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DEPARTMENT OF HISTORICAL GEOLOGY - PALAEONTOLOGY

MSc Thesis

"Stratigraphy, reservoir characteristics and paleogeographic distribution of the Triassic to Eocene carbonates in Western Greece and Albania, based on field, laboratory and well data."

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1. Introduction

The thrust belt in the Balkan Peninsula along the margin of the Apulian foreland is known as the External Hellinides in Greece and the Albanides in Albania. It has been divided into three tectonostratigraphic zones which are from east to west: the Gavrovo Zone in Greece, equivalent to the Albanian Kruja Zone; the Ionian Zone, equivalent to the Adriatic basin and the Pre-Apulian (or Paxoi) Zone in Greece, equivalent to the Sazani Zone in Albania (*Fig. 1*). The rock successions in all of these zones consist of Mesozoic and Cenozoic strata which have been thrust westwards onto the Apulian foreland. From Eocene to Miocene time, the migrating internal Hellinide orogeny to the west caused the similtanous migration and the compressional deformation of the foreland basin in front of the orogen (Underhill, 1985; Karakitsios, 1995; Roure et al., 1995; Karakitsios and Rigakis, 2007; Robertson and Shallo, 2000; Karakitsios, 2013).

Three major structural trends are recognized in Western Greece and Albania (*Fig. 1*). In the first place, major thrust fault trend NNW-SSE. These are locally offset by east-west oriented faults, some of which, such as those in the Gulf of Corinth, may have been inherited from Early Mesozoic rifting (Robertson et al., 1991); in the Cenozoic, they acted either as wrench faults during thrusting (e.g. the Petoussifault) or as basin-bounding normal faults (e.g. in the Gulf of Patras) (*Fig. 1*). Thirdly, a series of dextral, NE-SW trending strike-slip faults are present between the Cephalonia fault in the south and the Shkoder-Peje (Scutari-Pec) fault in the north. These strike-slip faults appear to have taken up relative motion in the Neogene between the Anatolian-Aegean Plate and the African-Apulian Plate north of the Hellenides subduction zone (Walcott and White, 1998).

The aim of this study is to synthesize, from literature and well data, the paleo-environments, nature, stratigraphy and reservoir characteristics of the Triassic to base Tertiary carbonates in Albania and Greece. Furthermore, as an additional research, the Epirus area in Greece has been studied. Another goal of this study is to map the repartition and paleo-environments of these carbonates and of their reservoir parameters and describe the evolution of these carbonates through time and location.

The area of interest that has been studied is the Western part of Greece and Albania. Specifically the study is focusing to the North-Western part of Greece and the South-Western part of Albania.

In order to do this evaluation about carbonate units in our study area, a big range of data, like: porosity, lithology, paleo-environment, well data and permeability, whenever was available (permeability values were very limited) have been analyzed carefully. Furthermore, after this has been done for the entire area, ArcGIS software has been used to visualize the results within paleogeographic and paleo-environment maps, as well as the reservoir characteristics of these units. In addition, the reservoir potential of these carbonate units will be discussed and also compared, in order to draw some conclusions about the petroleum potential of the area.

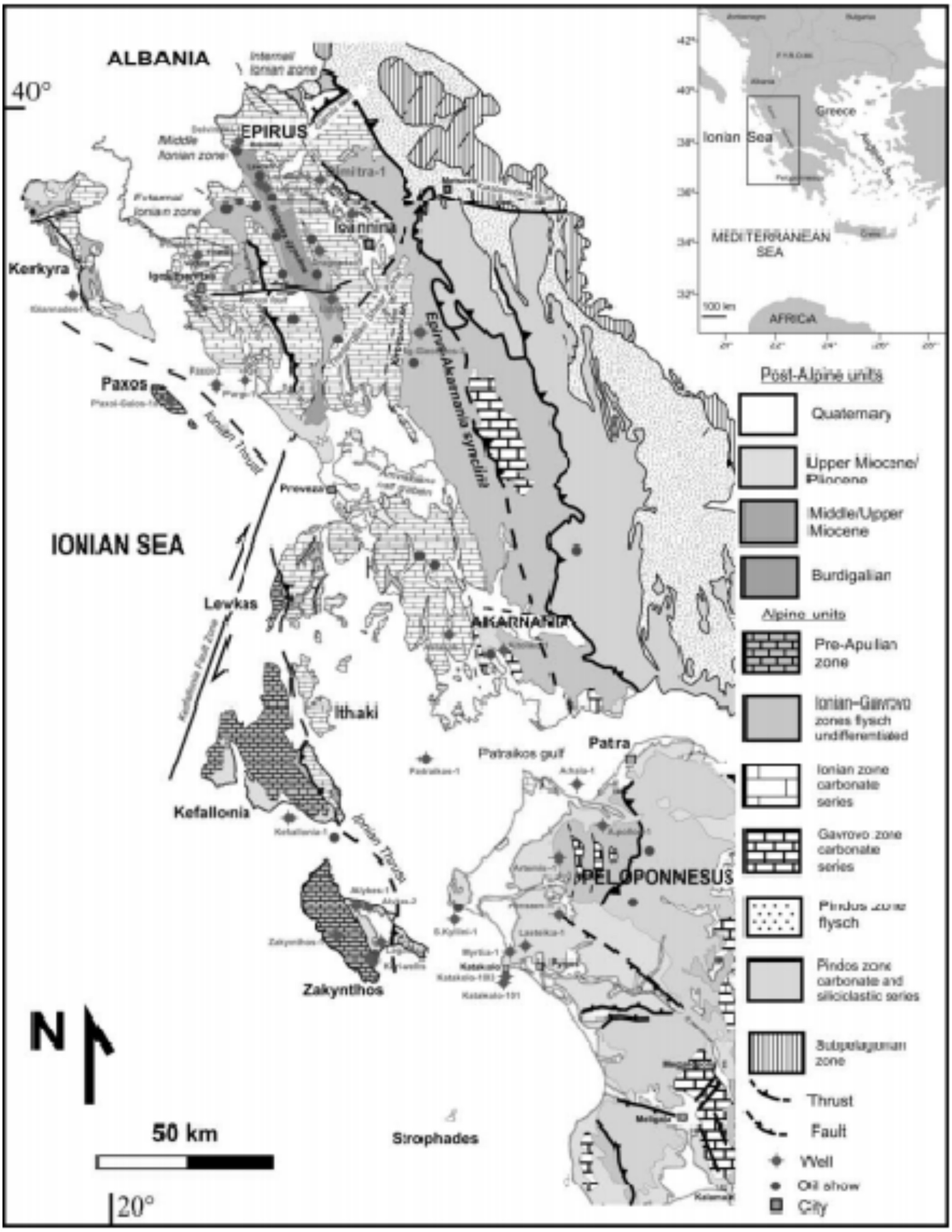


Figure 1: Geomorphological map Western Hellinides showing the major geological elements (tectonostratigraphic zones, basins, faults). (Karakitsios, 2013).

2. Stratigraphy

The lithostratigraphy description and basin fill evolution of the study area will be divided into Ionian, Pre-Apulian and Gavrono geotectonical zones. Also, a description of the Peri-Adriatic Depression will be included in this section. Within this chapter, each tectonostratigraphic unit will be described for both Greece and Albania as an entire section in order to highlight differences and similarities.

2.1 Ionian Zone (Greece-Albania)

The Ionian zone (*Fig. 2* and *3*) is made up of three distinct stratigraphic sequences: prerift, synrift and postrift (Karakitsios, 1995, 2013). The Ionian Zone continues up to Albania and can be considered as the same tectono-stratigraphic unit as in Greece (*Fig. 3*). However, some differences occur within the Albanian region. The Albanian part of the Ionian Zone consist of thrust belts. Thrust belts are the result of horizontal compression at convergent margins. Thrust follows a ramp-flat geometry cutting up-stratigraphy toward the foreland. Movement of a thrust sheet over a ramp-flat geometry of thrusts requires hanging-wall deformation, generating fault bend folds or ramp anticlines which may be accompanied by back thrusts.

Thrust belts are divided using only tectonic criterion. Based on this criterion the thrust belts are structured in different time. The part of the Ionian Zone, which is situated in the Albanian region, consists of three thrust belts which from east to west are: Berati belt, Kurveleshi belt and Cika belt.

The oldest known at outcrops and wells in the prerift sequence (Jurassic rifting), is represented by Lower to Middle Triassic Evaporites (>2000m), composed of anhydrites, gypsum and halite with usually thin interbeds of limestones or dolomites. They are assigned a Scythian-Ladinian age (Middle Triassic) (Karakitsios, 1995). This unit, represented by white gypsum and dark limestone, is exposed at surface in the hangingwall of thrust faults or as diapirs. The Albanian Mesozoic sedimentation seems to be the same as in Greece and began with Upper Triassic evaporites. The evaporites are composed mainly of halite, gypsum and anhydrite with interbedded dolomite and thin greenish and red shale. Evaporites are exposed at Kardhiqi, Dhrovjan-Delvina and Dumrea and farther south in Greece (Zavrohon, Corfu, Filat, Kefallonia, Zakinthos) (Underhill, 1988). Halite deposits up to 300m thick, and more than 2000m in some wells in the northern part of Greece, such as in *Thalis*, have been recorded in drill holes from the southern Dhrovjan salt mine in the Delvina sheet, where total evaporite thickness of 500-2000m are recorded.

The prerift sequence is completed by the Upper Ladinian-Rhaetian limestones and dolomites of the Foustapidima Formation and by the overlying shallow water limestones of the Pantokrator Formation (Hettangian to Sinemurian). Jurassic deposits feature remarkable facies homogeneity and consist of calcareous algae, benthonic foraminifera and locally brachiopods. On the other hand, in Albania, Upper Triassic dolomites and limestones with thin organic-rich shale interbeds are overlain by Liassic pelagic and neritic limestones, limestones with cherts, marl and shale interbeds, which were deposited almost continuously throughout the Jurassic and Cretaceous and up to the Eocene. Locally, limestones with chert of Middle Jurassic are deposited unconformably onto Lower Jurassic neritic limestones.

The overlying synrift sequence begins with the Pliensbachian pelagic Siniais limestones and his lateral equivalent Louros limestones, overlain by Ammonitico Rosso and 'Limestones with filaments', laterally replaced and overlain by Posidonia Beds (Karakitsios, 1995). The boundary between the Pantokrator Limestones and Siniais Limestones is gradational. Siniais Limestones correspond to the general deepening of the Ionian domain with the formation of the Ionian Basin. The structural differentiation that followed separated the initial basin into smaller paleogeographic units with a half –graben geometry. This is recorded in the abruptly changing thickness of the synrift formations that take the form of synsedimentary wedges. In the deeper parts of the half grabens, these wedges include complete Toarcian-Tithonian successions, whereas in the shallower parts of the half grabens, the successions are interrupted by unconformities. The directions of synsedimentary structures indicate that deposition was controlled both by structures formed during extension related to the opening of the Neotethys Ocean and by halokinesis of evaporites at the base of the Ionian Zone succession. Within the Siniais Limestones, chert beds, abundance of radiolarians and significant thickness variations are observed. The Siniais is assigned a Pliensbachian age. The Ammonitico Rosso (Toarcian-Aalenian) is represented by two facies: blue marls with intercalations of breccias and beds of nodular marly limestones with 'filaments' and pyrite, with an abundance of ammonite fauna. There is an unconformity between the base of the Ammonitico Rosso and the underlying formations which marks a period of uplift and erosion at the beginning of the Toarcian. This led to krastification of Pantokrator Limestones, and intensive erosion of the Siniais Limestones.

"Ammonitico Rosso" sediments are overlain by Limestones with Filaments (Bajocian-Bathonian), represented by a series of nodular limestones overlain by a calcareous-siliceous series with abundant 'filaments'. Both formations are laterally replaced by the Lower Posidonia beds, represented by siliceous shales. The Upper Posidonia Beds (Callovian-Tithonian) are integrated by layers of cherts and argillaceous cherts with intercalations of limestones and abundant Posidonia fauna. The thickness of this formation is extremely variable, from a few meters to 250m.

The post-rift sequence begins with the pelagic Vigla Limestones, whose deposition was synchronous throughout the Ionian Basin, beginning in the Early Berriasian. The Vigla Limestones are deposited on the synrift structures and, in some cases, directly overlie prerift units. The base of the Vigla Limestones represents the breakup unconformity of the postrift sequence in the Ionian Basin. Longlasting differential subsidence during the deposition of the Vigla Limestones was probably caused by continued halokinesis of the basal Ionian Zone evaporites. In the Epiros area (Ionian Zone), this unit consist of a series of fine sublithographic limestones occurring is small beds of 5-20cm, with numerous radiolarians and numerous layers of chert also enriched with radiolarians. These layers of chert become more abundant towards the upper part of the Vigla (Albian-Cenomanian), containing intercalations of green, red and locally black shales known as the 'Upper siliceous zone' or Vigla shales. They are equivalent of the general anoxic event of Bonarelli (OAE2) at the Cenomanian-Turonian boundary interval of the Ionian zone and equivalent also to the Paquier Evet (OAE1b) of Lower Albian age, also on the Ionian zone (Tsikos et al., 2004; Karakitsios et al., 2007) and extend to Italy (Aptici marls) and Albania. The formation features considerable thickness variations, from 900m at Nemertska to complete absence near Kanallakion, explained by the pre-existing relief before the Tithonian transgression as well as by continuing localized subsidence. The Senonian Limestones, which rest on the Vigla limestones, correspond to calciturbidites comprising limestones and rudists and microbrecciated intervals containing pelagic fauna. The facies distribution of the Senonian reflects the separation of the Ionian Basin into a central area (middle and outer part of the Ionian Zone) characterized by deeper water sedimentation and two surrounding talus slopes, issued from western Gavrovo platform and western Apulian platform. Both platforms provided the clastic carbonate material that was transported by turbidity currents into the Ionian Basin. The microbreccia limestones (Senonian) were deposited during the Turonian-Eocene. In Northwestern Epirus area, near Mitsikeli and Bureto, the maximum thickness in outcrops is about 345m.

During the Eocene, the supply of clastic material diminished significantly, especially in the central Ionian Basin. The main depositional facies during this period were platy wackestone and mudstone with Globigerinidae and siliceous nodules, analogous to those of the Vigla Limestones, but lacking continuous cherty intervals. The greatest thicknesses of the Eocene units can be found in the marginal parts of the Ionian Zone, where the microbreccias are more frequent.

Flysch sedimentation in the main part of the Ionian Zone began at the Eocene – Oligocene boundary. The flysch consists of alternations of fine sandstones, locally with coarser clastics, which are calcareous and glauconitic and micaceous, silty mudstones. Carbonaceous material occurs widely. Beds thickness ranges from 0.05 – 1m. The Flysch facies mainly occur in the Epirus-Akarnania syncline on the eastern flank of the Ionian Basin where it reaches 6000m thickness. In more external western areas it occurs as 'Basal Flysch' with progressively diminishing thicknesses. Sediments also become progressively finer in the same direction. In the western external Ionian Zone the Upper Oligocene is represented by the Ayii Pantes formation dated as Upper Oligocene – Lower Aquitanian. It is overlain by the 'Upper Flysch' (Aquitanian) and by the 'Radhovizi Formation' (Aquitanian – base Burdigalian) extending also to the middle Ionian Zone (IGRS-IFP, 1966). Younger Neogene sediments are only known in the external and middle parts of the Ionian Zone. In the latter they are represented by isolated lacustrine deposits, and in the former they are marine and continental sediments. Their accumulation after a major phase of tectonism at the end of the Burdigalian means that these formations are unconformable with the underlying sediments. This unconformity is marked by thick basal breccias. Two other major regional unconformities are associated with the top of the Miocene sequence and with the top of the lower Pliocene; they are associated with renewed compression, observed especially in the external Ionian zone and Paxos Zone. In Aitoloakarnania region, a regional unconformity occurs between the Oligocene and Miocene. Middle to Upper Miocene sediments are found only in Lefkas. The Middle – Upper Miocene sediments represent localized deposition and indicate that the eastern part of Lefkas Island was tectonically active in the Middle Miocene, while the western (Paxos) part was stable. Later deposits in Aitoloakarnania are confined to post – orogenic lacustrine infill of Pliocene to Recent age. During the Quaternary the area underwent intensive uplift and erosion. In most of the onshore Peloponnesos, Pliocene sediments directly overlie the Carbonate unit.

On the other hand, in Albania, a transitional zone of approximately 20-50m thickness marks the break in sedimentation from the pelagic platform carbonates to Oligocene clastics. The transition zone consists of marls that grade into turbiditic sandstones and shales informally refer to as flysch. This transitional change in regime is interpreted to be due to an increase in sediment supply from an eastern source within the Albanides as a result of Alpine tectonic activity (e.g. Pindos thrust in Greece). The sedimentation changed during this period of flysch deposition into shallower marine and into continental clastics towards the east and south. Both the carbonate sequence and the flysch thicken to the southeast, with the carbonates thickness increasing from less than 1km at Berati to 6km at Tomorrit Mountain. The flysch thickness increases from 2km in the north to 3km in the south.

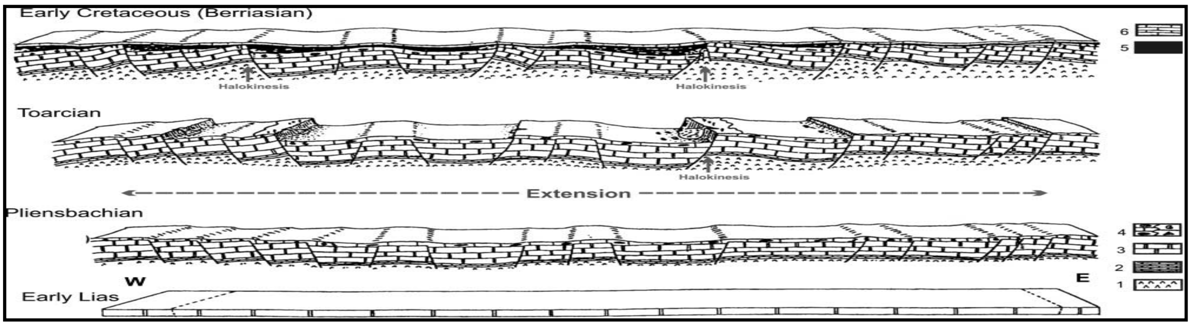


Figure 2: *Paleogeographic evolution of the Ionian zone, from the Early Jurassic to the Early Cretaceous (Berriasian) (Karakitsios, 1992). (1) Evaporites, (2) Foustapidima limestones, (3) Pantokrator limestones, (4) Siniais and Louros limestones, (5) Synrift formations, (6) Vigla limestones.*

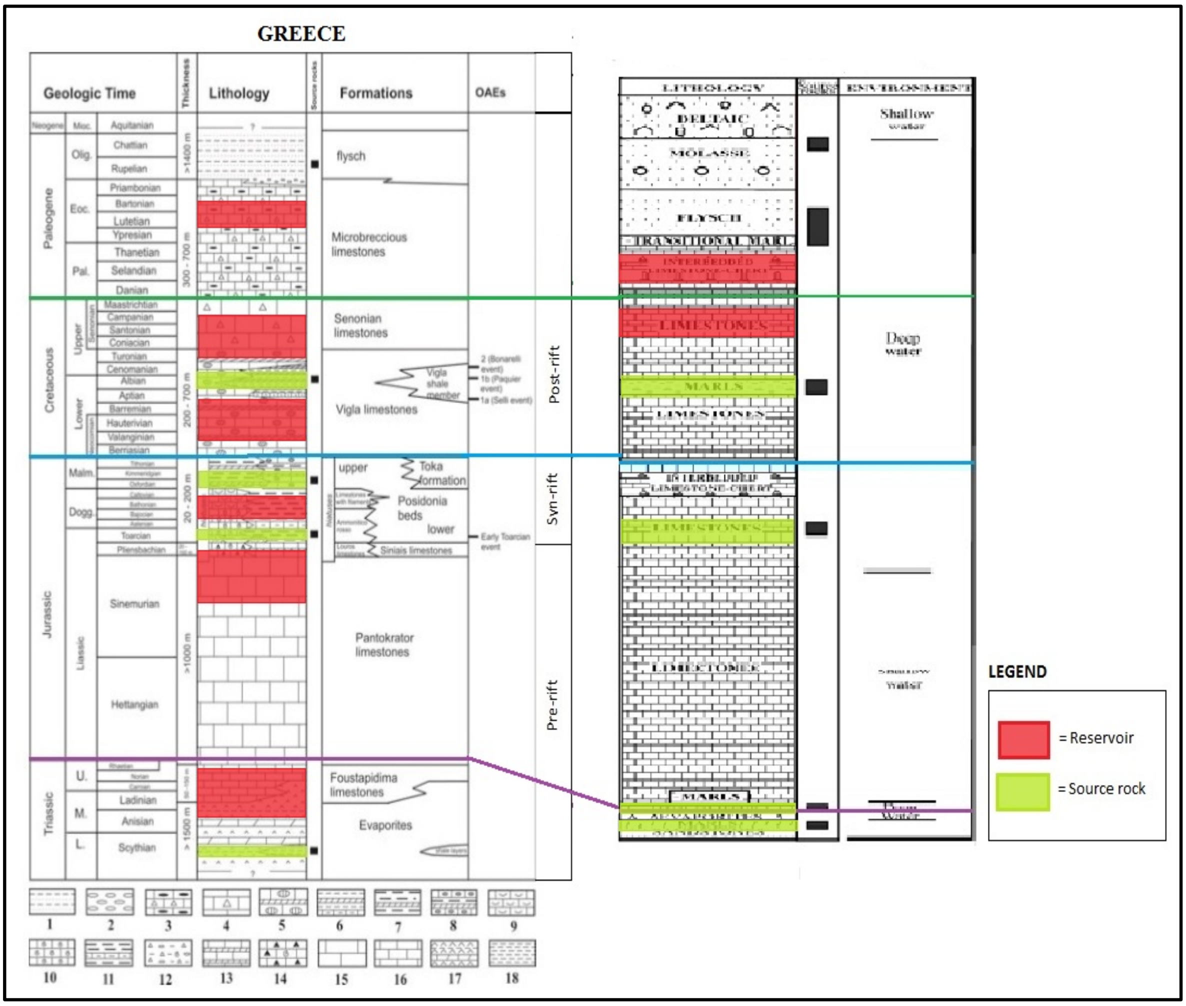


Figure 3: *Triassic to Quaternary stratigrafic columns for the Ionian zone of Greece and Albania. Stratigraphic is based on Rigakis and Karakitsios (1998), Velaj et al., (1999) and Robertson and Shallo (2000).*

2.2 Pre-Apulian (or Paxi) – Sazani Zone (Greece-Albania)

The Pre-Apulian (or Paxoi) Zone as is named in Greece and Sazani Zone as it is named in Albania (*Fig. 4*) correspond to the most external domains of the fold and thrust belt of the Hellenides and Albanides respectively. The Pre-Apulian Zone has traditionally been considered as a relatively uniform, Mesozoic – Cenozoic carbonate domain, transitional between the Apulian Platform and the Ionian Basin. Its general setting is complex as a result of intense tectonic deformation, including phases of extension, collision and flexural subsidence, with undetermined amounts of shortening and block rotation.

On the other hand, considering the equivalent Sazani Zone in Albania, it is difficult to understand the structure of this Zone, because it is very complicated. There are different opinions describing the Sazani zone, as an isolated, persistent carbonate bank on the edge of the Apulian platform, or as an extension of it.

The depositional sequence in the Pre-Apulian Zone begins with Triassic limestones, containing intercalations of black shales and anhydrites. The oldest of these beds, according to borehole data (ESSO Hel., 1960), are dated as Toarcian to Bajocian. The Triassic in the Pre-Apulian Zone differs from that in Ionian Zone in that anhydrites and halite play a noticeably less significant role and carbonates occur in greater proportion. Another major distinction is the extension of the evaporitic sequence into Liassic – Lower Dogger. The stratigraphically lowest outcrops, located in Lefkas Island, consist of Lower Jurassic dolomites and Middle Jurassic cherts and bituminous shales.

The Upper Jurassic-Lower Cretaceous succession consists of white chalky limestones with dolomite intercalations, accompanied by rare cherts and organic carbon-rich black shales, containing planktonic species. Lower Cretaceous limestones and dolomites crop out only on the Kefallonia Island, and their facies is less pelagic than their age-equivalent into the Ionian facies (Karakitsios, 2013). The depositional environment throughout the Cenomanian-Turonian interval is indicated by the presence of rudist fragments, benthic foraminifera, and algal species.

On the other hand, Sazani succession (Robertson and Shallo, 2000) consists mainly of Late Triassic-Jurassic limestones and dolomites. It is exposed, as a 2.500m thick succession (Kanalit and Karaburun mountains, Sazani Island) extending from Barremian to Oligocene and it is entirely carbonated, mainly made of shallow marine facies with algal and oolitic limestones, bioclastic calcarinites (with miliolids, orbitolinas and rudistids), lime mudstones and wackstones.

The Campanian-Maastrichtian platy limestones of the Pre-Apulian Zone gradually become chalky with thin argillaceous layers. They contain, especially towards the top of this formation, plaktonic foraminifera, in addition to rudist fragments. This coexistence indicates the reworking of slope and Apulian platform in the Ionian Basin. From Upper Cretaceous and up to Eocene, in Sazani Zone, neritic carbonates have been obtained, and it's the only available information throughout literature about this unit.

In the Pre-Apulian Zone, micritic limestones with planktonic foraminifera of Paleocene age sometimes rest on Santonian or Maastrichtian limestones and neritic facies with microbreccias and brecciated limestones usually occur at their base. This indicates intense tectonic activity that resulted in the differentiation of the Pre-Apulian Zone into relatively deep-water and relatively shallow (sometimes emergent) areas, which provided the brecciated material (BP, 1971, Mikrou, 1974 in Karakitsios, 2013).

The Lower Eocene comprises pelagic limestones with marl intercalations. Massive limestones with algae, bryozoans, corals, echinoids and large foraminifera (Nummulites sp., Alveolina sp.) compose the Upper Eocene, of Pre-Apulian zone.

The Oligocene Pre-Apulian sediments show the progressive passage from the Ionian typical flysch to a more calcareous (age-equivalent) facies. Oligocene sediments were deposited in small basins (tectonic grabens) between larger or smaller emergent areas, which were locally eroded, reflecting tectonic instability which continued throughout the Oligocene (Karakitsios & Rigakis, 2007). Furthermore, in Sazani Zone, the Cretaceous-Eocene limestones, unconformably overlain by thickening and coarsening-upward Early Miocene shallow marine to fluvial, terrigenous clastics.

Finally, in the late Early Miocene, progressive deepening occurred, flooding the former carbonate slope. In the Pre-Apulian Zone, the Burdigalian marks a transition between carbonate and clastic sedimentation. Younger sediments are represented by clastic, non-conglomeratic formations and marls with evaporitic sediments in the Messinian.

In addition for the Sazani Zone it has to be mentioned that, the platform was uplifted on the most external thrust of the exposed Albanides, and forms a pop-up anticline. The contact with the Ionian zone and Durres basin is thrusted. Uplift of the Sazani zone and the contractional faulting is interpreted to be early Aquitanian-Pliocene in age.

Despite, the limited data for Sazani Zone, the best stratigraphic description has been made. Although we have an incomplete description for the zone, it seems that there are several common elements in those two stratigraphic columns and that is the reason why they have been described overall and not separately.

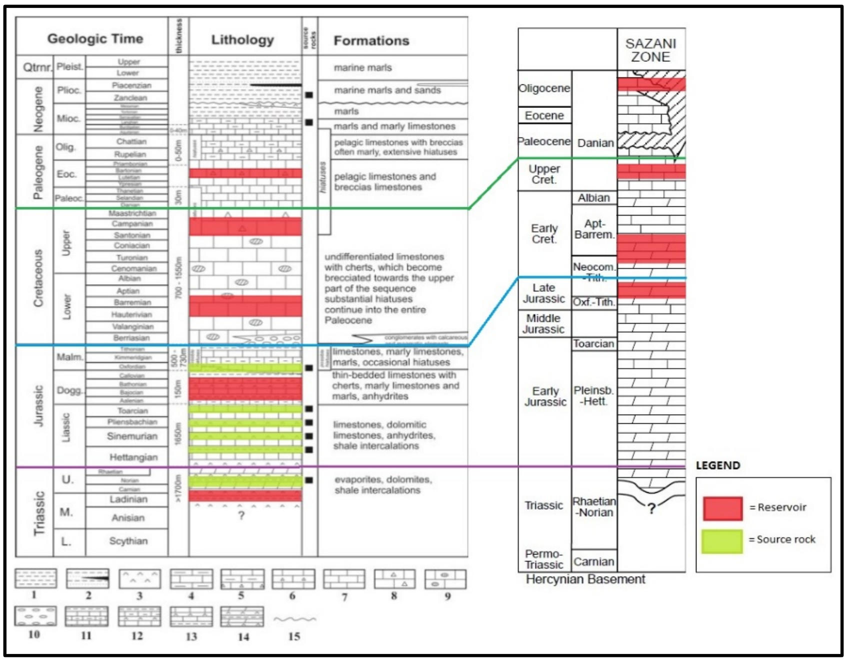


Figure 4: Triassic to Quaternary stratigraphic columns for the Pre-Apulian (or Paxoi) Zone in Greece (left column) and its equivalent Sazani Zone in Albania (right column). Stratigraphic information is based on Rigakis and Karakitsios (1998), Velaj et al., (1999). (1) Marine marls. (2) Marine marls and sand (in black, lignite intercalations). (3) Evaporites. (4) Limestones commonly marly. (5) Pelagic limestones or marly limestones and brecciated intercalations. (6) Mixed pelagic-neritic limestones sometimes with breccias. (7) Pelagic limestones. (8) Mixed pelagic-neritic calcareous sediments with rudist fragments. (9) Pelagic limestones with nodules and rare cherty intercalations. (10) Conglomerates with calcareous and magmatic elements. (11) Pelagic limestones commonly marly. (12) Limestones, shales, and basal anhydrites. (13) Limestones and dolomitic limestones, anhydrites, and shale intercalations. (14) Evaporites with shale intercalations. (15) Unconformity. Qtrnr = Quaternary; Pleist = Pleistocene; Plioc =Pliocene; Mioc = Miocene; Olig = Oligocene; Eoc = Eocene; Paleoc = Paleocene; U = Upper; M=Middle; L = Lower.

2.3 Gavrovo-Kruja Zone (Greece-Albania)

During Mesozoic-Early Tertiary time the passive margin of Apulia was bordered by regionally extensive carbonate platforms, known as the Kruja zone in Albania and the Gavrovo-Tripolitza zone in Greece (*Fig. 5*). In Albania, this unit is dominated by Mesozoic shallow-water carbonates, deformed into large-scale westward-verging anticlines and synclines, cut by reverse faults and minor thrusts. The present contact with the adjacent Ionian zone is a high-angle reverse fault, assumed to be a re-activated thrust. Also, reverse-faults cut the youngest, exposed, parts of the Miocene succession.

The exposed succession in Albania, about 1.5km thick, begins with Late Cretaceous platform carbonates, passing into pelagic carbonates and then into Late Eocene-Miocene turbidites, up to 5km thick (e.g. near Leskovik, Southern region), similar to those of the adjacent Ionian zone. These successions are locally transgressed by shallow water, to terrestrial, clastics of Serravalian-Tortonian age, similar to facies of both the Ionian and Sazani zones.

The Kruja zone extends southwards into the Gavrovo zone of northern Greece, where a shallow water carbonate succession of Jurassic-Mid Cretaceous age is succeeded by Late Cretaceous deep water carbonates, then Upper Eocene-Lower Miocene terrigenous turbidites (Dercourt et al., 1980). Further south, in the Peloponnese a facies counterpart, the Tripoliza zone, is well exposed in a large tectonic window through overlying thrust sheets of the Pindos-Olonos zone. In general, the succession begins with weakly metamorphosed argillaceous sediments overlain by shallow water carbonates and culminates in Paleogene terrigenous turbidites. The Kruja zone can also be compared with shallow water carbonate successions further north in the Dalmatian zone of Montenegro and Croatia. (Aubouin et al., 1970a; Polsak et al., 1982).

The Kruja zone and counterparts to the north and south, are interpreted as a shallow water carbonate platform and related shallow, intra-platform basins that bordered the eastern margin of Apulia from the Late Triassic onwards, although only Late Mesozoic-Early Tertiary facies are exposed in Albania. The carbonate platform was regionally submerged in the Late Cretaceous-Early Tertiary, followed by transition to a foreland basin related to westward thrusting of allocthonous units over the Apulian margin.

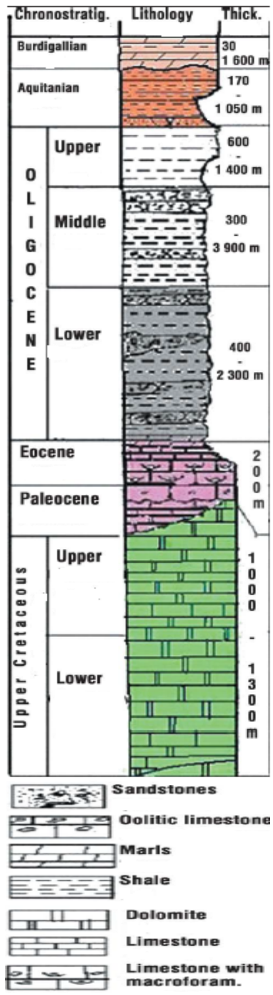


Figure 5: Lithological and stratigraphic column of Kruja Zone (Albania) (Velaj, 2012).

2.4 Peri-Adriatic Depression (PAD)

The Peri-Adriatic Depression (*Fig. 6*) represents the basin of the external zones of the Albanides-Dinarides-Hellenides and the Apennines in Italy, extending from the central southwest of Albania to the south and offshore into western Greece. The Peri-Adriatic depression is also known as the Durres basin and is the major hydrocarbon producing zone in Albania. Post-carbonate deposition is composed of terrigenous sediments, the placement and distribution of which definitely indicate a basin environment, which itself is included in the South Adriatic Basin. (*Fig. 8*) (Zappaterra, 1994; Picha, 2002). The southern and western part of this basin (Albania, Greece and Italy) overlies the Ionian, Kruja and Apulian Platform (Frasheri et al., 2009, Bega, 2010; Velaj, 2012), whereas in the north, it continues with the South Adriatic Basin, which has continuous sedimentation from the Upper Triassic to Pliocene age. It is filled with Neogen-Quaternary sedimentary rocks. The basin lies unconformably to the folded and thrusted Ionian Zone to the southeast and the Kruja zone to the east. Uplift and erosion of ophiolite in the Vardar zone and carbonate rocks in the Krasta and Kruja zones, located farther east, resulted in detritic material that was deposited in the Durres basin.

Middle Miocene thrusting and uplift of the external Albanides resulted in erosion of the frontal part of many compressional structures. The late tectonic deposits of the Durres basin began to accumulate on the Ionian and Kruja zones at the end of the Messinian and early Pliocene. The Durres basin consists of a thin-skinned fold and thrust belt, with rocks from the Apulian plate passive margin involved in the deformation. These are overlain by thick Tortonian-Pliocene sedimentary rocks (Albpetrol, 1993). Dry gas fields occur in the western part of the Durres basin (e.g., Patos, Marinza, Kucova, Pekisht and Kolonje-Bubullim). Some of these fields are trapped at the surface by their own biodegraded oil, which formed bitumen tar mats.

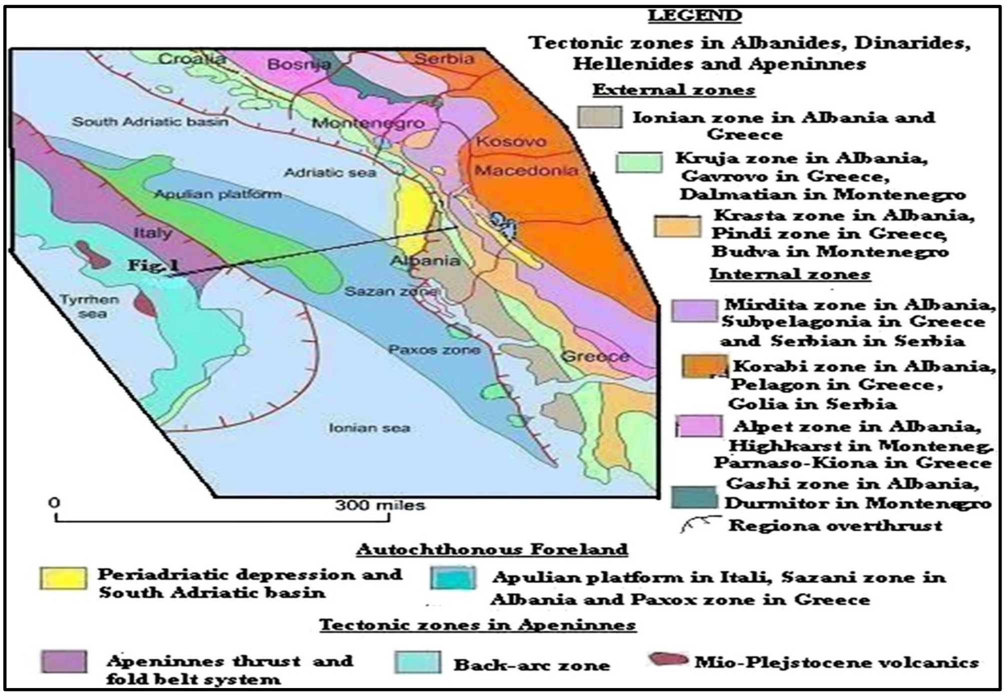


Figure 6: The tectonic scheme for the relationship between Albanides-Dinarides-Hellenides-Apennines. In the figure the Periadriatic depression can be obtained with the yellow color (According to Zappaterra, 1994; modified from Velaj, 2014).

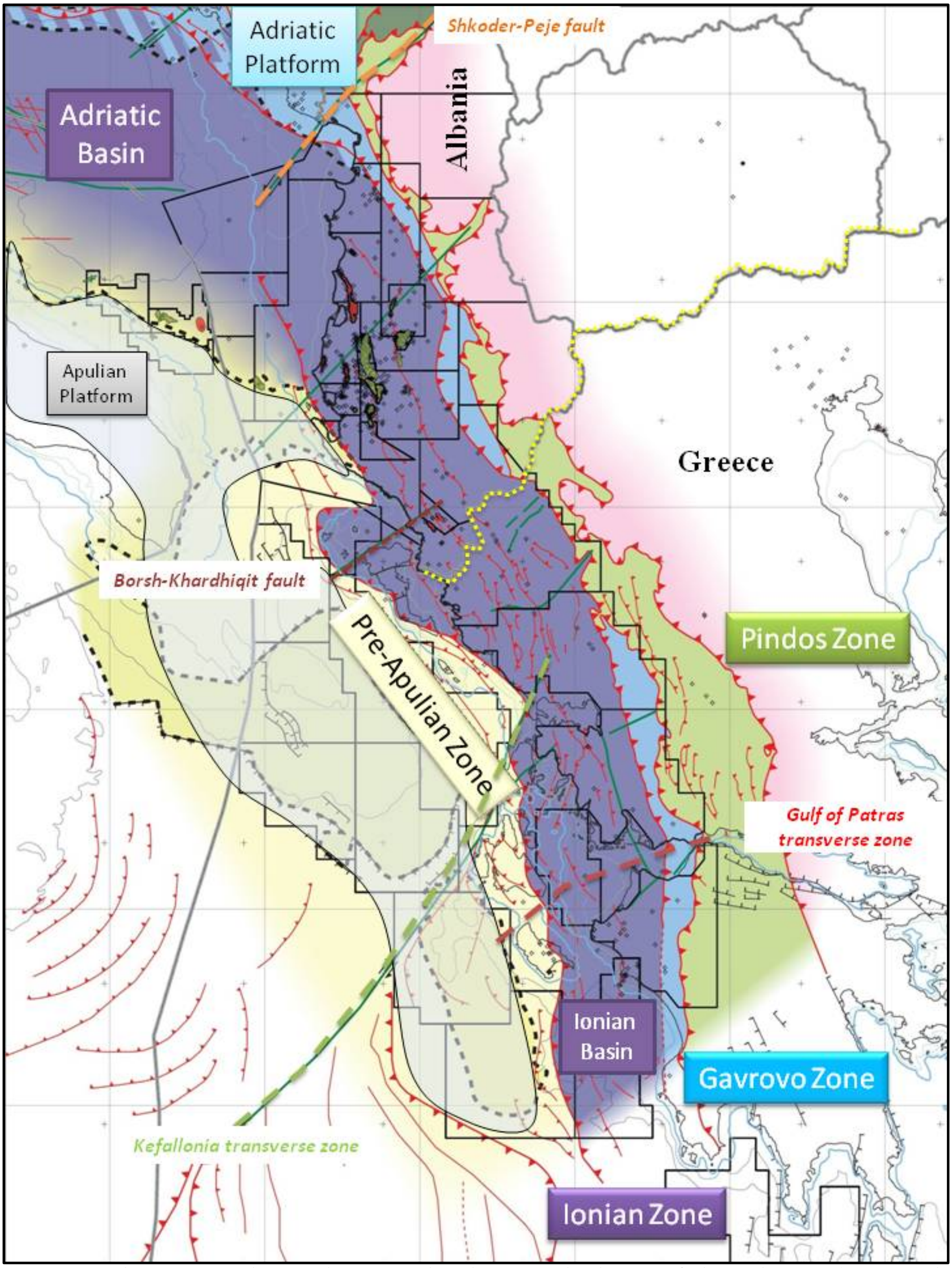


Figure 7: Schematic map showing the structural and stratigraphical units of the study area (Greece and Albania).(Neumann, C., 2014).

