İSTANBUL TECHNICAL UNIVERSITY ★ EURASIA INSTITUTE OF EARTH SCIENCES

GEOMETRY AND EVOLUTION OF THE EASTERN PART OF THE HERCYNIAN OROGENIC SYSTEM IN EUROPE AND ITS TRANSITION TO THE SCYTHIDES

M.Sc. THESIS BY

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HERSİNİYEN OROJENİK SİSTEMİNİN DOĞU AVRUPADAKİ KISMININ GEOMETRİSİ, EVRİMİ VE İSKİTİTLERE GEÇİŞİ

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FOREWORD

I would like to express my deep appreciation and thanks for my family whose moral support makes this thesis possible and my advisor who became also my mentor in the past three years.

May 2015

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SUMMARY

The Hercynian Orogen, one of the best-known orogenic belts in the world, still hides many secrets concerning its evolution. This orogen formed through the collision between Laurussia and Gondwana-Land, which resulted in the supercontinent of Pangaea. Pangaea's formation began in the late Devonian with the onset of subduction and continued from the early-medial Carboniferous to the Permo-Triassic by means of collision. However, at the eastern part of this supercontinent, collision never happened and subduction continued in the Permo-Triassic. The coast of the Palaeo-Tethys known as Alpine-type Triassic succession was the scene of high mobility events in the core of the Pangaea in terms of Hercynian and Post-Hercynian stages. It is a fact that when the subduction process was still continuing, a rifting event began in the Permo Triassic at the eastern part of Pangaea by disrupting a magmatic arc. The results show a continuous arc goes from the Rhodope-Pontide Fragment in the north, through the Eastern Carpathians, Tisza Block, Western Carpathians, and Pelagonian Zone, to the Eastern Pontides in the south. Additionally, the lithostratigraphic charts of all the tectonic zones indicate the volcano sedimentary complexes, which show a rifting event as their most likely interpretation. As a consequence of this rifting, a marginal basin started to form beginning from the eastern part and tore westward by tracing the weak zones of the former arc. It began to take shape from the Karakaya Complex, goes through the Pelagonian zone and the Inner Western Carpathians namely Meliaticum into the Tisza Block in the Late Permian-Early Triassic. From the medial to the end of the late Triassic, the entire Hellenic-Dinaric System and Italy began to disintegrate, which started from the Pindos Zone in Hellenides and Sicily in Italy, and joined together into the Southern Alps by passing through all along the coast of the present Adriatic Sea. This presentation shows a reconstruction of the Mediterranean Tethysides at the time of the early Triassic. It was done by palinspastically restoring all the orogenic

deformation for which data were to be had painstakingly and not just schematically. It is still incomplete, because it does not show the rift areas of the Sclafani-Imerese, Lagonegro and Pindos-Budva, except to show where they were. It also delineates the lie of the Karakaya and the Meliata rifts and shows that they were one and the same rift. Karakaya was later partly incorporated into the Vardar Ocean. Most of it closed during the earliest Jurassic, whereas the Meliata part was delayed until the late Jurassic. These closures are responses to two events: 1) Palaeo-Tethyan closure in case of Karakaya and 2) the opening of the South Atlantic in case of the Meliata. This paper addresses itself mainly to the solution of the Karakaya-Meliata problem.

HERSİNİYEN OROJENİK SİSTEMİNİN DOĞU AVRUPADAKİ KISMININ GEOMETRİSİ, EVRİMİ VE İSKİTLERE GEÇİŞİ

ÖZET

Hersinyen orojenezi, geç Paleozoyik zamanında Pangea oluşumu sırasında meydana gelmiş büyük bir orojenik kuşaktır. Lavrasya ve Gondwanaland'in çarpışması sonucu meydana gelen Pangea'nın, geç Devoniyen zamanında başlayan dalma-batma ve büyük ihtimalle erken-orta Karboniferden Permo-Triyas zamanına kadar devam eden çarpışma süreçleri batıda mevcutken, daha doğuda bu zaman içerisinde çarpışma hiç gerçekleşmemiş ve dalma batma süreci devam etmiştir. Orojenezin bu kısmında geç Permiyen-erken Triyas zamanında başlayan riftleşme dalma-batma yayını dogudan batıya dogru (bugünki Helenik-Dinarik Sistem ve Panoniyen-Karpatlar Bölgesi) yay ekseni boyunca parçalayarak bir kenar havzası oluşturmaya ve oluşan bu havza erken Jurada kapanmaya başlamıştır.

