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PRELIMINARY GEOCHEMICAL AND SEDIMENTOLOGICAL ANALYSIS IN NW CORFU: THE MIOCENE SEDIMENTS IN AGIOS GEORGIOS PAGON

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Abstract

A total of 80 samples of the Miocene deposits in Agios Georgios Pagon (NW Corfu) were selected and studied in regard of their geochemical and sedimentological characteristics. Organic content and calcium carbonate measurements were used and combined to investigate the depositional conditions and preliminary source rock potential. TOC analysis presented significant values ranging up to ~3% of organic carbon, with an average of 0,7%, and thus providing a promising basis for further assessment of their source rock potential. Calcium Carbonate measurements presented an average of ~27%. Fluctuations, correlative trends and the combined use of sieve analysis provide insights and alterations in the depositional conditions. The studied strata are part of an ongoing investigation throughout the Miocene to Pliocene sediment accumulations in Corfu, from Lefkimmi in the SW part to Agios Stefanos to the NW. The depositional conditions and source rock potential should provide new insights in understanding the geotectonic processes and basin development in the western margin of the Hellenic Fold and Thrust Belt.

Keywords: *TOC, $CaCO_3$, Corfu, Ionian Sea, grain size analysis, Hellenic FTB.*

Περίληψη

80 δείγματα από τις Μειοκαινικές αποθέσεις στον Άγιο Γεώργιο Πάγων επιλέχθηκαν για εργαστηριακές αναλύσεις των γεωχημικών και ιζηματολογικών τους χαρακτηριστικών. Η περιεκτικότητα σε οργανικό υλικό και ανθρακικό ασβέστιο υπολογίσθηκαν και συνδυάστηκαν τόσο για τον προσδιορισμό συνθηκών απόθεσης, όσο και για την εκτίμηση μητρικών πετρωμάτων στην περιοχή μελέτης. Η περιεκτικότητα σε οργανικό υλικό έδειξε σημαντικά αποτελέσματα που φτάνουν και το 3%, με ένα μέσο όρο ~0,7%. Το ανθρακικό ασβέστιο παρουσίασε μια μέση τιμή στο 27%. Διακυμάνσεις, συγκριτικές τάσεις και ο συνδυασμός της κοκκομετρικής ανάλυσης έδειξε διαφοροποιήσεις στις συνθήκες απόθεσης. Τα υπό μελέτη στρώματα είναι τμήμα μιας ευρύτερης μελέτης των Μειοκαινικών - Πλειστοκαινικών ιζημάτων στην Κέρκυρα, από την Λευκίμμη στο ΝΔ τμήμα ως τον Άγιο Στέφανο στο ΒΔ. Οι συνθήκες απόθεσης και η αξιολόγηση μητρικών πετρωμάτων δύναται να βαθύνει την κατανόηση για τις γεωτεκτονικές διεργασίες και την εξέλιξη της λεκάνης στο δυτικό όριο του ελληνικού συστήματος πτυχώσεων και επωθήσεων στη Δυτική Ελλάδα.

Λέξεις κλειδιά: *Οργανικό υλικό, Ανθρακικό ασβέστιο, κοκκομετρία, Κέρκυρα, Ιόνιο.*

1. Introduction

Research and commercial interest in oil and gas prospects in western Greece has risen in the past years. Existence of oil and gas is proven by surface shows and gas leaks throughout the Ionian Sea and Ionian islands (Fig.1). Corfu Island lies in the northern Ionian Sea and on the northwestern flanks of the Hellenic Fold and Thrust Belt (FTB). It consists of both the Ionian and pre-Apulian geotectonic zones, as most of the Ionian Islands.