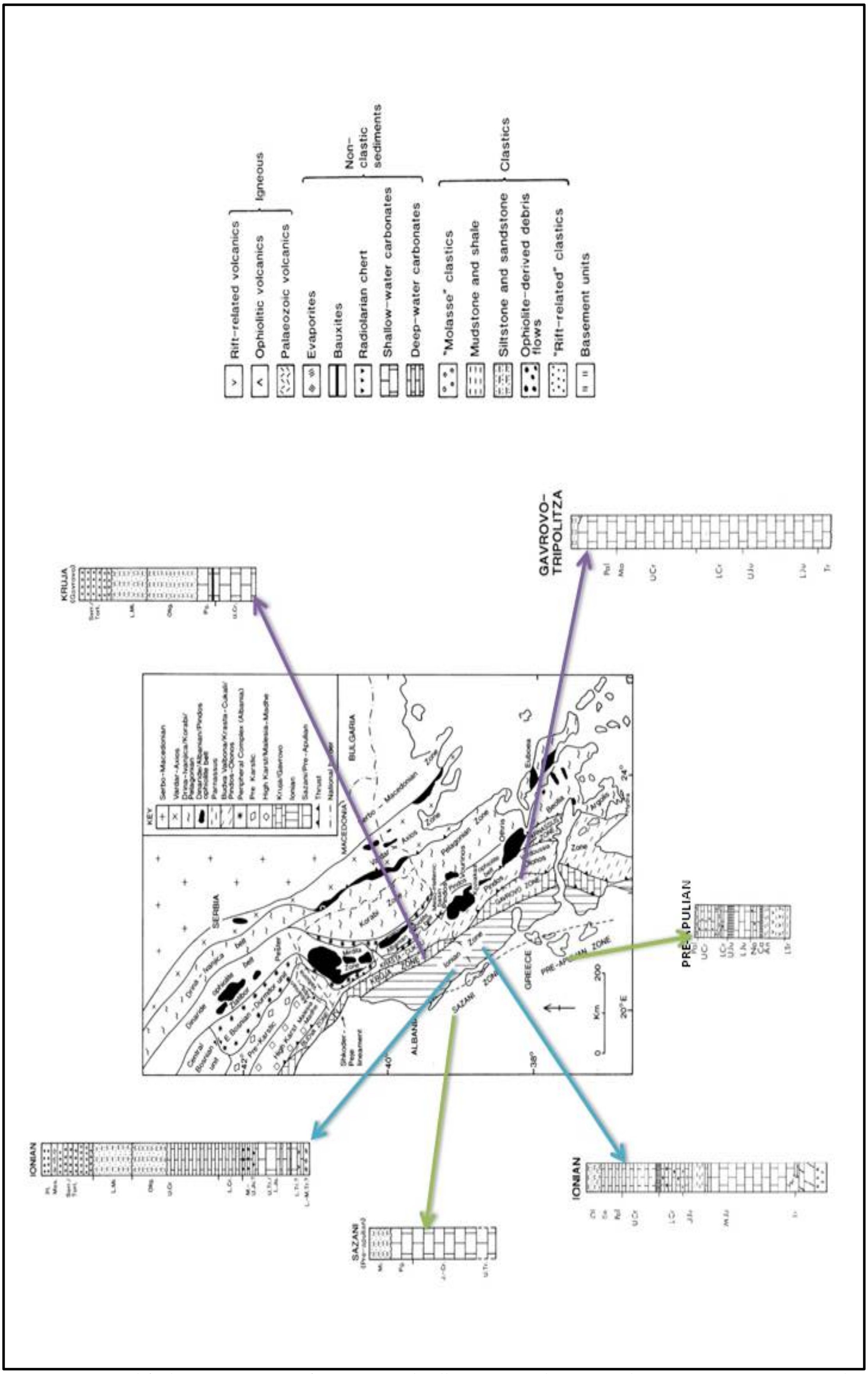


Figure 8: Simplified tectonic map of Greece and Albania, in relation to the main tectono-stratigraphic units.Compiled from various literature sources. Also within the figure the stratigraphic columns for each zone are shown (Modified after Robertson and Shallo, 2000).

3. Geological History and Tectonics

3.1 Geological Setting

3.1.1 Greece

Western Greece is dominated by the external zones of the Hellinides fold-and-thrust belt, namely the Pre-Apulian (or Paxos), Ionian and Gavrovo-Tripolis zones. From the Triassic to the Late Cretaceous, Western Greece was part of the Apulian continental block on the southern passive margin of Tethys. Rocks in the Pre-Apulian zone consist of Triassic to Miocene deposits, mainly neritic-pelagic carbonates. Hydrocarbon source rocks include pelagic deposits rich in marine organic material, although terrigenous organic matter is also found in siliciclastic sediments, of Miocene age. The Ionian zone comprises sedimentary rocks ranging from Triassic evaporates to Jurassic – Upper Eocene carbonates and minor cherts and shales, which are overlain by Oligocene flysch. Organic-rich intervals occur within Triassic evaporates and Jurassic to Cretaceous Pelagic argillaceous-Siliceous sediments. The Gavrovo-Tripolis zone constituted a shallow-water platform from the Triassic to the Middle-Late Eocene iin which no organic matter-rich intervals have so far been recorded.

At a regional scale (hundreds of kilometers), the Alpine belt can be considered to be the margin of the Tethys Ocean which has been inverted in response to the collision of Apulia with Europe (de Graciansky et al., 1989). On a smaller scale (tens of kilometers), the various sub-basins of the Hellenic Tethyan margin have been inverted to produce the main Hellenic thrust sheets or folded zones. This occurred progressively from the innermost (eastern) zones to the more external western) zones (Karakitsios, 1995). The occurred successively from inner (eastern) zones to external (western) zones. One of the most representative examples of this inversion is the Ionian zone of the external Hellenides (Karakitsios, 1990, 1992).

The thrust boundary between the Ionian and Pre-Apulian zones is marked by intrusive evaporates. This suggests that compressional deformation was the most important structural control on orogenesis in Western Greece. Although halokinesis was important along boundary faults during Mesozoic extension, thrusting has overprinted the Mesozoic extensional structures to such an extent that the latter are almost impossible to distinguish. Field observations of the relationship between the Pre-Apulian and Ionian zones emphasize the close association between Hellenide thrusts and folds and areas of evaporate exposure (evaporate dissolution-collapse breccias (Karakitsios and Pomoni-Papaioannou, 1998) even where the precise location of the thrust is unclear. Evaporites crop out along the leading edges of thrust sheets in both zones. This location, together with their occurrence in tectonic windows above tectonized flysch (observed in many places), suggests that the evaporates represent the lowest detachment level of individual over thrust sheets in the external Hellenides. Furthermore, the absence of pre-evaporite units from outcrops in Western Greece (Permian is outcropping just South of Peloponnesus, in Hydra island), the great thickness of the evaporates (more than 2km in some boreholes in the Ionian Zone), and the probable incorporation of Permian basement into the thin-skinned orogenic wedge east of the Pindos thrust (Smith and Moores, 1974) all support the idea that the evaporates form a moderate to major decollement level throughout the external Hellenides, rather than widespread diapirism (Underhill, 1988; Karakitsios, 1992, 1995). Thus, the role of the evaporates is similar to that in thin-skinned thrust belts in Western Europe (Rigassi, 1977; Laubscher, 1978; Williams, 1985; Allen et al., 1986; Ricci Lucchi, 1986).

3.1.2 Albania

Albania forms part of the Dinaric-Albanic-Hellenic arc of the Alpine orogeny, the formation of which took place mainly in the Tertiary, giving the country its mountainous relief (Roure, 1995; Valbona, 1995). Structurally, the mountains are divided in the Internal and External Albanides. The Internal Albanides consist partly of ophiolites, on top of which three sedimentary basins have developed, the small Bajram Curri basin in the north, the Burell basin, and the Korca basin in the south. The Internal Albanides are divided in four major thrust tectonic zones, the Mirdita zone, which is the main ophiolite bearing zone, the Korabi zone and in the Alpet-Shqiptare and Gashi zones;

The External Albanides are divided in three thrust zones, from east to west, the Krasta-Cukali zone, the Kruja zones and the Berati, Kurvaleshi and Cika belts which together form the Ionian zone. All five zones are characterized by carbonate deposition in syn-rift and post-rift settings, covered by flysch. Triassic platform and Jurassic pelagic carbonate deposition in the Krasta-Cukali zone was interrupted, due to compression, during the Upper Jurassic to Lower Cretaceous, when tectonic mélange developed. Renewed carbonate deposition in the Upper Cretaceous is of pelagic origin, and is followed by Paleocene-Eocene carbonates and flysch. In the Kruja zone no sediments older than Upper Cretaceous have been encountered. Upper Cretaceous to Paleocene platform carbonates give way to Eocene pelagic carbonates and Oligocene flysch in Ionian and Kruja zones. The oldest sediments recognized in the Ionian zone are Triassic evaporites. They are covered by Upper Triassic to Lower Jurassic platform carbonates and Middle Jurassic to Eocene pelagic carbonates, covered by Oligocene to Burdigalian flysch. Depositionally the zones are distinguished by their Cretaceous to Eocene facies distribution. The shallow marine Cretaceous of the Kruja zone is flanked by predominantly pelagic mudstones of the Krasta-Cukali and Ionian zones. This lateral change in facies seen today may be the result of tectonic processes (trust sheets). During the Paleocene, flysch is deposited in the easternmost Krasta-Cukali zone, whilst in the Kruja zone non deposition or shallow marine carbonate deposition occurred and in the Ionian zone deep marine carbonates were deposited. In the Eocene, flysch deposition continues in the Krasta-Cukali zone, while in the Kruja and Ionian zones pelagic carbonate deposition prevails, followed only in the Oligocene by the first flysch sediments. The westernmost cape of the Albanian coast is formed by the Sazani zone, which is a thrusted, eastward verging promontory of the Apulian platform. This zone contains Triassic to Upper Cretaceous platform carbonates, and was an area of non deposition from Paleocene to the Lower Miocene.

Two major NE-SW striking lineaments with uncertain origin are present. The northern Shkoder-Peje lineament separates the Gashi zone and the Alpet-Shqiptare zone from the rest of the Internal Albanides. The Vlora-Elbasan lineament roughly delineates the northern boundaries of the Cika Belt, Kurvaleshi Belt and Berati Belt, of the Ionian zone, and forms also the Southern boundary of the Peri-Adriatic Depression (PAD).

Both Hellenides and Albanides can be divided into two major parts: internal part (eastern) and external part (western). These major units can be split into several tectono-stratigraphic sub-units each of them being characterized by a former typical paleo-geographic environment. These sub-units are almost the same in Greece and Albania and some of them continue northwards and they have been differentiated from east to west as follow: the Krasta-Cukali Zone in Albania, which is equivalent to the Pindos Zone in Greece; the Kruja Zone in Albania equivalent to the Gravovo Zone in Greece; Ionian Zone; and the Sazani Zone in Albania which is equivalent to the Pre-Apulia (or Paxos) Zone in Greece. These zones originally correspond to horst and graben structures resulting from extensional tectonic regimes. Only the most external part of Hellenides and Albanides consisting of the Pre-Apulian and Sazani Zone is autochthonous and forms the extension of the Apulia platform.

Furthermore, the Peri-Adriatic Depression represents the basin of the external zones of the Albanides-Dinarides-Hellenides and the Apennines in Italy. Post-carbonate deposition is composed of terrigenous sediments, the placement and the distribution of which definitely indicate a basin environment which itself is included in the South Adriatic Basin (Zappaterra, 1994; Picha, 2002). The southern and western part of this basin (Albania, Greece and Italy) overlies the Ionian, Kruja and Apulian platform (Frasheri et al., 2009; Bega, 2010; Velaj, 2012), whereas in the north, it continues with the South Adriatic Basin. (Velaj, 2014).

3.2 Tectonic Evolution

Although the tectonic evolution of Greece and Albania, and more specifically in this case study seems to be similar, some differences have been observed. The descriptions of those two countries from literature are also quite different, due to the fact that the tectonic evolution of these countries may be presented and described in different ways. However, in order to present a general tectonic evolution, the data from each area have been combined together, and a general description of their tectonic evolution throughout time has been constructed.

Pre-Mesozoic

Not a lot is known about the pre Mesozoic evolution of Western Greece, due to the fact that pre-Mesozoic rocks are neither been exposed at surface, nor have they been penetrated by boreholes.

However, one of the most fossiliferous sequences of Permian rocks in the western Tethys can be found in the island of Hydra and also in the Eastern part of Crete island. The Permian sequence is at least 500m thick and ranges in age from Asselian to Dorashamian. The succession is not complete as several unconformities are present. (Grant R., et al, 1991).

In Albania the oldest reconstruction presented, represents the Upper Permian-Lower Triassic, when the different micro-continents that will eventually make up the eastern Mediterranean area, were still connected to the mega continent Gondwana and separated from Eurasia by the Paleo Tethys ocean (240 Ma). The mechanically weak, viscous Triassic evaporite level, which has been recorded in large areas, plays an important role in the later deformation history, when it forms the major decollement for the Albanide thrust belts.

An Upper Permian rifting event, which was inverted in the Lower Triassic (Robertson & Dixon, 1984), left a depression bounded by NE-SW transform faults. This depression continued to exist and it is currently expressed in the topography of Albania as the PAD (Peri-Adriatic Depression). The relatively deep water in the depression prevent the formation of Triassic evaporites, which have only been reported to the south of the Vlora-Elbasan line, the southern boundary of the PAD. (*Fig. 9*)

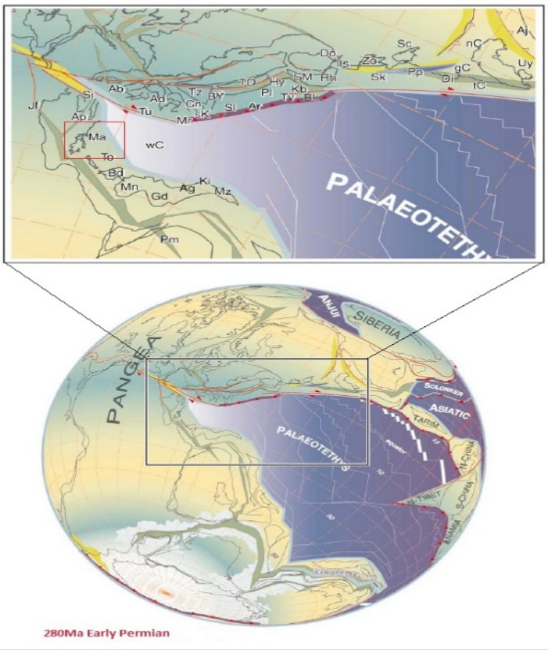


Figure 9: *280Ma Early Permian reconstruction of the western Tethyan realm, (modified from Stampfli et al., 2001a; Stampfli and Borel, 2002), rift zone are shown in greenish color, foreland in orange color. The study area is shown within the red box.*

Triassic to Sinemurian

The oldest known rocks in Western Greece are Triassic evaporates. Evaporites are exposed at surface in the Ionian Zone and occur in the subsurface in the Paxos Zone to the west, although their precise areal extent is unknown. The evaporates are exposed at the surface in the hanging wall of thrust faults or as diapirs. They are dominated by gypsum, whilst the apparent lack of halite is attributed to surface dissolution. The precise age of the evaporites is unknown but they have been assigned a pre-Ladinian age (Karakitsios, 1995).

The 'pre-rift' sequence is completed by the Upper Triassic Foustapidima Limestones and the Lower Jurassic Pantokrator Limestones. The Pantokrator Limestones are believed to have formed an extensive carbonate platform which covered the entire region from the Paxos Zone to the Gavrovo zone, although pre-Cretaceous rocks have not been encountered in the Gavrovo Zone (Karakitsios, 1995).

In the East, Middle Triassic rifting in the Pindos Ocean separated the Pelagonian micro-continent from the (Gondwana) Paxos – Ionian – Gavrovo micro-continent. Sea floor spreading was initiated in the Late Triassic and the Pindos ocean opened, possibly as a Red Sea type basin (Jones and Robertson).

In Albania the Lower Jurassic (~180 Ma), has undergone a large scale crustal extension utilizing the transform faults formed in the Earlier Permian-Triassic phase. The extension resulted in crustal necking (Ziegler, Cloetingh & van Wees, 1995), expressed in the formation of two main rift systems in the Adriatic-Apulian promontory. The promontory failed eventually along the most eastern necking zone, opening the Pindos ocean and resulting in the formation of the ophiolites in the spreading centre, separating the Pelagonian micro-continent from the promontory. The second rift, which later formed the Ionian zone, failed to develop into an ocean at this stage, but during the Late Eocene the southern extent of this Ionian rift zone developed into what became the Aegean Sea, which still is an oceanic basin. The high between the Ionian rift and the Pindos ocean forms the Kruja platform, equivalent to Gavrovo zone in Greece. East of Pelagonia, the Paleo-Tethys ocean floor moved away from the Adiatric-Apulian promontory. In the Pindos ocean ophiolites started to form, but had not yet extruded. (*Fig. 10*)

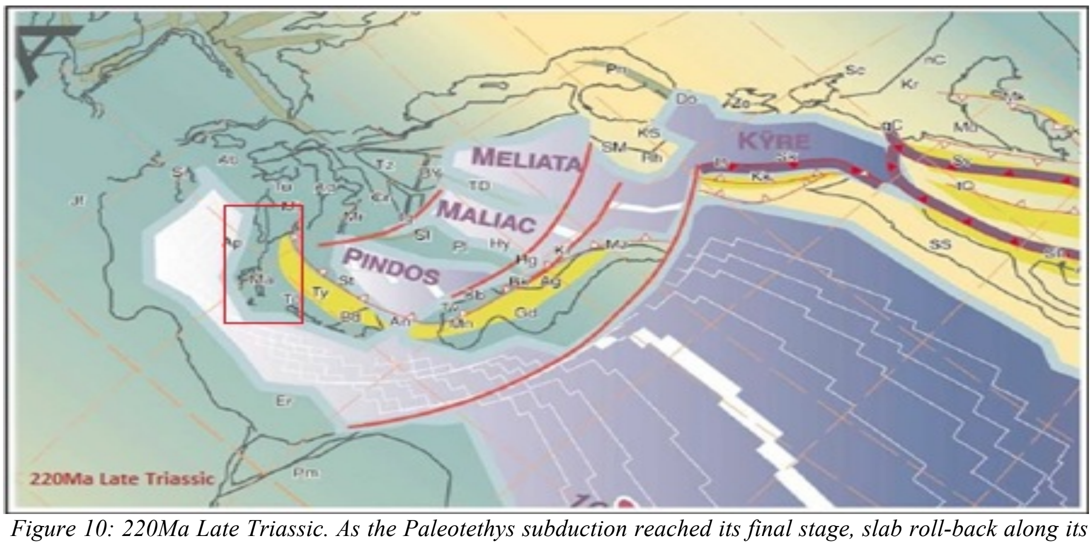


Figure 10: 220Ma Late Triassic. As the Paleotethys subduction reached its final stage, slab roll-back along its northern margin accelerated and was marked by the opening of successive oceanic back-arc basins before the final closure of Paleotethys in Late Carnian times. (Stampfli et al., 2002).

Pliensbachian to Tithonian

During the Pliensbachian, the extensive Liassic carbonate platform began to founder and Neotethyan rifting resulted in the formation of the Ionian Basin. This basin is thought to have been sandwiched between the platform carbonates of the Paxos and Gavrovo Zones (Karakitsios, 1995).

The beginning of the syn-rift sequence in the Ionian Zone is represented by the pelagic Siniais Limestones and their lateral equivalent the Louros Limestones, both of which have been assigned Pliensbachian ages (Karakitsios, 1995). These limestones were then locally overlain by the Jurassic sediments of the “Ammonitico Rosso”, the Lower Posidonia Beds, the “Limestones with filaments” and the Upper “Posidonia Beds”. Mapping of the Lower “Posidonia Beds” and the “Ammonitico Rosso” facies belts indicates that they followed a north-south trend (Karakitsios, 1995). These sediments were all deposited during a time of general sediment starvation.

By the Pliensbachian, the thickness of the pre-rift sediments above the evaporitic substratum (>1700m) would have been sufficient to facilitate salt diapirism and may account for the occurrence of gypsum clasts in Toarcian conglomerates at the base of the Lower Posidonia Beds in the vicinity of Lithino (Karakitsios, 1995). The extensional phase may therefore have provoked halokinetic movements in the substratum which then influenced the syn-rift mechanism by increasing the amount of throw on the extensional faults (Karakitsios, 1995).

During the late Middle Jurassic, the onset of ‘Eohellenic’ compression was marked by convergence within the Pindos Ocean and the formation of a southwest-dipping subduction zone (Jones and Robertson, 1991). This compresional phase was apparently initiated in response to the opening of the North Atlantic Ocean (Smith and Spray, 1984). Displacement of the Pindos-Vourinos ophiolite began as a result of the relative eastward movement of the Apulian micro-continent which gave rise to the ophiolite via supra-subduction zone spreading within the ocean. (*Fig. 11*)

In Albania area, during the Middle Jurassic (170 Ma) extension continued, leading to the formation of the Ionian and Krasta-Cukali zone pelagic carbonates. On Apulia, platform carbonates indicate the continued existence of these areas as crustal highs. In the Kruja zone, the oldest sediment record is of Upper Cretaceous age, but as the Kruja platform was not affected by tectonic thinning, it probably existed as crustal high throughout its history. In response to the continued opening of the Pindos ocean, the ophiolites penetrated the crust, intruding the pelagic carbonates and extruding onto the ocean floor.

Spreading continued until the Late Middle Jurassic. As the Central Atlantic began to open, Eurasia moved westward relative to Africa. This resulted in closing of the Pindos ocean and tectonic emplacement of the Pindos ophiolites onto the western margin of the Pelagonian micro-continent. (*Fig. 12*)

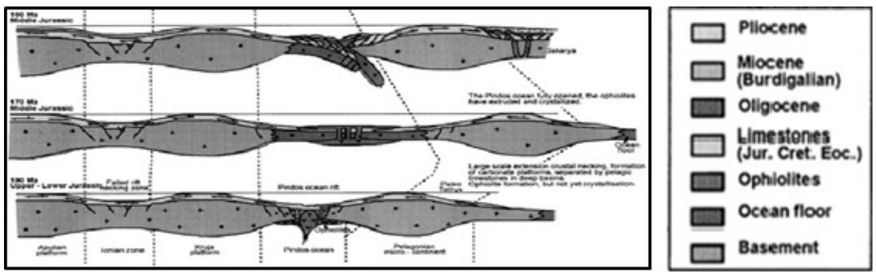


Figure 11: *Plate tectonic reconstruction, Upper-Lower Jurassic. (Nieuwland et al., 2001)*

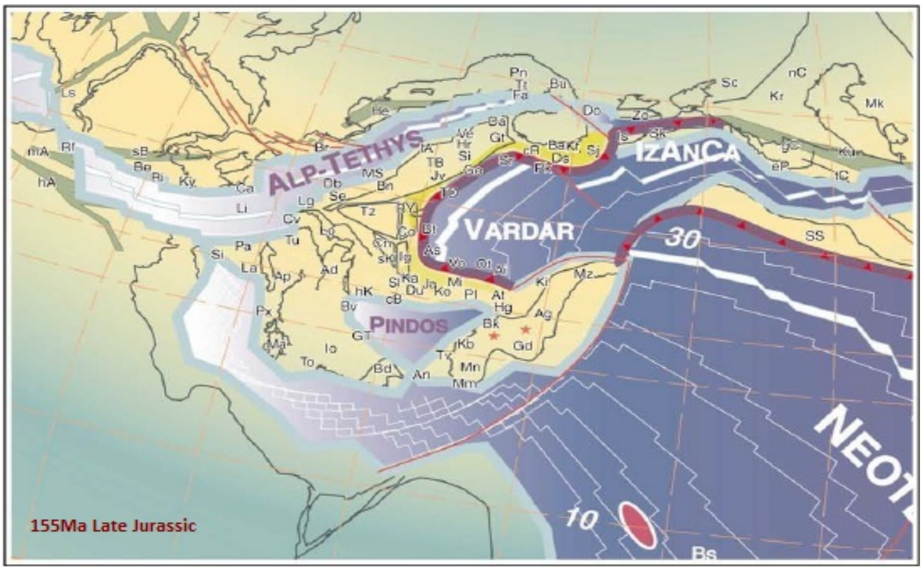


Figure 12: *155Ma Late Jurassic. Spreading in the Alpine Tethyan ocean now reached the Carpathian domain. On the west Central Atlantic start to open. (Stampfli et al., 2002).*

Cretaceous (Berriasian to Turonian)

The post rift period, in Western Greece, was initially marked by an early Berriasian unconformity above which the pelagic cherty Vigla Limestones were deposited (Karakitsios, 1995). Locally these limestones directly overlie the Lower Jurassic Pantokrator Limestones. The transgressive nature of the Vigla Limestones is attributed to post-rift thermal subsidence as opposed to a eustatic sea level rise. The substantial thickness variations may be attributed to either the preservation of syn-rift half graben geometry due to sediment starvation or continued halokinetic activity (Karakitsios, 1995).

In the Ionian Zone, the Vigla Limestones are overlain by Upper Cretaceous pelagic and detrital limestones. The brecciated nature of these deposits may reflect the onset of tectonic instability associated with the Hellenide Orogeny. Further west, in the Paxos Zone around the island of Zakynthos, shallow water platform carbonates were deposited throughout the Cretaceous, Paleocene and Middle Eocene.

To the east, in the remnant Pindos Ocean basin, pelagic limestones, radiolarian cherts and deep water turbidites transgressed across the area throughout the Cretaceous. Local, Upper Cretaceous rudistid build-ups are developed on the eastern margin of the basin (Jones and Robertson, 1991).

In Albania, in the Early Cretaceous (120 Ma), the westward movement of Paleo-Tethys has completed the emplacement of the Pindos ophiolites on the western margin of the Pelagonian micro-continent. The Pindos ocean was now fully closed and became inactive, the E-W motion locked and the remaining movement of Pelagonia was directed to the north.

Continued northward movement of Pelagonia, resulted in the development of a connection between the Serbo-Macedonia/Rhodope block and the north-eastern margin of Pelagonia, along the Vardar transform zone. The Serbo-Macedonian/Rhodope blocks were now connected with the ophiolites that formed along the oblique collision zone. Following locking-up of the moving micro-continent in the Upper Cretaceous, continued compression resulted in thrusting of the Inner Albanides and initiation of the flysch deposition in the Krusta-Cukali zone. (*Figs. 13 , 14 and 15*)

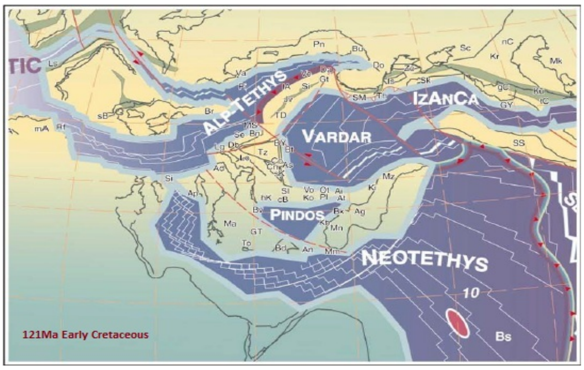


Figure 13: *121 Ma Early Cretaceous. (Stampfli et al., 2002)*

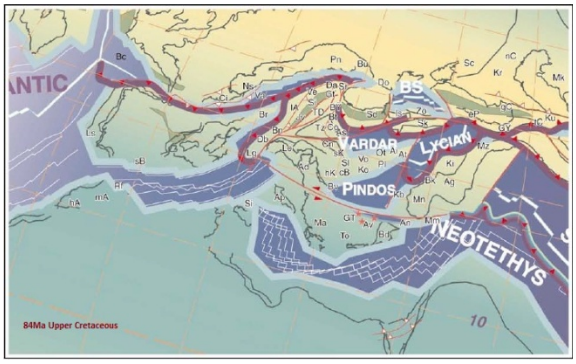


Figure 14: *84 Ma Upper Cretaceous. (Stampfli et al., 2002)*

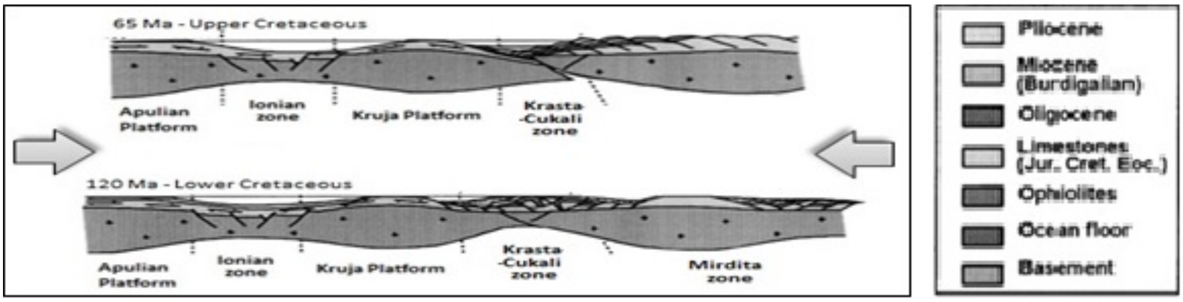


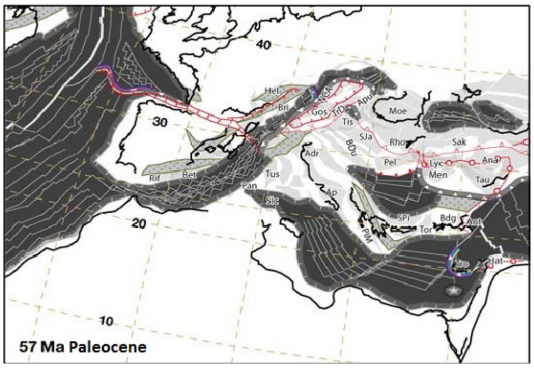
Figure 15: *Plate tectonic reconstruction, Lower-upper Cretaceous. (Nieuwland et al., 2001)*

Paleocene to Middle Eocene

In the Early Tertiary, the initiation of an eastward-dipping subduction zone resulted in renewed compression and the eventual closure of the remnant Hellenide segment of the Pindos Ocean basin (Jones and Robertson, 1991). The Jurassic ophiolites sand the associated sediments were thrusted westwards over the Cretaceous deep water sediments and the whole assemblage was transported westwards over a flexural subsiding fore deep, or distal foreland basin (the depocentre of Pindos Flysch) and finally the Apulian carbonate margin. This thrusting event caused extensive deformation of the Pindos flysch as it was overridden.

In this area, some Maastrichtian sequences are absent due to erosion, the basal unit of the Tertiary being a massive calcirudite of Upper Paleocene age. The Early Paleocene (*Fig. 16*) was evidently a time of emergence, uplift and erosion which may have been related to the final closure of the Pindos Ocean and the emplacement of the Pindos ophiolites in the east. The Upper Cretaceous limestones of the Gavrovo Zone and the Upper Paleocene limestones of the Ionian Zone are overlain by transgressive neritic-pelagic foraminiferal limestones of Eocene age. These reflect subsidence in this region during the Eocene.

In Albania area, during the Eocene (*Fig. 17*) Pelagonia and Apulia had almost reached their current positions relative to each other. The ocean basins had closed, the subduction system was locked and further compression had to be accommodated by crustal thickening.



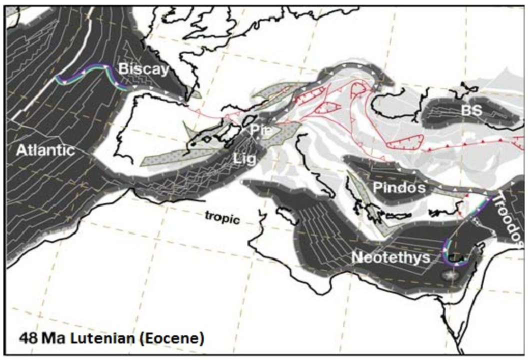


Figure 16: *57 Ma Paleocene. (Stampfli & Hichard, 2009).*

Figure 17: 48 Ma Eocene (Lutenian). (Stampfli & Hochard, 2009).

<u>Middle Eocene (Bartonian) to Early Miocene (Aquitanian) (Gavrovo Syn-orogenic Phase)</u>

During the Bartonian (*Fig. 18*), westward migration of the Hellenides deformation front resulted in the initiation of activity on the Pindos Thrust (Fleury, 1980). Deposition of a thick succession of Upper Eocene to Lower Miocene flysch occurred in a rapidly subsiding foredeep which developed in front of the advancing Pindos thrust sheets and stretched from the Gavrovo Zone in the east to the Paxos Zone in the west. The newly uplifted Pindos mountains provided the predominant source area and the lithologies range from coarse clastics in the Gavrovo Zone to deep water turbidities in the Ionian Zone and marls in the Paxos Zone (Clews, 1989). In the Ionian Zone during this time may be considered a fore-arc basin, the Paxos Zone representing the slope of the Apulian Platform (African foreland). The Late Paleogene to Neogene records several pulsations of subsidence of carbonate platforms, accompanied by the synchronous progradation of turbidite basins from the external Ionian Zone to the Paxos Zone.

In the Paxos Zone around Kefallinia, activity on NNE-SSW and NW-SE trending extensional faults (e.g. the Argostoli Fault) resulted in local detrital sedimentation (Sorel, 1976; Mercier et al., 1976, 1979). These faults are believed to be long-lived Mesozoic faults (Underhill, 1988) which were reactivated in response to lithospheric flexure on the distal margin of the subsiding foredeep (Clews, 1989).

Activity on the Pindos Thrust is believed to have ceased in the Late Oligocene, at approximately 26 Ma (Fleury, 1980) after which, the locus of Hellenide deformation migrated westwards to the Gavrovo Thrust (Dercourt and Thiebault, 1979).

In Albania, during the Oligocene (*Fig. 19*), the deformation was expressed by uplift of the Mirdita zoneand deposition of the Oligocene flysch on the Kruja and the Ionian zone.

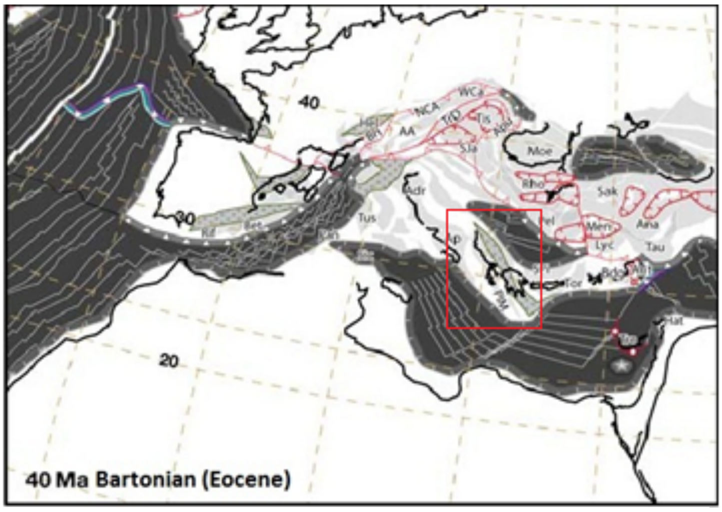


Figure 18: 40Ma Bartonian (Eocene). (Stampfli & Hochard, 2009)

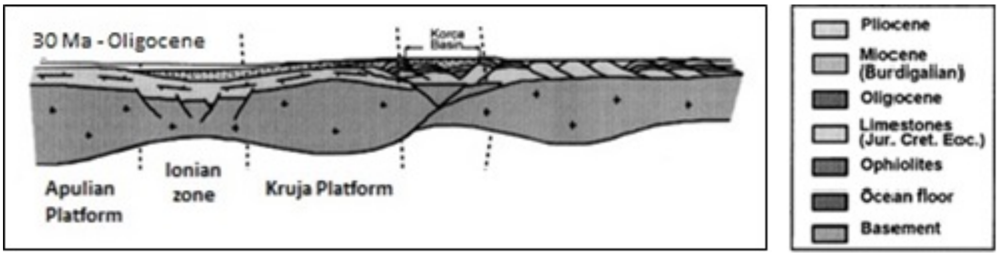


Figure 19: *Plate tectonic reconstruction, Oligocene. (Nieuwland et al., 2001)*

Early Miocene (Burdigalian) to Early Pliocene (Ionian Syn-orogenic Phase)

In the Early Miocene (*Fig. 20* and *21*), the locus of Hellenides deformation migrated further westwards to the Kalamitsi Thrust of Lefkas (Clews, 1989). This marked the start of a major Early Miocene compresional event which affected the entire Ionian Zone. The onset of this event was dated as late Burdigalian to Early Langhian and it closely coincided with the initiation of subduction along the Hellenic Arc, which has been dated around 13 My or at 16 My. The Pre-Apulian Zone has traditionally been regarded as the underformed autochthonous foreland to the Hellenide thrust belt. However, recent studies have shown that the deformation front continued to migrate westwards into the Paxos Zone during the Late Pliocene and Quaternary. This compressional phase occurred at approximately the same time as clockwise rotation of the Ionian islands which rotated between 20° and 25° during the Pliocene to Quaternary.

Folding of Upper Quaternary marine sediments in the footwalls of the Aenos and Ionian thrusts provides evidence for Quaternary out-of-sequence reactivation of these structures. In the Ionian Zone a linked system of extensional and transtensional basins developed in the Late Pliocene to Quaternary. These include the WNW-ESE trending Gulf of Amvrakia, Lake Trihonis, Gulf of Patras and Gulf of Corinth Basins.

The late orogenic, orogen-parallel strike-slip tectonics in the frontal Dinarides-Hellenides represents the last stage of the mountain-building process, when the foreland thrust propagation was locked by stacking of thrust sheets and overall thickening of the continental crust (Picha, 2002). In a process of adjusting to regional compressional stresses, as well as to geometries of principal crustal units, some segments of systems were attenuated and others compressed. The late orogenic, orogen-parallel strike-slip faulting, partly disrupted the depositional continuity of the foreland and the structural coherence of the thin-skinned Dinaric-Hellenic thrust belt, thus further complicating the paleo-geographic reconstruction and structural balancing of the area. The dextral strike-slip faults in the Adriatic region provided a means of tectonic transport, or escape, from the collision zone of Apulia with Europe toward the oceanic realm of the Ionian Sea and the Hellenic trench (Picha, 2002). In Western Greece, the southeastward-moving Dinarides-Hellenides apparently deflected the westward motion of the Anatolian plate toward the southwest. The whole Alpine belt can be considered as the inverted margin of the Tethys Ocean is response to African/Europe collision.

In Albania, during the Burdigalian (20 Ma) the major thrusting took place in the Kruja zone and the Ionian zone.

