Andavakoera and Barabanja, then invading the monoclinal territory of Sambirano - Ampasindava. Its body is lanticular in shape, with a maximum thickness reaching 2000 m in the monoclinal continental platform of Sambirano. In the Morondava basin, in general, the thickness of this formation decreases towards the north to 70 m.

In the Diego basin, the roof of this sub-formation dips westward to a deph of 7 km towards the Strait of Mozambique and gradually changes composition from clay to aleurith.

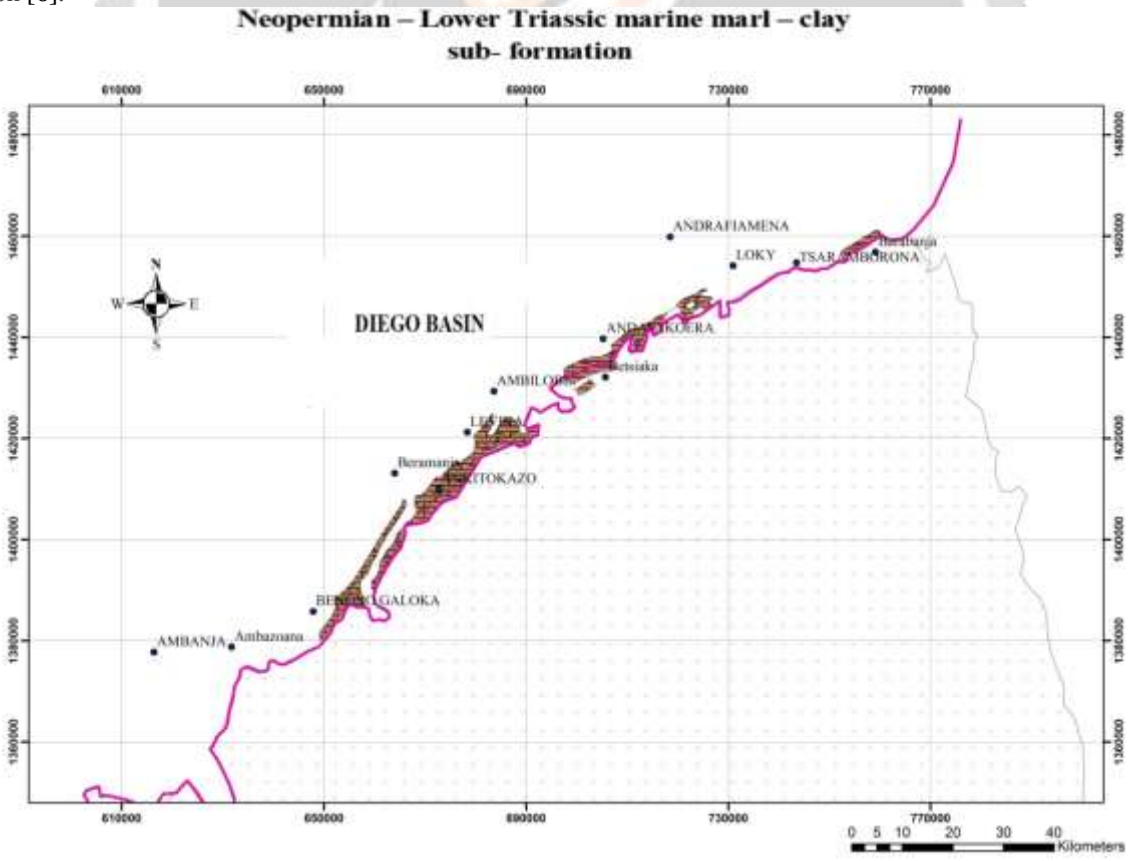
The lithological composition of this sub-formation is predominated by the clays constituted of montmorillonites, hydromica, of rarely kaolins and the limestones of marine origin, intercalatedwith sand and sandstone. From bottom to top, the alternations of the layers, according to the lithological section n°3, n°4 shows the marine transgression, followed by the regional metamorphism. During the period of sedimentation, repeated and significant variations in sea level and the climate were observed in this sub –formation, composed of diferrent layers, namely : arkosic conglomerate and sandstone layer, about 80 m thickness , containing fauna of productus, spirifer and xenaspis and intercalated with micaceous clay shales « sandy-clayey layer, about 50 m thickness, containing Cyclolobus,and Claraia faunas with intercalation of marly limestones, closing in ammonites faunas,exclusively marine animals mostly living near the bottom of inland seas and fish.