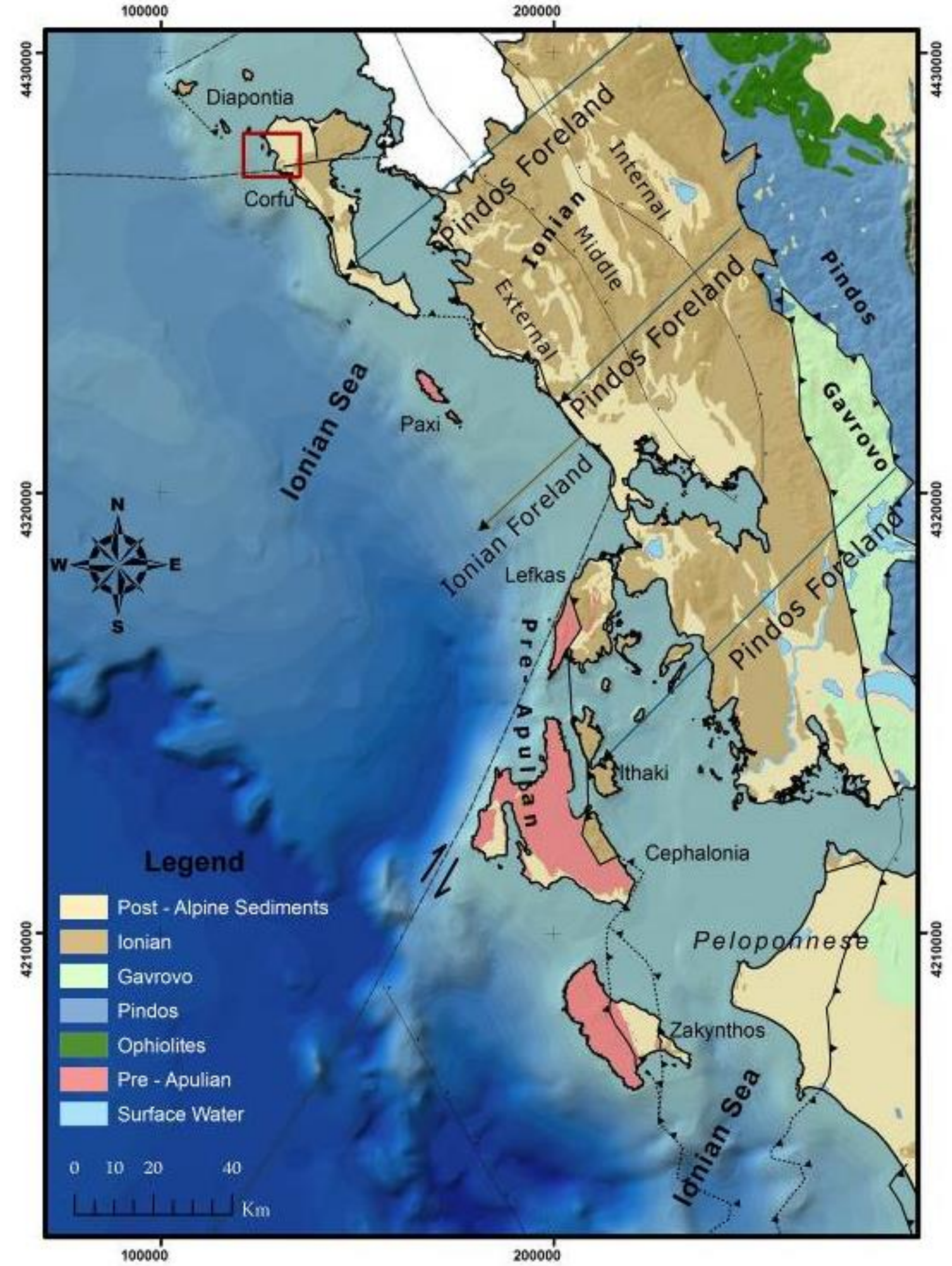


Figure 1 - Generalized geotectonic map of Western Greece (modified by Zelilidis *et al.*, 2015).

The Balkan peninsula FTB consists of the external Hellenides and Albanides in Albania. The geological setting of the broad on-shore and off-shore western Greece is the southern extension of the important Albanian oil and gas provinces, where two potential hydrocarbon systems (Mesozoic and Tertiary) have been distinguished (Zelilidis *et al.*, 2003; Maravelis *et al.*, 2012; Maravelis *et al.*, 2014a; Zelilidis *et al.*, 2015). Important hydrocarbon reserves have been associated with fold and thrust belts throughout the world (e.g. Central Italy, Albania, and Saudi Arabia), increasing academic and industrial interest (see ref. Maravelis *et al.*, 2012). It has been established that ~14% of the world's reserves are discovered within FTBs developed at convergent plate boundaries.

Western Greece still remains poorly explored despite petroleum seepage evidence and thorough academic research (see ref., Zelilidis *et al.*, 2015). Corfu's widespread sedimentary accumulations are under an ongoing and detailed investigation, combined with previous and ongoing studies in Zakynthos, Diapontia Islands and Lefkada (Maravelis *et al.*, 2014a and 2014b); in order to further understand the mechanisms and characteristics of the Hellenic FTB. The present preliminary report includes results of geochemical and sedimentological investigations in the Miocene sediments of Agios Georgios Pagon, in Northern Corfu (Fig.2).