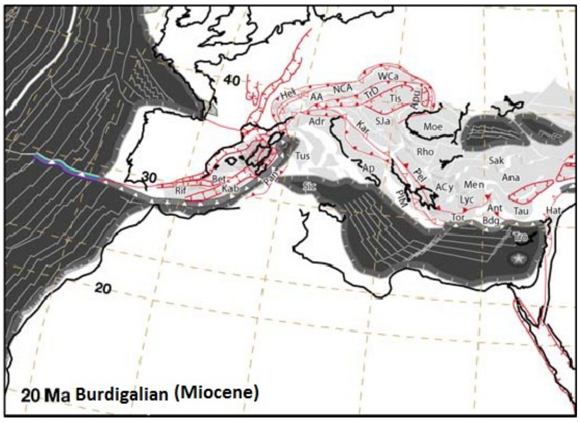


Figure 20: *20 Ma Miocene (Burdigalian). (Stampfli & Hochard, 2009)*

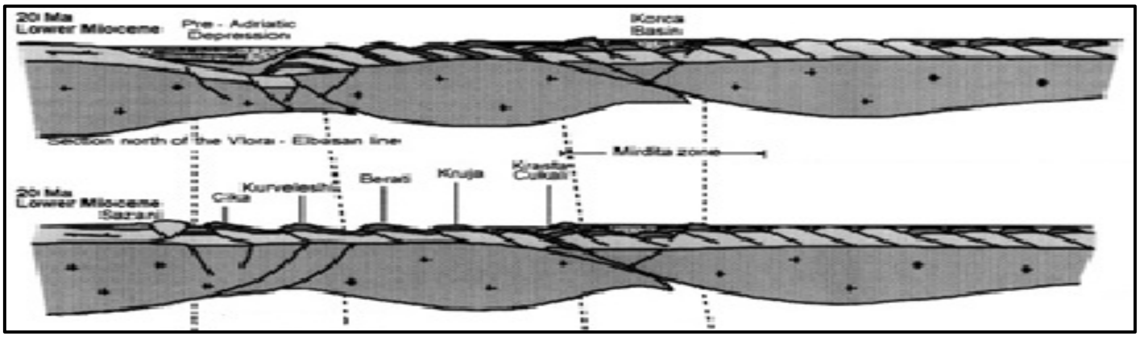


Figure 21: Plate tectonic reconstruction, Lower Miocene. (Nieuwland et al., 2001)

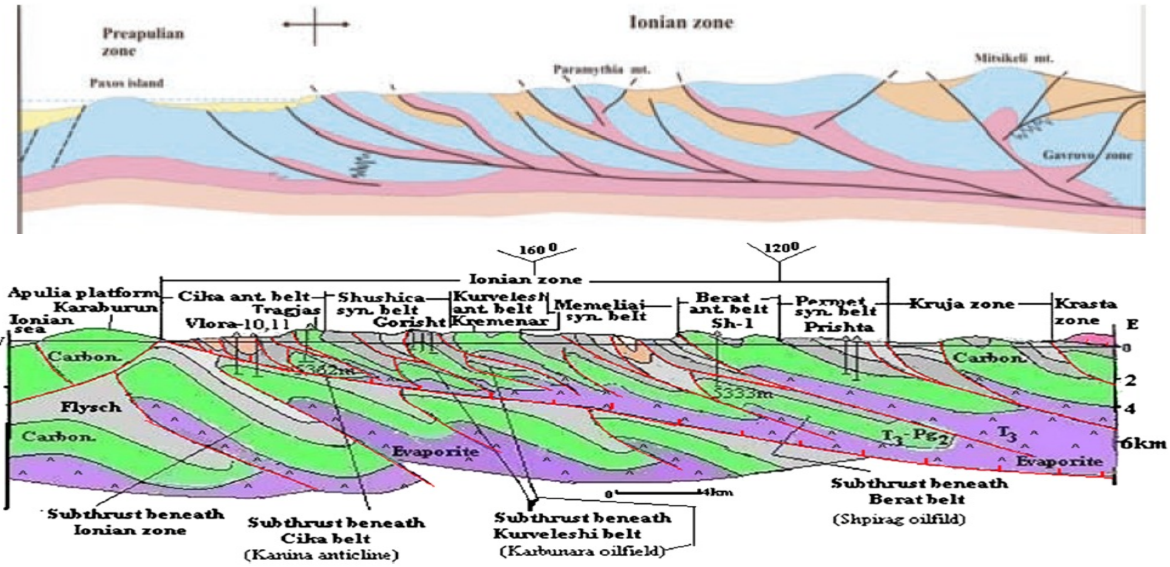


Figure 22: *(a) Section across the Ionian zone. The pre-evaporitic basement does not participate in the deformation of the sedimentary cover. A major decollement at the evaporitic level is present. The pre-evaporitic basement underthrusts the more internal zones, thus being subject to basement deformation related to continental subduction east of the Ionian zone. Zig-zag lines in this figure indicate lateral facies transitions. (Karakitsios & Rigakis, 2007),* (b) *Geologic cross-section through the Apulian Platform, Ionian and Kruja zones. (Velaj, 2014). For profile locations see Figure 25*

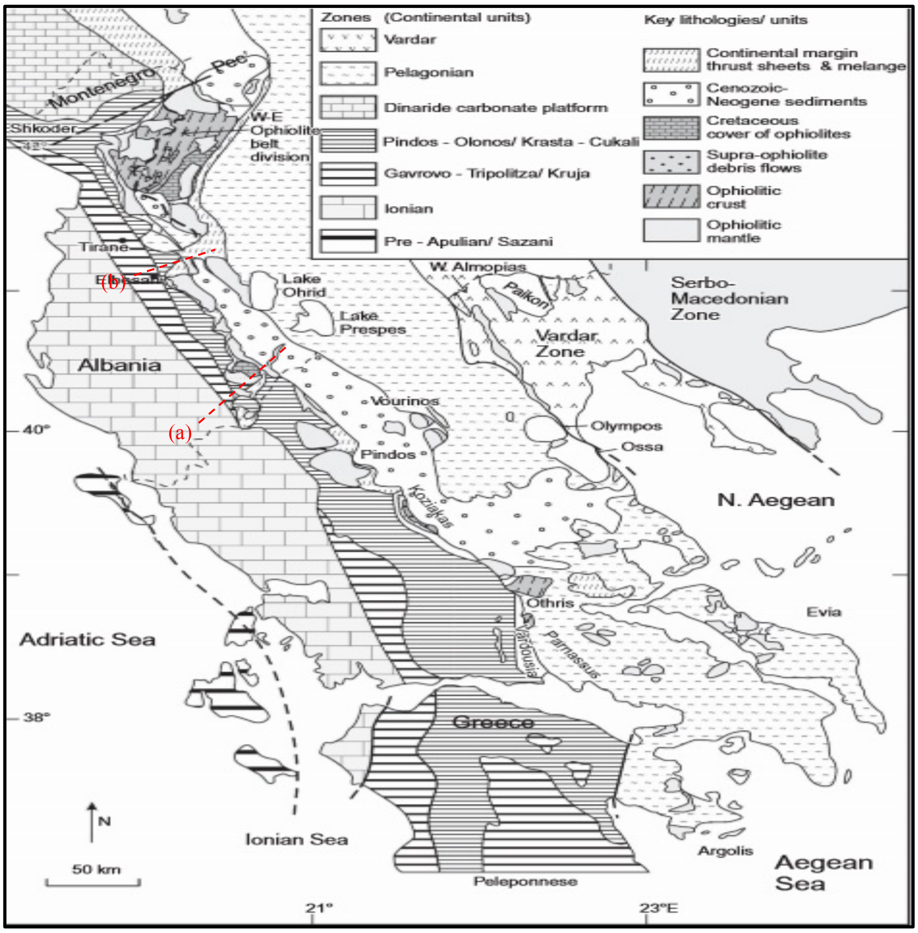


Figure 23 : Outline tectonic map of central and northern Greece and Albania, showing the main units discussed in the text. Base: IGME Geological Map of Greece (1983); Geological Map of Albania (1983, 2003)

4. Data set

Within this study TOTAL provided most of the data, which is composed of:

- Well data in the form of composite logs
- Well reports
- Well log interpretation results
- Internal bibliography and reports
- External bibliography and reports
- Outcrop data
- Geological and Paleographic maps
- Data throughout ArcGIS
- Information and suggestions provided after discussions with people from TOTAL

Furthermore, except from the above data, samples have been collected from the Epirus area for further examination.

4.1 Well Data Set

For the study area (Greece and Albania), onshore and offshore wells have been taken into consideration.

The following onshore wells for Greece have been analyzed:

Nefeli-1, Nefeli-2, Nefeli-3, Thalis, Ismini, Aliki, Ivi, Iraklis-1, Sokratis, Hermione-2, Hermione-1, Danae, Electra, Minerva, Platonas, Aristofanis, Ikaros, Xenofon, Irodotos, Meropi, Ifikratis, Kassandra, Themistoklis, Omiros, Galini, Melpomeni, Sofoklis, Athina, Areti-1, Areti-2, Areti-3, Areti-4, Antigoni, Agamemnon, Kritias-1.

The following onshore wells for Albania have been analyzed:

Kevin, Paul, Kleopatra, Planck

The following offshore wells for Greece have been analyzed:

Alkiviadis, Alexandros, Dafni, Epafos, Afroditi-1, Afroditi-1A, Afroditi-2, Achilleas, Aristotelis, Orion-1, Orion-2.

The following offshore wells for Albania have been analyzed:

PSV, PSG, Safira, Kepler, Newton, Tesla.

Furthermore, some wells near to our study area have been analyzed, in order to make some correlations. These wells are:

Franklin.

5. Case study: Epirus area

For the purpose of this study, a further investigation has been made in the Ionian zone. Six sections have been studied and 150 samples have been collected in order to make extended laboratory analysis. The reservoir parameters that have been examined were porosity and permeability. Furthermore, thin sections have been constructed in order to verify the sedimentological characteristics of the involed carbonate rocks.

5.1 Field Work

In this thesis the results that have been analyzed are provided exclusively by measurements from surface sections. The six sections are situated within the Ionian Zone, near Ioannina area at the Western part of Greece, in Epirus region (*Fig. 24*).

Since the samples have a surface origin, therefore special emphasis has been given in order to collect as much "clear" samples as possible.

The field work completed in 3 days. The sections are listed below by visiting order:

- Section A (Koloniati Section)
- Section B (Perivleptos Section)
- Section C (Asprageli-1 Section)
- Section D (Asprageli-2 Section)
- Section E (Vigla Section)
- Section F (Louros Section)

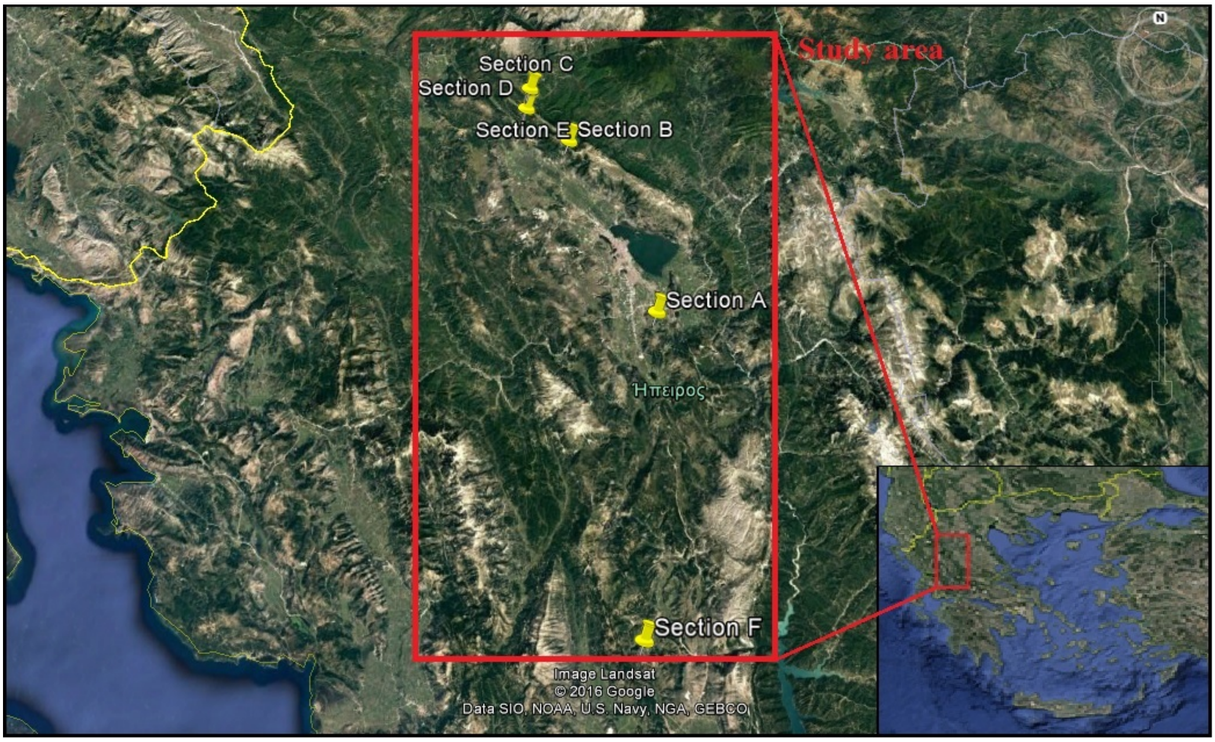


Figure 24: Map showing the position of each section that have been studied.

Section A (Koloniati section)

Section A (*Fig. 24)* is situated at the north part of Koloniati village (lat: 39^{0}34’52.46’’N, lon: 20^{0}53’11.41’’ E). This section covers the stratigraphic Upper part of Vigla limestones and the Lower part of the Senonian limestones, which are separated by an unconformity (*Fig. 31)*. The total length of the section is 60m, where 30 samples have been collected per 2 meters (*Fig. 25)*.

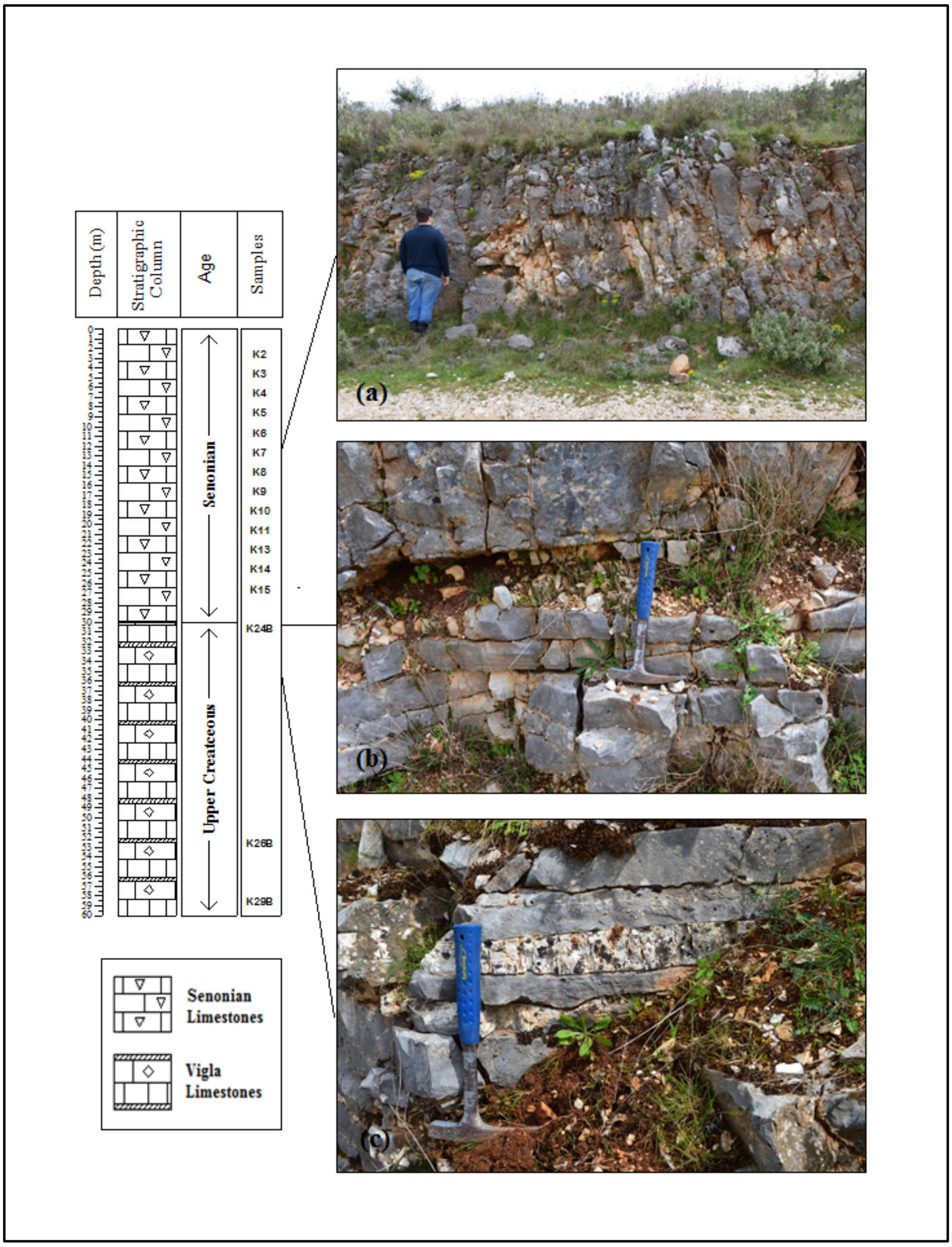


Figure 25: Lithostratigraphic column of Section A (Koloniati Section). (a) Senonian limestones, (b) Uncomformity between Senonian and Vigla limestones, (c) Vigla limestones.

Section B (Perivleptos section)

Section B (*Fig. 24*) is situated at the north part of Perivleptos village (lat : $39^0$46'21.90'', lon : $20^0$46'48.34''E). This section covers the stratigraphic parts of Pantokrator limesttones and (Vigla) shales (*Fig. 31)*. The total length of the section is 20m, where 20 samples have been collected per 1m (*Fig. 26)*.

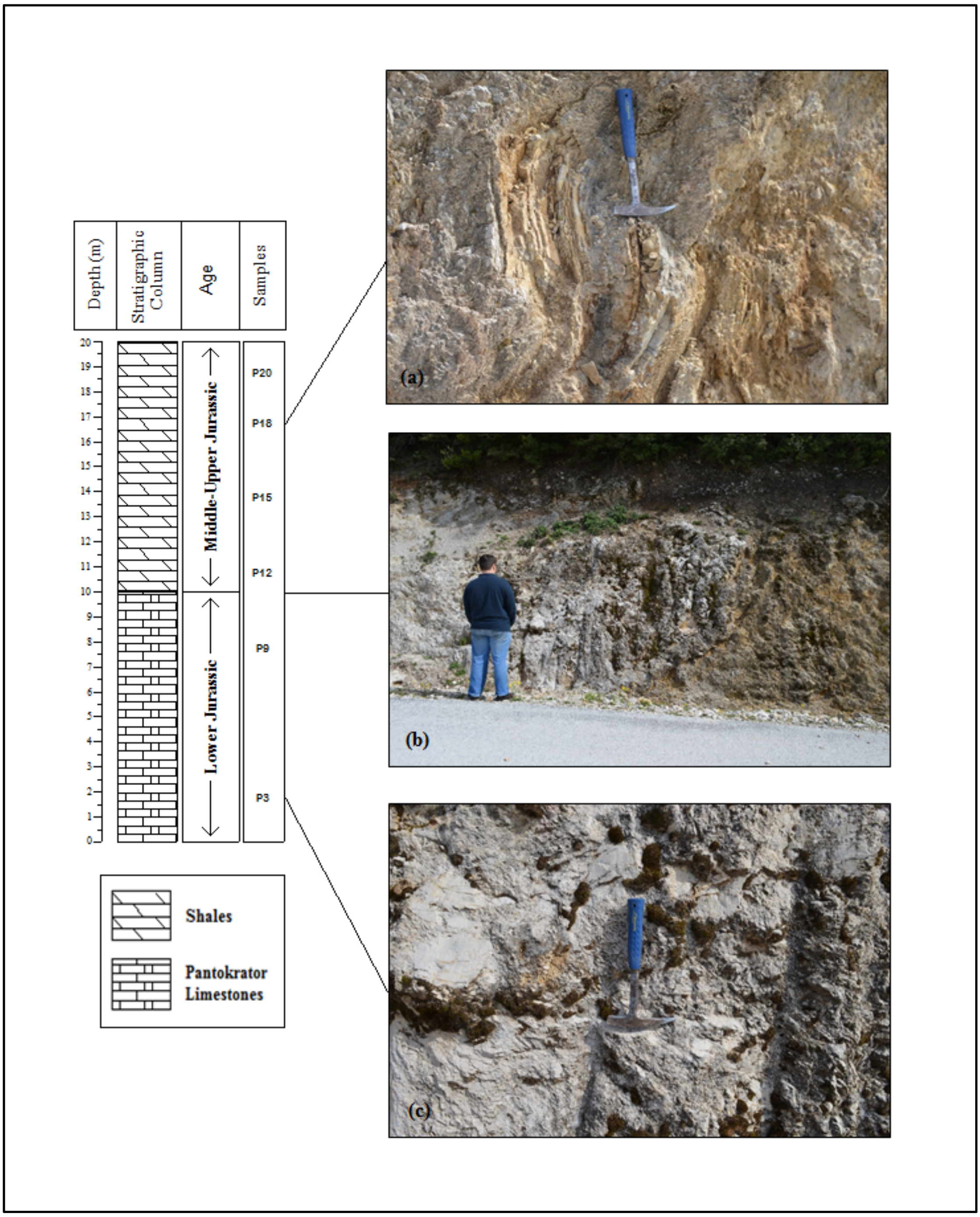


Figure 26 : Lithostratigraphic column of Section B (Perivleptos Section). (a) Shales, (b) contact between Pantokrator limestones and shales, (c) Pantokrator limestones.

Section C (Asprageli-1 Section)

Section C (*Fig. 24*) is situated at the North-east part of Asprageli village (lat: $39^0$45'57.42''N, lon: $20^0$43'58.25''E). This section covers the part of Paleocene-Eocene limestones (*Fig. 31*), with a total length of 25m, where 25 samples have been collected per 1m (*Fig. 27*).

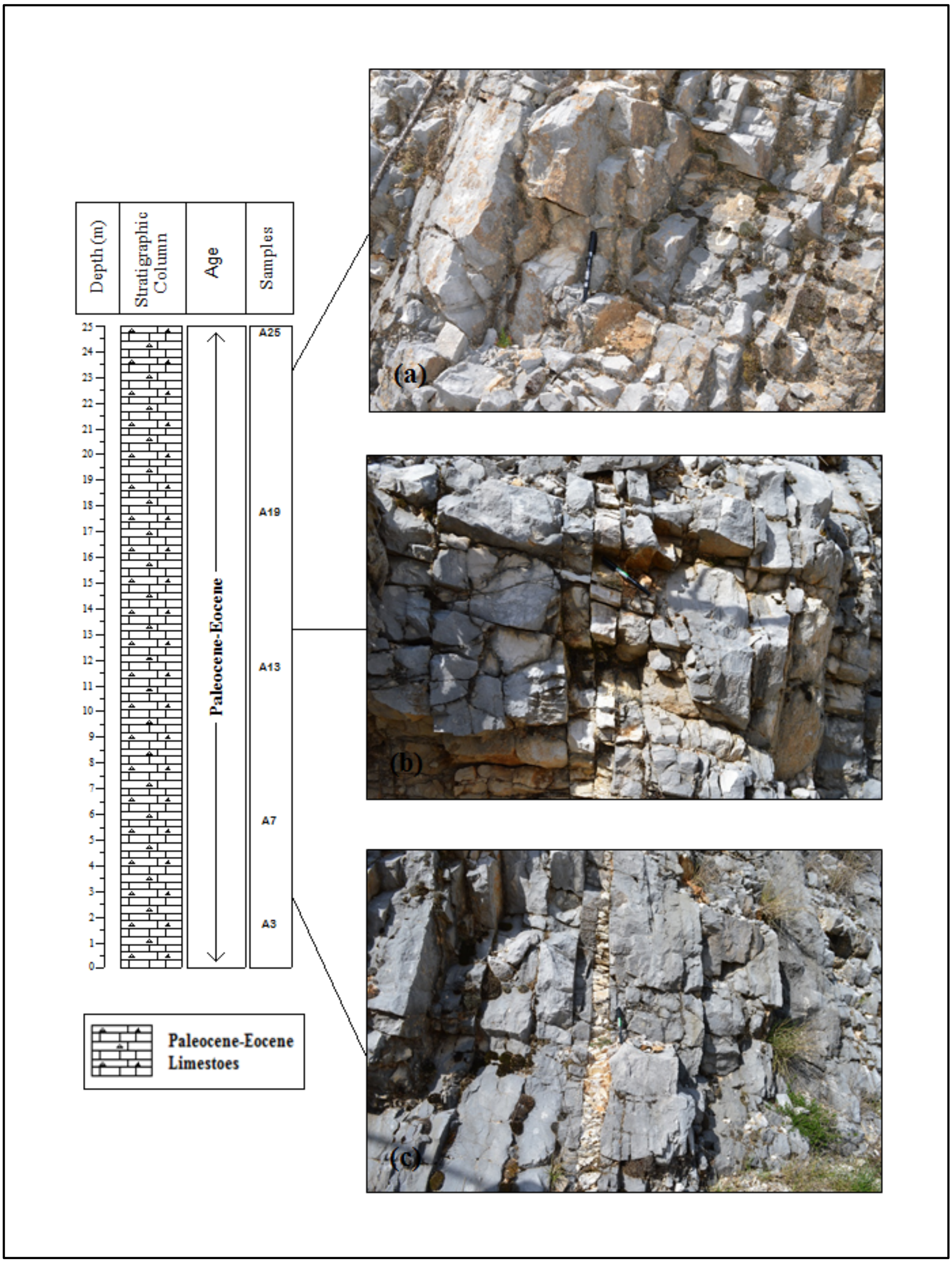


Figure 27: Lithostratigraphic columns of Section C (Asprageli-1 Section). (a), (b), (c)Paleocene-Eocene limestones.

Section D (Asprageli-2 Section|)

Section D (*Fig. 24*) is situated at the North-east part of Asprageli village, near the section C (lat : 39°49'54.00'' N, lon : 20°43'58.25''E). This section covers the Senonian limestones (*Fig. 31*), with a total lenght of 10m, where 10 samples have been collected per 1m (*Fig. 28*).

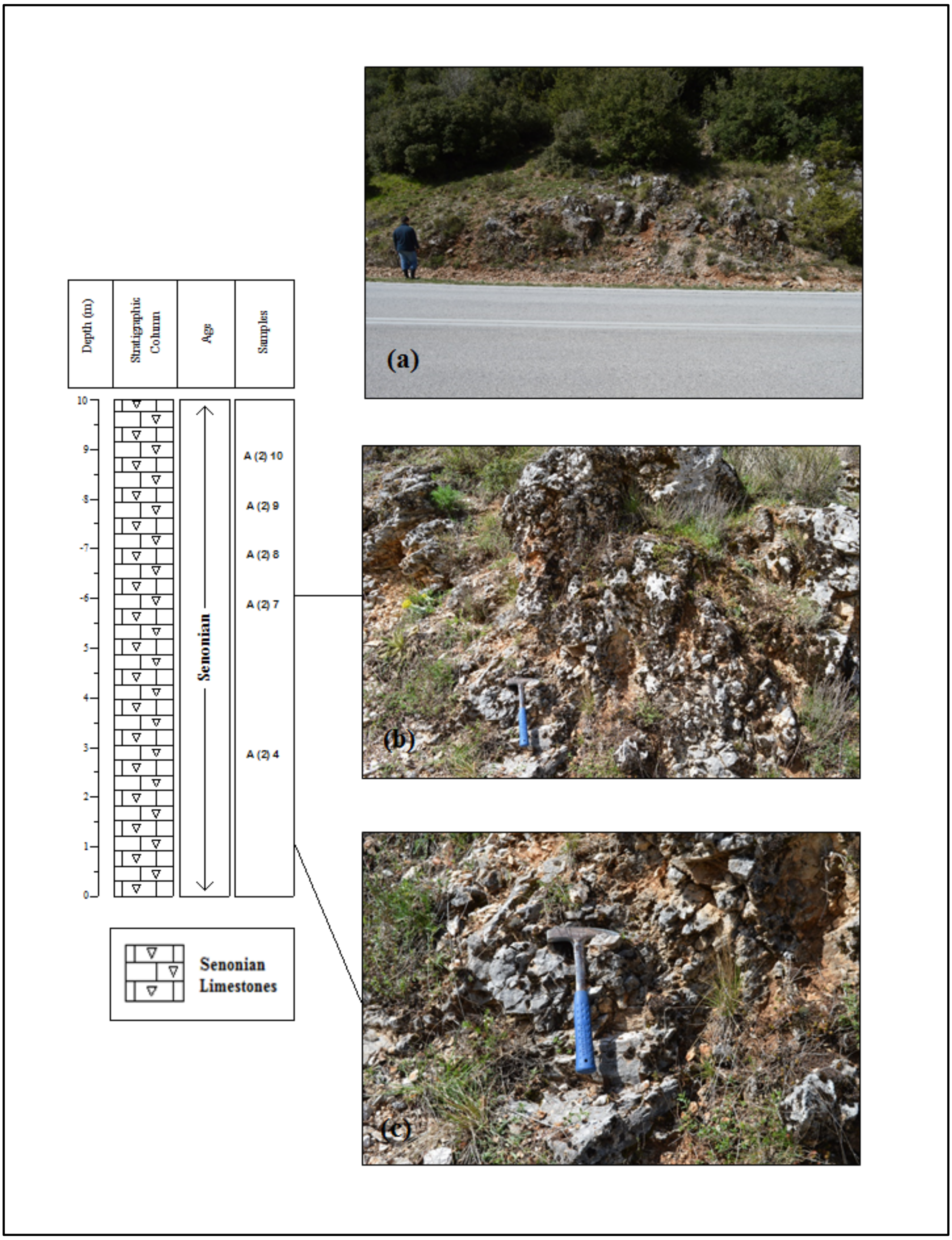


Figure 28: Lithostratigraphic column of Section D (Asprageli-2 Section). (a), (b), (c)Senonian limestones.

Section E (Vigla Section)

Section E (*Fig. 24*) is situated at the south part of Asprageli village (lat: 39°48'33.45'' N, lon: 20°43'38.73''E). This section covers the stratigraphic horizon of Vigla limestones (*Fig. 31*) with a total lenght of 20m, where 20 samples have been collected per 1m (*Fig. 29*).

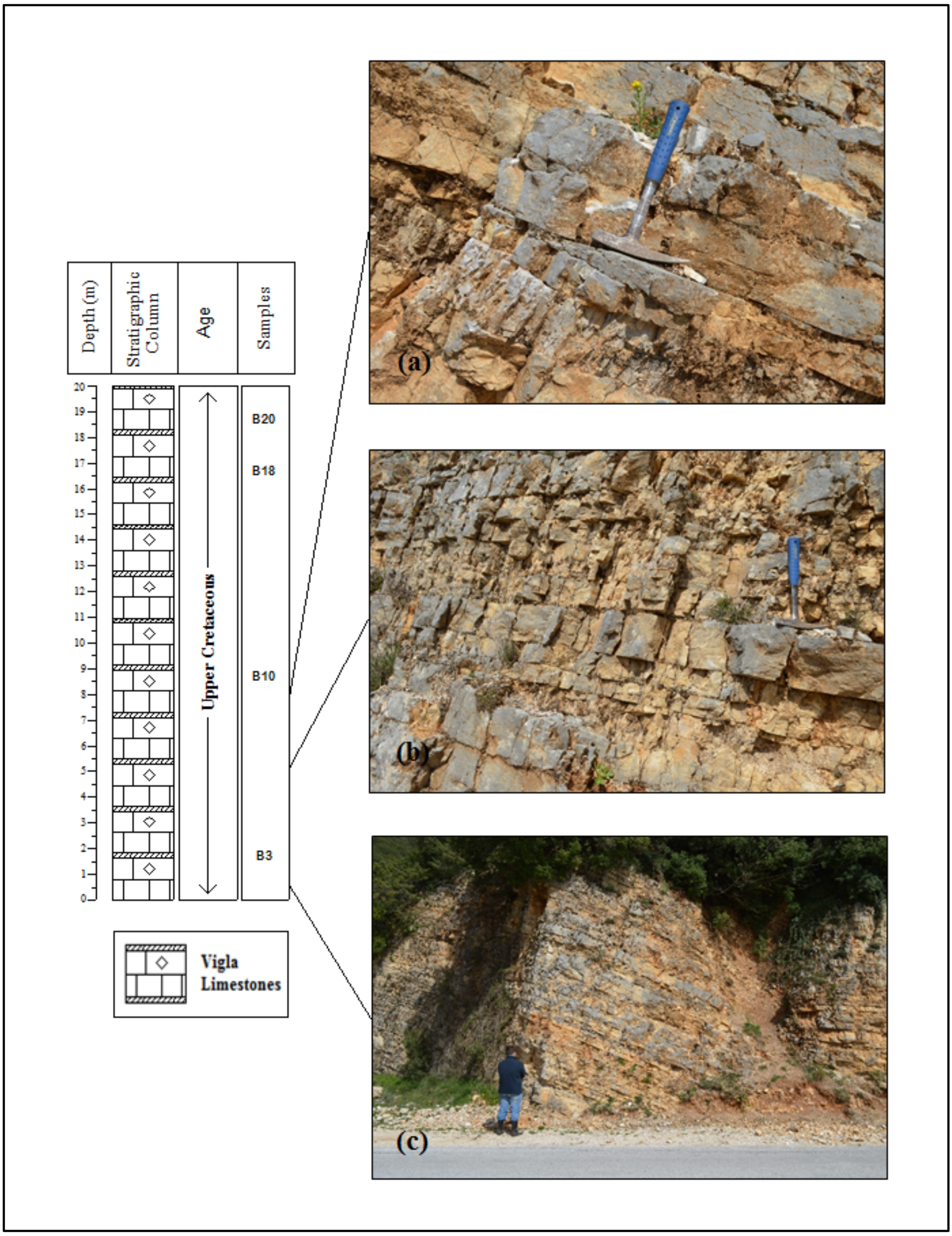
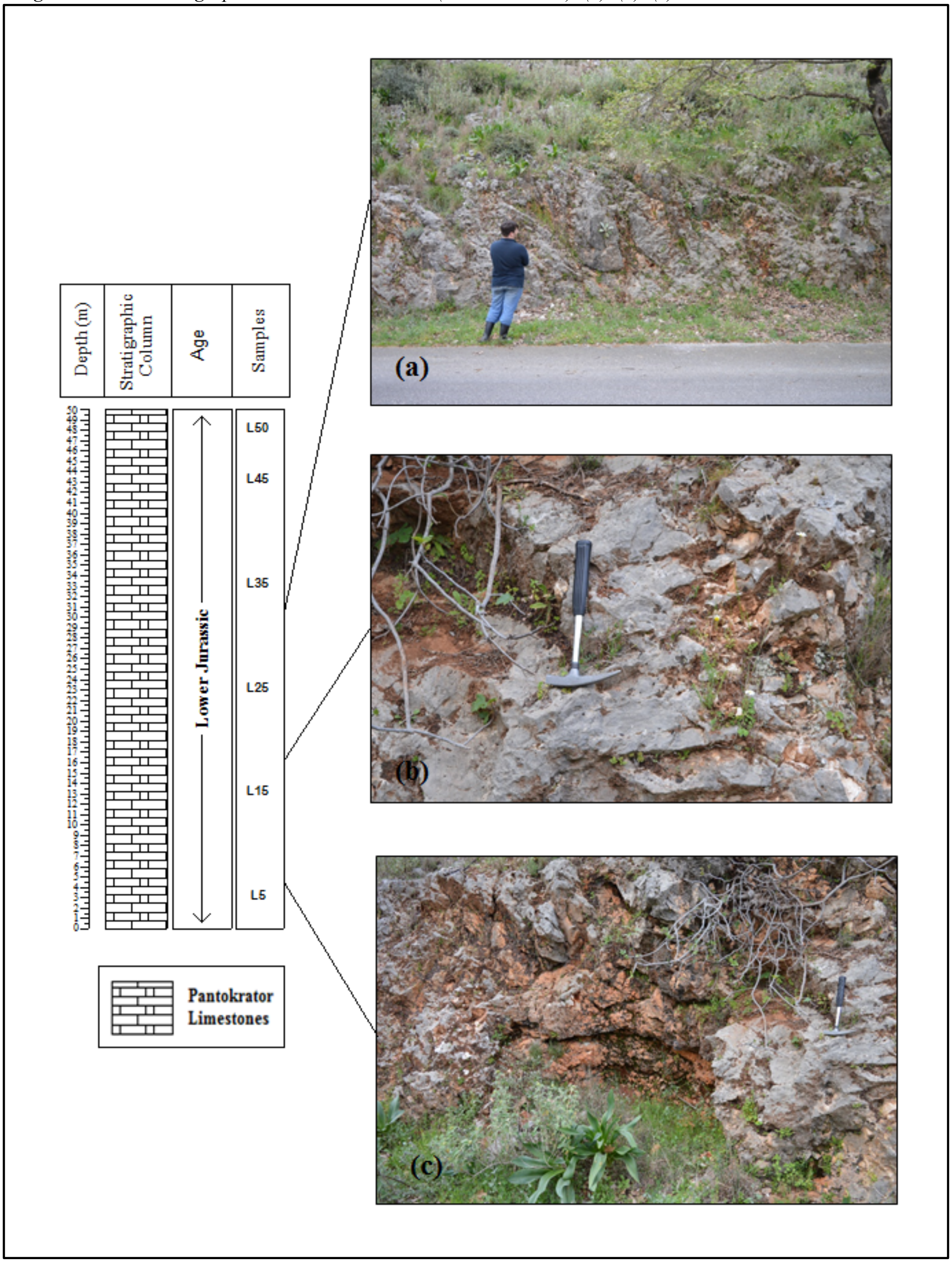


Figure 29: Lithostratigraphic column of Section D (Vigla Section). (a), (b), (c) Vigla limestones.

Section F (Louros Section)

Section F (*Fig. 24*) is situated at the entrance of Agios Georgios village (lat: 39°16’14.99’’ N, lon: 20°50’59.43’’E). This section covers the stratigraphic horizon of Pantokrator limestones (*Fig. 31*), with a total lenght of 50m, where 50 samples have been collected per 1m (*Fig. 30*).

Figure 30: Lithostratigraphic column od Section F (Louros Section). (a), (b), (c) Pantokrator limestones.



5.2 Stratigraphy

As it is mentioned above, six sections have been studied within the Central Ionian Zone. In this chapter the stratigraphy of each section will be described and also the stratigraphic columns will be presented.

Pantokrator Limestones : The Pantokrator Limestones formation can be described as a solid neretic formation, consisted of limestones and dolomites with calcareous algae of 1500m total thickness. Furthermore, the Pantokrator Limestones can be considered as the pre-rift sediments of the Ionian Zone (Karakitsios, 1999). The Pantokrator Limestones have been found within Section F and Section A.

Senonian Limestones: The Senonian Limestones formation are characterized as microbrecciated limestones with roudist fragments that alternate with sub-lithographic pelagic limestones and cherts (100-300m). In addition the Senonian limestones can be described as solid, thick bedded that can easily separated from the thin bedded formations (Auboin, 1959. IGRS-IFP, 1996. Bernier and Fleury, 1980). The Senonian limestone formation have been found within Section A and D.

The same sedimentary facies are continuously deposited during Paleocene-Eocene period (200-400m).

Vigla Limestones: The Vigla limestones can be described as sub-lithographic thin bed formations, rich in plaktonic organisms (Calpionelles, Radiolaires, and Globotruncanes). Their continuity is interrupted by thin intercalations, tubers or chert lenses, prevailing in the upper layers. Vigla limestones show significant lateral variations in thickness and can be considered as the first post-rift sediments of the Ionian zone (Karakitsios, 1990, Karakitsios and Koletti, 1992).

The beds consists of yellow to red marly limestones or shaly limestones and chert alterations, as well as clay layers that are usually green and red. The calcareous beds consistmainly of micrites (mudstones, wackestones), biomicrites with foraminafera and radiolaria (foraminiferal or radiolarian wackestone to packstone) and silicious biomicrites.

Along the eastern border of the central Ionian Zone, posphatic horizons are intercalated with the uppermost beds of the Vigla limestone formation, usually above thin bed of green clay. Locally (Koloniati) brecciated horizons have been reported.