- Layer of ordinary shales and schistose or scaly clays, with average thickness of 600 m, with the intercalations and lenses of the feldspars and quartz sandstones, containing some ammonites, and of the fish fossils, marl-calcareous concretions and remains of Stegocephalus amphibian, which lived in the tropical swamp forests.
- Layer of argillaceous oolitic limestones of calcic chemical origin, which are formed in the marine environment, sometimes in the lagoon, at shallow depths and high temperatures or in warm and clear waters, having 200 m, a structural shale.

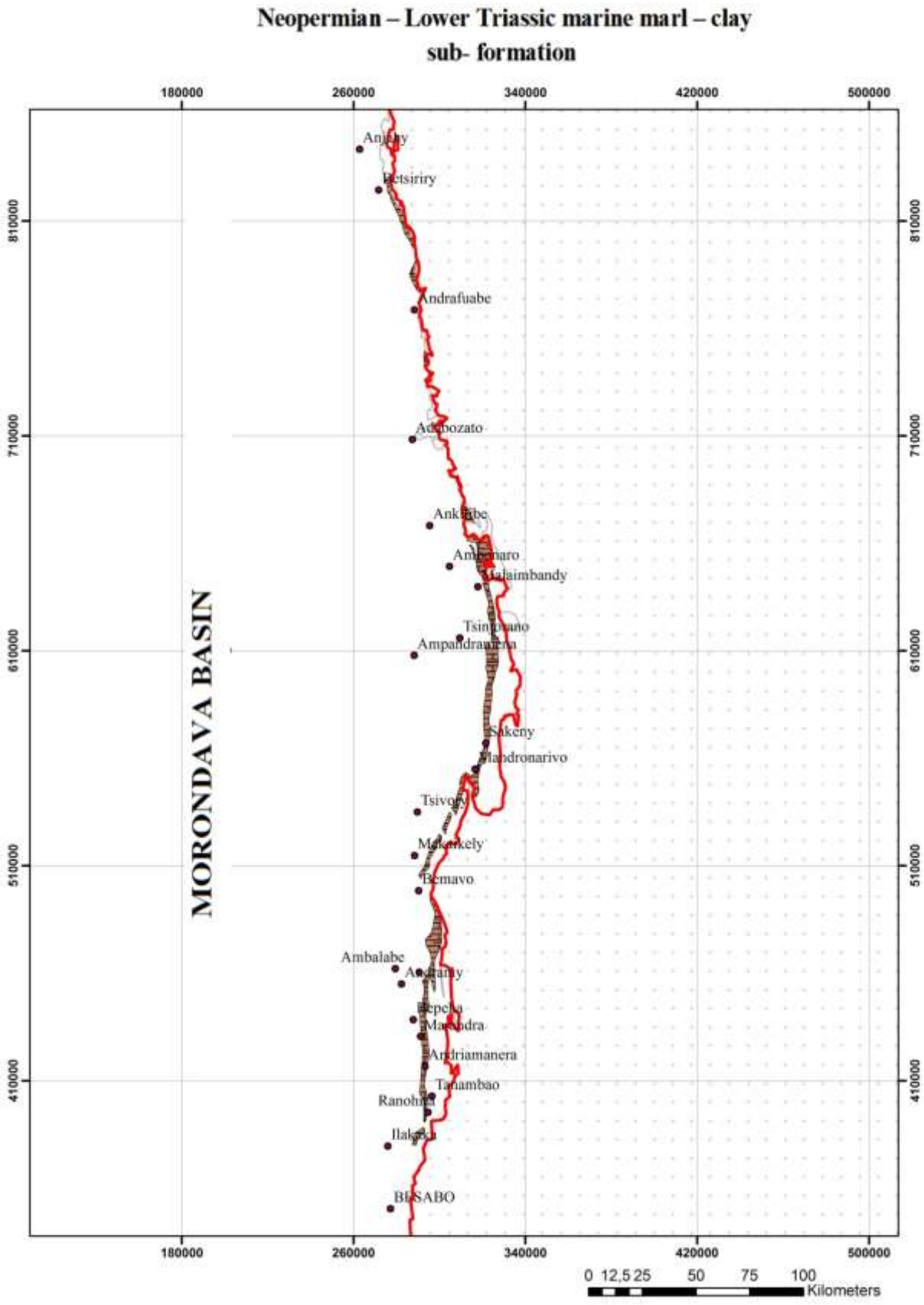
The presence of coral and oolitic limestones in this sub-formation is important, so that it marks a warm sea, specific for the northern part of the Diego basin.