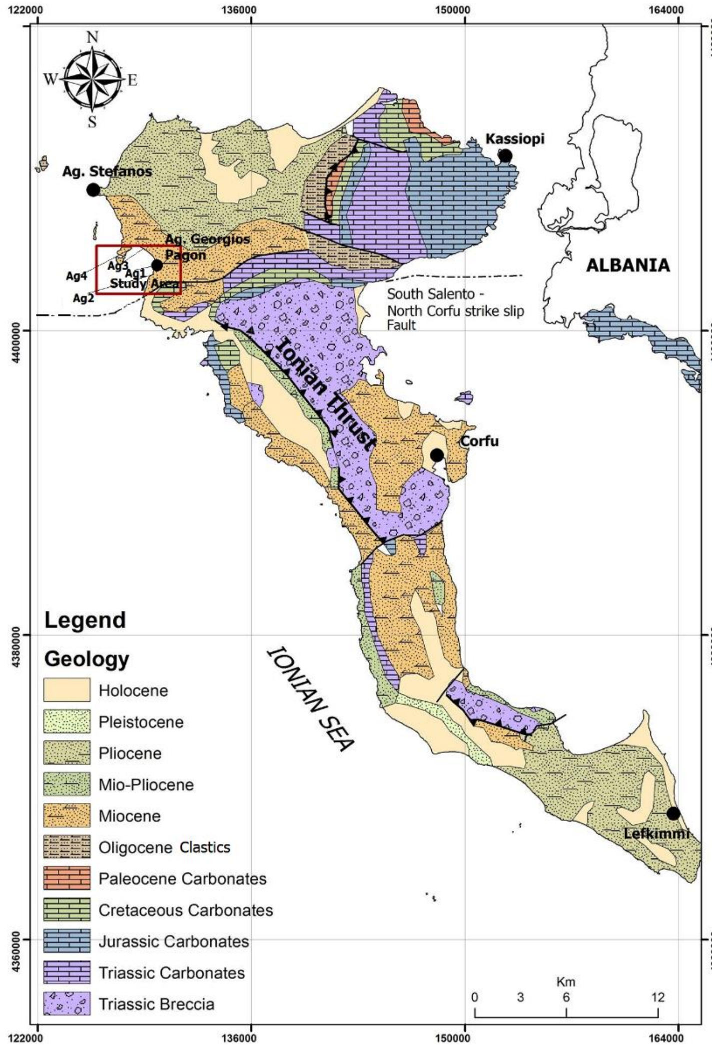


Figure 2 - Generalized Geological map of the study area (modified by IGME, 1971).

2. Geotectonic Setting

Corfu Island lies on the northwestern edge of the Hellenic FTB system of Greece, south of Diapontia islands (Fig.1). Sedimentation on the Hellenic FTB occurs in platforms, such us the pre-Apulian and Gavrovo zones, and deep basins, such us the Ionian and Pindos Zone. The most external zones, pre-Apulian and Ionian Zone, where Corfu is situated, are mainly separated by the Ionian Thrust system. The Ionian Thrust is a crustal-scale fault system which pushes the lower Ionian Zone over the pre-Apulian zone. The thrust boundary is marked by intrusive Triassic evaporites and corresponding Triassic Breccia, which can be observed in various sights in Western Greece (Epirus, Akarnania) and are present in the central part of the island (Fig.2). Major strike-slip faults have separated the Ionian Thrust into two major parts: The northern part, which bisects the island east of the study area (Fig.2) and the southern part, where the thrusting area moves parallel to the western shoreline. The South Salento - North Corfu strike slip fault zone is another major tectonic feature which controls the evolution of the basin, since the Oligocene. Such faults present significant role in basin evolutions in Pindos Foreland (Konstantopoulos *et al.*, 2013).