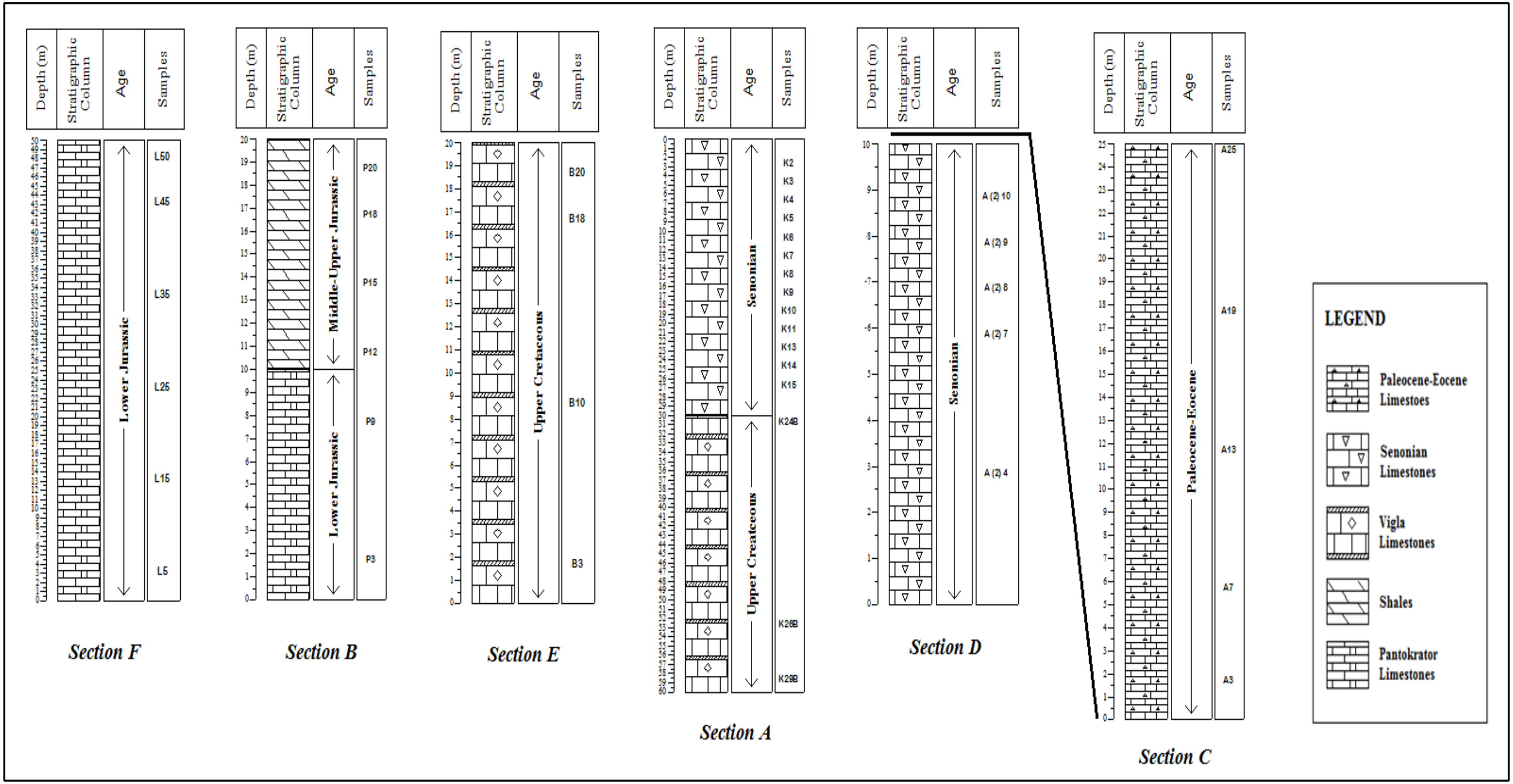


Figure 31: Stratigraphic columns from each section that have been studied. The stratigraphic columns are presented by aging order, from older (Pantokrator Limestones) to younger (Paleocene-Eocene) formation. Furthermore, within this image the samples for laboratory analysis (porosity, permeability and thin sections) are also shown.

5.3 Lithofacies Interpretation

Lithofacies studies aim for the recognition of overall patterns that reflect the history of carbonate rocks, by means of a thorough examination of their sedimentological and paleontological characteristics. The evaluation of microfacies in the context of facies interpretation requires a synopsis of microfacies type (MFT). Microfacies types and facies associations are fundamental to the development of models for carbonate sedimentation (Flugel, 2010).

Section A (Koloniati Section)

In Section A, *pisoid lithofacies*, is the one that is distinguished from all other lithofacies. Pisoids have been described in the classical paper of Dunham (1972) and interpreted as caliche soil pisoids formed by subaerial vadose diagenesis during episodic lowstands of sea level. The range of depositional interpretations of these pisoids includes caliche formation in continental or coastal-spray-zone, supratidal settings, vadose-marine inorganic precipitation in inter- and subtidal environments of formation in marine seepage or groundwater springs. (*Fig. 56, 61*) (Flugel, 2010). Within this section the following lithofacies have been observed as well: *biomicrite (mudstone-wackestone)* which refers to deep depositional environment. (*Fig.62, 68, 69* and *70*).

Section B (Perivleptos Section)

This section is characterized by the lithofacies *biospirite (grainstone)*. The Pantokrator limestones give evidence of a depositional environment characterized by a carbonate platform with both intertidal and subtidal environments. Vadose diagenesis of some redeposited carbonate clasts points a subaerial exposure of parts of the platform. (*Fig. 71* and *72*).

Section C (Asprageli-1 Section)

In Section C the lithofacies that has been identified is *biomicritic (packstone).* Within this lithofacies pelagic foraminifera have been observed, that represent a medium energy environment, possibly corresponding to a deep depositional environment. (*Fig. 73-78*).

Section D (Asprageli-2 Section)

In Section D, the following three lithofacies have been observed: *bioclastic (packstone)*, which represents a medium energy environment. Possibly, sediments have been transported within the basin from the platform (*Fig. 79* and *82*). *biomicrite (wakestone-packstone-floatstone)* with plaktonic foraminifera, deposited in a medium energy pelagic depositional environment (*Fig. 80, 81* and *83*), *biolithitic (bounstone)* corresponding to the margin of the platform (*Fig. 84*).

Section E (Vigla Section)

Section E consists of *radiolarian biomicrite (wackestone)* characterizing a low energy deep environment.(*Fig. 85-88*)

Section F (Louros Section)

The principal lithofacies of this section is *biolithitic (boundstone)*. *(Fig. 89-95)*

6. Reservoir characterization

Reservoirs are usually defined as storage receptacles. Reservoirs are porous and permeable rocks bodies that contain commercial amounts of hydrocarbons or water. Reservoirs are three – dimensional bodies composed of rock matrix and networks of interconnected pores. If the three-dimensional geometry (size and shape) of a connected pore system is known, it is possible to (1) estimate the volume or the resource in the reservoir or aquifer, (2) achieve optimum extraction of the resource, (3) determine the drilling pattern of additional (infill) wells to achieve the optimum spacing between production wells during development, and (4) predict the path that will be taken by injected fluids as they “sweep” remaining hydrocarbons during secondary and enhanced recovery (Ahr, 2008). Within this study the focus will be on carbonate reservoirs throughout Greece and Albania.

Reservoir characterization, deals with physical characteristics of the reservoir. It differs from geological description in that data on petro-physics and fluid properties are included; In addition to data from direct examination of reservoir rocks, reservoir characterization involves interpretation of borehole logs, porosity – permeability measurements, capillary pressure measurements, reservoir fluid saturations and reservoir drive mechanisms. (Ahr, 2008)

An understanding of the geology of the reservoirs is essential to its development, production and management. This include both the external geology of the reservoir, i.e. what created the hydrocarbon trap, and the internal geology of the reservoir, i.e. the nature of the rocks in which the hydrocarbons exist.

Differences between sandstone and carbonate reservoirs influence the way we study them. Sandstone porosity is mainly interparticle; therefore it is related geometrically to depositional texture and fabric. Because permeability usually collates rather well with interparticle porosity in sandstones, it can be related to depositional texture and fabric, as illustrated in a study of pore geometry in sphere packs and in terrigenous sandstones. Assuming that porosity and permeability are closely related, laboratory measurements made on small core plugs of terrigenous sandstones may be assumed to be representative of large populations if the populations are homogeneous. Carbonates do not always exhibit interparticle porosity; they may have a variety of pore sizes, shapes and origins and measured porosity values do not always correspond closely with permeability. Thus entire core segments inches in diameter and 1 foot long may be required for reliable measurements on carbonates. Relatively simple porosity classification schemes are useful for siliciclastics but a compound scheme of genetic classification augmented by measurements of pore geometry is needed for carbonates.

6.1 Lithology

The identification of a bed’s lithology is fundamental to all reservoir characterization because the physical and chemical properties of the rock that holds hydrocarbons and/or water affect the response of every tool used to measure formation properties. Understanding reservoir lithology is the foundation from which all other petrophysical calculations are made. To make accurate petrophysical calculations of porosity, water saturation (S_w) and permeability, the various lithologies of the reservoir interval must be identified.

From the above, it can be easily understood that there is a strong link between lithology and reservoir quality. Within this paragraph only the type of lithologies that have been found in the carbonate units of Greece and Albania will be discussed.

For the characterization of the different types of lithologies Dunham’s (1962) and Folk’s carbonate rocks classifications have be used. (*Fig. 31*)

Mudstones : Muddy carbonate rock containing less than 10 % of grains (Dunham, 1962). Generally, mudstones are hard mudrocks composed of variable proportions of quartz silt, with grain sizes less than 32 μm (<0.032 mm), and clay minerals generally less than 4 μm (<0.004

mm) in size. Mudstones may contain silt-rich and clay rich bands. Some mudstones also, contain a high proportion of carbonate minerals, such as calcie or siderite, and such minerals may form cm-sized calcareous concretions. Furthermore, mudstones have been compacted and hardened by burial in thick sedimentary deposits, and changed mineralogically by diagenetic processes associated with burial. (Merriman et al., 2003)

Wackestone: Mud-supported carbonate rock containing more than 10% grains (Dunham, 1962). Generally indicates calm water and restriction of grain-producing organisms (low-energy depositional setting). In case where grains are exceptionally large, Embry and Klovan (1971) designated these carbonates as “floatstones”.

Packstones: Grain-supported muddy carbonate rock (Dunham, 1962). Lucia (1999) divided packstones into mud-dominated (pore spaces totally filled with mud) and grain-dominated (some intergrain pore space is free of mud) packstones. This division is important in understanding reservoir quality because mud plugs interparticle porespaces. Packstones indicate a range of depositional properties. Mud suggests lower-energy processes, whereas the abundance of grains suggests higher-energy processes. Dunham (1962) provided several scenarios for the origin of packstones: 1) they may be a product of compacted wackstones, 2) they may result from early or late mud infiltration of previously deposited mud-free sediments, 3) they may result from the prolific production of grains in calm water, or 4) they may record the mixing by burrowers of different layers of sediment. In cases where the grains are exceptionally large, Embry and Klovan (1971) designated these carbonates as “rudstones”.

Grainstones: Mud-free carbonate rocks, which are grain-supported (Dunham, 1962). They generally are deposited in moderate-to high energy environments, but their hydraulic significance can vary. Dunham (1962) provided several suggestions for their origin: 1) they may be produced in high energy, grain productive environments, where mud cannot accumulate, 2) they may be deposited by currents that drop out the grains and bypass mud to another area, or 3) they may be a product of winnowing of previously deposited muddy sediments. In cases where the grains are exceptionally large, Embry and Klovan (1971) designated these carbonates as “rudstones”.

Boundstones: Carbonate rocks showing signs of being bound during deposition (Dunham, 1962). Embry and Klovan (1972) further expanded the boundstone classification on the basis of the fabric of the boundstone. Boundstones generally are deposited in higher energy environments, where currents can provide nutrients to the organisms that form the boundstone, as well as carry away waste products.

Crystalline carbonates: Carbonate rocks that lack enough evidence of depositional texture to be classified. Extensive dolomitization commonly obliterates the original depositional texture.

Limestones and Dolomites: Limestone is a sedimentary rock composed primarily of calcium carbonate (CaCO3) in the form of the mineral calcite. It most commonly forms in clear, warm, shallow marine waters. It is usually an organic sedimentary rock that forms from the accumulation of shell, coral, algal and fecal debris. It can also be a chemical sedimentary rock formed by the precipitation of calcium carbonate from lake or ocean water. The high porosities needed to make limestones good reservoirs are often produced by fracturing of the rock after formation or by dissolution of some of the rock by circulating groundwater. On the other hand dolomites are also sedimentary rock but are composed primarily of the mineral dolomite ($CaMg(CO_3)_2$). It is thought to form by the post depositional alteration of lime mud and limestone by magnesium groundwater.

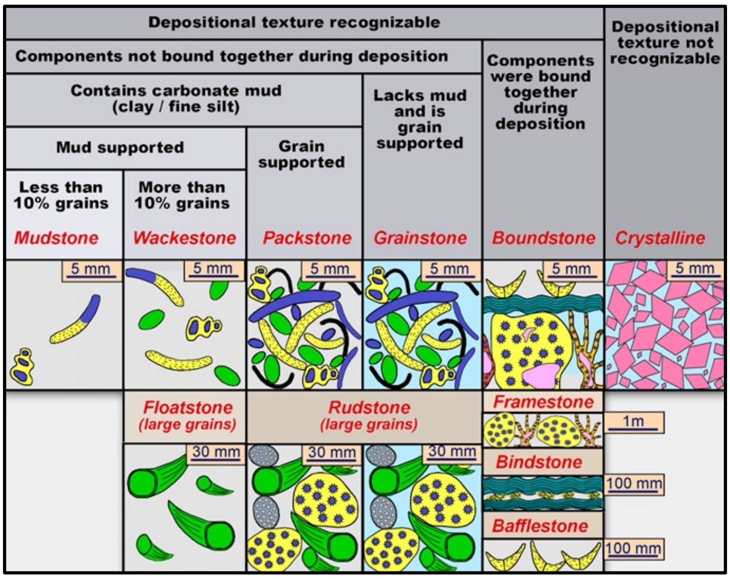


Figure 32: The carbonate rock classification of Folk and Dunham (1962) and Embry and Klovan (1971).

6.2 Porosity

The porosity of a porous medium describes the fraction of void space in the material, where the void may contain, for example air or water or hydrocarbons.

Most carbonate reservoirs have porosity of about 5-15 % (sometimes less than 15%), as compared with terrigenous sandstone reservoirs, which have porosities of 15-30%. The porosity within carbonates depends on the sedimentation and diagenetic processes that occurred during burial history. Diagenesis includes cementation in pores, fractures and caverns, recrystallization, compaction and pressure solution, replacement and dissolution (Ahr, 2008). The percentage of sample surface area covered by visible porosity can be used to obtain a qualitative estimate of the "quality" of reservoir porosity.

Lower porosities, such as 5% or less, are usually the result of chemical modification of the pore structure, i.e., cementation, precipitation of additional minerals, or leaching and precipitation.

Porosity can be described using several classifications that help describe the flow of fluids through the formation and into the wellbore. The major classifications are briefly described in the following paragraphs:

1. Matrix porosity or intergranular porosity – Is the porosity between the grains of the formation.

2. Vug porosity – is pore space that is within grains or crystals or that is significantly larger than grains or crystals. Vugs are commonly present as dissolved grains, fossil chambers, fractures and large irregular cavities. (Lucia, 1999)

3. Fracture porosity – is the void space created between the walls of an open natural fracture.

4. Micro-porosity – is the void between the clay platelets or particles. Although a large micro porosity may exist, production of fluids is often difficult since the fluids are usually held by strong cohesive forces.

To define the reservoirs quality (*Table 1*), the following porosity level qualitative description has been used:

CARBONATE RESERVOIR ROCK PROPERTIES - POROSITY	
POROSITY RANGE	QUALITATIVE DESCRIPTION
5% or less	Poor
5-10%	Fair
>10%	Good
>20%	Excellent

***Table 1:** Qualitative description of porosity.*

6.3 Permeability

Permeability, denoted by a lower case k, is a measure of the conductance of the formation to flow of a fluid. The higher the permeability, the easier it is for a fluid to flow through the rock matrix.

Dolomitization plays an important role in controlling porosity and permeability. This is important for the external parts of the Ionian zone, because extensive dolomitization occurred during the Jurassic and Cretaceous, whilst in the central parts of the Ionian zone, it stopped in until the Middle Jurassic. As a result, the precise location of a rock unit within the Ionian zone will have an important influence on dolomite related porosity and permeability.

Permeability to oil, water and gas may be different because of viscosity differences and other influences such as wetting and the issue of the thickness of the liquid coating on the pore wall. Oil wet formations are usually thought to be less permeable to the flow of water than water wet formations because the molecular thickness of the oil coating is thicker than that of water. This leaves less pore space for fluids flow. When more than one phase exists in the pore, relative permeability relationships govern the flow.

In our study and when permeability values where available, the following permeability level qualitative description has been used. (*Table 2*)

CARBONATE RESERVOIR ROCK PROPERTIES	
PERMEABILITY (md)	QUALITATIVE DESCRIPTION
< 1.0 - 15	Poor to fair
15 - 20	Moderate
50 - 250	Good
250 - 1000	Very good
>1000	Excellent

***Table 2:** Qualitative description of permeability.*

6.4 Reservoir Quality

In order to determine the quality of the reservoirs, some aspects like tectonic evolution, lithology, paleo-enviroments, porosity and permeability have been analyzed. After completing the study of those aspects and in association with the data from literature, the quality of the reservoirs has been divided into three main groups:

- Poor Quality Reservoirs: P
- Fair Quality Reservoirs: F
- Good Quality Reservoirs: G

Furthermore, no excellent potential reservoir has been indicated. This is, because, it is assumed that excellent potential reservoirs are characterized by higher than 10% porosities in combination with good permeabilities of more than 100mD. Due to the lack of data for permeabilities in our study area, those that have been examined are not characterized by such high values of more than 100Md.

It is important to mention that only in well *Afroditi-1*, excellent reservoir within the Eocene unit has been detected. Very good reservoir quality characteristics have been also recognized in well *Planck*. The carbonate reservoir (3840-4203m/MD), has primary (vuggy) porosity and secondary (fractured) porosity. But as in case of *Afroditi-1*, a further investigation is needed.

Poor quality reservoirs: Poor potential reservoirs have low or any commercial hydrocarbon productivity. Those reservoirs have effective porosities below 5%. These carbonate units have mainly highly destroyed porosity by cementation or anhydrite and gypsum precipitation. Furthermore, within these units there is almost no fracturing porosity or dolomitization or any other process that could increase the porosity. However, these carbonate units with low porosity and permeability could work as a perfect seal rock for underlying good quality carbonate reservoirs.

Fair quality reservoirs: Fair potential reservoirs have fair capacity to store hydrocarbons. The effective porosity of these reservoirs will be between 5-10%. Generally, the lithologies for fair carbonates reservoirs are: early diagenetic dolomites, early and late diagenetic dolomites with anhydrite and gypsum inclusions, partly fractures Cretaceous limestones and Eocene basinal limestones. (Ahr, 2008)

Good quality reservoirs: Good potential reservoirs are reservoirs with a high capacity to store hydrocarbons. These types of reservoirs must have a high porosity more than 10%. The porosity within these reservoirs can be increased or enhanced by periods of emergence and diagenesis or affected by dolomitization which also enhances the reservoirs characteristics. In general, the lithologies for a good carbonate reservoir are: late diagenetic dolomites, early diagenetic dolomites with high fracture porosity, and reef limestones that are dolomitized and highly porous.

7. Depositional Environments

A depositional environment is a specific type of place in which sediments are deposited, such as a stream channel, a lake or the bottom of the deep ocean. They are sometimes called sedimentary environments. The layers of sediment that accumulate in each type of depositional environment have distinctive characteristics that provide important information regarding the geological history of an area. The characteristics that can be observed and measured in a sedimentary rock to reduce its depositional environment include its lithology, which is essentially its rock type, its sedimentary structures and any fossils it may contain.

Carbonate sediments are commonly formed in shallow, warm, but also cold, oceans either by direct precipitation out of seawater or by biological extraction of calcium carbonate from seawater to form skeletal material. The result is a sediment composed of particles with a wide range of sizes and shapes mixed together to form a multitude of depositional textures. The sediment may be bound together by encrusting organisms or, more commonly, deposited as loose sediment subject to transport by ocean currents

Carbonate sediments accumulate in depositional environments that range from tidal flats to deep water basins, as ancient rocks, and as economically important mineral deposits (Ahr, 2008). Most carbonate sediments originate on a shallow water platform, shelf or ramp and are transported landward and basin ward.

Within this study seven depositional environments have been subdivided and have been taken into account in order to characterize our study area. (*Fig. 24*)

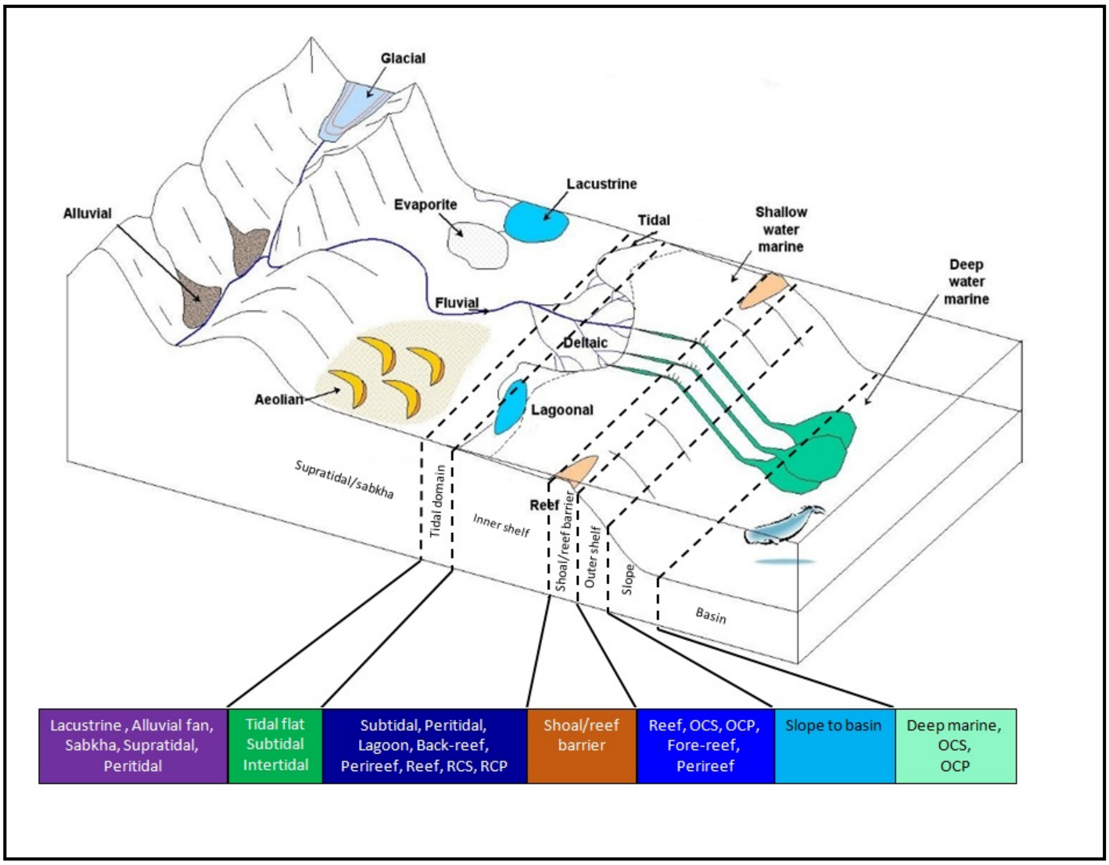


Figure 33: *Schematic block diagram showing the main sedimentary depositional environments. RCS= Restricted Carbonate Shelf, RCP= Restricted Carbonate Platform, OCS= Open Carbonate Shelf, OCP= Open Carbonate Platform.*

7.1 Supratidal/sebkha domain

The supratidal environment is where the sediment is deposited above normal high tide by spring and storm tides. The sediment is exposed for long periods of time to subaerial conditions. Diagnostic supratidal sedimentary structures include mudcracks, fine laminations, algal mats and domes, fenestrae structures, bioturbation and crasts of evaporite minerals. Rock types include laminated mudstones to wackestones, algal boundstones (stromatolites), intraclasts conglomerates and rare storm-deposited grainstones. These rock types are commonly dolomitized.

In arid climates, the supratidal zone known as sebkha, is partially covered with siliclastic sands. In the shallow subsurface of the lower supratidal zone, or sebkha, interstitial evaporites are common. In addition, these zones are characterized by diagenesis processes, which means changes on the chemical properties of the sediments or existing sedimentary rocks, resulting in a different type of sedimentary rock during and after formation. Also, during emersion periods, karstifications and bauxites are common within supratidal and sebkha areas.

7.2 Inner shelf

Restricted shelf, bay or lagoonal environments can be reasonably well defined geographically or hydrographically in modern settings. In the geologic record, these terms are typically used somewhat more loosely to form a "waste-basket" category for low-energy, shallow water carbonates, especially if a demonstrable barrier occurs seaward, or if lateral facies equivalents reflect severe restriction, as in the case of evaporitic or euxinic (organic carbon-rich) sequences. Generally inner shelf is restricted to shallow marine platforms.

Geographically bays and lagoons are partly enclosed bodies of water. A bay is a shoreline recess or inlet between headlands. Lagoons are more completely enclosed, for example by barrier islands or reefs, so that connection to the sea is distinctly restricted. Lagoons are normally shallow, although lagoons of some larger atolls reach 70m deep; bays have no particular depth connotation. Restricted shelves may be defined as any part of a continental or island shelf with slow water circulation resulting in abnormal salinity, depleted nutrients, or temperature extremes. Restriction that reduces normal wave or current energy may result from any physical barrier such as reefs, islands skeletal or oolitic sand shoals or from the damping effect of vast expanses of shallow water.

In ancient settings, restricted shelf, bay or lagoonal depositional environments may be inferred from stratigraphic evidence or paleogeography similar to that described for modern settings, for example by transition to reefal or sand-shoal (ooid, skeletal, terrigenous) deposits on one hand and to shoreline, tidal flat or evaporitic facies on the other hand. With less stratigraphic resolution, restriction may be inferred from impoverishment of fauna or from lithofacies, such as muddly sediment, especially if it contains abundant organic matter, pyrite or evaporites.

7.3 Reef

A reef, rising above the sea floor, is an entity of its own making – a sedimentary system within itself. Numerous, large calcium carbonate secreting organisms stand on the remains of their ancestors and are surrounded and often buried by the skeletal remains of the many small organisms that once lived on, beneath and between them. Reefs tend to form is shallow warm, but also cold waters in the edge areas of shoal/reef barriers.

7.4 Tidal domain

Tidal flats are mud-dominated environments because they are protected from open ocean waves and currents, and they are undergoing the effects of the tides. They are sinks for lime that formed in, sheltered environments behind barrier islands or wave filtering rims on rimmed shelves. In addition, tidal flats offer limited potential for the formation of depositional porosity because they are mud-dominated systems.

These low energy flats lack waves and strong currents that concentrate grainy sediments and they are inhospitable places for reef organisms to grow. Consequently, depositional porosity is limited to small areas of grainy sediment accumulations in tidal channels and to zones where fenestral porosity is common. (Ahr, 2008)

7.5 Slope

Characteristics of slope environments vary depending on the mechanical slope stability, the slope angle and the rigor of the physical oceanographic environments. Slope environments characterize both rimmed and open shelves but not ramps. Slope areas are high-energy zones where coarse grained sediments, grainstones and occasionally gravels, tend to be deposited. Carbonate slopes differ from siliclastic slopes in that carbonate slopes are steeper (5^o – 15^o as compared to 3^o – 6^o), so the angle of the slope makes it difficult for sediments to settle within this zone. Physical processes that characterize slope environments vary depending on water depth, on the nature of the hydrologic regime, on slope characteristics and on proximity to the slope.

Environmental processes in slopes are dominated by gravitational forces and pounding from waves. Upper slope zones in relatively shallow water may be subject to wind or storm waves, oceanic currents and tides much the same as the slope-break environment. Slopes are commonly sites for upwelling, initiation of density or turbidity currents and initiation of slumps, rock falls and debris flows triggered by slope failures. Middle slope and base of slope zones are typically below fair-weather wave base, below the influence of surface currents and relatively less influenced by tidal currents than the upper slope zone, where the shorter water column is more vigorously moved during tidal exchange. Deeper parts of slope zones are sites where rocks and sediments swept off the slope by shallow-water processes come to rest. Currents on the middle and outer slope are mainly geostrophic and density currents.

7.6 Basin

The Basinal environment is simply the end of the marine environmental spectrum that began at the strandline and ended at the deepest part of that particular sedimentary basin. There is no unique depth that identifies the “basinal” environment. With the increase in water-depth when we are going from slope to basinal environments the energy regime will become less. For carbonate sediments to accumulate in the basinal environment, water depths must be shallower in order carbonate particles not being dissolved,

Basinal environments, even those only a few hundreds of meter deep, are generally protected from wave action, surface currents and ordinary tidal effects, but they are not immune from being swept by geostrophic and density currents. These deep-water currents can transport fine sediments and create sedimentary structures.

The lithology of basinal environments mainly consists of fine-grained carbonate and siliclastic mud and sand, particles of organic matter, pelagic microfossil remains, clays, laminated beds and distal turbidites.

8. Materials & Methods

8.2 Laboratory analysis

In order to determine the porosity and permeability in our samples different steps have been followed. From the total 150 existing samples, only 40 of them have been chosen carefully for further laboratory measurements. For the purpose of these measurements, the AccuPyc 1330 Pycnometer and GeoPyc 1360 from Micromeritics have been used.

In the following sections a more analytical method on how the measurements have been observed is stated.

8.2.1 Porosity measurements

ACCUPYC 1330 PYCNOMETER

The AccuPyc 1330 Pycnometer determines density and volume by measuring the pressure change of helium in a calibrated volume. It also reports the chamber temperature at the end of the requested runs. The schematic diagram, which is included above the keypad, indicates system status. The three indicators show the current state of the fill, expansion and vent valves. The indicator is lit when a valve is open. In addition to analysis, there are two other automatic operations performed by the pycnometer: calibration and transducer zero reset.

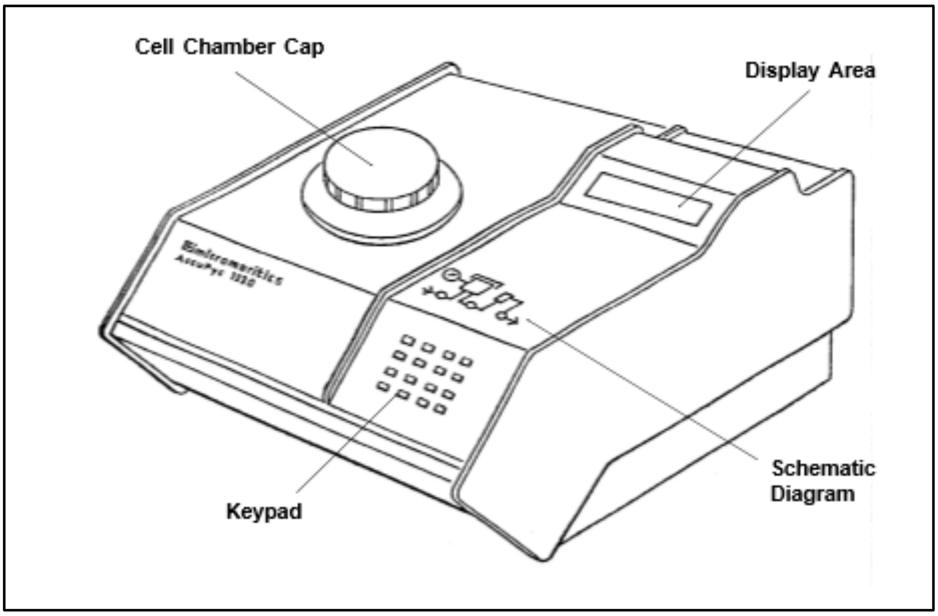


Figure 34: AccuPyc 1330 Pycnometer

The AccuPyc 1330 Pycnometer, shown in the above illustration (*Fig. 41*), contains a keypad, a display area and an analysis chamber. The pycnometer is controlled by commands entered through the keypad. The operational status of the pycnometer can be continually monitored on the display. The optional printer connected to the pycnometer prints out the complete analysis and calibration results.

PERFORMING AN ANALYSIS

In order to perform an analysis with AccuPyc 1330 Pycnometer, the following steps have been followed:

- Setting Regulator Pressure
- Preparing and loading a sample
- Starting an analysis
- Printing analysis results

Setting Regulator Pressure

Before setting regulator pressure we should make sure that the tank pressure for the gas regulator is at least 200 psig. Pressures less than 200 psig may cause the sample to be inadequately saturated, resulting in inaccurate data or termination of analysis.

Preparing and Loading a Sample

Preparing the sample is the first step in obtaining accurate results from the pycnometer. Samples must be free of moisture in order to obtain true sample weight and to avoid the distorting effect of water vapor on the volume measurement.
The important point is that each step should be conducted to avoid exposure of the dried sample to atmospheric moisture. This means weighing as rapidly as possible and installing in the instrument without unnecessary delay.

1. Weigh the empty sample cup.
2. Place a quantity of sample in the cup. The cup should be at least two-thirds full.
3. Weigh the cup and sample and record the weight. Subtract the empty sample cup weight from the sample cup plus sample weight to determine the sample weight.
4. Remove the cell chamber cap.
5. Insert the sample cup with sample into the cell chamber.
6. Replace the cell chamber cap.

Starting an Analysis

In order to start an analysis we can use the default parameters or modify the analysis parameters. This step is very important in order our parameters follow our research goals.

Printing Analysis Results

As the analysis is performed, operational status messages are displayed. When the analysis is complete, the pycnometer beeps three times and we can remove the sample from the cell chamber. In addition, a report is automatically printed with the results.

8.2.2 Permeability measurements

GEOPYC 1360

The GeoPyc 1360 Envelope Density Analyzer (*Fig. 42*) is an instrument for rapidly measuring the envelope density of porous objects of irregular size and shape. Particle size should exceed 2 mm for best results. Envelope density, or bulk density as it is sometimes called, is the mass of an object divided by its volume where the volume includes that of its pore and small cavities.

The GeoPyc follows a unique displacement measurement technique that uses a quasi-fluid composed of small, rigid spheres having a high degree of flowability (DryFlo). The sample is placed in a bed of DryFlo and the DryFlo is agitated and gently consolidated about the sample. The GeoPyc collects the displacement data, performs the calculations and prints the results. The unit also reports percentage porosity and specific pore volume when absolute density information is entered.

Figure 35: GeoPyc 1360 Analyzer.

8.2.3 Preparation of thin sections

In order to study our samples, thin sections have been produced at the laboratory of thin sections at the Department of Geology and Geo-environment at the University of Athens. Making thin sections is both an art and a science. The laboratory has sufficient equipment so that the art aspects are relatively minor. But every rock is different and technique can best be learned by perseverance and practice.

General, rock samples-typically cores or individual grab samples, require processing before they can be used for mineral analysis. The sample has to be thin enough for light to pass through in a light microscope and have a polished surface for electron microscope studies.

In this chapter is going to be described the way that thin sections have been made in order to be examined at the microscope.

SUMMARY INSTRUCTIONS

1. “Frost” the glass slide.
2. Cut the slab
3. Initial lapping of the slab
4. Glass slide is added
5. Cut off the chip from the slide
6. Grinding of thin section
7. Final lapping

STEP 1: “FROST” THE GLASS SLIDE

Before beginning with the preparation of thin sections, we should first prepare the glass slides. In order the glass slides to be frosted from one site we have to hand grind them by using 400 grit carborondum.

STEP 2: CUT THE SLAB

The left hand side of Discoplan-TS takes care of the cutting. A choice of two types of diamond cut-off wheels ensures perfect cutting of all materials, with a minimum of deformation.

STEP 3: INITIAL LAPPING OF THE SLAB

After marking the slab, we must lap the samples on the RotoPol-35 PdM-Force-20 with 400 grit and then with 600 grit.

STEP 4: GLASS SLIDE IS ADDED

After drying on a hot plate both the glass slides and the slabs, we glue the glass slide to the lapped face of the slab with epoxy.

STEP 5: CUT OF THE CHIP FROM THE SLIDE

Using again the left hand of Discoplan-TS the slab is cut-off close to the slide.

STEP 6: GRINDING OF THIN SECTIONS

The glass slides are placed on ceramic vacuum holders and are then moved across a cup wheel with diamonds on the left hand on the right hand of Discoplan-TS. The slides may be ground with accuracy of ±2 μm in a couple of minutes.

The ceramic vacuum holder allows for dressing of the cup wheel. This feature is important to ensure absolute precision. The vacuum holder is designed for up to three standard specimens or standard slides at a time, or one specimen of up to as much as 75×75 mm.

9. Results

9.1 Reservoir Quality

For the present study, the summary of the reservoir potential is based on existing studies, publications and well summary information, such as core descriptions, composite logs and summary logs provided from TOTAL. Generally, the available database for studies of reservoirs is extremely restricted due to the lack of analyses on cores and of data on reservoir properties and sedimentology.

Potential reservoirs in the study area are described below using the following stratigraphic intervals:
Miocene, Oligocene, Eocene, Upper Cretaceous, Lower Cretaceous, Jurassic and Triassic.

At this point it is important to mention that due to limited data, in some cases the reservoir quality has been characterized by using all the regional data, like the lithology or any shows of gas and oil that have been recorded. Furthermore, only well data has been used to determine the reservoir quality, because the carbonate outcrops units can be modified by secondary atmospheric influences.

9.1.1 Triassic

Potential reservoirs in the Triassic section could be associated with carbonate lithologies (limestones, dolomites) which in the Ionian Zone occur within a predominantly evaporitic section of anhydrites and dolomites, and in the Pre-Apulia Zone from the dominant lithology, which consist of limestones, dolomites and interbedded evaporates. Potential reservoirs are likely to be affected by fracture porosity and sealed by anhydrites.

Lower Triassic clastic deposits are postulated to underlie the thick Middle to Upper Triassic evaporites. These formations are not known in Greece, the nearest outcrops are in former Yugoslavia and Romania. Even if reservoir quality rocks are present, it would be difficult to predict structures within them because pre-evaporite structures may be unrelated to structures in the overlying carbonates.

Lithologically, Triassic sediments are represented as follows: in the Ionian Zone by an evaporite sequence of anhydrites, gypsum and rock salt interbedded with limestones and dolomites and the limestone/dolomite Foustapidima Limestones series of the Upper Triassic developed in Epirus area. In the Pre-Apulian Zone, limestones, dolomites and interbedded evaporates are predominant. No Triassic sediments are known in the Gavrovo zone. These carbonates form very thin intervals within the evaporitic section and are unlikely to form a substantial reservoir horizon. However, in some cases they have been tested oil bearing, like in well *Danae*.

Poor reservoir potential

Two DSTs performed in well *Thalis*, within the Triassic and resulted all dry. The total thickness of Triassic level is 1014m. Reservoirs are associated to carbonate levels within Triassic evaporites. Within the Triassic unit minor gas and bitumen shows have been recorded. It must be mentioned that below Triassic evaporites, the well has drilled Tertiary (Oligocene) clastics. However, due to the lack of any other data available about this unit, the reservoir potential has been characterized as poor. Also, in well *Meropi*, below the thick evaporate-dolomite sequences of the dyapir, at 3770m/MD, the well drilled 50m of Oligo-Miocene deposits (subthrust). Furtermore, oil, bitumen and fluorescence shows in Lower Triassic level have been recorded.

The primary objective of well *Aliki* was to drill the sub-thrust carbonate. During the drilling, very high pressures were encountered in the Triassic evaporite section and well *Aliki* had to be abandoned before reaching the sub-evaporites series. For the Triassic, 2000m of evaporates have been drilled. A side track was then drilled (*Ismini*) and has been abandoned after having encountered high pressures in Triassic level (720m Evaporites drilled). So, in both cases the quality of the reservoirs has been described as poor.

The objective of well *Platonas* was to drill the Mesozoic carbonates beneath Triassic evaporites. Within the Triassic evaporites, which has a thickness of 1059m, several gas shows and fluorescence associated to dolomites have been recorded. However, due to the lack of further data, this unit has a poor quality reservoir.

In well *Areti-3*, occasional gas shows are identified, possibly from fractured dolomites within the interval. In addition, open hole test in the Triassic section provided water and allow to calculate 1mD permeability, which seems to be very low. Furthermore, these lithologies only form very thin intervals within the evaporite section and are unlikely to form a substantial reservoir horizon. So the quality of the reservoir has been described as poor.

In well *Alexandros*, within the Triassic level, which has 137m thickness, anhydrites, gypsum and traces of dolomites and clays have been recognized. No important reservoirs have been identified and the well was also poorly documented. A 50m interval of Triassic breccias, dark grey to black rounded pebbles in anhydritic and dolomitic cement has been recognized on the top of the diapir, which is probably the cap rock of the diapir. The quality of the reservoir has been described as poor.

Oil and gas shows were detected in Upper Triassic evaporites at well *Minerva*. More than 2000m of Triassic level drilled with alternance of evaporites and dolomites, but no important dolomite levels within evaporites have been identified. So the quality of the reservoir has been described as poor.

In well *Galini* anhydrites, gypsum and dark dolomites of Triassic age have been drilled. The Triassic unit has a thickness of 268m. Also within this unit no shows were recorded and in combination of no further information available for this unit, the quality has been described as poor.

Dolomites with calcareous cement, fractured with small vugs have been drilled within the Triassic in well *Melpomeni*. The thickness of this unit is 25m and no shows recorded. *Melpomeni* well has been abandoned due to strong flow of sulphur water at 296m MD. There is a doubt whether the carbonates below the clastics are of Triassic or Jurassic age. Finally the quality of the reservoir has been described as poor.

In well *Aristofanis*, Triassic dolomite breccias (anhydrite, microcrystalline with inclusions of thin dolomite breccias) have been drilled. The thickness of this unit is 205m and no shows have been recorded. No other detailed information was available, so the quality of the reservoir has been described as poor.

In well *Achilleas*, 20m of dolomitic limestones with anhydrite and salt (breccias) have been recognized. Furthermore, oil shows have been recorded within this unit. In addition oil presence and fluorescence have also been recorded from core 3 in the Triassic level, (2842m/MD to 2844m/MD). No porosity values were available for this unit, so the quality of this reservoir has been described as poor.