Anahtar metodolijisi karşılaştırmalı orojenez anatomisi olan bu makalede, sistemin en az bilinen ve Türkiye'den Avusturya'ya kadar olan Doğu Avrupa segmentine ait tektonik zonlarının jeolojik yapıları Karboniferden Jura- Kratese zamanına kadar çalışılarak Hersinyen Orojenezi'nin evrimindeki etkileri tartışılmıştır. Karpatlar, Balkanlar ve Anadolu bloklarının, ve diğer Akdeniz bölgelerinin palinspastik rekonstrüksüyonları yapılarak Paleozoyik-erken Mesozoyik zamanındaki orjinal yerleri için bir çözüm sunulmuştur.

Sonuç olarak, dalma-batma zonuna ait magmatik yayın Doğu Pontidler'den Batı Karpatlar'a kadar Pelagonyen Zonu'ndan ve Rodop-Pontid Bloğu'ndan geçerek bir süreklilik izlediği görülmektedir. Bunun yanı sıra, bahsi geçen rift zonu Karakaya Karmaşığı'ndan başlayıp Pelangonyen Zonu, İç Helenidler ve Meliata'dan geçerek Batı Karpatlar'a kadar devam etmektedir.

1. INTRODUCTION

It is well known for a long time that there are major cycles of plates in the Earth geological history. The first mentioned type of cycle was ocean's opening and closing (Wilson, 1966). Wilson stated the idea by studying the distribution of the faunal realms between North America and Europe. Besides Pacific type faunal assemblages in North America, there are also Atlantic type faunal assemblages in the eastern coast of North America and vise versa. However, Pacific type faunal assemblages are in the western coast of Europe. Therefore, he concluded that in order to explain the boundary between the faunal realms, a proto-Atlantic ocean existed, closed during the Middle-Upper Palaeozoic period, and re-opened by forming the present distribution of the faunal realms and today's Atlantic ocean. This repeated ocean cycles are now called "Wilson Cycles" (Dewey and Burke, 1974). Later, the idea of episodic continental crust formation (Holmes, 1954) and of orogenesis and crustal growth provided by subduction process of ocean closing propounded after Wilson's idea (Dewey, 1969) were led to proposition of Supercontinent cycle including the assembly and break up of continents (Worsley et al., 1982; 1984). By using the geochronological data, Worsley et al. (1982, 1984) identified the episodic peaks of continental orogenesis for collision indicated assembly and mafic dyke swarms for rifting indicated break up. With regard to these data, they suggested five supercontinents except the youngest one at 2.6, 2.1, 1.8-1.6, 1,1, and 0.6 Ga in the Earth history (Worsley et al., 1985), four of which are now familiar and known as Kenorland (Superia and Sclavia) (Halla et al., 2005), Columbia or Nuna (Rogers and Santosh, 2002), Rodinia (McMenamin and McMenamin, 1990; quoted after Meert 2012), and Pannotia (Dalziel, 1997) from the old one to the young one. Although the Wilson Cycle rarely synchronizes with the Supercontinent Cycle, they both agreed upon the youngest supercontinent which is already known since Wegener (1922), Pangaea, whose closure gave rise one of the major orogeny in the world, namely Hercynian Orogeny.