The geological complexity of the area corresponds to the collision and convergence of the African and Eurasian plates since the Mesozoic (see ref. Maravelis *et al.*, 2014a). The pre-Apulian Zone is the eastern continuation of the Apulian platform, while the Ionian Zone was initially a fault-controlled extensional basin adjacent to the Pindos Ocean (up to early Jurassic). In both zones, carbonate sedimentation took place during the Mesozoic. Submarine fan deposits took place during the Tertiary, as part of Pindos Foreland Basin. Agios Georgios Pagon is part of the broad Karousades Miocene to Pliocene sedimentary basin, which is suggested to correspond to distal turbidite fan deposits from Pindos foreland (Monopolis and Bruneton, 1982). Field stratigraphic observations provided evidence of deep-sea sedimentation (Fig.3a). It has already been established that Ionian Thrust activity during the early Miocene has changed the tectonic regime of the northern Ionian sub-basins, as is evident in the piggy-back basins in Diapontia Islands to the North (Makrodimitras, 2011). Local branching of the Ionian Thrust and strike-slip fault activity may explain spatial differences and different sub-basin evolutions. During the Middle Miocene, further activity of the Ionian Thrust in Corfu results to the elevation of the Mesozoic Carbonates to the northeastern part of the island.

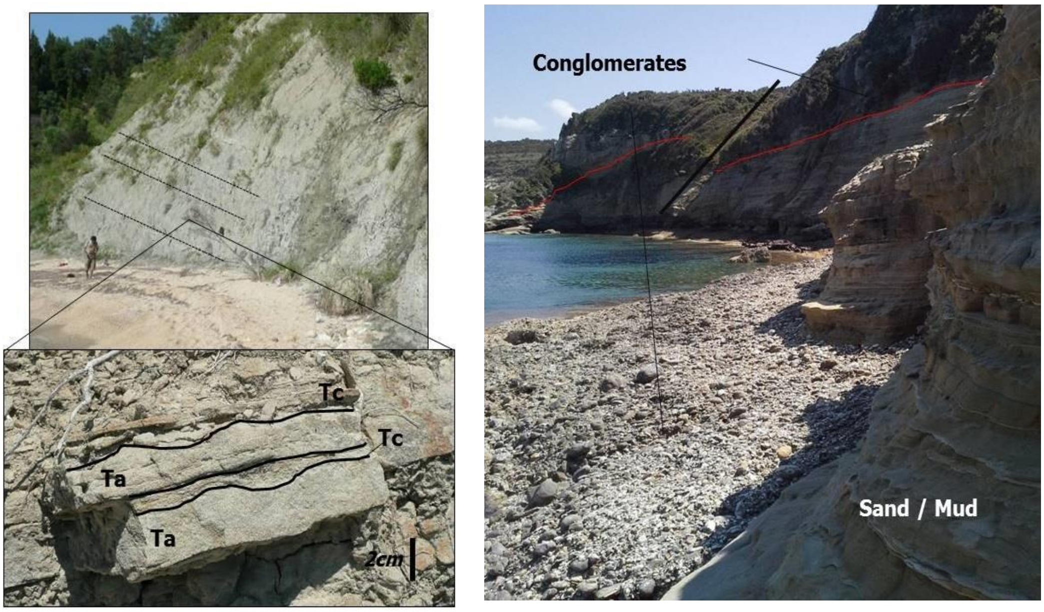


Figure 3 a, b. - a. Ag2 section, with probable Bouma sequence. b. Miocene-Pliocene border in Ag. Stefanos cape.

Karousades basin expands westward of the anticline structure of the Mesozoic Carbonate series, where the Jurassic Limestones (also known as Pantokratoras Limestones) dominate the eastern part of the island. South Salento - North Corfu strike slip zone bounds the basin to the south, where the Mesozoic Carbonates are exposed after a thick transitional zone of loose breccia. The Pliocene succession continues comfortably to the North of Agios Stefanos cape (Fig.2). The Miocene - Pliocene interval is marked by two conglomerate beds with sandstone intercalations, of approx. 10m thickness each (Fig. 3b). The typical, in other examples of the Ionian basins such as Zakynthos, occurrence of the Messinian evaporates is absent in the study area. The Messinian deposits can be identified in the Arillas beach, north of the study area, and comprise of siltstone and unconsolidated sandstone alterations. To the south, the series is slightly altered, with the Miocene-Pliocene generally undivided.

3. Stratigraphy

Agios Georgios Pagon sediments are part of the early to middle Miocene sedimentation in the broad Karousades basin of Northern Corfu. The stratigraphy of the Ionian Zone has been extensively studied (see ref. Zelilidis *et al.*, 2015). Most of the zone's features are present in Northern Corfu (Fig. 4). Namely, the Mesozoic carbonate series are exposed in the NE part of the island. Jurassic «Pantokratoras» and Senonian «Vigla» limestones form a large anticline.