In *Ifikratis*, abundant oil shows and bitumen traces in the whole column have been recorded. The lithology within the Triassic unit is described as grey, brownish dolomites with sulphur in fractures. The thickness of the Triassic unit within this well is 2774m. Porosity within this unit ranges between 1% to 8%. At the top of the Triassic section, from 3800m to 4200m, source rocks consisting in shales have been identified, with some bitumen traces. As a result from the above data, the quality of the reservoir has been characterized as poor to fair.

In well *Kassandra*, 220m thick dolomites have been recognized. Within this unit some oil shows have been also recorded, but no other data was available for this unit, so the quality of the reservoir has been described as poor.

Dolomites with tarry hydrocarbon within the Triassic unit have been recorded in well *Athina*. The thickness of the unit is 1450m. No further data were available for this unit, so the quality of the reservoir has been described as poor.

Well	Area	Lithology	Reservoir Quality	Thickness unit (m)
Thalis	Greece	Evaporites	P	1014m
Aliki	Greece	Evaporites	P	800m
Platonas	Greece	Evaporites	P	1059m
Minerva	Greece	Alternance of evaporites and dolomites	P	2293m
Galini	Greece	Anhydrites, gypsum and dark dolomites	P	268m
Aristofanis	Greece	Dolomite breccias (anhydrite, microsrystalline with inclusions of thin doloomite breccias)	P	205m
Alexandros	Greece	Anhydrites, gypsum and traces of dolomites and clays	P	137m
Achilleas	Greece	Dolomitic limestones with anhydrite and salt	P	20m
Areti-3	Greece	Anhydrite, salt and gypsum	P	185m
Melpomeni	Greece	Dolomites with calcareous cement	P	25m
Ifikratis	Greece	Grey, brownish dolomites with sulphur in fractures	P-F	2774m
Kassandra	Greece	Dolomites	P	220m
Meropi	Greece	Evaporite-dolomite sequences	P	3700m
Ismini	Greece	Evaporites with thin interbeds of dolomite and dolomitic limestones	P	2000m
Athina	Greece	Dolomites	P	1450m

Table 3: Table showing poor quality reservoirs within the study area, Triassic. On the table well name, lithology and thickness of the units are also presented.

Fair reservoir potential

The most important hydrocarbon occurrence in the Triassic section is the flow of 14 ft3 (2.5 bbls) of 37^{o} API oil from Triassic limestones interbedded in evaporates (3935-3947m/MD) in well *Danae*. The limestones levels, 5-30m thick, are sealed by anhydrites. No further information is available on these limestones levels, but they can be characterized as a fair quality reservoir, due to the fact that they are thin layers as it is mentioned above and will not be able to store a high amount of hydrocarbons. (*Table 4*)

Well	Area	Lithology	Reservoir Quality	Thickness unit (m)
Danae	Greece	Limestones interbedded in evaporites	F	2473m

Table 4: Table showing fair quality reservoirs, Triassic.

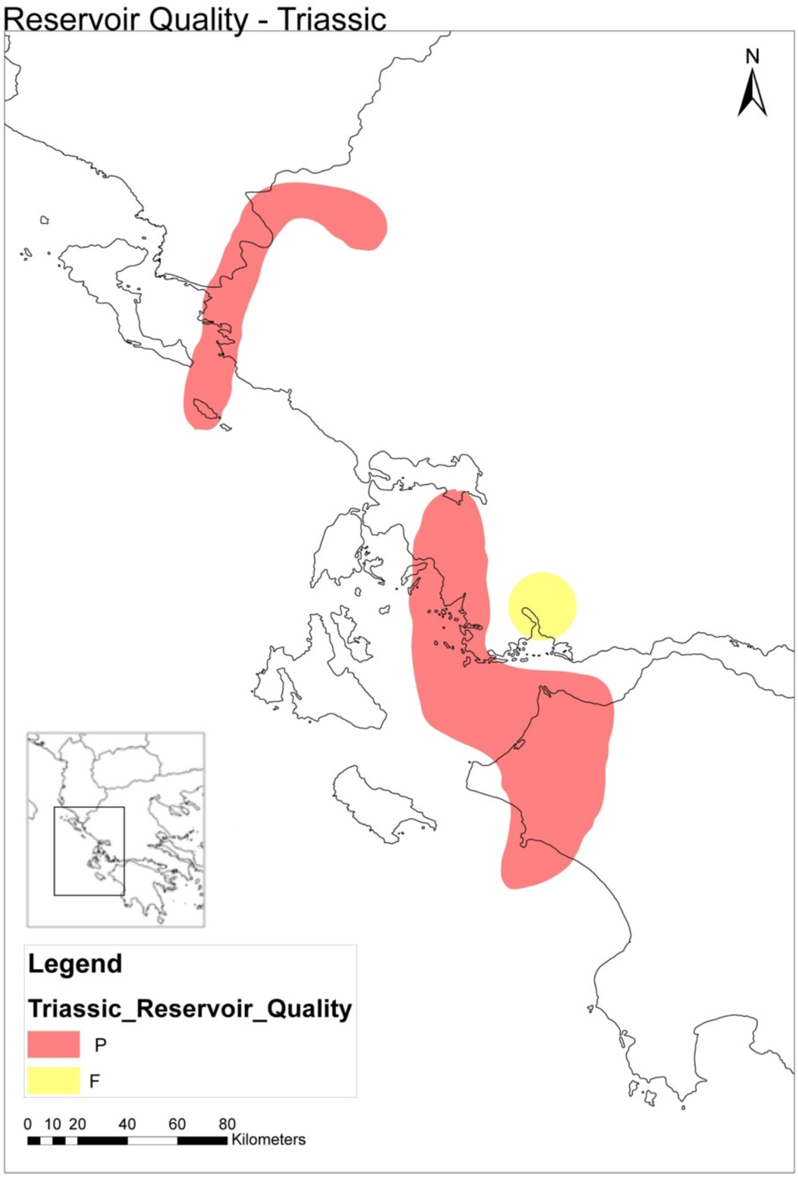


Figure 37: *Reservoir quality, Triassic. (P= Poor reservoir quality, F= Fair reservoir quality)*

9.1.2 Jurassic

Jurassic sediments (Pantokrator limestones, Siniais limestones and lateral equivalents) represent the lower part of the Carbonate unit in Greece. Currently they do not contain any proven reservoirs and future reservoir potential may be associated with the development of fracture and/or diagenetic zones.

The Jurassic is widespread. Over much of the southern and central parts of Greece it consists of a uniform, largely, condensed limestone unit. In the western part of the study area thick units have been recognized, as for example in well *Ifikratis*, where the Jurassic unit is more than 2000m thick. In the Ionian zone the thickness of Jurassic range between 1000-1200m.

In well *Sofoklis*, white microscrystalline limestones with vugs, local caves and losses have been recognized. The thickness of this unit is 50m. DST produced water within this carbonate unit, with 21000ppm salinity and presence of H_2S.

In well *Danae*, dolomites of Jurassic age, with a thickness of 1147m, have been recognized. Within this unit oil and gas shows have been also recorded, but no further information about the reservoir was available.

Within the Albanian region, Jurassic carbonates levels, 1000m thick, were recognized in well *Tesla*, but no further information were available for this well.

Poor reservoir potential

In well *Hermione-1*, core samples from the interval 3.224,5m – 3.225,7m have porosity values from 0.8% to 1.7% and corresponding lithologies are described as “hard limestones” (mudstones), compacted, with vertical joints and dolomitic limestones, hard, compacted with interbeds of fissile shale. This Jurassic carbonate unit, with 992m thickness, can be characterized as a poor quality reservoir due to low porosities.

Jurassic Pantokrator limestones and limestones interbedded with crystalline dolomites, have been recognized in well *Minerva*. The thickness of the unit is 1030m and only in the Lower Jurassic oil and gas shows have been detected. Due to the limited data, the quality of the reservoir has been characterized as poor.

Well	Area	Lithology	Reservoir Quality	Thickness unit (m)
Hermione-1	Greece	"hard limestones' (mudstones), compacted with vertical joints and dolomitic limestones, hard, compacted with interbeds of sfissile shale	P	992m
Minerva	Greece	Limestones interbedded with crystalline dolomites (limestones partially dolomitized) "Pantokrator Limestone"	P	1030m

Table 5:Table showing poor quality reservoirs, Jurassic.

Fair reservoir potential

In well *Ifikratis*, Jurassic core samples are described as interbedded limestones and anhydrites, with occasional shales. Within this well abundant oil shows, bitumen traces and some gas shows have been recognized. The total thickness of the Jurassic unit is 2775m. Porosity values range between 1% and 18% within the Jurassic unit. So the quality of the reservoir can range from poor to good.

In order to describe the quality of the reservoir for well *Kassandra*, as we do not have further data, a comparison with the near situated well of *Ifikratis*, has been done. It seems that in both wells we have the same lithology, which mainly is limestones. In well *Kassandra* the thickness of Jurassic unit is 1860m. Also, in both wells abundant bitumen and heavy oil traces have been detected, which were mainly in Jurassic deposits, so we can assume that the quality of the reservoir in well *Kassandra* is fair.

In well *Aliki*, Jurassic is made of cherty limestones, marls and bituminous material with micro-fractures (780m thick). Within this unit bitumen presence has been recorded. No further information is available for this well, but due to the presence of fractures the quality of the reservoir can be described as fair to good.

In well *Dafni*, fractured Jurassic carbonates have been drilled, they are overlain by Cretaceous carbonates. The thickness of the unit is 179m. Furthermore, no shows were detected in carbonates. A test has produced 4,6 MMcfd gas, in the sandstones levels in Miocene deposits (943-946m MD). Due to the presence of fractures within the Jurassic, the quality of the reservoir has been characterized as fair to good.

Mesozoic carbonates, dolomites and limestones mainly, with a thickness of 1200m, have been recorded in well *Antigoni*. Fractures were identified in several cores in Jurassic. Also 3 DSTs were performed at Jurassic levels and all recovered drilling mud with sulfur water. No further information is available for this unit, so due to the presence of fractures the quality of the reservoirs might be described as fair to good.

In well *Afroditi-2*, Jurassic is made of dolomitic limestones, with a thickness of 365m, described as locally cherty, fractured with strong losses. Also for this well no further data are available, but due to the presence of the strong losses the quality of the reservoir can be described as fair to good.

Within well *Ivi*, limestones of Jurassic age have been recognized. Specifically, the Lower Jurassic consists of microbreccias with some gas shows. In the Middle Jurassic, hard limestones have been recorded, while the Upper Jurassic is composed of limestones, locally microcrystalline with abundant fractures filled with microcrystalline calcite and locally with residual asphalthenes. Within Middle and Upper Jurassic two DSTs were performed. Both recovered gas. Generally within the whole Jurassic unit, which has a thickness of 782m, oil and gas shows have been recorded. So we can assume that the quality of the reservoir is fair to good, due to the fractured carbonates and the recovered gas.

Well	Area	Lithology	Reservoir Quality	Thickness unit (m)
Ifikratis	Greece	limestones (gas and bitumen traces)	P-G	2775m
Kassandra	Greece	Micritic limestones with pellets, cherts and radiolarians	F	1860m
Afroditi-2	Greece	Dolomitic limestones, locally cherty, fractured with strong losses	F-G	365m
Dafni	Greece	"Hard limestones" interbedded with claystones	F-G	179m
Antigoni	Greece	Dolomites and limestones mainly. Fractures were identified is several cores in Jurassic levels.	F-G	1200m
Ivi	Greece	Fractured limestones. Fractures rich in asphaltenes. Middle Jurassic composed by shaly and silty limestones. Lower Jurassic is mainly represented by hard limestones.	F-G	782m
Ismini	Greece	Cherty limestones, marls, bituminous material and microfractured	F-G	780m

Table 6 : Table showing fair quality reservoirs, Jurassic.

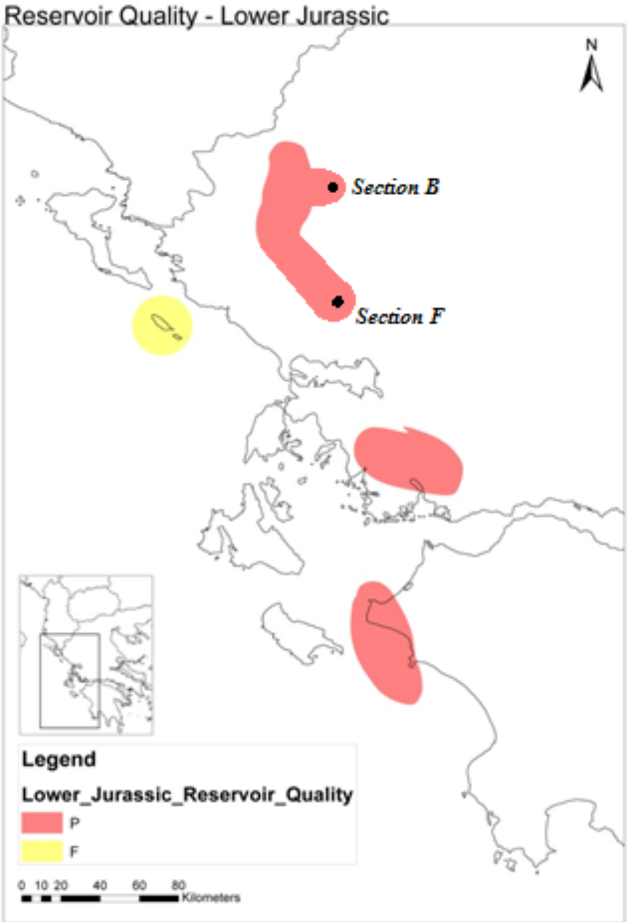
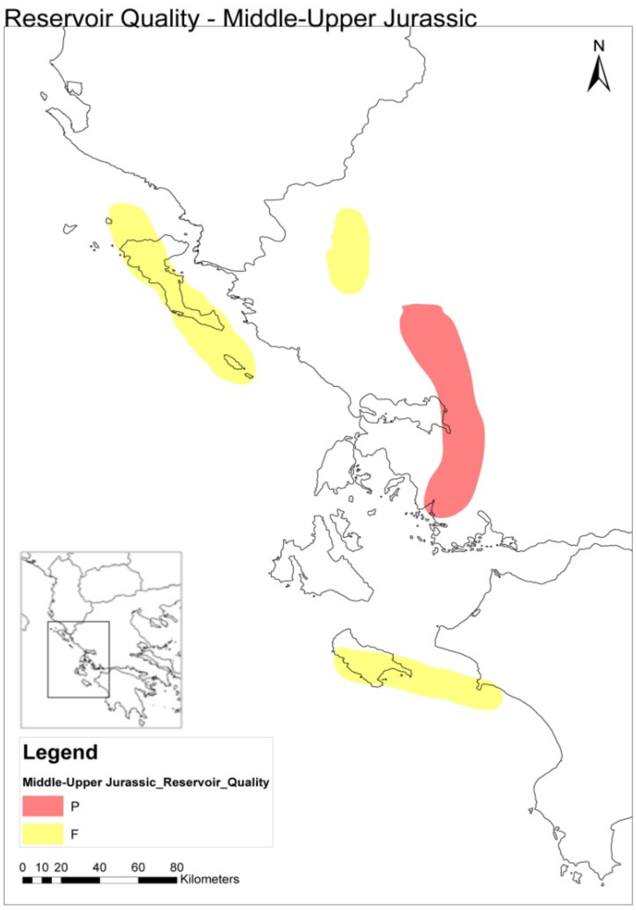


__Figure 38:__ Reservoir quality, Lower Jurassic. (P= Poor reservoir quality, F= Fair reservoir quality).

__Figure 39:__ Reservoir quality, Middle-Upper Jurassic. (P= Poor reservoir quality, F= Fair reservoir quality).



9.1.3 Early Cretaceous (to Turonian)

Lower Cretaceous, as Jurassic, is widespread, in Greece. Over much of the southern and central parts of the area it consists of a uniform, largely condensed limestone unit. In the Gavrovo zone, the oldest sediments are Lower Cretaceous in age, represented by oolitic and reefal limestones as well as dolomites which occur in the north of the zone. In the Pre-Apulian zone, the Cretaceous is represented by limestones and dolomites, with residual asphalthene. Observed stylolites are filled with marly material and there are interbeds of cherts and black shales.

In Albania, from the wells that have been examined we can see that the carbonate units are mostly of Upper Cretaceous age. The carbonate reservoirs of Upper Cretaceous age are being described within the next chapter.

Poor reservoir potential

In well *Hermione-1* Lower Cretaceous carbonates consist of mudstones with vertical joints and dolomitic limestones. The thickness of this unit is 520m. Within this unit some oils and gas shows have been recorded. The porosity range between 4% % to 7 %, so the reservoir quality has been described as poor to fair.

Bitumen presence in Lower Cretaceous carbonates, with a thickness of 460m, have been recognized in well *Ismini*. The reservoir lithology corresponds to mudstones-wackestones, with pelagic fauna and cherts, possible Vigla shales has been recorded from the composite log. No further data are available, so the quality of the reservoir has been described as poor.

In well *Franklin*, located in offshore Italy, near the Apulian shelf edge, fair to good reservoir was found in the Upper Cretaceous which is composed of packstones-grainstones locally vuggy and locally dolomitic made of bioclast and rudists. The total thickness of this unit is 936m. Furthermore, no shows were detected within the whole column, as well as no source rock levels were identified. So the quality of the reservoir has been described as poor.

Well	Area	Lithology	Reservoir Quality	Thickness unit (m)
Hermione-1	Greece	Limestones with cherts and breccias	P-F	520m
Ismini	Greece	Mudstones-wackestones, pelagic fauna and cherts	P	460m
Franklin	Italy	Packstones-grainstones made of bioclast, rudistes, vuggy and locally dolomitic.	P	936m

Table 7:Table showing poor quality reservoirs, Lower Cretaceous.

Fair reservoir potential

In well *Ifikratis* mudstones and wackestones of Cretaceous (Barremian-Neocomian) age have been recorded. Cretaceous reservoir porosity is 5,2% with some abundant oil shows and bitumen traces in the whole column.

Well	Area	Lithology	Reservoir Quality	Thickness unit (m)
Ifikratis	Greece	Mudstones-wackestones, reservoir porosity 5.2%	F	400m

Table 8: Table showing fair quality reservoirs, Lower Cretaceous.

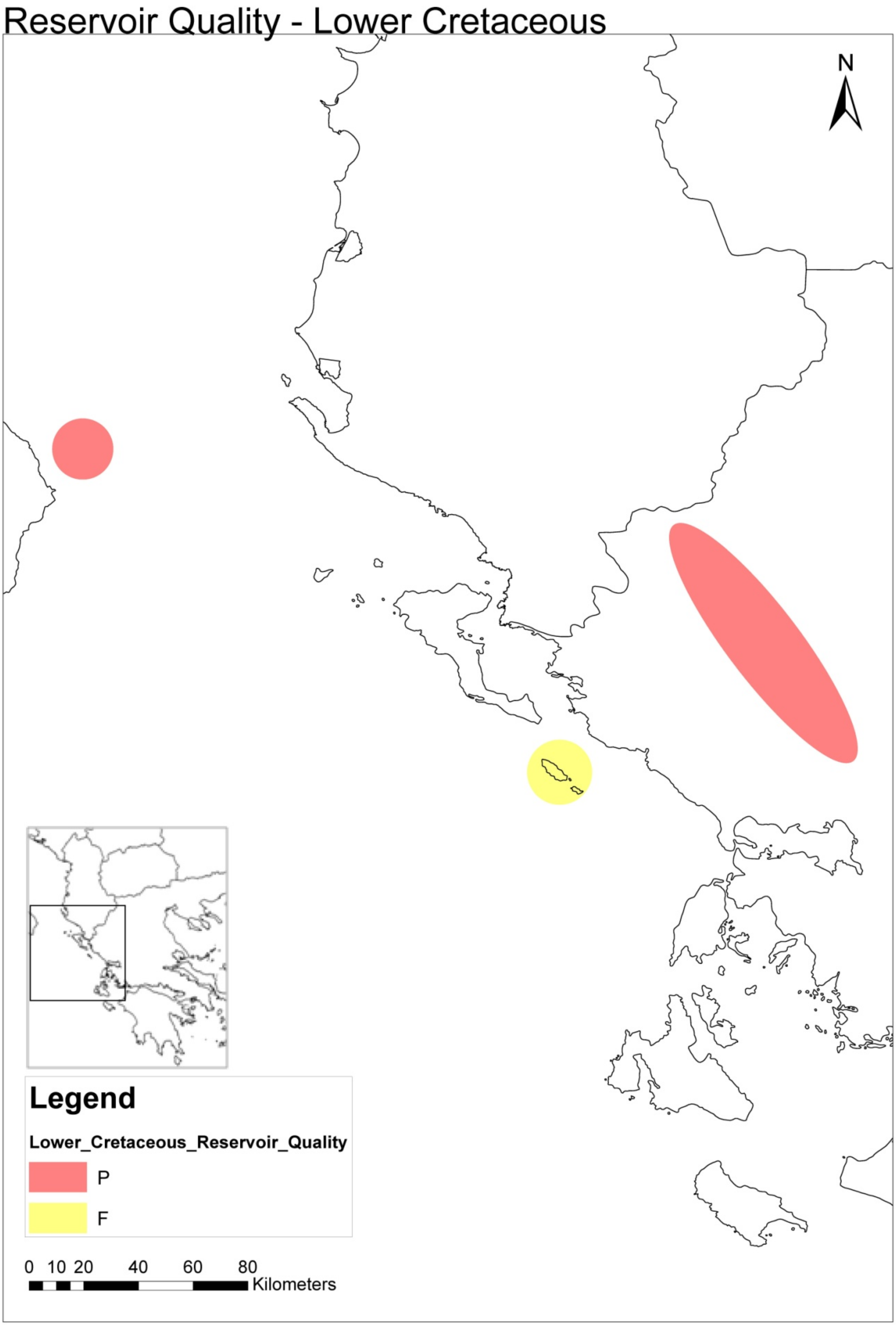


Figure 40: *Reservoir quality Lower Cretaceous. P (Poor reservoir quality), F (Fair reservoir quality).*

9.1.4 Late Cretaceous (Coniacian to Maastrichtian)

Poor reservoir potential

In *Themistoklis* well, gas and oils shows are present in the whole Cretaceous Gavrovo carbonate column (350m thickness). Oil is mainly present in matrix and also in fractures. Fractures within the limestones are often calcite cemented, so the quality of the reservoir can be described as poor.

Nefeli-1 well shows a poor quality reservoir within the Upper Cretaceous with low porosity, below 3% (from well log) and consisting of chalky limestones and breccias in the lowermost part of the unit, stylolites and fractures are cemented by calcite.

In well *Electra*, 670m thick Cretaceous, shallow water reservoir has been identified. It consists of limestones (wackestones to packstones) levels with residual bitumen at the bottom of the interval and dolomitic limestones, interbedded with limestones at the uppermost part of the interval. Furthermore, some gas shows have been detected. Porosity in this reservoir ranges from 2.7% to 3.4%, the quality of the reservoir can be characterized as poor.

An onshore poor quality reservoir has been recognized in *Omiros* well, in which 300m of Upper Cretaceous chalky limestones has been drilled with calcite cemented fractures, isolated vugs filled by calcite and breccias with subangular pebbles on top. Porosity for this unit is below 4%.

Poor reservoir quality has been also found on Upper Cretaceous carbonates (1086m thickness) in well *Alkiviadis*. This unit comprises hard, cryptocrystalline and argillaceous limestones that have been depositioned in a slope environment and are possibly turbidites. (Karakitsios, 2013). Upper Cretaceous section is eroded by the Messinian unconformity at 1100 m depth and the possible cause of failure of this well is probably due to the fact that the Cretaceous is outcropping in Kefallinia island.

In *Aristotelis* well, Cretaceous interval is reported as a tight rock. It is made of hard, compact limestones, chalky with fractures filled up by calcite. The main possible reason of failure for the carbonate reservoir is the lack of good reservoir conditions, lack of fractures and/or dissolution. Maybe, also a possible leakage problem along nearby faults can be suggested. So, the quality of the reservoir can be described as poor.

In well *Aliki*, the Upper Cretaceous reservoir corresponds to creamy mudstones and packstones described as hard, intrabioclastic with no porosity and some fractures which are calcite cemented. These properties make this unit a poor quality reservoir.

Limestones of Pantokrator Formation have been found within the Cretaceous unit in well *Athina*. No more information are available.

In well *Xenofon*, gas shows have been detected in Cretaceous carbonates. The lithology of this unit, which has a thickness of 50m, is described as hard, compact limestones, chalky, calcarenites. Also, abundant calcite veins and fractures filled by shales have been identified. The quality of this reservoir has been described as poor due to the lack of any other data and to filled fractures and veins that have been recorded.

Cretaceous reservoir has been found in well *Ikaros*. It seems to be reworked and possibly only the base of the well is from Upper Cretaceous age. Boundstones-grainstones have been identified from lithology with strong calcite cementation, no matrix porosity but residual hydrocarbons in fractures. As a result the quality of this unit has been described as poor.

In well *Hermione-1*, Upper Cretaceous (to Lower Eocene) carbonates are described as limestones with chert levels. However, no porosity values were available and also no shows have been recorded within this unit. As a result the quality of the reservoir has been described as poor.

Chalky, cherty, micritic limestones of Cenomanian age with fractures filled with tar have been observed in well *Kassandra*. The whole thickness of this unit is 1000m. The quality of this reservoir can be described as poor.

Upper Cretaceous limestones and dolomites have been recognized in well *Danae*, with scattered chert levels and total thickness of 850m. No further information was available for this unit so the quality of the reservoir has been described as poor.

In addition, the offshore well *Afroditi-1*, chalky and cherty limestones have been recognized. The reservoir has been described as tight, so the quality can be characterized as poor.

In well *Franklin* (Italy), mainly grainstones, bioclastic, recrystallized and locally dolomitized have been recognized. Sediments have been deposited in an open shelf environment. No hydrocarbon shows were detected within this unit and it has been described as a poor quality reservoir.

In well *Agamemnon* the Upper Cretaceous unit consists of limestones that have been described as hard, friable and chalky. Within this unit porosity ranges from 1% to 25%. Furthermore, two Upper Cretaceous outcrops samples were analyzed and showed porosities between 6,1% to 33,7% and permeability of 0.24mD. Despite the fact that within this well high porosity values have been recorded, the description of the carbonates as chalky and the absence of fractures, lead us to characterize the quality of the reservoir as poor.

Well	Area	Lithology	Reservoir Quality	Thickness unit (m)
Nefeli-1	Greece	Chalky limestones and breccias, stylolites and fractures cemented by calcite	P	200m
Aliki	Greece	Cream mudstones to packstones, hard, intrabioclastic, no porosity and calcite cemented fractures	P	500m
Hermione-1	Greece	Dolomitic limestones	P	520m
Danae	Greece	Limestones with scattered chert levels	P	850m
Electra	Greece	Limestones (wackestones to packstones) with residual bitumen at the bottom of the interval and dolomitic limestones, interbedded with limestones at the uppermost part of the interval	P	150m
Alkiviadis	Greece	Limestones, cryptocrystalline, argillaceous. Possible turbidities	P	1086m
Themistoklis	Greece	Peritidal limestones, fractures calcite cemented, matrical porosity, good permeability.	P	350m
Ikaros	Greece	Boundstone-grainstones, strong calcite sementation, no matrix porosity but residual intraclastic hydrocarbons.	P	20m
Xenofon	Greece	Hard, compacted limestones, chalky, calcerinites. Abudant calcite veins and fractures filled by shales.	P	50m
Omiros	Greece	Chalky limestones, calcite cemented fractures, breccia with subangular pebbles on top, shaly matrix porosity and isolated vugs filled by calcite.	P	300m
Aristotelis	Greece	Hard, compacted limestones, chalky (probable out of turbidities), calcite filled fractures.	P	330m
Kassandra	Greece	Chalky, cherty, micritic limestones with fractures filled with tar	P	1000m
Agamemnon	Greece	Limestones, hard-friable and chalky.	P	341m
Afroditi-1	Greece	Chalky and cherty limestones	P	298m
Franklin	Italy	Grainstones, bioclastic, recrystallized and locally dolomitized	P	900m

Table 9: Table showing poor quality reservoirs, Upper Cretaceous.

Fair reservoir potential

Mesozoic carbonates with a total thickness of 285m have been drilled in well *Afroditi-1A*. Consisting of chalky and cherty limestones with porosity values ranging from 6% to 9% at the top part of the carbonates. Within this unit high hydrocarbon production has been also recorded from DST 3, (2956-3033m MD), which produced 11MMCFGD and 55^0 API condensate. So, the quality of this carbonate unit can be described as fair to good.

In well *Afroditi-2*, chalky limestones with cherts and fractures, with a thickness of 180m and with porosity up to 9% (in DST 4: 2557-2575m/MD) this carbonate unit seems to have all required properties for a fair to good quality reservoir. Furthermore, it is important to mention that within this unit, DST 5, (2513-2521m MD), has produced oil and condensate (1380-1440 bbl/day – 27^o API).

In well *Tesla*, Mesozoic carbonate levels, with a thickness of 600m (1450m/MD to 2050m/MD), of Upper Cretaceous age have been recognized. Within this unit rudists biostromes have been recorded, so the quality of the reservoir can be assumed as fair to good.

Mesozoic carbonates, dolomites and limestones have been recognized in well *Antigoni*. Fractures were identified in several cores in the Cretaceous unit, which has a thickness of 2339m. No porosity values were available for this reservoir, so has been described as fair, due to the presence of fractures. It is important to mention that the carbonates are outcropping at well location.

In well *Kevin*, carbonates, wackestones and mudstones, of Upper Cretaceous age have been recorded. Within this unit we have oil production in DSTs but the average matrix porosity is below 3%, so the quality of the reservoir can be described as fair as it is fractured.

Fractured Cretaceous carbonates sealed by Tertiary shales deposited in a basin environment have been recognized within well *Dafni*. However, no oil or gas shows have been detected in the carbonates. The thickness of the unit is 400m. Despite the fact that is not any oil or gas shows recorded within this unit, the quality of the reservoir has been described as fair, due to the presence of fractured carbonates.

In well *Epafos*, 351m of Cretaceous fractured carbonates, unconformably covered by Oligo-Miocene clastic series of Langhian-Burdigalian age, intercalated with Messinian evaporites have been recognized. No shows were detected within carbonates and also no measurements for porosity or permeability were available. These series can be described as a fair quality reservoir, due to the presence of fractures.

In well *Ifikratis*, Cretaceous (to Eocene) mudstones and wackestones have been recognized. Average porosity is 5,2%. Furthermore, no oil shows have been recorded within the Upper Cretaceous. The thickness of this unit is about 542,5m. The quality if the reservoir has been described as fair.

Well	Area	Lithology	Reservoir Quality	Thickness unit (m)
Tesla	Albania	Limestones	F-G	500m
Antigoni	Greece	Dolomites and limestones with fractures	F	2339m
Afroditi-1A	Greece	Chalky and cherty limestones	F-G	285m
Afroditi-2	Greece	Chalky limestones	F-G	180m
Kevin	Albania	Limestones (wackestones -mudstones)	F	-
Dafni	Greece	Fractured limestones	F	400m
Epafos	Greece	Fractured(possible turbidites) limestones	P	351m
Ifikratis	Greece	Mudstones and wackestones	F	200m

Table 10: Table showing fair quality reservoirs, Upper Cretaceous.

Good reservoir potential

Best reservoir conditions in the Late Cretaceous interval (3840m/MD to TD 4203m/MD) have been recognized in well *Planck*. The lithology is described as limestones with moldic, vuggy and micro-breccia porosity. Log analysis shows, for the whole interval, an average porosity of 12% (core permeability 0.1-110mD). Also some oils shows have been detected within the Mesozoic carbonates. As a result this reservoir can be characterized as a good quality.

In well *Newton*, dolomitic limestones and limestones characterize the Upper Cretaceous. The dolomitic limestones are white, cryptocrystalline mudstone, hard, with abundant pale beige crystalline dolomite rhombs and the limestones are very light grey, firm-hard, crypto-microcrystalline mudstone, variably argillaceous and slightly dolomitic. Porosity within this unit is comprised between 12% to 13%, that’s why it has been characterized as a good quality reservoir.

Kepler well has been bottomed at 3500mMD in a carbonate sequence of Senonian age ascribed to the Cupello limestone Formation. This succession, with a thickness of 215m, is mainly constituted by wackestone-packstones. At the top of the interval, an unconformity occurs. Above this unconformity the Scaglia Formation, equivalent of Senonian, age has been identified. This formation extends up to 3289m. Within the Upper Cretaceous unit no shows have been detected. Log interpretation on this well gave an average porosity of 11%. So the quality of the reservoir has been described as good.

Well	Area	Lithology	Reservoir Quality	Thickness unit (m)
Newton	Albania	Dolomites	G	204m
Planck	Albania	Limestones, moldic, vuggy and micro-breccia porosity	G	600m
Kepler	Albania	Hard fossiliferous with rare plaktonics foraminafers with med/high porosity	G	215m

Table 11: Table showing good quality reservoirs, Upper Cretaceous.

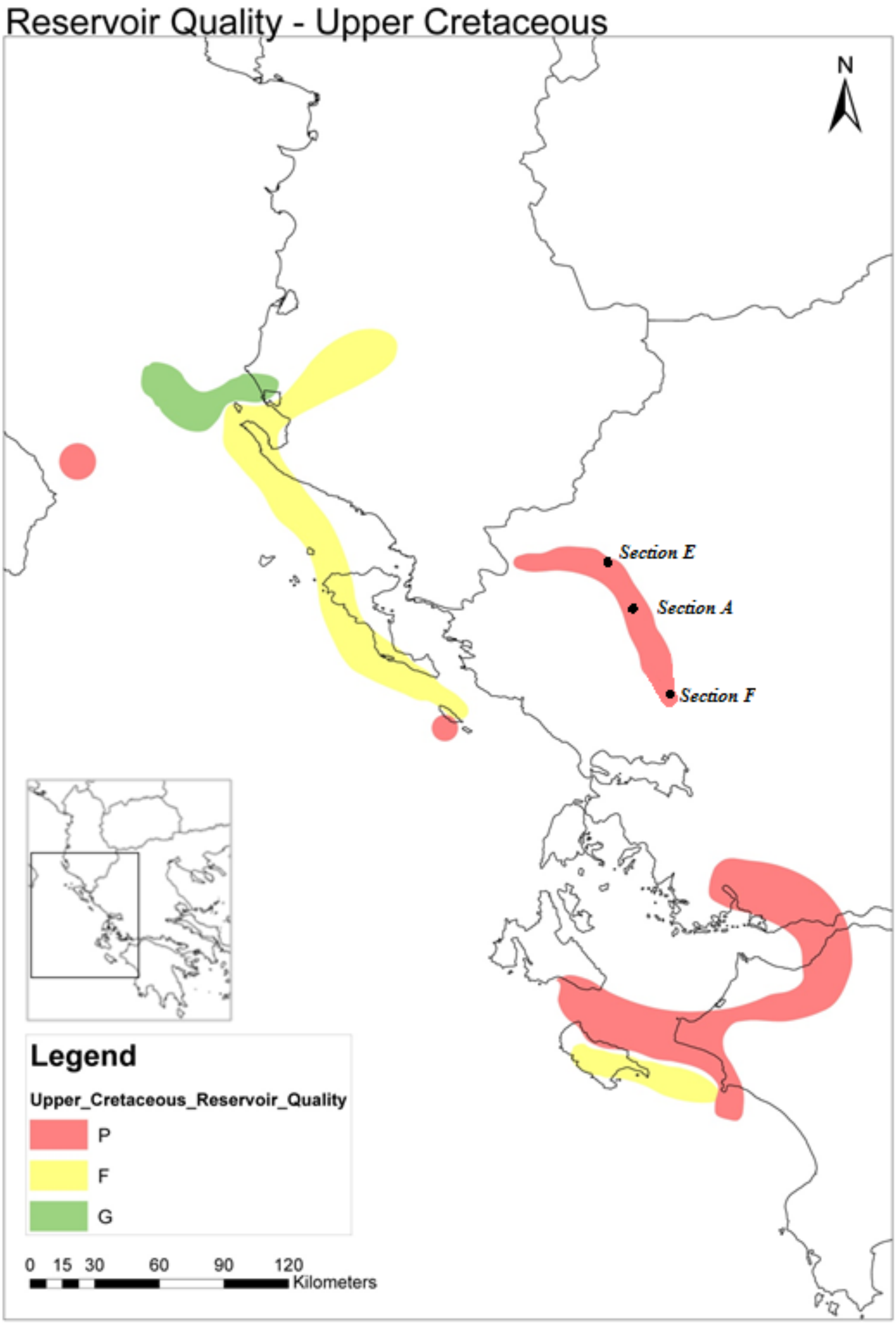


__Figure 41:__ Reservoir quality, Upper Cretaceous. (P= Poor reservoir quality, F= Fair reservoir quality and G= Good reservoir quality).

9.1.5 Eocene

The Eocene part of the Carbonate Unit is considered, like the Upper Cretaceous part, the primary target in Greece, since it contains the only existing discovery of oil and gas in the Western part of Greece as well as many gas and oil shows. Reservoirs may be associated with clean microporous chalky basinal limestones at the top of the Carbonate unit or could also be associated with karstification, as well as with development of fractures as in the case of West Katakolon discovery.

On the other hand, in Albania, the Eocene carbonate formations, are widespread in External Albanides and are represented by a variety of limestones and dolomites. Reservoir rocks in the Ionian Zone, mainly consist of Cretaceous-Eocene carbonates with <10% primary porosity. Related to the tectonic context porosity is improved by fracture development and oil is produced from interconnected fracture systems.

Poor reservoir potential

Within the Eocene carbonate from *Nefeli-1* well, porosities do not exceed 3%. Cores from this age, interval have been described as limestones, light, grey-light, creamy, hard, compacted with stylolites, filled with marly material and traces of pyrite and small fractures which are filled with crystalline calcite. The total thickness of this unit is 120m and can be described as having a poor reservoir potential.

In well *Themistoklis*, gas and oil shows were recorded in the whole Eocene carbonate column, which has a thickness of 170m. Oil within this unit is present in matrix and also in fractures, but some of them were cemented. Furthermore, migrated hydrocarbon traces are present in Eocene carbonates. From the log analysis, carbonates with oil shows intervals present a complete absence of matrix porosity and any fractures present were not connected to an effective fracture porosity system. So the quality of this reservoir has been described as poor.

Some gas and oils shows have been recorded within the bioclastic limestones of the Eocene unit (mainly in fractures) in well *Ikaros*. Within this well carbonate reservoir has been found at 1986 m MD (possible top of the Cretaceous at 2300M MD). However, no further information was available from those wells so the quality of the reservoir was assumed as poor.

Well	Area	Lithology	Reservoir Quality	Thicknes s unit (m)
Nefeli-1	Greece	Limestones, light, grey-light, creamy, hard, compacted with styliolites, filled with marly material and traces of pyrite and small fractures filled with crystalline calcite	P	120m
Themistoklis	Greece	Peritidal dolomitic limestones. Oil mainly present in matrix and also in fractures, with some of them cemented. Also some stylolites-none impregnated.	P	170m
Ikaros	Greece	Characteristic thick series (<200m) of bioclastic PG	P	321m

Table 12: Table showing poor quality reservoirs, Eocene.

Fair reservoir potential

In well *Hermione-1*, within the Eocene carbonate, wackestones and mudstones, have been recognized. Some gas shows have been recorded. Furthermore, porosity values range between 5% to 9%, so the quality of the reservoir has been described as fair.

Close to this well, is situated *Hermione-2* well, with an alternance of limestone and microbreccias. Within this unit two tests have been done. The first one was producing water and the second one a slight amount of gas. So the quality of the reservoir can be described as fair to good.

Eocene carbonates, wackestones and mudstones, have been drilled in well *Kevin*, situated in Albania. However, the average porosity for this unit is 3%, which means that is poor. So the quality of the reservoir was described as fair to good.

Well	Area	Lithology	Reservoir Quality	Thickness unit (m)
Hermione-1	Greece	Limestones (wackestones and mudstones)	F	800m
Hermione-2	Greece	Alternance of limestones and microbreccia calcaire	F-G	316m
Kevin	Albania	Wackestones and mudstones	F-G	200/225m

Table 13: Table showing fair quality reservoirs, Eocene.

Good reservoir potential

Eocene shallow water reservoir, of Gavrovo platform, has been recognized in well *Electra*. The thickness of this unit is 220m. The quality of the reservoirs depends on the fracture intensity. Within Eocene unit heavy losses have been recorded and the most porous intervals seem to be located within this unit. The porosity within this carbonates ranges between 2,7–3,4% (matrix porosity). The quality of the reservoir can be described as good due to the fact that heavy losses have been recorded, which means that the reservoir is highly fractured.

Well	Area	Lithology	Reservoir Quality	Thickness unit (m)
Electra	Greece	Limestones , calcilutite-micrite-packstone, bitumen veins and heavy losses.	G	220m

Table 14: Table showing good quality reservoirs, Eocene.