1.1 Purpose of the Thesis

This dissertation is an outcome of my youth interest of Tethys-Pangaea union and almost three years old hard work of Hercynian Orogeny and Post-Hercynian Events in the Mediterranean Region. The eastern European part of this system which is the starting point of this thesis, may be its least-known sector. Therefore, I aim to follow the trace of Hercynian Orogeny in these little-known areas and enlighten the speculative Permo-Triassic period in the framework of Tethys and Pangaea. Here, I present the geological structure of the tectonic units of Eastern Europe from the Carboniferous to the Jurassic-Cretaceous and discuss their tectonic implication for the evolution of the Hercynian Orogenic System.

In Chapter II a brief explanation is given about the methodology which constituted the key guide of this study, namely Comparative Anatomy of Orogens. Chapter III represents the research of geology and stratigraphy of the Eastern Europe while Chapter IV treats tectonic evolution of the Mediterranean Region during Permo-Triassic period including an attempt of palinspastic reconstruction. Finally, in Chapter V the general conclusions of this study are stated with some recommendations of uncertainties.

1.2 Background

The concept of Tethys and Pangaea is known since over a century when the geologist noticed that the present continents, now separated from each other by oceans, broke up in the past by controversial geological processes and therefore, once they should be together to form a supercontinent with a giant ocean around it. First attempt of restoration of this supercontinent was made by Antonio Snider-Pellegrini (1858) (Şengör, 2015, personal communication). However the name of this supercontinent, namely Pangaea, is mentioned first by Alfred Wegener as Pangäa in "Die Entstehung der Kontinente und Ozeane". On the other hand, Eduard Suess (1831-1914), the great Austrian geologist, invented the term Tethys in 1893. He stated that "Modern geology permits us to follow the first outlines of the history of a great ocean which once stretched across part of Eurasia. The folded and crumpled deposits of this ocean stand forth to heaven in Thibet [*sic!*], Himalaya, and the Alps. This ocean we designate by the name 'Tethys', after the sister and consort of Oceanus. The latest successor of the Tethyan Sea is the present Mediterranean" (Suess, 1893, p.183; quoted after Şengör and Atayman, 2009). Suess' Tethys was originally for a Mesozoic ocean, but it remained as a general term until Stöcklin (1974) used the name "Palaeo-Tethys" for the ocean at the Permo-Triassic period. Only afterwards, Suess' Tethys gained its original meaning as a Mesozoic ocean and became Neo-Tethys (Stöcklin, 1974).

After these inventors, many geologists continued to study on Pangaea and Tethys concept (e.g. Argand, 1924; Schucherts, 1928; Chouberts, 1935; Carey, 1958; Wilson, 1963; quoted from Şengör, 2015, personal communication). In 1965, Bullard, Everett and Smith came up with the idea, so-called "Bullard fit" which is now known as Pangaea A1. Later Van der Voo and French (1974), Irving (1977), and Smith et al. (1981) generated the different versions of Pangaea reconstructions called Pangaea A2, Pangaea B, and Pangaea C, respectively.

Evolution of the Pangaea was governed by the collision between Laurussia and Gondwana-land during the late Palaeozoic. While its subduction process was initiated in the late Devonian, collision began probably during the early to medial Carboniferous and convergence continued until the Permo-Triassic. The Hercynian Orogen, one of the best-known orogenic belts in the world, built a large orogenic system as a consequence of the formation of the Pangaea. Farther east, the collision never happened and subduction continued. A late Permian to early Triassic rifting started to form a marginal basin by disrupting the former arc in the east and it tore westward, using dextral strike-slip segments, into the present Hellenic/Dinaric System and the Pannonian/Carpathian area. This basin closed only during the early Jurassic (Sağdıç et al., 2014).

1.3 Methodology of Comparative Anatomy of Orogens

The paramount mainstay of this study is the comparative anatomy of orogens. The underlying methodology of this procedure is based on that every orogenic belt has its own organs formed by discrete rocks and these organs represented by the same type of rocks in every orogen (Fig. 1.1).