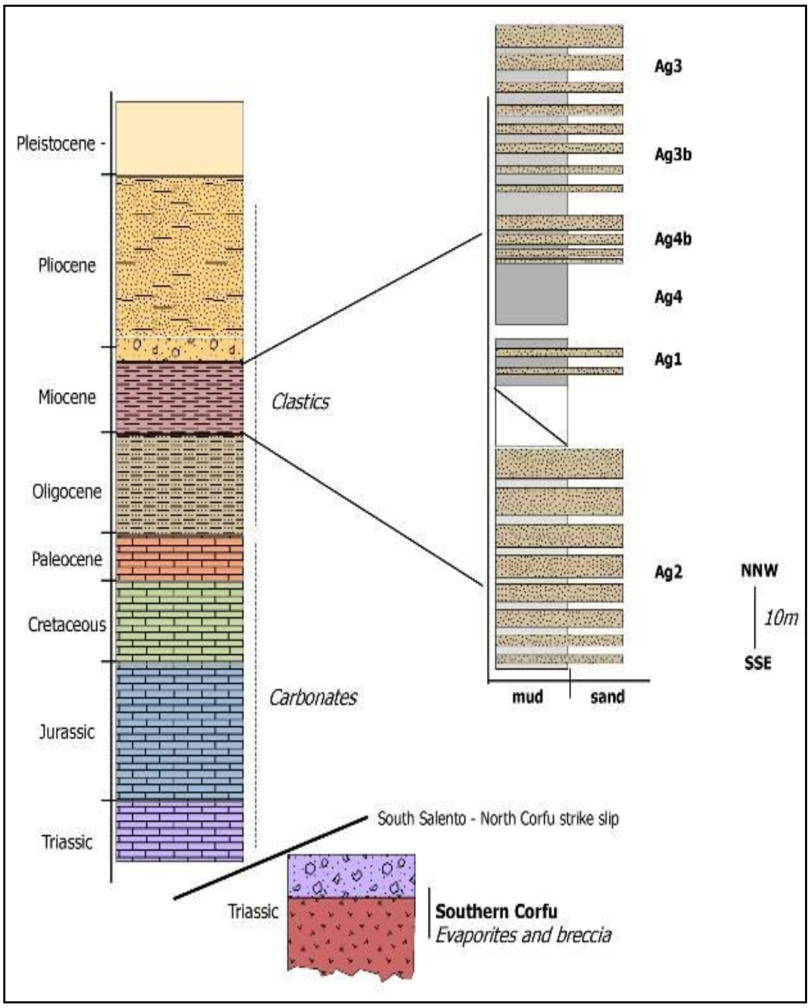


Figure 4 - Stratigraphic Column of Northern Corfu and study area.

Several sections where investigated and measured in the Agios Georgios Pagon bay, regarding both their vertical and horizontal characteristics. A normal fault to the North exposes the Mesozoic basement, while the South Salento- North Corfu fault zone controls a transitional zone of unconsolidated conglomerates and breccia to the south, after which the carbonate basement is also exposed (Cretaceous limestones). The bay was studied at both its flanks, southern (Ag1, Ag2) and northern (Ag3, Ag3b, Ag4) and at its central parts (Ag4b) and a synthetic column is presented in figure 4.

The southern flank dips towards the fault zone, suggesting Ag2 section as the oldest. Ag2 section is a ~30m succession of grey mudstone and sandstone alterations. Sandstone thickness and ratio increases upwards. Section Ag1 is approx. 5m, with blue-grey mudstones and thin sandstone intervals. The northern equivalent, Ag3b and Ag3 sections may be the youngest sediments, of a combined thickness ~30m of sand/mud alterations, starting with 1:1 ratio and with sandstone thickness increasing upwards. Section 4 consists of mudstone strata with a variable thickness from 2 to 10 cm, while section 4b presents four sandstone beds. These sandstone beds are more consolidated than in the lower parts, and also present a thickening trend upwards. The Agios Georgios Pagon overall thickness is approx. 150m, while ~30m of strata (between Ag1 and Ag2) where not exposed due to recent landslides.

4. Laboratory Results

3.1 Organic matter content

Quantitative determination of organic carbon in the sample based on the oxidation of organic carbon content in the samples was performed with the titration method (Gaudette *et al.*, 1974).