Excellent reservoir potential

Eocene limestones have been recognized in *Afroditi-1*. Within these Eocene carbonate, gas shows have been recorded. Core-2 samples (2729-2734m/MD) display porosity around 20%. Furthermore, some losses also have been recognized, which means that the reservoir is fractured. So, according to the above data the quality of the reservoir can be described as excellent. This evaluation has to be taken with care as data available are scarce.

Well	Area	Lithology	Reservoir Quality	Thickness unit (m)
Afroditi-1	Greece	Mod to hard limestones. Core sample with losses and anhydrite traces	E	200m

Table 15: Table showing excellent quality reservoirs, Eocene.

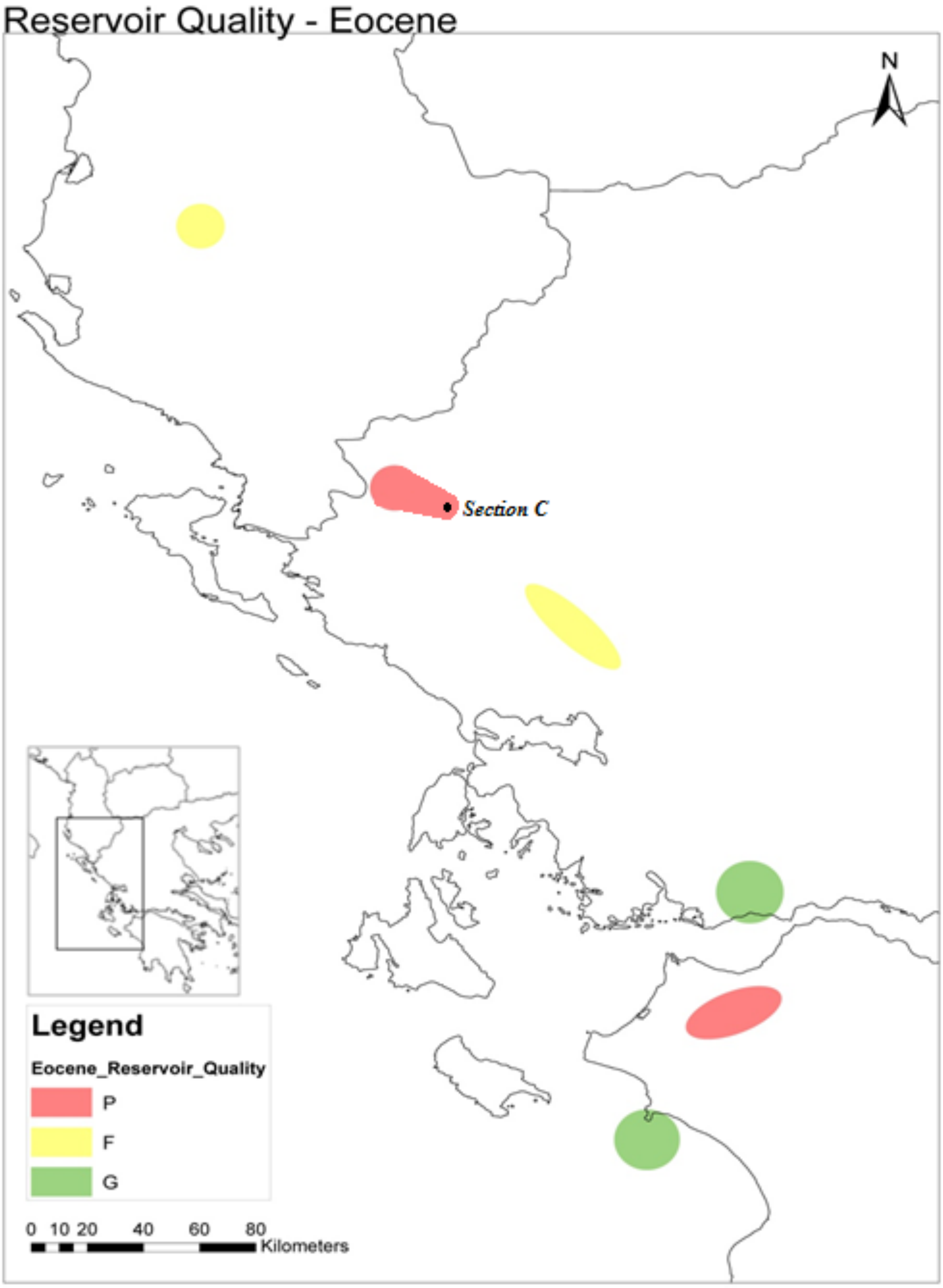


Figure 42: *Reservoir quality, Eocene. (P= Poor reservoir quality, F= Fair reservoir quality and G= Good reservoir quality)*

9.1.6 Oligocene

Oligocene sediments are represented by the Flysch Unit in the Ionian and Gavrovo zone in Greece. Sometimes the uppermost Eocene sediments in the Ionian zone also recognized as Flysch or transitional deposits. Potential reservoirs and seals in this formation would be associated with clastic sediments, with shaly deposits serving as caprocks and potential reservoirs associated with conglomerates and sandstones. In the Pre-Apulian Zone the Oligocene to Lower Miocene comprises carbonates which, if porous and fractured, can represent a potential reservoir.

Within our study area, only in Albania, in well *Newton*, Oligocene open shelf bioclastics have been recognized. The top of this carbonate unit has been recorded at a depth of 3002m/MD. From the log analysis the average porosity of this unit is 6%. The total thickness of the Oligocene unit is 50m and from the data that had been examined it can be characterized as a fair quality reservoir.

In Greece, measurements have been made for some outcropping Oligocene white limestones with thin marly interbeds in *Zakynthos* (Pre-Apulian Zone in Greece), where porosity is reported to reach a maximum of 20.96% and permeability reaches 1.93 mD.

Furthermore, in well *Franklin*, in Italy, Oligocene (Portobadisco Formation) carbonate unit is made of bioclastic, vuggy, dolomitized and recrystallized packstones –grainstones, with macro-foraminafera, deposited in an open shelf platform (reefal facies). The thickness of the unit is 105m and the well is located near the Apulian shelf edge. Fair to good quality is expected for the Oligocene carbonate unit.

Well	Area	Lithology	Reservoir Quality	Thickness unit (m)
Franklin	Italy	Packstones-grainstones, macro-foraminafera and bioclastic, vuggy, dolomitized and recrystallized.	F-G	105
Newton	Albania	Open shelf bioclastic	P	50

Table 16: Table showing the quality of the reservoirs, Oligocene.

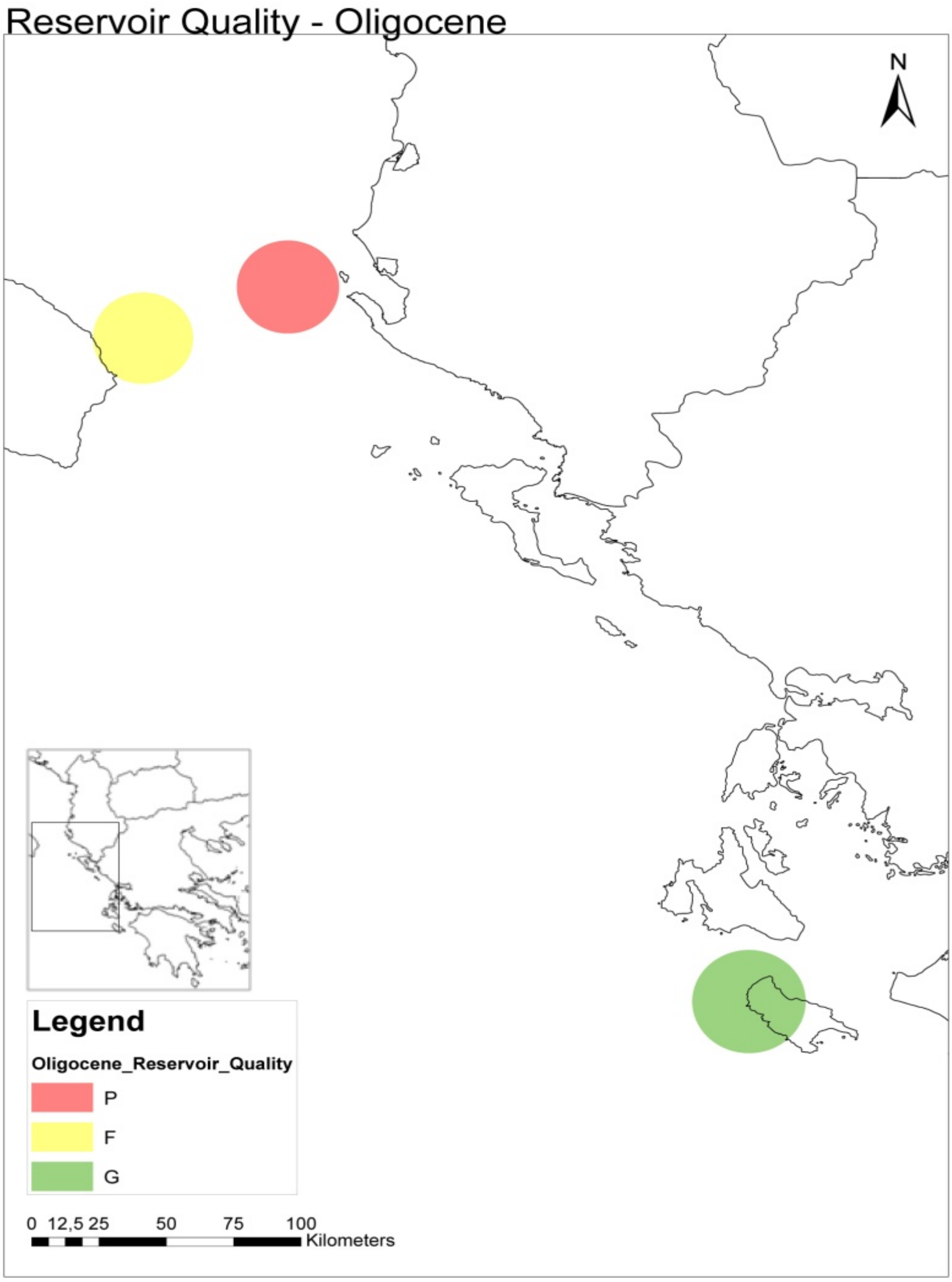


Figure 43: *Reservoir quality, Oligocene. (P= Poor reservoir quality, F= Fair reservoir quality and G= Good reservoir quality)*

9.1.7 Miocene

Miocene sediments, in Greece are represented mainly by the Flysch unit in the Ionian and Gavrovo Zones. In the Pre-Apulian Zone the Miocene comprises carbonates which, if porous or fractured, can represent a potential reservoir, as it is mentioned also above.

The Miocene in the offshore well *Kepler*, in Albania, consists of Burdigalian wackestones-packstones locally grainstone and whitish to grey, hard, locally dolomitic coral boundstone, deposited in shallow water-carbonate reef environment, very similar to the Bolognano Formation. The thickness of this unit is 140m. The occurrence of Microcodium in the upper part of the section (Core 1) is an evidence of emersion with subaerial exposure of the carbonate reef. (Agip, 1994). The porosity of the Burdigalian carbonate ranges from 1 to 15%, with some fractures filled by bitumen. Within this unit a fair to good reservoir quality has been recognized.

In the near offshore well *Newton*, Early Miocene limestones, with a total thickness of 25m, have been drilled at the top of the carbonate unit below 3002 m MD. This section consists of white, locally very light grey limestone, firm-medium hard, crypto-microcrystalline mudstone, occasional foraminiferal wackestones, slightly dolomitic and glauconitic, locally argillaceous with a porosity ranging between 8% and 14%. So this unit has been described as a fair to good quality reservoir. Furthermore, no oil shows were recorded within this section. In addition, above the Early Miocene unit there is a thin basal interval, from 2998m/MD to 3002m/MD, described as light-grey limestone, microcrystalline wackestone to packstone, slightly argillaceous, with poor to fair intercrystalline porosity and it can be described as a fair quality reservoir. (BHP Petroleum Corp, 1996).

In well *Franklin*, vuggy limestones have been recognized on the top of the Messinian interval, with a thickness of 60m. These carbonates have been cored and described as mudstones with interbeds of grey marls, but no further data are available for this unit. So, the quality of this reservoir has been described as poor to fair.

Well	Area	Lithology	Reservoir Quality	Thickness unit (m)
Franklin	Italy	Vuggy limestones on the top of the Messinian interval	P-F	60m
Kepler	Albania	Hard, fossiliferous with rare planktonics foraminafers. Med/high porosity, chalky limestoneS	F-G	140m
Newton	Albania	Mud losses at the top of the carbonates	F-G	25m

Table 17: Table showing the quality of the reservoirs, Miocene.

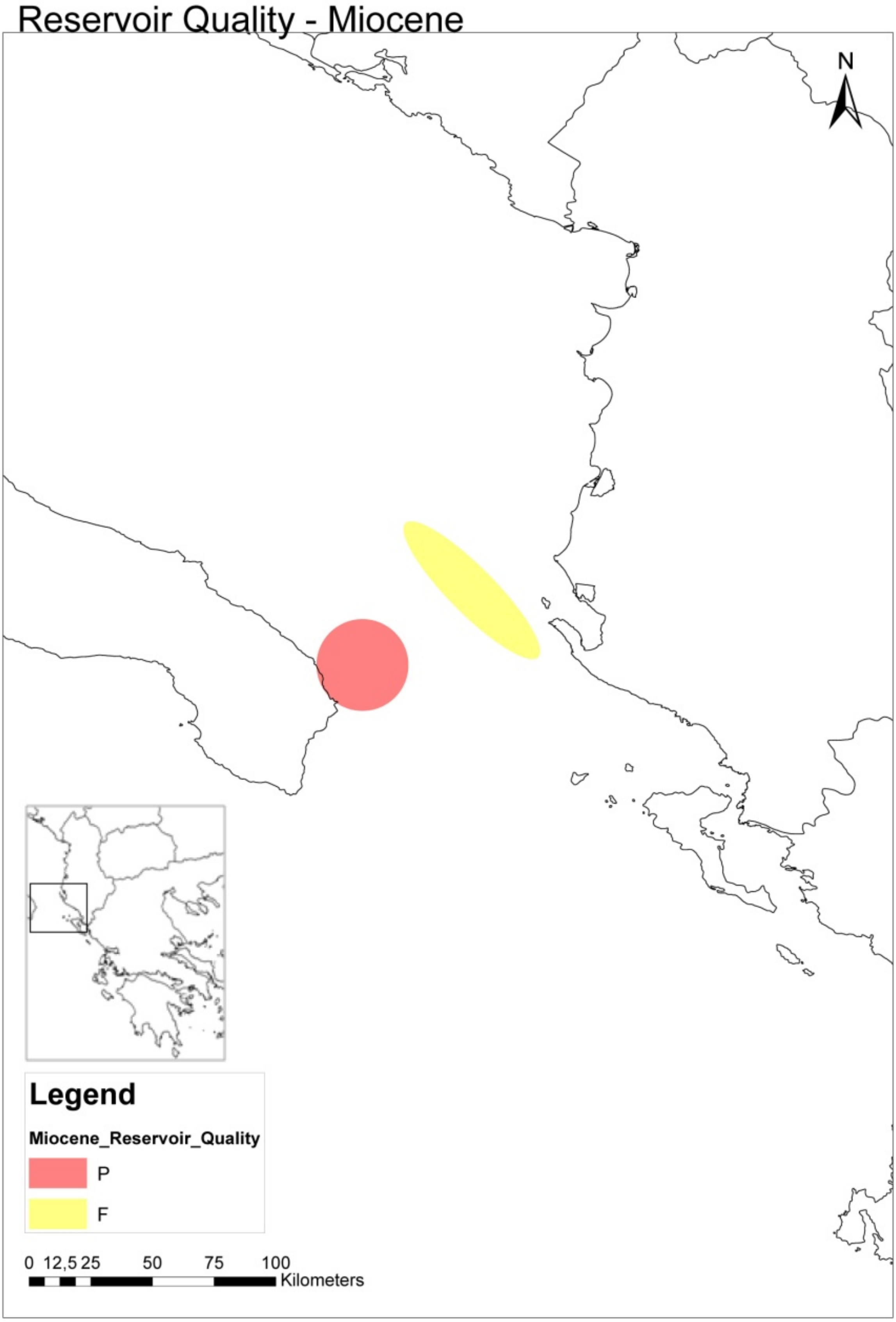


Figure 44: *Reservoir quality, Miocene. (P= Poor reservoir quality, F= Fair reservoir quality)*

9.2 Paleo-environmental Synthesis

Within this chapter a paleo-environmental synthesis for the study area will be done. After the description of the tectonic evolution, the stratigraphy, the lithology and the paleo-environments a clear view of the paleo-environmental evolution is given.

It is important to mention that the stratigraphic successions in Western Greece and Albania are similar, except from the Early Miocene clastics that are coarser grained in Albania than in the Northern Greece. These clastics relate to erosion of the orogen after Early Tertiary collision deformation.

9.2.1 Permo-Triassic

The middle Permian age corresponds to the opening of the Neotethys Ocean. Generally the Permian deposits are not identified in Western Greece, because they are not outcropping. Although, they have been described in the Southeast of Peloponnesus, in Hydra Island.

The island of Hydra contains one of the most fossiliferous sequences of Permian rocks in the Western Tethys. These Permian sequence is at least 500m thick (Grant et al., 1991) and ranges in age from Asselian to Dorasharnian.

In Greece, only the Upper Triassic series have been described. It consists of evaporites, limestones and black dolomites. The Upper Triassic evaporitic section has more than 1700m thickness in the Ionian and Pre-Apulian zones. In the Ionian zone, over the evaporitic series, the Foustapidima limestones have been deposited and have 50-150m thickness (Karakitsios, 2013).

The Upper Triassic section has been deposited in supratidal to intertidal conditions as has been recognized form the examined wells (*Athina*, *Meropi*, *Platonas*). Only in wells *Ifikratis* and *Kassandra* the depositional environment has been described as inner shelf.

Also in Albania, a supratidal to intertidal depositional environment has been recorded from the Triassic sections in wells *Tesla* a0nd *Kleopatra*. (*Fig. 25*)

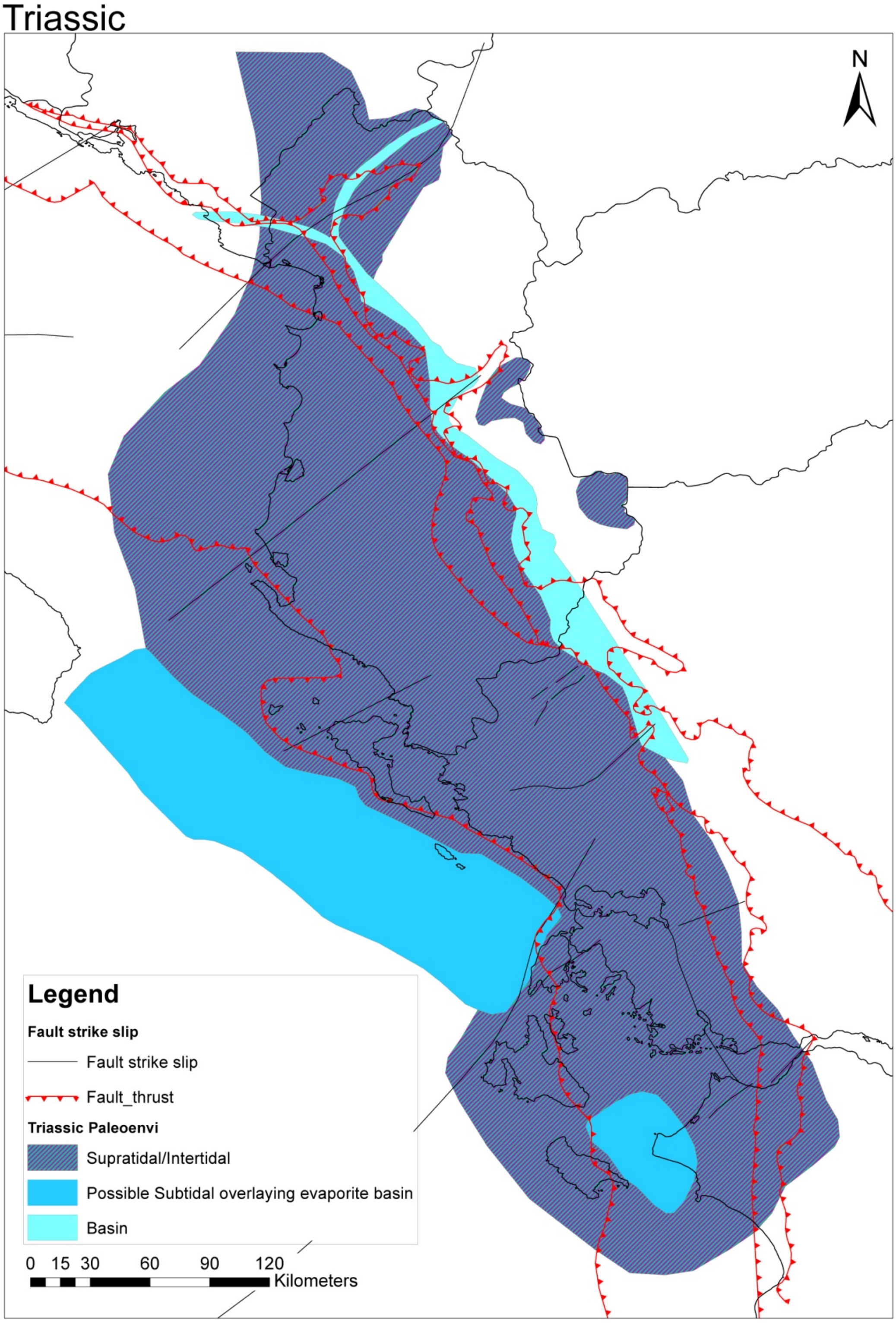


Figure 45: *Paleo-environmental map of the study area during Triassic.*

9.2.2 Jurassic

From the Middle Triassic to the Liassic (*Fig. 26*), an extensive shallow sea spreads all over the study area. These extensive platforms are developed until the Hettangian –Pliensbachian age. Also, at this time a "proto" Ionian basin has been created.

The prevalence of the restricted, supratidal-intertidal environments has been recorded in several wells, like *Aliki*, *Athina*, *Danae* and *Kassandra*, both in Ionian and Pre-Apulian zones. In the Ionian zone, the "Foustapidima Limestones" are capped by the "Pantokrator Limestones" (Auboin, 1959; IGRS-IFP, Karakitsios & Tsaila-Monopolis, 1988). This progressive transition has been recognized in well *Minerva*.

During the Pliensbachian (Late Lias) the subduction of Neotethys in its northern part caused the opening of Alpine Tethys as a back arc basin. The extensional stress is linked to the opening of the Tethys, which then caused the opening of the Ionian basin (*Fig. 27*). A general subsidence is observed in the Ionian zone, from the wells *Aliki*, *Hermione-1*, *Athina*, which shows pelagic facies within the Upper Jurassic series. On the other hand shallow restricted conditions persist at the adjacent Apulia and Gavrovo platforms. The Ionian basin and the adjacent platforms will keep their morphology up to top carbonates (Eocene age).

Furthermore, the drowning of the Ionian basin has been recorded in wells *Ifikratis* and *Kassandra*, where the sedimentation shows an upward transition from restricted to pelagic environment. The first deepening of the Ionian area was recorded by the Siniais and Louros limestones, dated as Upper Jurassic. Louros and their lateral equivalent, the Siniais limestones, correspond to the first synrift sediments on the Ionian series. The Posidonia shales, which are dated as Upper Jurassic, are synchronous to a general anoxic period and organic carbon can be found as mixture of marine and continental origin (Karakitsios, 1995). This observation shows that the anoxic conditions are synchronous to the syn-rift period and drowning of the platforms.

In Albania the same depositional conditions, as in Greece, have been recognized in the Ionian zone, as well as in the adjacent Kruja and Apulian platform. In well *Kevin* pelagic facies have been recorded in the Upper Jurassic carbonates. On the other hand in well *Tesla*, shallow restricted carbonates have been recognized within the Upper Jurassic section.

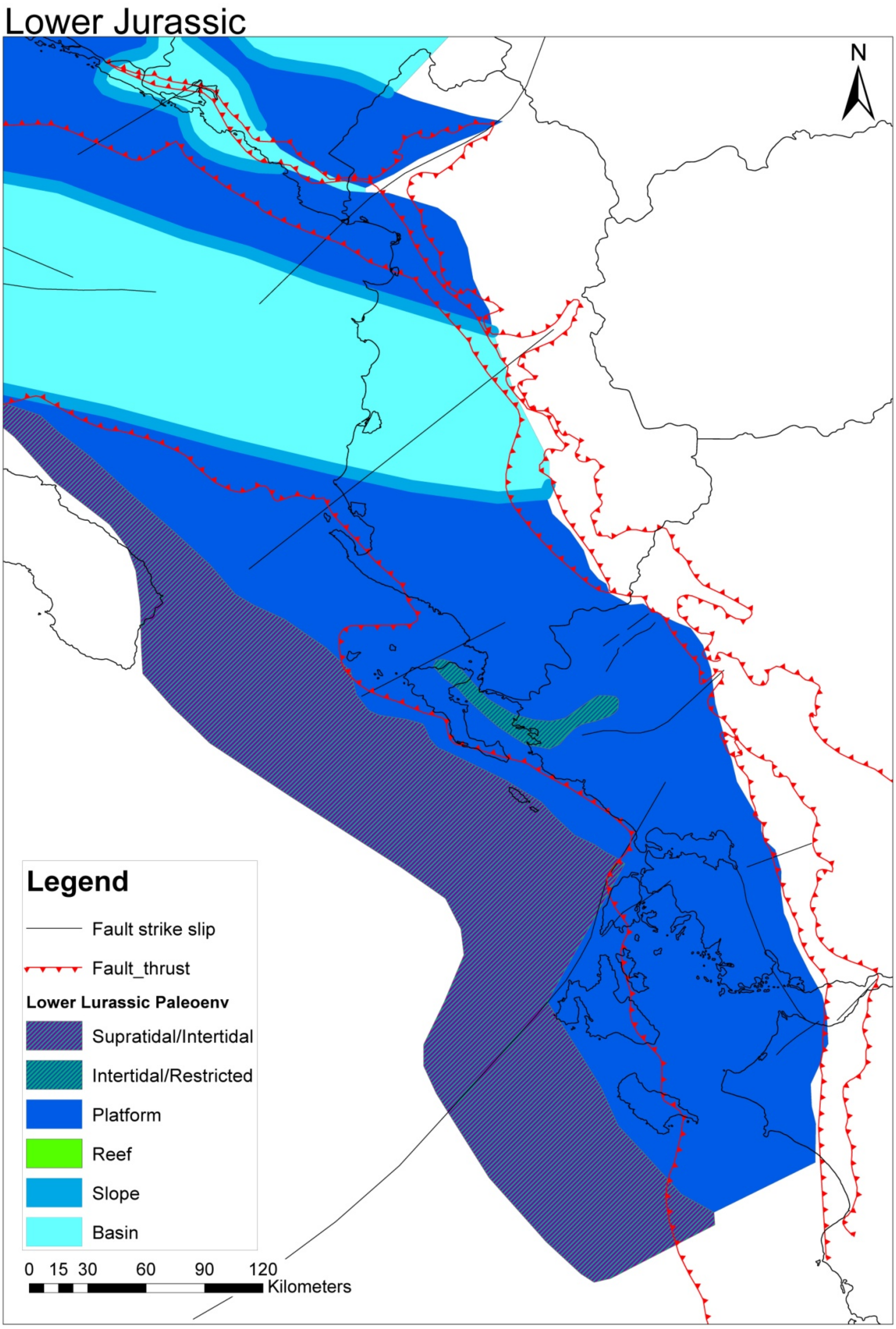


Figure 46: *Paleo-environmental map of the study area during Lower Jurassic.*

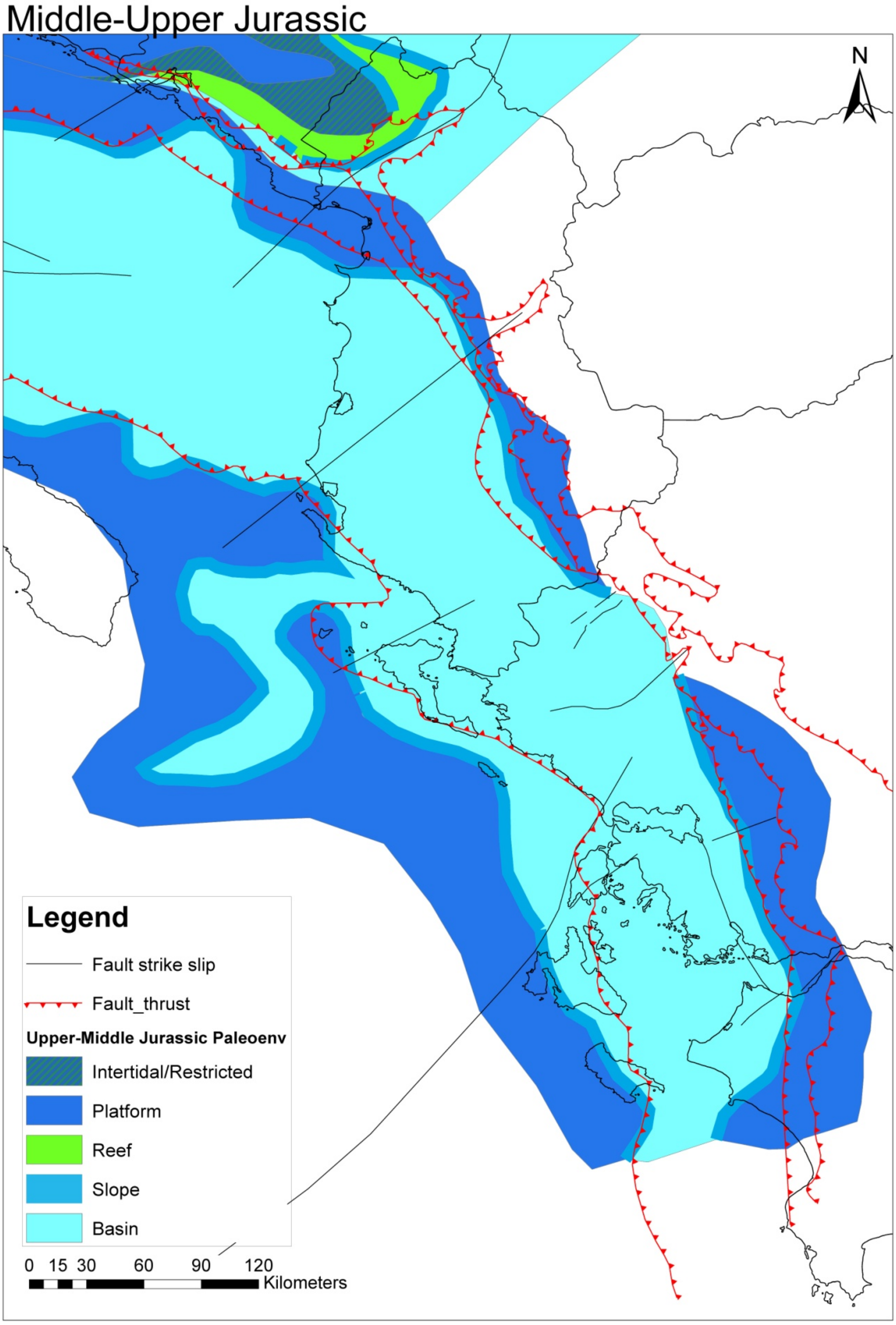


Figure 47: *Paleo-environmental map of the study area during Middle-Upper Jurassic.*

9.2.3 Lower Cretaceous (to Turonian)

During the Early Berriasian (*Fig. 28*), a general sinking of the entire basin is attested to be the onset of the deposition of pelagic Vigla limestones in the entire Ionian zone. Apart from the halokinetic movements, which probably caused the variation in thickness of Vigla limestones, the pelagic conditions persisted until the Late Eocene, when flysch sedimentation began. The pelagic sedimentation continued to accompany clastic sedimentation derived from the adjacent Gavrovo and Apulian platforms.

In the Ionian Zone, the Vigla limestones Formation, comprises a thick succession of thin layered (5-10), sublithographic, pelagic limestones, with abundant radiolarian and frequent cherty beds with radiolarian. The Vigla limestones are also time equivalent of the anoxic events 0AE-1 and OAE-2 and are extended to Italy and Albania (Karakitsios, 2004). In the upper part, the Vigla shales member present, which consists of organic matter-rich marlstones and shales interbedded in limestones and cherts beds. Possible Vigla shales have been recorded from the composite log in well *Aliki*, where pelagic depositional conditions have been described. Also pelagic conditions have been described within the Lower Cretaceous series in well *Hermione-1*.

Peritidal and subtidal limestones (Vigla limestones) have been observed in Gavrovo and Apulian platforms.

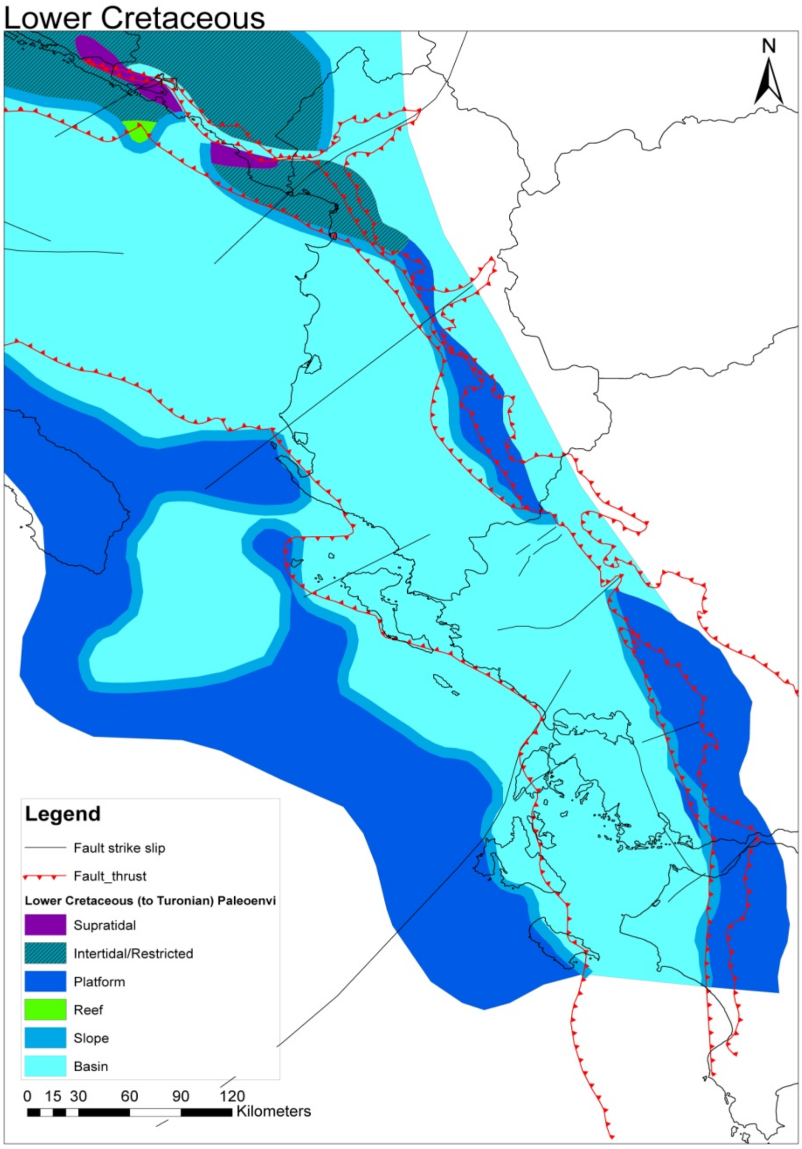


Figure 48: *Paleo-environmental map of the study area during Lower Cretaceous.*

9.2.4 Upper Cretaceous (Coniacian to Maastrichtian)

The Upper Cretaceous (*Fig. 29*) corresponds to the first compressional features, which lead to the closure of the Neotethys.

During the Upper Cretaceous the carbonate Gavrovo and Apulian platforms are broken and locally uplifted. The tectonic activity during the Upper Cretaceous produced gravity flows along the slope of Gavrovo and Apulian platforms. Within the Ionian basin, sediments form the adjacent Gavrovo and Apulian platforms have been deposited.

In the Ionian zone, in Epirus area, pelagic depositional conditions were recorded from wells *Aliki*, *Nefeli-1* and *Hermione-1*. Similar environment has been recognized within the Upper Cretaceous section in the NW Peloponnesus area, in well *Ikaros*. Although, in well *Electra*, which is situated in the Gavrovo platform, shallow restricted environment has been recorded. Furthermore, in Peloponnesus area, facies also change from the Ionian zone to the Gavrovo and Apulian platforms, from pelagic to shallow water carbonates. In that area, from the drilled wells *Xenofon*, *Omiros*, *Athina* and *Aristotelis*, basinal environment has been recognized while in well *Themistoklis*, restricted carbonate shelf within the Upper Cretaceous section is observed. In addition, in West Katakolon area, the transition from shallow to pelagic conditions has been observed, as the Upper Cretaceous carbonates are deposited in a deep marine slope environment recorded from wells *Afroditi-1*, *Afroditi-1A* and *Afroditi-2*. Also, the platform-basin transition has been recorded from wells *Antigoni* and *Agamemnon*, in Zakynthos Island.

In the Ionian zone in Albania, pelagic facies are recorded from well *Kevin*. Also, from the wells *Kepler* and *Franklin* (Italy) the same conditions have been recognized. On the other hand restricted shallow environment is observed from wells *Newton* and *Tesla*. Furthermore, slope breccias are observed at the toe of the platform, and they have been calibrated by well *Planck*.

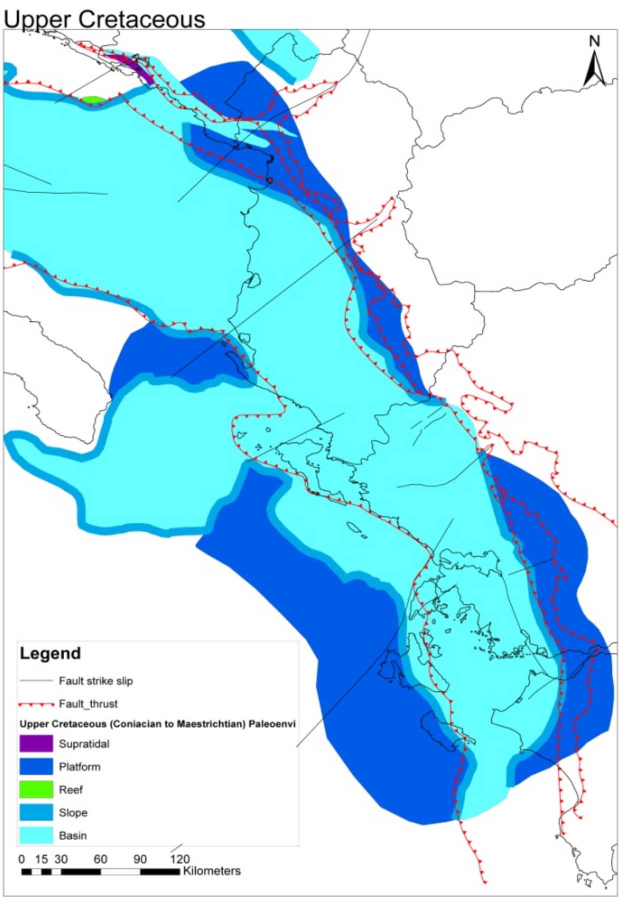


Figure 49: *Paleo-environmental map of the study area during Upper Cretaceous.*

9.2.5 Paleocene-Eocene

In Western Greece and Albania wells, The Paleocene is not distinguished from Eocene or Cretaceous age (*Fig. 30*). During this period the Hellenic compressional phase caused an intensive tectonic activity. As a result, turbidites were deposited in the Ionian basin, while Gavrovo and Apulian platforms show erosions. The same conditions are extended up to Albania, where the erosion of the Upper Cretaceous carbonate platforms, from the Kruja zone in the East and the Sazani zone in the West contributed as a source for the deposition of thick carbonate turbidites (*Kevin*) in the Ionian basin during the Upper Cretaceous and Paleocene (Velaj et al., 1999; Roure et al., 2004). These turbidites, which reworked platform carbonate, are interbedded within finer-grained pelagic limestones.

From the examined Eocene sections within the wells *Nefeli-1*, *Hermione-1*, *Electra*, *Themistoklis*, *Ikaros* as well as in the West Katakolon area, the depositional environments seem to remain the same as in Upper Cretaceous age.