The repositories of this sub-formation formed a strongly reducing geochimical environment justified by the reduction of the majority of the minerals and the absence of the oxidized rocks.

The organic substance content of this sub-formation is strong and stable and of sapropel type predominated by plankton [6].



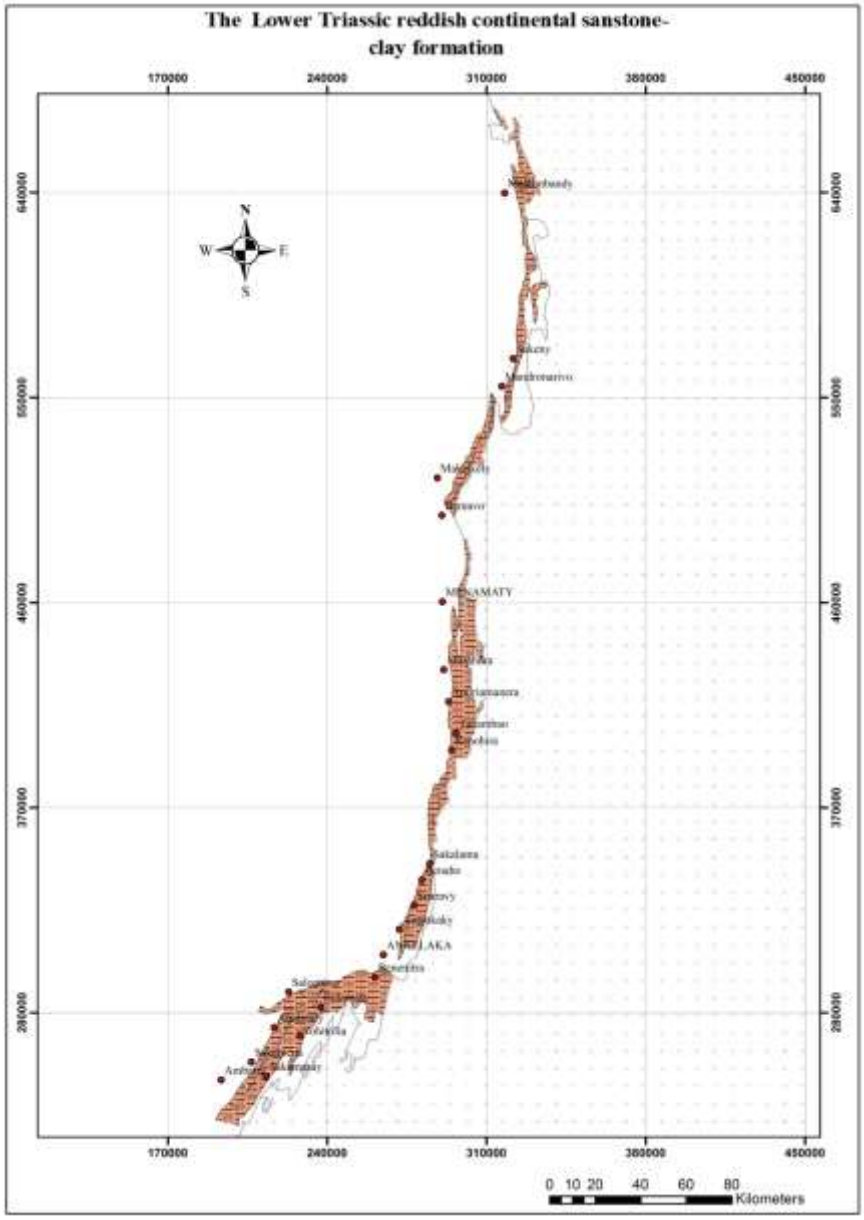
Map 4a : Neopermian – Lower Triassic marine marl – clay sub- formation