The studied samples present a variable TOC content (Fig.5), ranging from 0% up to 2,7%. The highest TOC content values were found in the NE sections (Ag1, Ag2) where numerous samples are above the 0,5% mark. The northwestern flank and central part of the bay (Ag3, 3b, 4, 4b), present lower TOC values, with some samples presenting values over 0,5%. As a result, further studies and organic matter evaluation will be focused in the southern flank of Agios Georgios Pagon.

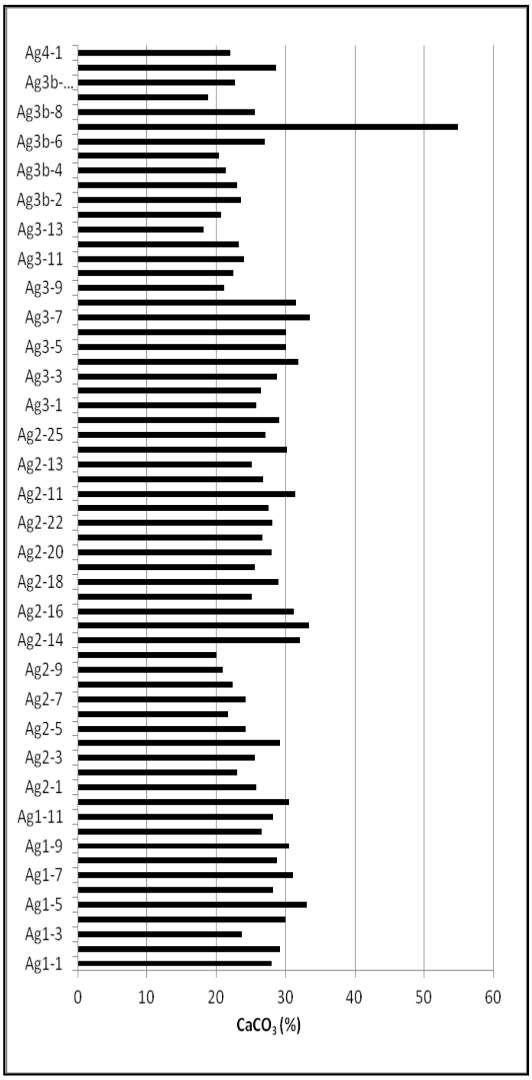
3.2 $CaCO_3$ measurements

For the determination of calcium carbonate ($CaCO_3$) content, the method for decomposition of the $CaCO_3$ with CH_3COOH (acetic acid) is used (Varnavas, 1979). This method relies on the full decomposition of calcium carbonate ($CaCO_3$) with acetic acid (CH_3COOH), to form a soluble salt of calcium acetate ($(CH_3COO)_2Ca$) and escape the produced carbon dioxide (CO_2). The samples present a general trend between 20% and 30% with the exception of one sample (Fig. 6).

3.3 $CaCO_3$ - TOC correlations

Certain physical and geochemical characteristics control the relation between TOC and $CaCO_3$ in sediments and several studies have correlated these two parameters in Greek sites (see ref. in Nioti *et al.*, 2013). The decomposition of TOC in deeper parts produces CO_2 which in turn accelerates dissolution of $CaCO_3$ and this process is often portrayed with proportional values of the variables.

Positive relations can also be observed where $CaCO_3$ productivity is present or by other controlling factors such as sedimentation and/or burial rates. A comparative observation of the variables' fluctuations presents a general inverse trend: TOC presents higher values in the southern flank (Ag1, Ag2), while calcium carbonate presents its lower values. A general increasing trend of $CaCO_3$ is accompanied with a general decrease of the organic matter content, moving from the lower to the upper parts of the column.