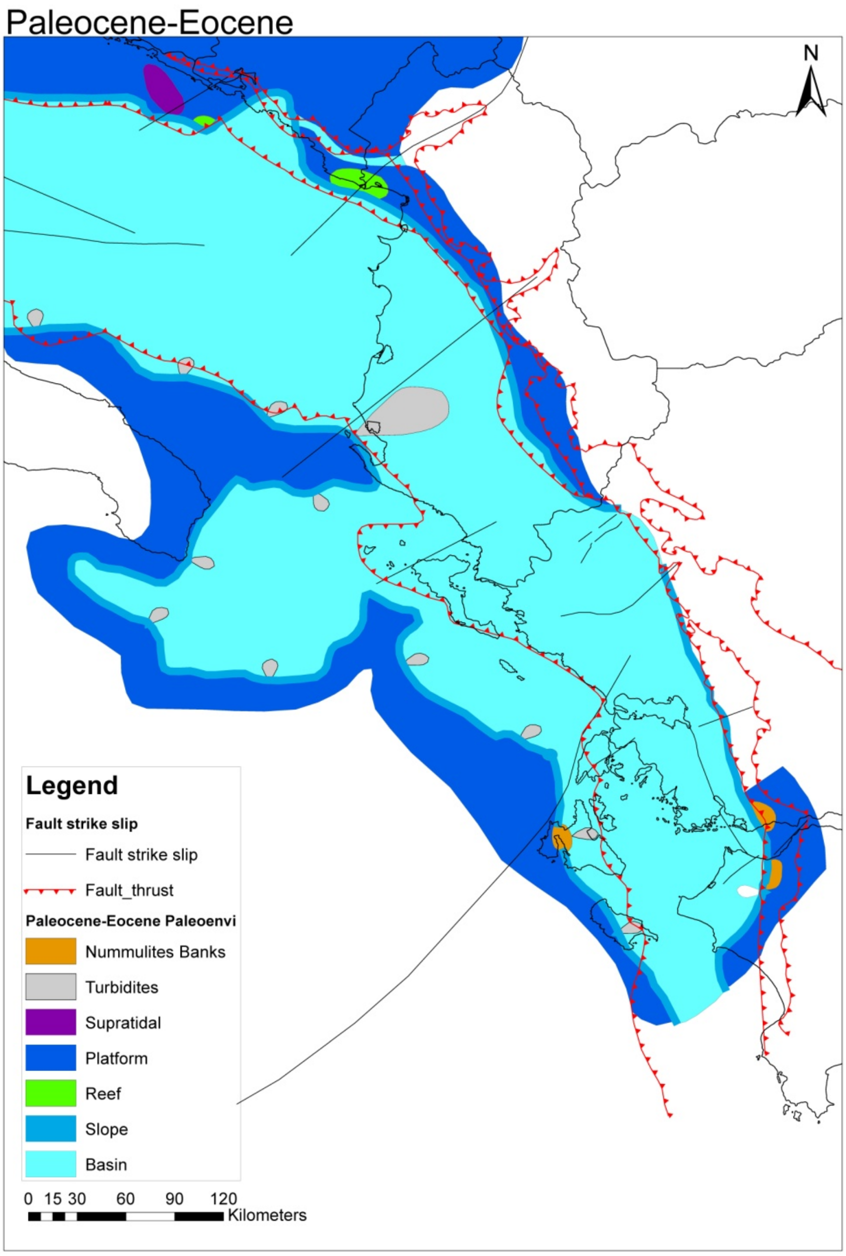


Figure 50: *Paleo-environmental map of the study area during Paleocene-Eocene.*

9.2.6 Miocene

At the end of Early Miocene (Burdigalian), the major compressional phase affected the Ionian basin. Early to Late Miocene is characterized by a rapidly subsiding foredeep from Gavrovo to Paxos, with deep water clastic turbidites (Fore arc basin).

The Upper Tortonian-Messinian deposits are interpreted to result from a regional regression (Albpetrol, 1993). The Messinian regression is marked by gypsum-bearing clastics in the west and northwest of the Durres basin.

The Messinian salinity crisis started at 5,96 Ma (Krijgsman et al., 1999a) with the deposition of the lower evaporites. The Messinian salinity crisis resulted from the progressive closure of marine gateways, in the east during the early Tortonian (Husing et al., 2009), and in the West during the Messinian.

Extraordinary thick evaporitic sequences and extensive erosional surfaces have been established in most of the Mediterranean basin. The Mediterranean during the Messinian was an evaporation basin, water losses needed to be balanced by water inflow from rivers and the global ocean to preserve sea level.

9.3 Outcrop measurements

9.3.1 Porosity & Permeability

Generally, from the mesearuments, different percentages of porosity have been revealed. In this chapter we are going to present the porosity results and also the diagrams of each section.

The porosity range that have been used in order to describe the quality of the carbonate rocks has been presented in sub-chapter 7.2 (*Table 1*).

Section A (Koloniati Section)

The average porosity from section's A samples is 7,57 % (*Table 18*). The highest porosity value has been reported within sample K3 (19,26 %), while the lowest value presented by sample K28 (1,28 %). On the other hand, permeability measurements showed the highest value within sample K8 (2,718) and the lowest value within sample K28 (2,6707).

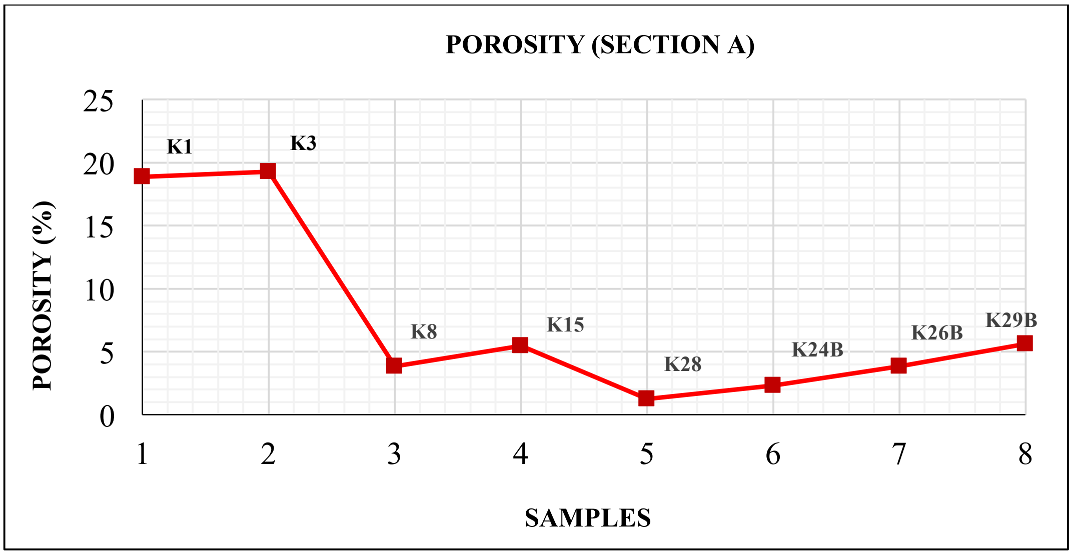


Diagram 1 : Diagram showing the porosity values from section A.

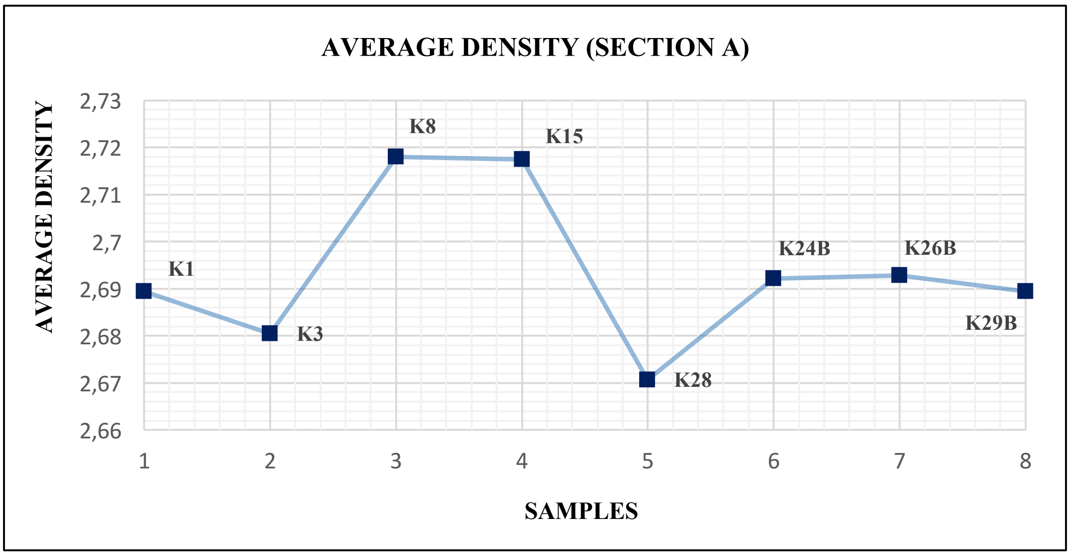


Diagram 2 : Diagram showing the permeability values from section A.

Sample	Porosity (%)	Average Density
K1	18,878	2,6894
K3	19,262	2,6805
K8	3,858	2,718
K15	5,457	2,7175
K28	1,281	2,6707
K24B	2,329	2,6921
K26B	3,865	2,6928
K29B	5,653	2,6894

Table 18: *Porosity and permeability measurements from section A.*

<u>*Section B (PerivleptosSection)*</u>

For Section B the average porosity is 8,46 %. Sample Π15 showed the higest porosity value (23,8 %), while the lowest value reported within sample Π3 (3,752 %). According to the permeability measurements sample Π12 showed the highest value of 2,7319 and sample Π18 (2,6496) the lowest value (*Table 19*).

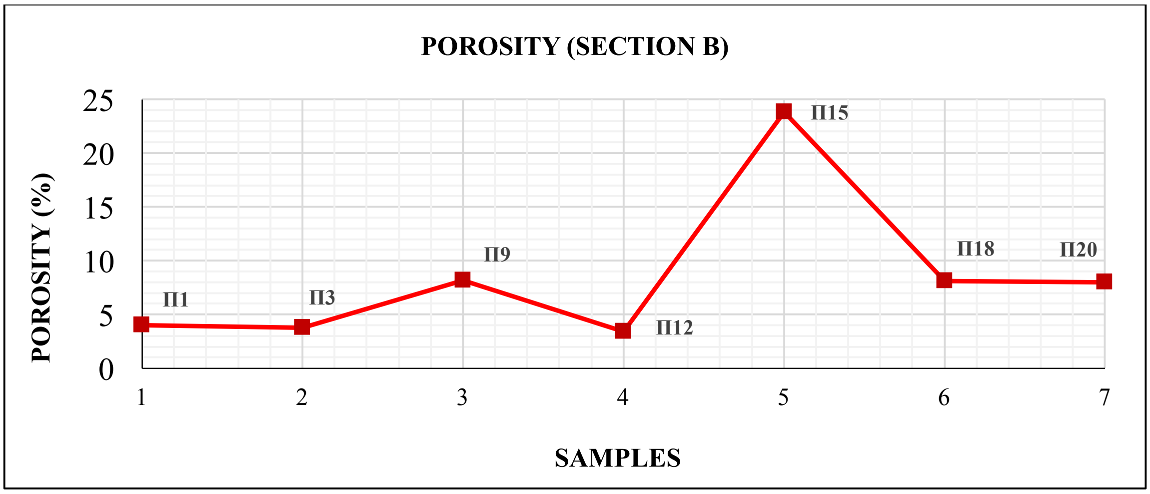


Diagram 3 : Diagram showing the porosity values from Section B.

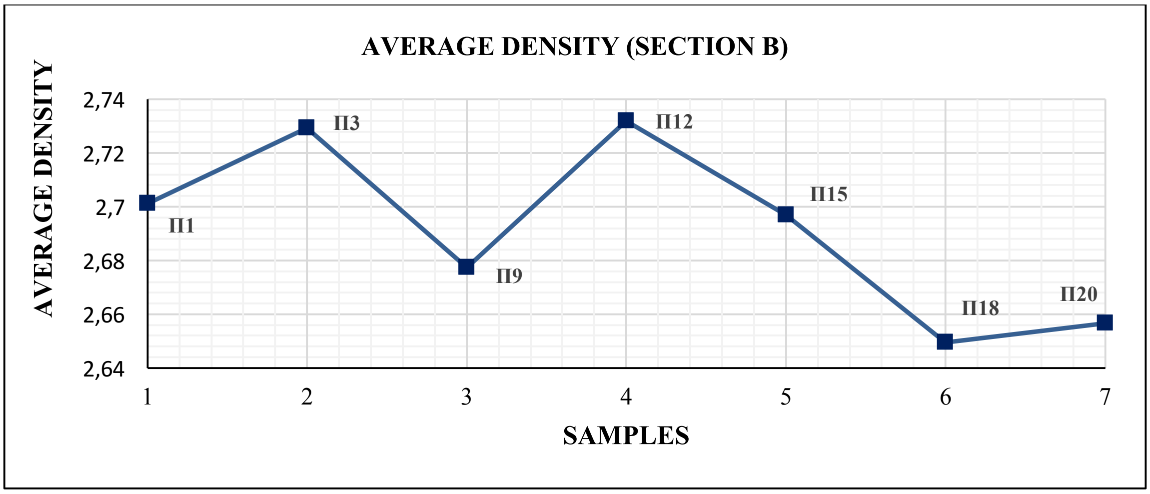


Diagram 4 : Diagram showing the porosity values from Section B.

Sample	Porosity	Average Density
Π1	4,024	2,7012
Π3	3,752	2,7293
Π9	8,182	2,6774
Π12	3,384	2,7319
Π15	23,823	2,697
Π18	8,099	2,6496
Π20	7,996	2,6567

Table 19: *Porosity and permeability measurements from section B.*

Section C (Asprageli-1 Section)

For Section C the average porosity is 6,29 %. The highest porosity value has been reported in sample A1 (16,88 %) and the lowest value within the sample A13 (2,50 %). For the permeability measurements, the highest value presented in sample A23 (2,7193), while the lowest appeared within sample A3 (2,5799) (*Table 20*).

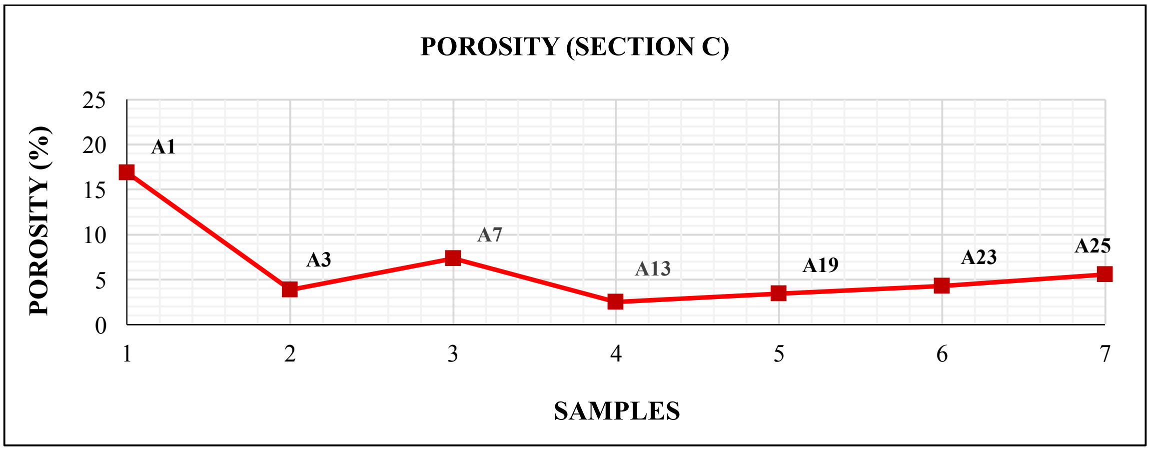


Diagram 5: Diagram showing the porosity values from Section C.

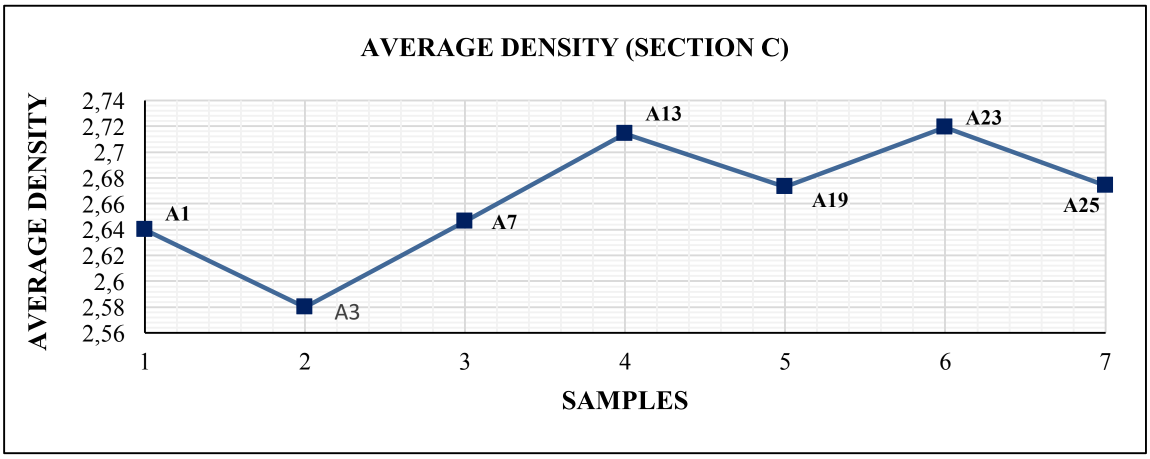


Diagram 6: *Diagram showing the permeability values from Section C (Asprageli 1 Section).*

Sample	Porosity	Average Density
A1	16,884	2,6399
A3	3,899	2,5799
A7	7,383	2,6464
A13	2,501	2,7143
A19	3,456	2,673
A23	4,323	2,7193
A25	5,598	2,6739

Table 20: *Porosity and permeability measurements from section C.*

<u>*Section D (Asprageli-2 Section)*</u>

For Section D the average porosity is 11,59 %. The highest value for porosity represented by sample $A_2$8 (19,63 %) and the lowest by sample $A_2$4 (2,6 %). On the other hand the highest permeability value showed within sample $A_2$4 (2,7411) and th lowest value within sample $A_2$9 (2,6204) (*Table 21*).

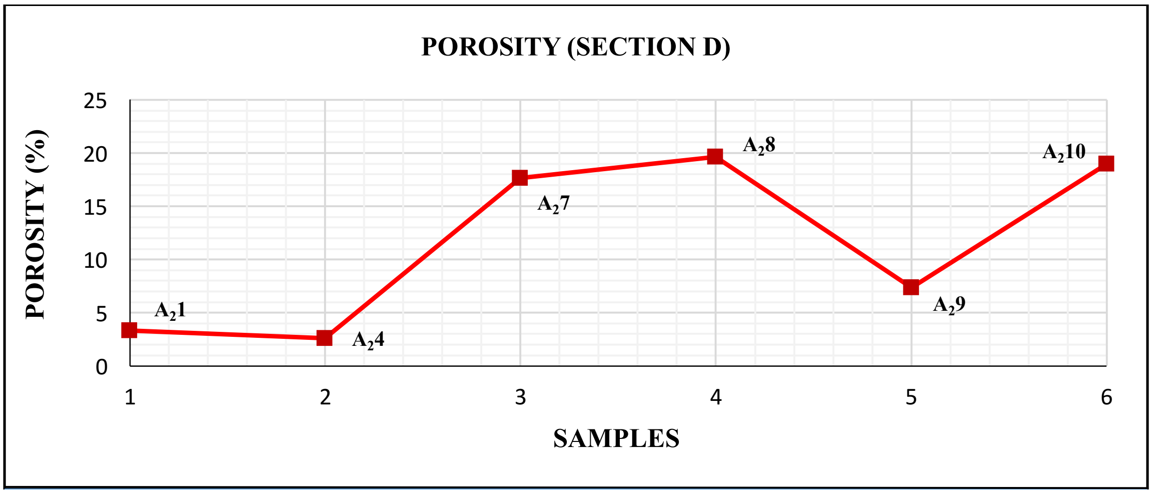


Diagram 7: Diagram showing the porosity values from Section D (Asprageli-2 Section).

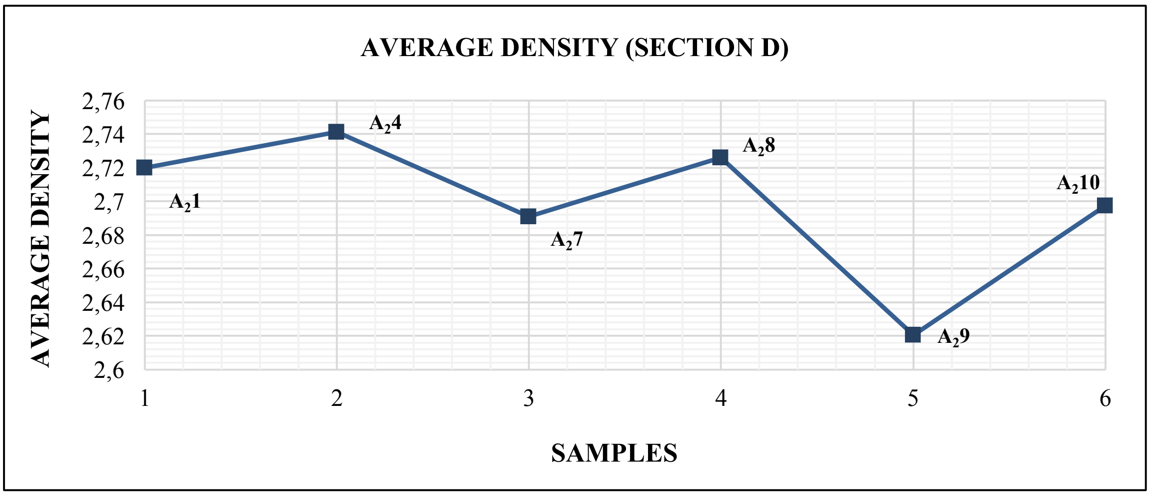


Diagram 8: *Diagram showing the permeability values from Section D (Asprageli-2 Section).*

Sample	Porosity	Average Density
$A_2$1	3,31	2,7198
$A_2$4	2,6	2,7411
$A_2$7	17,644	2,6908
$A_2$8	19,634	2,726
$A_2$9	7,356	2,6204
$A_2$10	18,992	2,6974

Table 21: *Porosity and permeability measurements from section D.*

Section E (Vigla Section)

For Section E the average porosity is 8,67 %. Sample B10 showed the highest porosity among other samples (23,09 %) and sample B20 the lowest porosity (2,98 %). For the permeability measurements, sample B1 showed the highest value (2,7277), while sampple B10 showed the lowest value (2,6811) (*Table 22*).

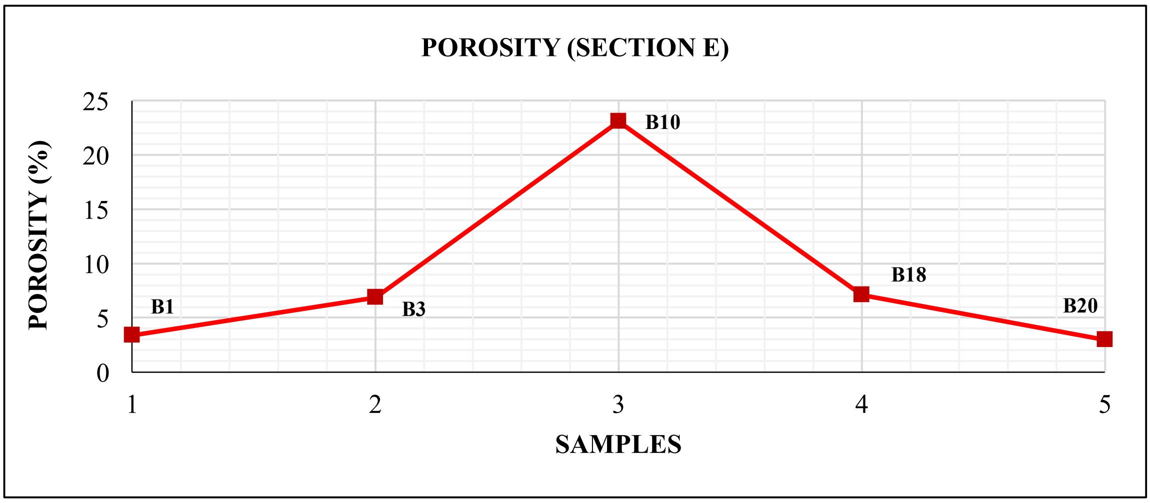


Diagram 9: Diagram showing the porosity values from Section E (Vigla Section).

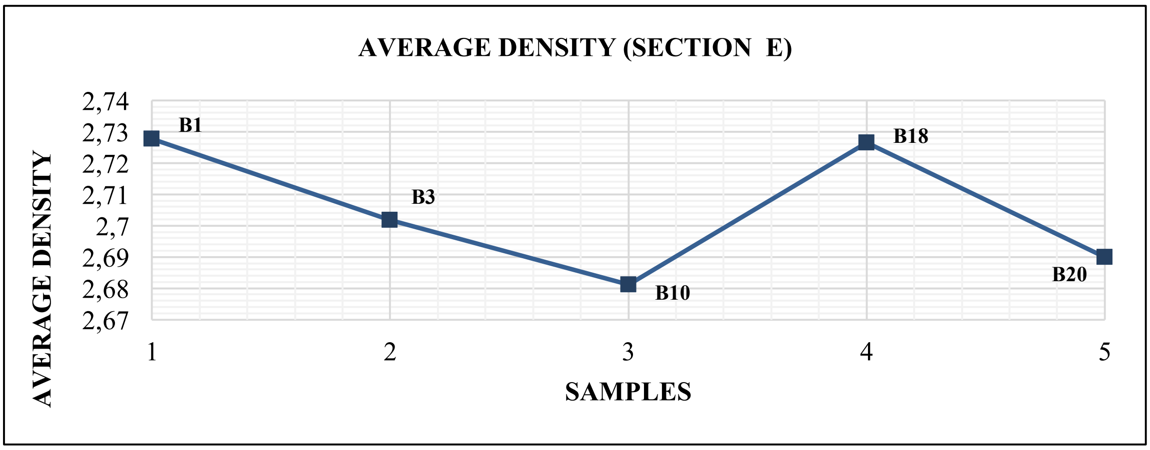


Diagram 10: *Diagram showing the permeability values from Section E (Vigla Section).*

Sample	Porosity	Average Density
B1	3,36	2,7277
B3	6,855	2,7017
B10	23,087	2,6811
B18	7,066	2,7265
B20	2,982	2,69

Table 22: *Porosity and permeability measurements from section E.*

<u>Section F (Louros Section)</u>

For section F the average porosity is 3,92 %. Sample Λ15 showed the highest porosity, around 9,62 %, while sample Λ35 presented the lowest porosity value (2,30 %). The highest permeability measurement presented by sample Λ25 (2,7319) and sample Λ45 showed the lowest (2,6496) (*Table 23*).

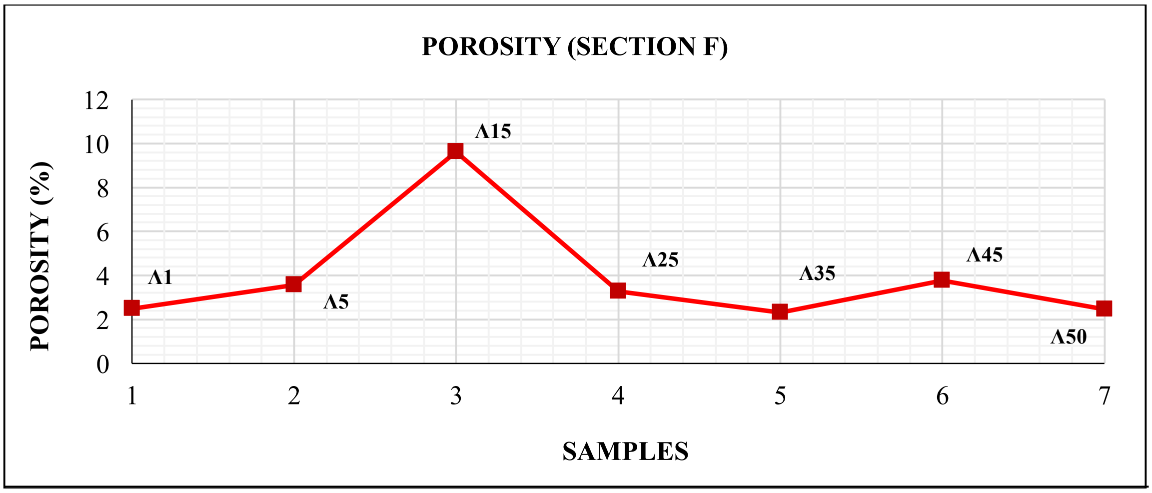


Diagram 11: Diagram showing the porosity values from Section F (Louros Section).

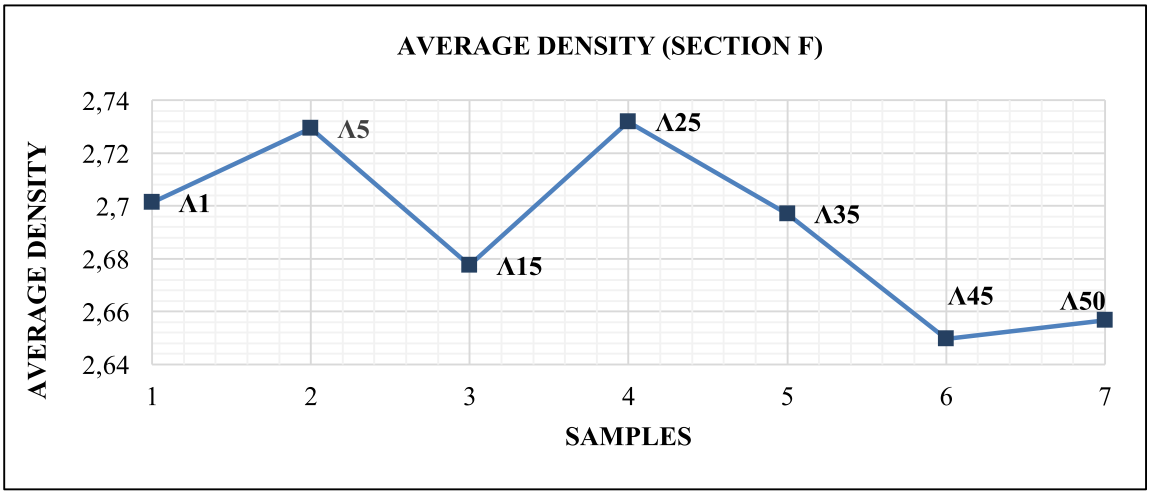


Diagram 12: Diagram showing the porosity values from Section F (Louros Section).

Sample	Porosity	Average Density
Λ1	2,492	2,7012
Λ5	3,551	2,7293
Λ15	9,617	2,6774
Λ25	3,281	2,7319
Λ35	2,305	2,697
Λ45	3,757	2,6496
Λ50	2,447	2,6567

Table 23: *Porosity and permeability measurements from section F.*

9.3.2 Porosity & Permeability relationship

Permeability of porous media is usually expressed as function of some physical poroperties of the interconnected pore system such as porosity and turtuosity. Although it is natural to assume that permeability values depend on porosity, it is not simple to determine which is the appropriate relationship since this would require a detailed knowledge os size distribution and spatial arrangement of the pore channels in the porous medium.

For example, two porous systems can have the same porosities but different permeabilities. Generally, it is known that the higher porosity, the higher permaebility we should have. However because of the complexity and the large number of related parameters no simple single functions can exist.

Because of its viral importance in many fields, from industrial manufacturing processes to the success of hydrocarbon recovery processes, many semi-empirical corrections have been proposed to improve the estimation of permeability. (Costa, 2006)

In our samples, it has been observed that as the porosity increases the permeability values seem to decrease. For instance, in Section E (Vigla Section), sample B3 with porosity 6,85 % has higher permeability value (2,7017) than sample B10 which presented a higher porosity value (23,1 %) but a lower permeability meseaurement (2,6811). This principle can be observed in several samples within our study area.

10. Petroleum System and Play Prospectivity

After comparing the paleo-environmental maps with the carbonate reservoir quality, there is not a clear view for the reservoir quality that can be associated with a specific depositional environment. Generally, most of the good potential reservoirs are deposited in high energy environments, such as tidal domains, reef barriers and slopes. Within our study area, most of the good potential reservoirs, in Greece, have been deposited during Lower Jurassic and Upper Cretaceous to Eocene age, while in Albania they are deposited during Eocene to Miocene age.

In the Ionian zone, the best reservoir characteristics have been found within the wells that have been drilled in West Katakolon area, and especially in well *Afroditi-1*. Within the Eocene unit, which mainly consists of limestones, very good porosity values have been recorded (20%). This unit has been deposited in a deep marine slope environment and reservoir characteristics are probably enhanced by fracturation. In addition good reservoir characteristics have been also recorded within the adjacent wells *Afroditi-1A* and *Afroditi-2*, in the Upper Cretaceous limestones, deposited in the same type of environment. In addition, within the Ionian zone, in wells *Hermione-1* and *Hermione-2*, fair to good reservoir characteristics have been recorded, in the Eocene carbonate units. These units have been deposited in a deeper environment than the previous units (basin). Also, fair to good reservoir characteristics have been recorded within the Lower Jurassic fractured carbonate units in wells *Aliki* and *Ivi* (Epirus area), in the Ionian zone. These units have been also deposited in a basin environment.

Furthermore, Eocene carbonate unit within the well *Electra*, situated in Gavrovo platform, has good reservoir quality. Carbonates were deposited in an open shelf platform environment.

In the Pre-Apulian zone, fair to good reservoir characteristics, have been recognized within the wells *Ifikratis*, *Antigoni*, *Dafni* and *Epafos*, in Upper Cretaceous carbonate units. Carbonates in wells *Dafni* and *Epafos* have been deposited in a basin environment while in wells *Ifikratis* and *Antigoni*, restricted shallow marine conditions have been determined.

On the other hand in Albania, good reservoir conditions have been recorded within the Cretaceous carbonate units in wells *Newton*, *Kepler* and *Planck*, situated in the Apulian platform. These carbonates have been deposited in a deep marine environment (basin). However, fair to good reservoir characteristics have been also recognized in the Miocene units, composed of limestones in wells *Kepler* and *Newton*. These units have been deposited in an outer shelf environment.

It seems that the most promising tectonic zone, for good reservoir characteristics is the Ionian zone, which includes the main carbonate reservoir levels, because of the presence of fracturation (Upper Cretaceous to Eocene age). Furthermore, good reservoirs can be expected in Gavrovo platform carbonates close to its transition to the Ionian zone (as in well *Electra*), but also in the thrust sheets of the Ionian and pre-Apulian zones (Cretaceous-Eocene age)

10.1 Play Prospectivity

After compiling all the data of our study area, a brief review of the most promising areas for petroleum potential have been determined.

Generally, within the wells that have been drilled, numerous oil and gas shows have been recorded. Also, oil seeps have been found all over the study area (*Fig. 40*) (i.e Herodotus spring, Dragopsa seep.). This relates to an active petroleum system that generates hydrocarbons.

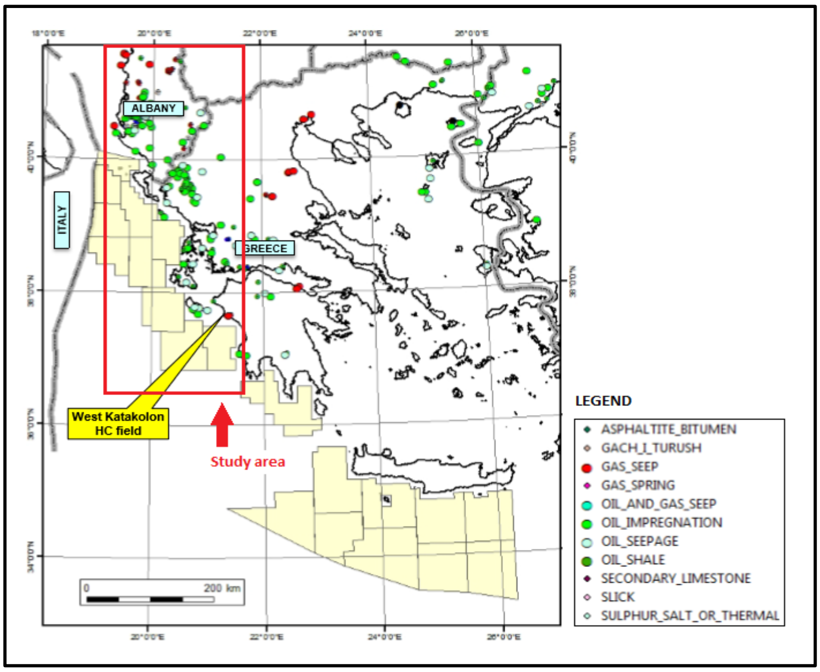


Figure 51: *Map of the study area with the oil and gas seeps and shows.*

In order to determine the exploration potential, within our study area, several factors have been described above. The main factor in our study was the quality of the carbonate reservoirs. Although, this factor must be connected with other aspects, like: source rocks, seals, traps as well as the hydrocarbon potential within our area.

The following table is summarizing all the aspects that have been examined in order to determine the exploration potential in our study area. The table presents each zone with the best reservoir, seal and source rocks associations that have been found.

	Reservoir		Seal	Source Rock	Types of traps
	Age	Type			
Gavrovo	Eocene	Platform carbonates	Oligocene flysch shales	Upper Cretaceous shales	Synclinal-Anticlinal structures
Ionian	Cretaceous-Eocene	Basin Carbonates	Neogene flysch and marls	Triassic-Upper Cretaceous	Subthrust structures
Pre-Apulian	Cretaceous-Eocene	Platform carbonates	Neogene clastics	Upper Triassic-Jurassic	Anticlinal closures
Apulian	Cretaceous	Platform carbonates	Tertiary shales - Messinian evaporites	Probably located within deeper parts	Not Identified

Table 24: *Table summarizing reservoirs, seals, source rocks and types of traps for each zone within our study area.*

At the present, only West Katakolon oil field has been discovered so far and it produces from Upper Cretaceous to Paleocene/Eocene carbonate reservoir rocks of the Ionian zone, sealed by Plio-Quaternary shales. Possible oil plays are located in anticlinal closures in the Cretaceous to Eocene carbonates of the Pre-Apulian and Ionian zone successions. According to Zelilidis et al., (2003), target areas are near the Cephalonia fault, which maybe analogous to the Vlora-Elbasan lineament. Examples are the northern part of Lefkas Island and also near to Kalpaki fault near Delvinaki.

Albania, in spite of the existing oil and gas fields, still has good potential and is a promising area for further exploration both onshore and offshore. According to Kotenev (2015), possible discoveries could be found under the existing ones in the deeper levels.

Within our study area the following scenarios of reservoirs-seals-source rocks associations have been found. In the Ionian zone Jurassic to Cretaceous reservoirs are sealed by Neogene marls and flysch. Source rocks are identified from Triassic (organic rich shales within evaporites) to Upper Cretaceous age (Albian-Turonian), with fair to excellent hydrocarbon potential, as for example in wells *Iraklis* and *Ivi*. Although, within Ioannina area, which is the target area, the Lower Posidonia Beds (Upper Jurassic) are probably the most significant oil source rocks. Favorable structural traps are also present, but also traps related to diapiric processes and the detachment of the Ionian thrust sheets along the Triassic evaporites. (Karakitsios, 1995; Karakitsios, 2013)

In Gavrovo zone, Eocene platform carbonates, can be expected as good reservoirs (as in well Electra), close to transition to the Ionian zone. These reservoirs are sealed by Oligocene flysch shales and source rocks are present in Upper Cretaceous. A possible prospective area can be located in Aitoloakarnania region, near the well *Electra*.

Within the Pre-Apulian zone, possible oil plays are located in anticlinal closures in the Cretaceous to Eocene carbonates, near to the transition with the Ionian zone. These carbonates are sealed by Neogene shales and source rocks have been found within Upper Triassic to Jurassic. According to Zelilidis et al., (2003), target areas are near the Cephalonia fault, which maybe analogous to the Vlora-Elbasan lineament. Example of this potential prospective area is the northern part of Lefkas Island.

Furthermore, According to Zelilidis et al., (2015) another target for exploration is the Carboniferous to Permian carbonate succession below the Triassic evaporites within the Ionian zone (*Fig. 41*). Organic rich intervals in this succession will be thermally mature and may be capable of generating hydrocarbons, which will be sealed by the overlying evaporites. Potential traps are linked to major thrust zones and salt-related structures.