Map 4b: Neopermian – Lower Triassic marine marl – clay sub- formation

3 - ***Lower Triassic reddish continental sanstone-clay formation***

The Lower Triassic reddish continental sanstone-clay formation (Map 5) is arranged and widespread form Malaimbandy to the vicinity of Sakamasay, in the system of pits of the Morondava basin and in the Maromandia and Kalabenono territory. Its body look like a lens, the thickness of which decreases toward the north, varying from 1100m in the Sakaraha region to a few meters. The upper limit of this formation is materialized by the unconformity at the level of the upper part according to the geological section n°5, n°6. This formation is of continental origin including lacustrine, fluviatile, deltaic but sometimes lagoonal with arid climatic conditions. This formation consists of fine reddish and arkosic sandstoneand the intercalations of schistose clays and sometimes marls and dolomites, varyind from 1 to 10 m in thickness. Brachiopes and the residues have been observed in the rocks of this formation.The particularities of the reddish sandstone-clayey formation are the absence of the materials indicating intensive mechanical treatments and the traces of the significant displacements during sedimentation and the predominance of hydromicaceous clay with episodic appearance of kaolinite the impurities. The reddish color of the rocks determines the presence of iron oxides and indicates a geochemical oxidation environment [6].



Map 5: Lower Triassic reddish continental sanstone-clay formation

4. DISCUSSION

INSTALLATION OF CONTINENTAL, MARINE AND LAGOON AREAS.

4.1. MARINE AND LAGOON EPISODE

NEOPERMIEN - TRIASSIC
Brief marine and lagoon incursions, marked within the Sakamena series (Neopermian - Triassic), were the origin of the sedimentary deposits that present the lagoon and marine sub-formations. They are the following [3] [6]:

- Marine marl-clay sub-formation Neopermian – Lower triassic (middle Sakamena).
- Upper Permian deltaic clay –sandstone sub-formation.

4.2. CONTINENTAL EPISODE

During this set of Sakamena series, the depositional regime is predominantly continental at the roof.
The sediments of the Sakamena series are generally composed of the detrital and coarse deposits, with alternations of conglomerates, sandstones, some lacustrine and marine limestones. The size of these detrital elements and the sedimentation testifies to a rapid mode of deposition, due to the fluvial transport of high energy reflecting a torrential character.
The formations or sub-formations of continental origin are as follows [3] [6]:

- Upper Permian continental conglomerato- sandstone formation.
- Lower Triassic reddish continental sandstone –clay formation.

The presumed existence of the Neopermien – Lower Triassic deltaic lagoon marl-cleyey sub-formation in the Majunga basin, poses for discussion. Indeed, no well could reach this sub-formation. Apparently, the geophysics seems given its justification of its existence in depth in the pits around Ambalanjanakomby - Ambondromamy. Indeed, the marine incursion of the Neopermian is really confirmed in the northern part of the Diego basin, from the Ankarana graben, in particular the Andavakoera and Barabanja grabens.

5. CONCLUSION

The analysis of the litho-stratigraphic, paleogeograpic, structural formations and the release of the different formation and sub-formations allow us to discern the variations in the Sakamena sedimentary series of Morondava and Majunga-Diego basin. It show two distinct deposition regimes constituting the formations and sub-formation:

- The first, essentially continental, and corresponds to a period of intracontinental rifting. Most of the formations are synrifts and often end in very sarp uncoformities. The variations of these formations are rapid and delimited by accidents of limited extension.
- The second, mainly marine, shows an important development of formations composed of limestones, marls, which are practically found in the Karroo –Isalo grabens.

After the analysis of the characteristics of the formations, in the composition of the Sakamena series it released:
Three (03) formations with two (02) sub-formations, including:

- Two (02) sub-formations of marine or mixed which are likely source rocks (rich in organic matters, planktons), covers rocks (of thick layers of clays) and reservoir rocks or traps (reefs and ooliticcoral massifs, fissured limestones) ;
- two (02) formations of continental origin, which are likely reservoir rocks.

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