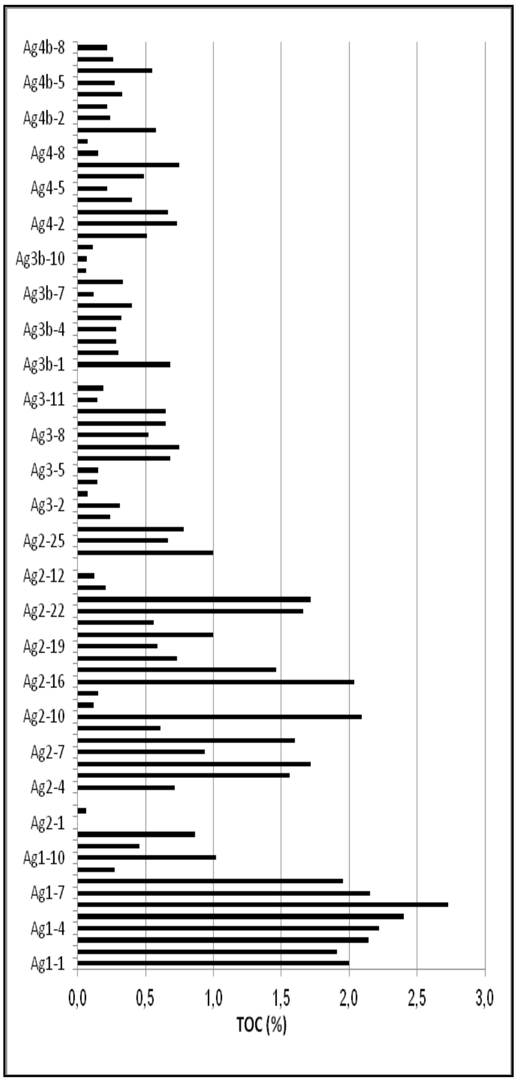


Figure 5 - TOC content in studied samples **Figure 6 - $CaCO_3$ content in studied samples.**

3.4 Grain size analysis

The grain size analysis, aims to determine the lithology and grain size parameters to describe the particle size distribution of sediments. The method of sieve analysis for the sediments > 63mm, and the method of the pipette analysis for the sediments was according to the classification of Folk and Ward (1957), whereas the statistical parameters were also calculated (median Md, mean average Mz, standard deviation σi, asymmetry SK1 and curvature KG).

According to the classification by Folk (1968), as derived from the grain analysis results, the samples can be generally described as mud and sandy mud. The constructed Passega (1964) plot presents that the samples were transferred primarily as a homogeneous and pelagic suspension (fig.7). The σ1/Md plot by Stewart (1958) indicates slow deposition of sediments in calm water, while the σ1/Sk1 plot (fig. 8) by Valia and Cameron (1977) indicates deep water environment for the majority of the samples. A few samples from sections Ag3b and Ag4b present shallower environments, possibly representing a general paleoenvironmental change in the upper parts of the stratigraphic column.

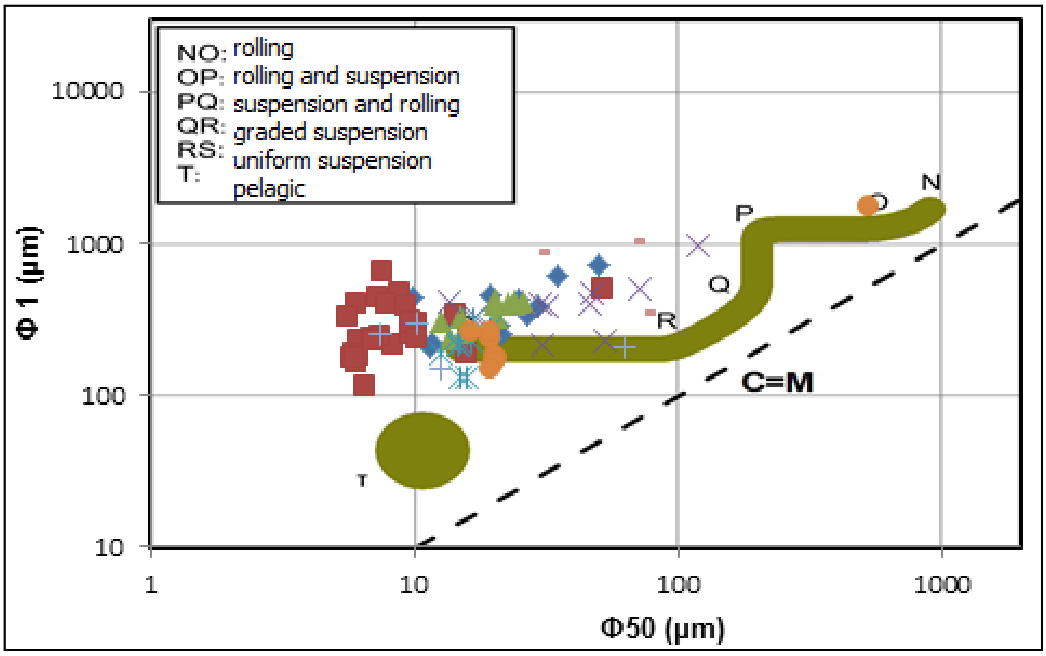


Figure 7 – Passega diagram for studied samples.