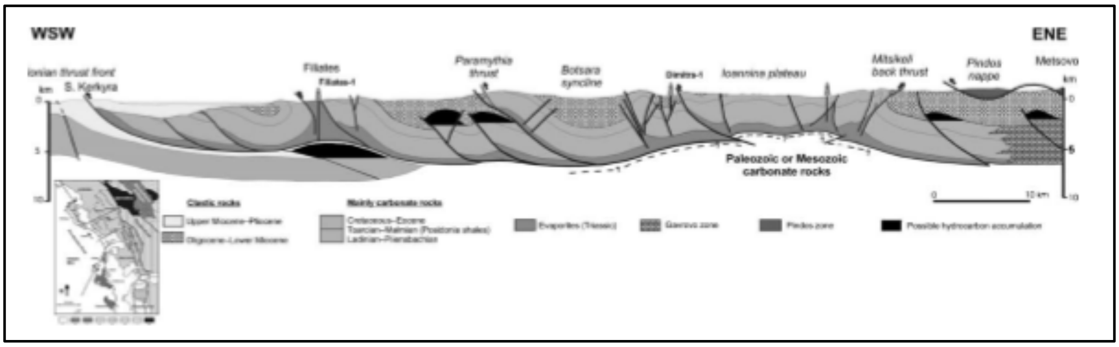


Figure 52: *SW-NE oriented cross section across the Ionian Zone of NW Greece (Karakitsios, 2013).*

Also within the Apulian platform possibilities for new oil potential accumulations are found in the platform carbonates reservoirs (Upper Cretaceous/Miocene age), as in the case of wells *Kepler* and *Newton* where good potential reservoirs have been recognized. In well *Kepler*, reservoirs are sealed by anhydrites and Tertiary shales, while in well *Newton* reservoirs are sealed by Pliocene and Miocene marls, as well as, by Messinian evaporites. Although, in both cases, no source rock intervals have been found (probably, located within deeper parts of the basin). Both wells are situated in offshore Albania, in the Apulian platform.

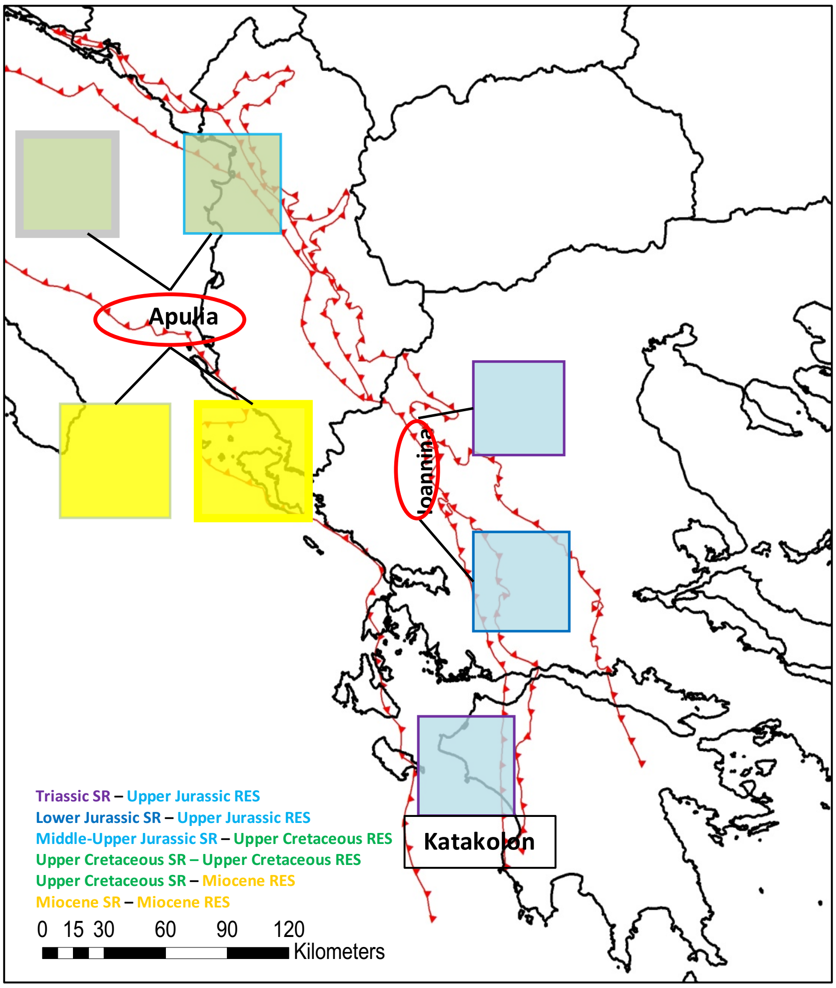


Figure 53: *Map showing possible combinations of best reservoirs and source rocks.*

11. Conclusions

In our study (Greece and Albania), several wells have been drilled. More specifically, most of the wells have been drilled in the onshore part of Southwest Greece (few wells in the offshore part). On the other hand, in Albania, the available wells are from the Southwest onshore and offshore part of the country.

Within this study a low amount of data were available, such as porosity and permeability, which were the main parameters in order to determine a reliable reservoir quality of the carbonate units. Therefore, other factors like gas and oil shows or the presence of bitumen and fluorescence have been taken into account in order to help determining the quality of the reservoirs. In some cases, when a large amount of data where missing from a well description, a correlation with a nearby well helped us to determine the quality of the reservoirs. Although, this way of characterization of the reservoir quality is to be taken cautiously.

Good quality carbonate reservoirs in general have porosities above 10% and permeabilities above 10mD. However, some factors, like the presence of fractures, can increase the potential of a reservoir. Carbonate reservoir rocks are located in several stratigraphic levels within the Mesozoic sequences in the Western part of Greece. Most of the good potential reservoirs are in Upper Cretaceous to Eocene series and they are associated with the carbonate deposits of the Ionian zone. However, some attractive potential reservoirs can also be found in the Lower Jurassic. Furthermore, some promising carbonate reservoirs can be found in the Gavrovo platform close to its transition to the Ionian zone. On the other hand, in Albania, from the examined wells, it can be assumed that good potential reservoirs are belonging to Upper Cretaceous to Miocene age, within the Ionian zone and the Apulian platform (offshore).

Within our study area the paleo-environments of these carbonate reservoirs can range from shallow to basinal conditions. Most of the good reservoirs have been deposited in shallow to restricted platforms. Although, deeper depositional environments can be associated with the deposition of good potential reservoirs

11.1 Further Study and Improvements

Western Greece and Albania have undergone similar geological histories. In terms of petroleum exploration in Greece and Albania and in order to have a deeper understanding of the structure of the reservoirs, more wells should be drilled within our study area (offshore and onshore). In addition, greater drilling depths should be achieved.

The geological structures within our study area should also be further investigated. This can be achieved by more offshore/onshore seismic acquisitions with adapted parameters to investigate the deeper parts of the thrust belt. This will help to investigate and better understand the global petroleum systems and to define areas where potential traps may exist.

Furthermore, field trips, outcrop samples and core samples analysis can always improve the study within an area and lead us to safer and more accurate interpretations.

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APPENDIX 1: THIN SECTIONS PHOTOS

SECTION A (KOLONIATI SECTION)

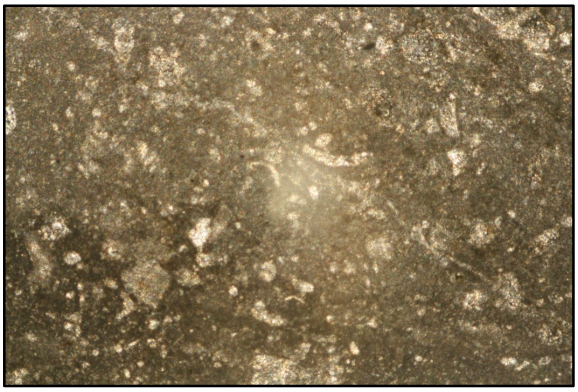


Figure 54: *Section A, Senonian limestone, Sample K2.*

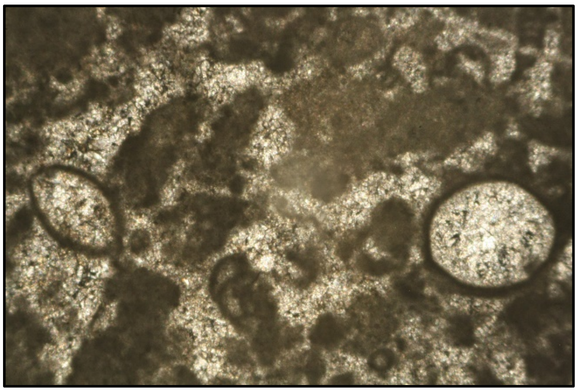


Figure 55: *Section A, Senonian limestone, Sample K3.*

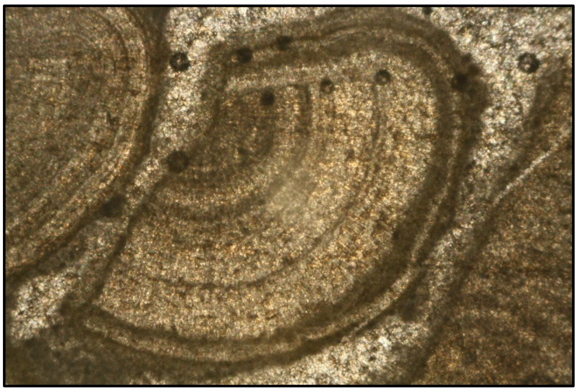


Figure 56: *Section A, Senonian limestone, Sample K4.*

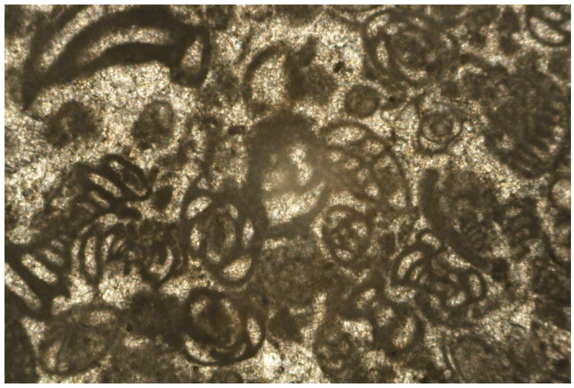


Figure 57: *Section A, Senonian limestone, Sample K5.*

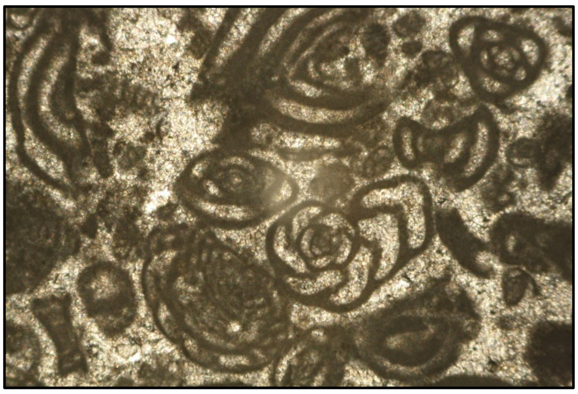


Figure 58: *Section A, Senonian limestone, Sample K5.*

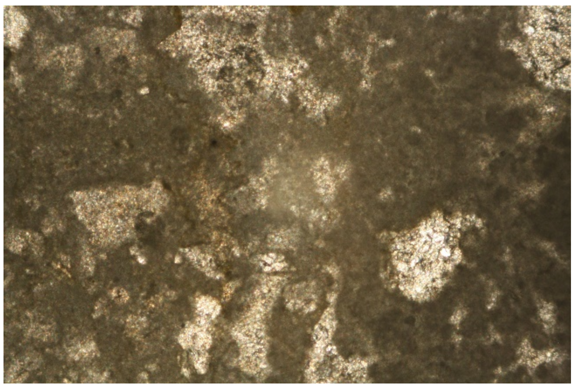


Figure 59: *Section A, Senonian limestone, Sample K6.*

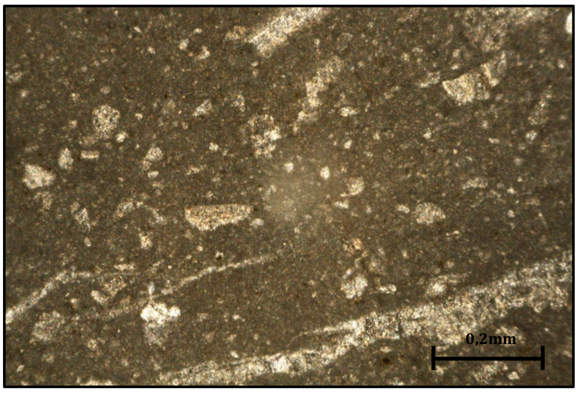


Figure 60: *Section A, Senonian limestone, Sample K7:*

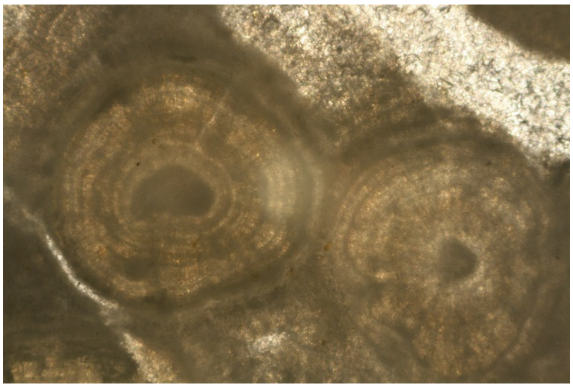


Figure 61: *Section A, Senonian limestone, Sample K8:*

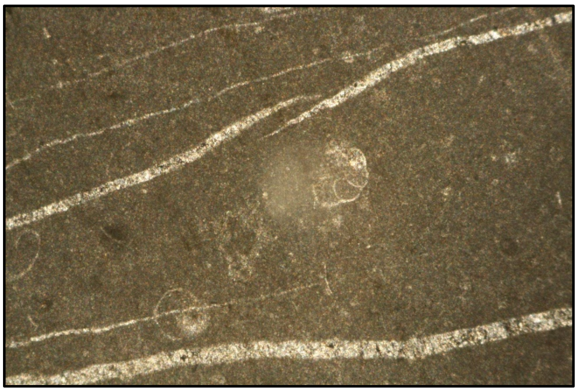


Figure 62: *Section A, Senonian limestone, Sample K9:*

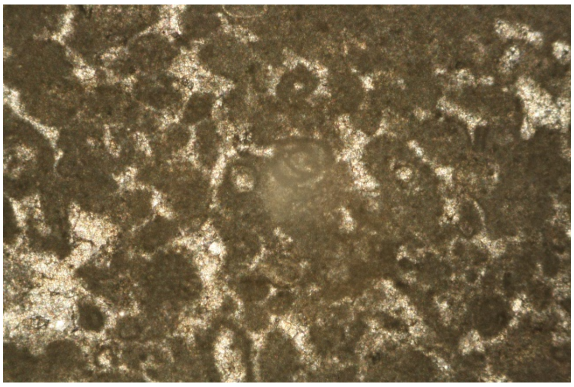


Figure 63: *Section A, Senonian limestone, Sample K10:*

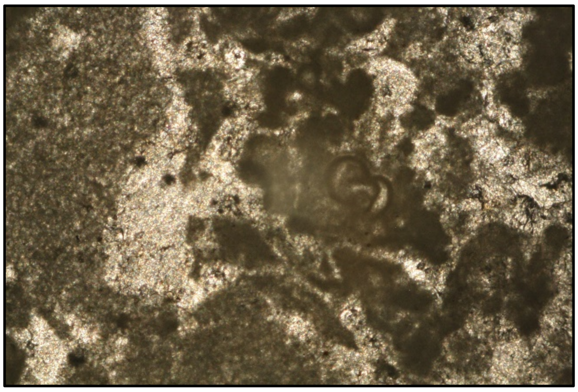


Figure 64: *Section A, Senonian limestone, Sample K11:*

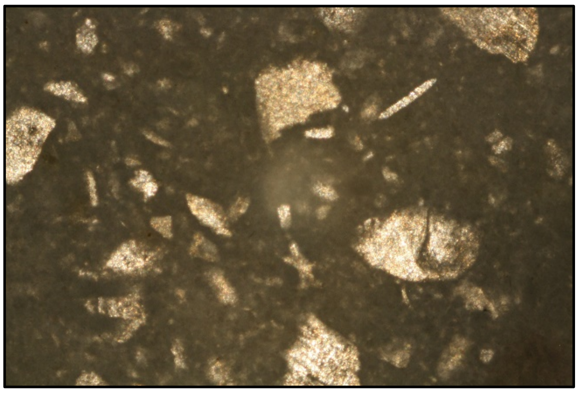


Figure 65: *Section A, Senonian limestone, Sample K13:*

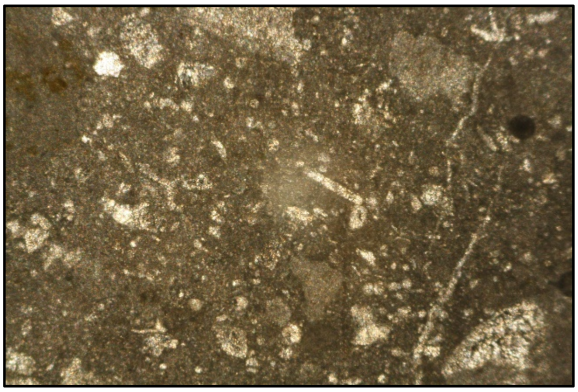


Figure 66: *Section A, Senonian limestone, Sample K14:*

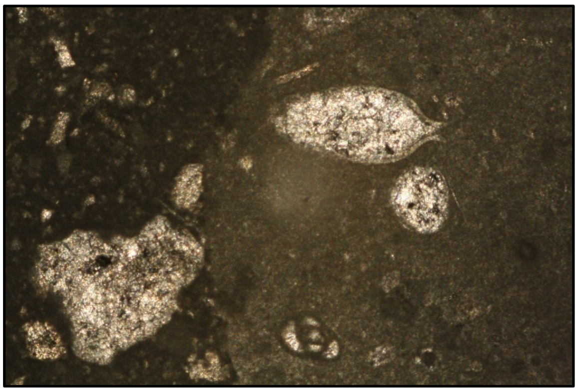


Figure 67: *Section A, Senonian limestone, Sample K15:*

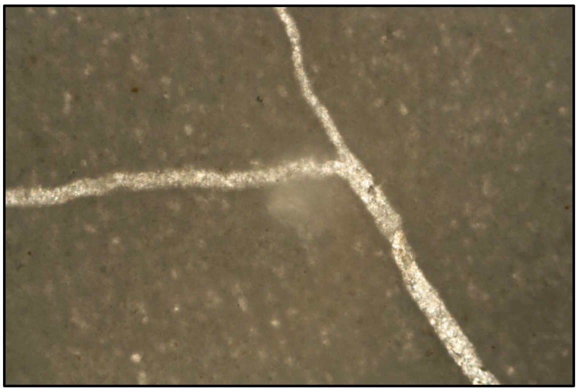


Figure 68: *Section A, Vigla limestone, Sample K24B:*

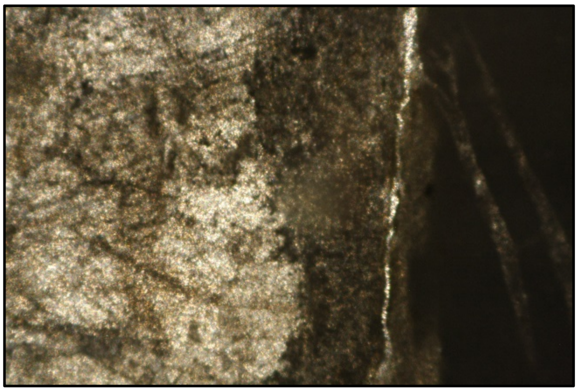


Figure 69: *Section A, Vigla limestone, Sample K26B:*

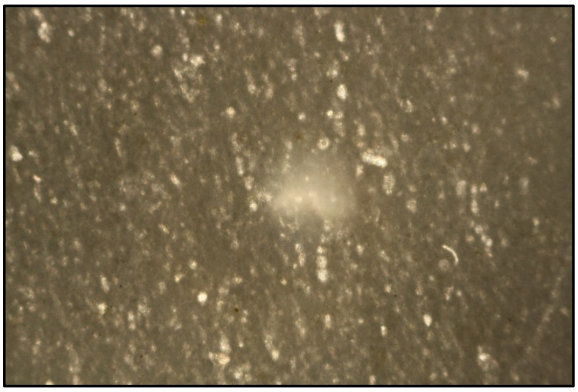


Figure 70: *Section A, Vigla limestone, Sample K29B:*

SECTION B (PERIVLEPTOS SECTION)

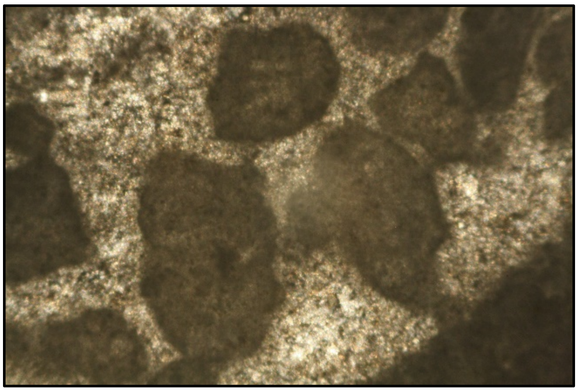


Figure 71: *Section B, Pantokrator limestone, Sample P3.*

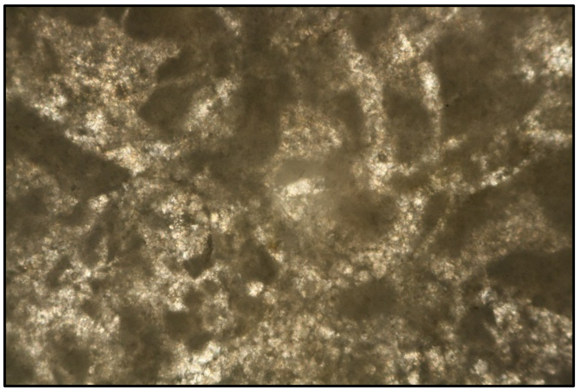


Figure 72: *Section B, Pantokrator limestone, Sample P9.*

SECTION C (ASPRAGELI-1 SECTION)

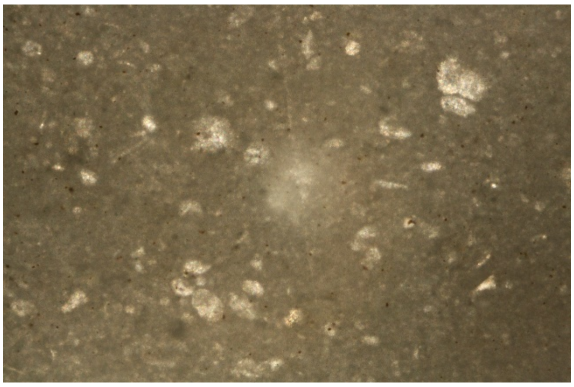


Figure 73: *Section C, Paleocene-Eocene limestone, Sample A1.*

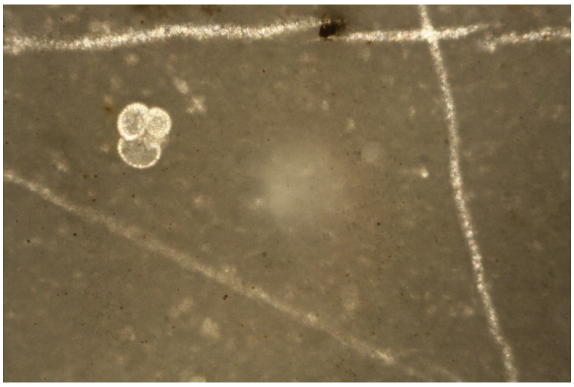


Figure 74: *Section C, Paleocene-Eocene limestone, Sample A3.*

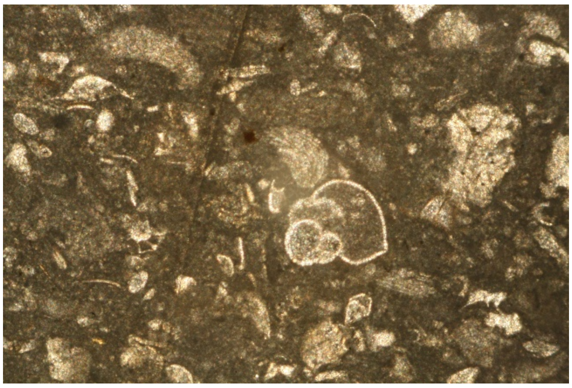


Figure 75: *Section C, Paleocene-Eocene limestone, Sample A7.*

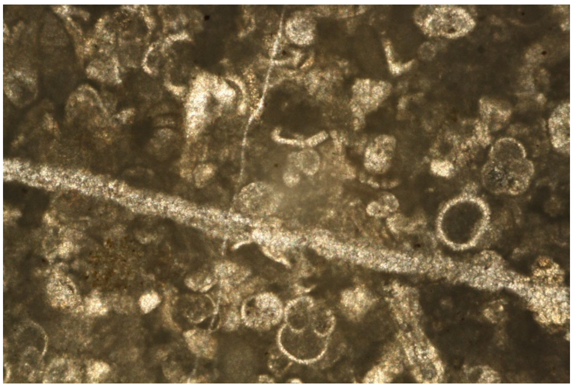
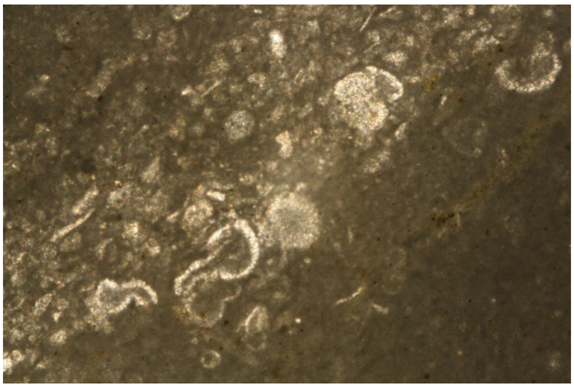


Figure 76: *Section C, Paleocene-Eocene limestone, Sample A13.*



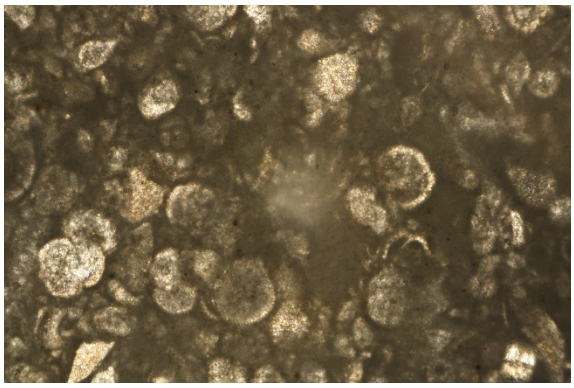
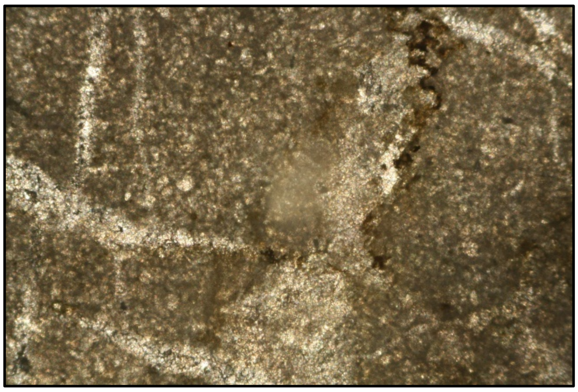


Figure 77: *Section C, Paleocene-Eocene limestone, Sample A19.*

Figure 78: *Section C, Paleocene-Eocene limestone, Sample A25.*

SECTION D (ASPRAGELI-2 SECTION)



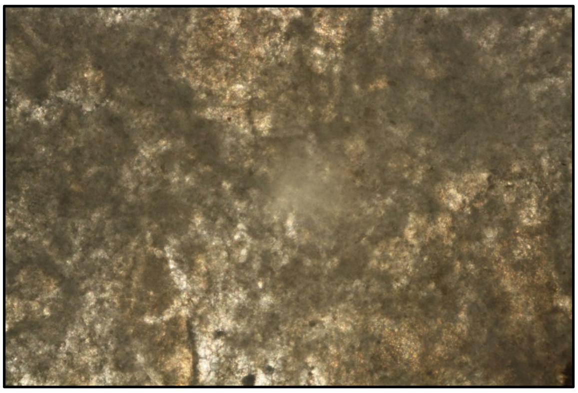
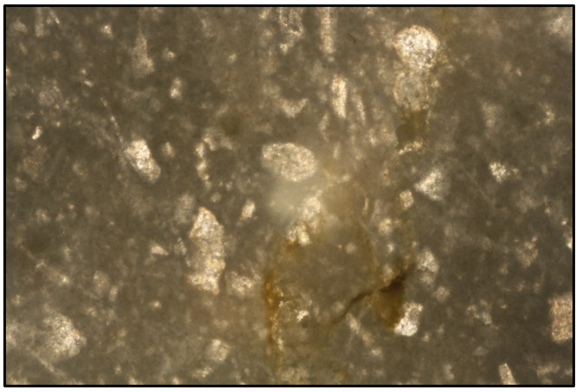


Figure 79: *Section D, Senonian limestone, Sample $A_2$1: Bioclastic limestone (Folk) – Packstone (Dunham), High Energy (HE).*

Figure 80: *Section D, Senonian limestone. Sample $A_2$4: Biomicrite (Folk) – Packstone – Floatstone, Medium Energy (ME).*



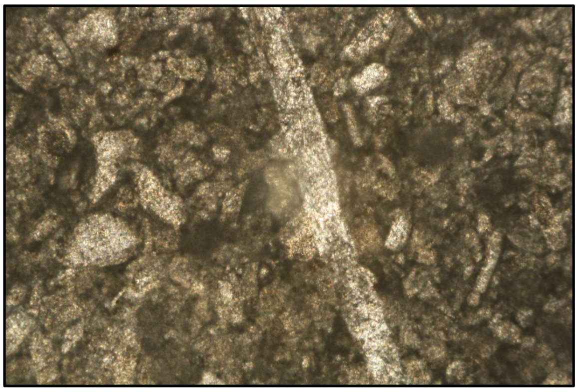


Figure 81: *Section D, Senonian limestone, Sample $A_2$7: Biomicrite (Folk) – Wackestone (Dunham) with Globotruncana.*

Figure 82: *Section D, Senonian limestone, Sample $A_2$8: Bioclastic limestone (Folk) – Packstone (Dunham) with Globotruncana.*

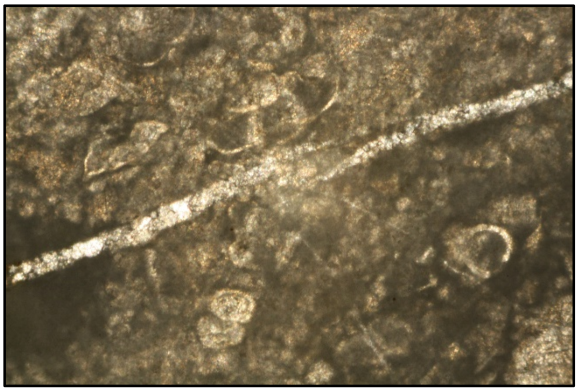


Figure 83: *Section D, Senonian limestone, Sample $A_2$9: Biomicrite (Folk) – Wackestone (Dunham).*

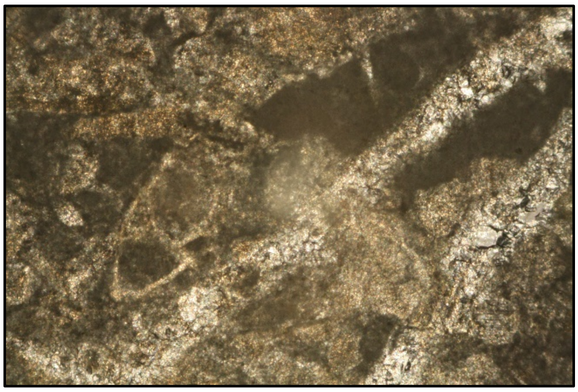


Figure 84: *Section D, Senonian limestone, Sample $A_2$10: Biomicrite (Folk) – Boundstone (Dunham).*

SECTION E (VIGLA SECTION)

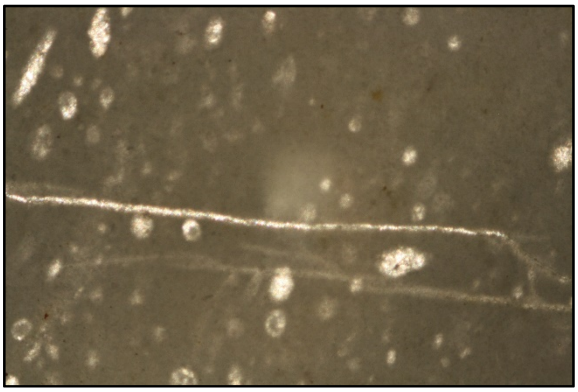


Figure 85: *Section E, Vigla limestone, Sample B1: Biomicrite (Folk) – Wackestone (Dunham) with Radiolaria.*

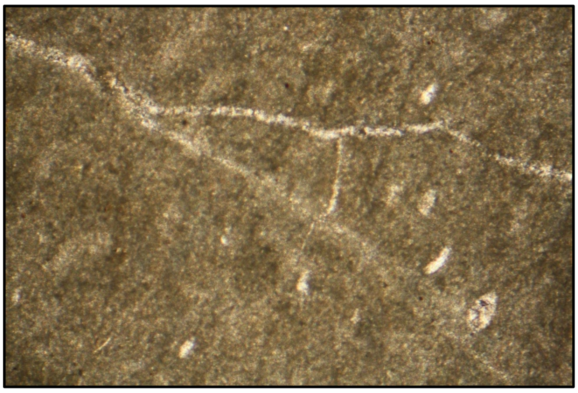


Figure 86: *Section E, Vigla limestone, Sample B3: Biomicrite (Folk) – Wackestone (Dunham) with Radiolaria.*

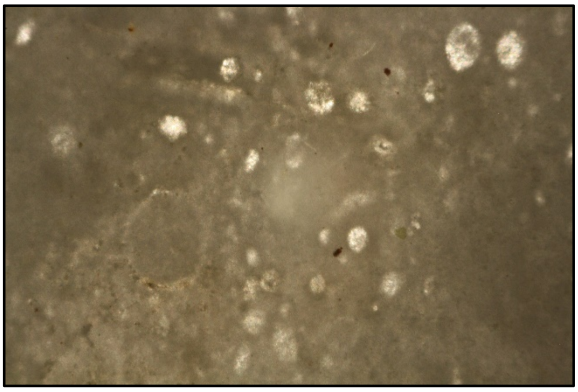


Figure 87: *Section E, Vigla limestone, Sample B18: Biomicrite (Folk) – Wackestone (Dunham) with Radiolaria.*

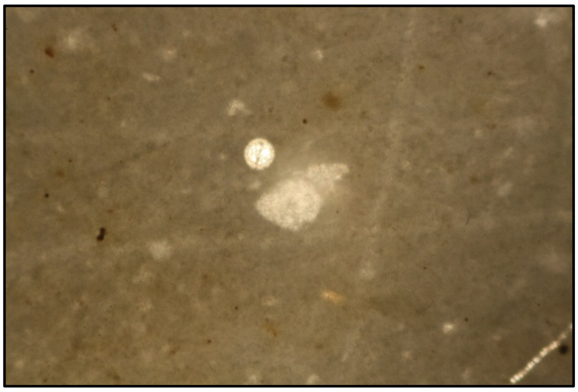


Figure 88: *Section E, Vigla limestone, sample B20: Biomicrite (Folk) – Wackestone (Dunham) with Radiolaria.*

SECTION F (LOUROS SECTION)

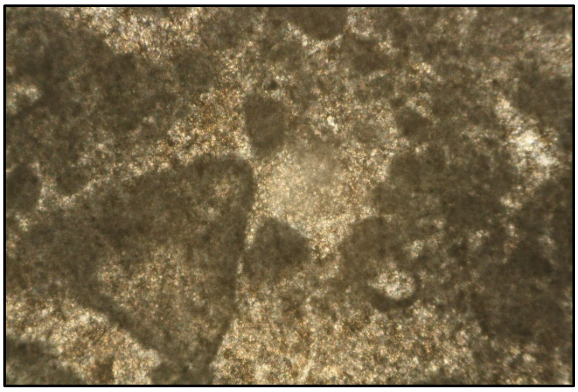


Figure 89: *Section F, Pantokrator limestone, Sample Λ1:*

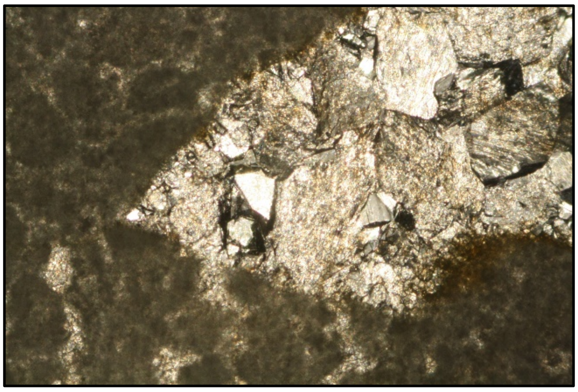


Figure 90: *Section F, Pantokrator limestone, Sample Λ5:*

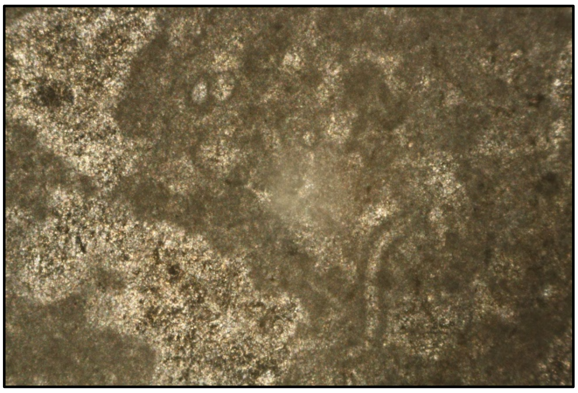


Figure 91: *Section F, Pantokrator limestone, Sample Λ15:*

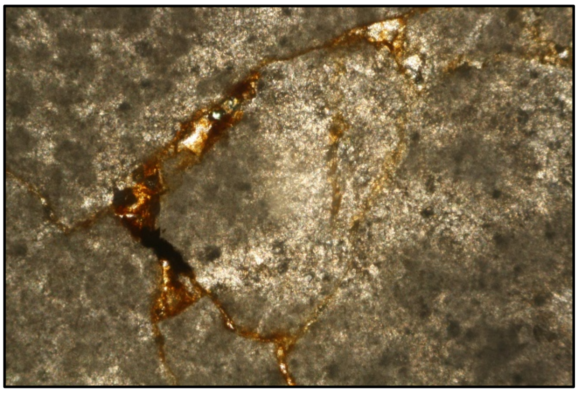


Figure 92: *Section F, Pantokrator limestone, Sample Λ25:*

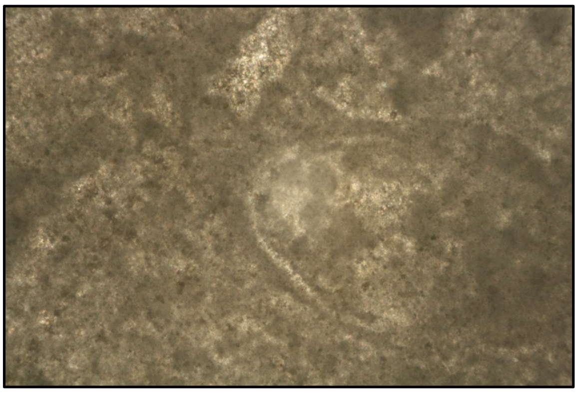


Figure 93: *Section F, Pantokrator limestone, Sample Λ35:*

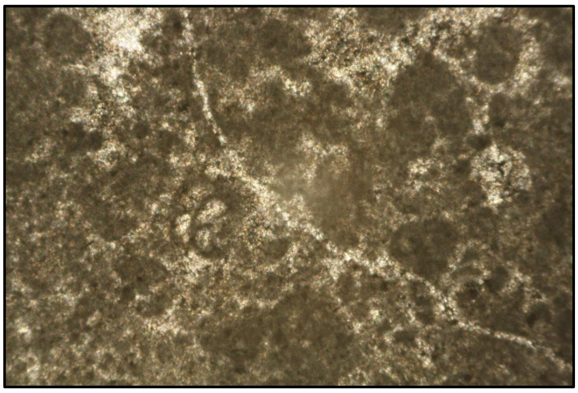


Figure 94: *Section F, Pantokrator limestone, Sample Λ45:*

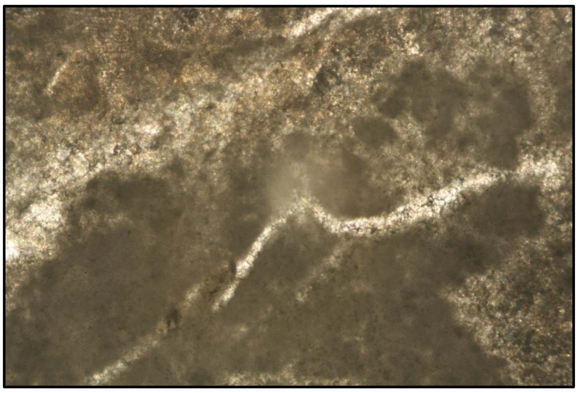


Figure 95: *Section F, Pantokrator limestone, Sample Λ50:*