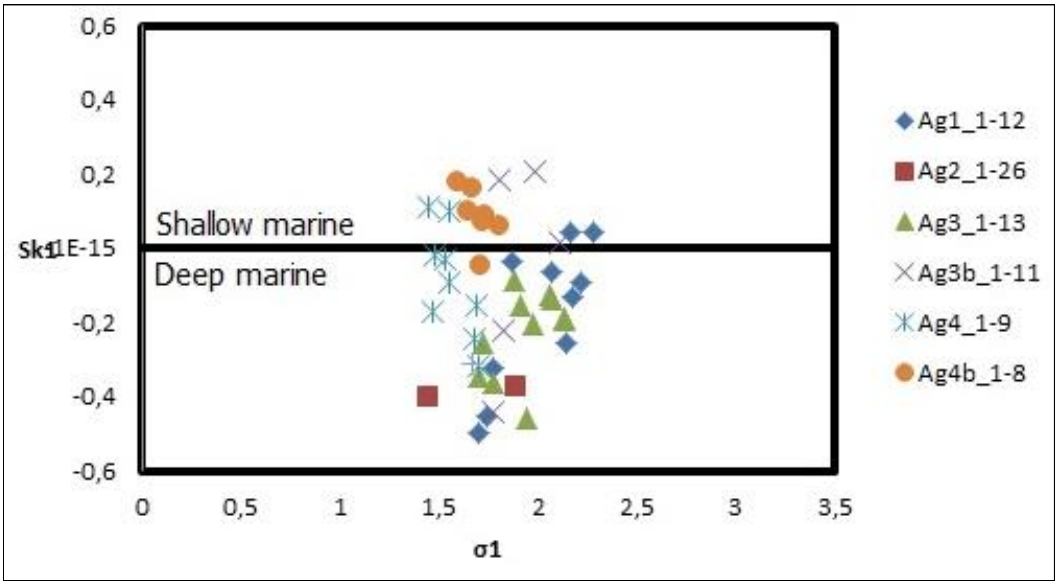


Figure 8 - Valia and Cameron diagram, with σ1/Sk1 plot where studied sediments mostly deposited in deep marine conditions.

5. Conclusions

The Miocene sediments in Agios Georgios Pagon bay are part of a broad Miocene to Pliocene sedimentary basin in Northern Corfu, which corresponds to the distal submarine fan deposits of the westernmost Pindos Foreland. The evolution of the Pindos foreland basin, after the Oligocene, is mainly controlled by major strike-slip fault systems (mainly the South Salento-North Corfu fault system) and by the activity of the Ionian Thrust. The Messinian evaporites, present throughout the Ionian Zone and other basins of the Hellenic domain, are absent from the studied area.

Sequence stratigraphy, extensive field work and grain size analysis support the conclusion that the sediments where deposited in deep, calm waters as a homogenous suspension. A number of sandstone beds, in sections Ag2 and Ag3, present Bouma sequence. Samples from Ag3b and Ag4b, which comprise the upper part of the stratigraphic column, present shallower depositional environments, possibly indicating sea level changes during the Middle Miocene and/or uplift incidents due to the activity of the Ionian Thrust. The Miocene-Pliocene boundary is exposed north of the study area, marked by two 10m thick conglomerate beds.

Laboratory examination presented promising TOC values (>1%) for the southern part of the study area, which corresponds to the lower part of the stratigraphic column. Further investigation is required, in order to evaluate the type of the organic content and the evaluation of source rock potential.

Ongoing investigations in the Pliocene succession in the north and in the Miocene to Pliocene sediments in Southern Corfu will provide not only a general modeling of the basin evolution in the western margins of the Pindos Foreland, but will also provide helpful insights in the evaluation of the Tertiary hydrocarbon generation prospects in the broad area.

The absence of the Messinian evaporites, a very important seal in the Hellenic domain, as far as petroleum systems are concerned, further focuses the investigation in discovering alternative trapping and sealing of produced hydrocarbons. The anticline structures in the northern part of the island, which are controlled by the Ionian Thrust and the strike-slip fault systems, may require further research concerning their role as traps. On the other hand, the thick Pliocene succession in Agios Stefanos (observed over ~500m alterations of mud/sand) needs to be studied in regard of its source rock potential but also of its reservoir capabilities.

Studied deposits are the major source of the Ionian foreland and in relation with the fact that these deposits are buried within Ionian foreland could be act as the major source for hydrocarbon generation of Miocene deposits in Ionian foreland basin.

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