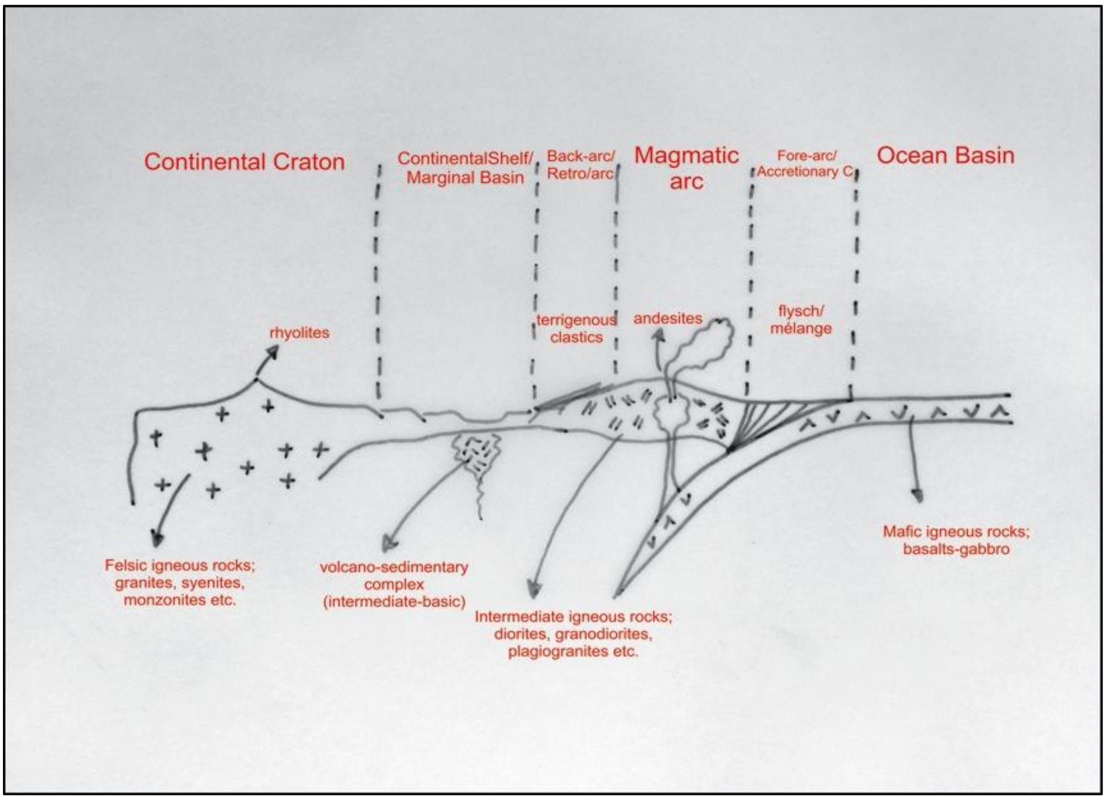

Figure 1.1 : Schematic presentation of the organs of an orogen

The major organs of an orogenic belt can be specified as fore-arc, arc, back-arc basins, with the accompanying continental shelf, which include clastic shelf, shallow shelf, and carbonate platform. The subduction zone is the fundamental organ of any orogenic belt and the most widespread geological expression of a subduction zone is the magmatic arc. To identify the magmatic arcs, which is the first step in this study, the intermediate and felsic magmatic rocks, namely granodiorites, diorites, andesites, granites, and rhyolites are used (for example see Fig. 1.2). However, where only granites and rhyolites exist, they can be taken as arc products in the second step if other organs closed to the magmatic arc such as fore-arc or accretionary complex could be identified. Flysch basins are generally accepted as fore-arc basin, whereas mélanges indicate the accretionary complex even though they can be found rarely (for example see Fig. 1.3). Both the magmatic arc and the fore-arc/accretionary complexes associate with the HP-LT metamorphic rocks. Back-arc or retro-arc basin include mostly terrigenous clastics like a molasse basin. Continental shelf is occupied by clastic shelf, shallow shelf, and carbonate platform. Clastic shelf consists of the limestones or dolomites with the clastic rocks like sandstones or siltstones in most cases. While the shallow shelf is dominated by dolomites/limestones, the carbonate platform represents the extensive carbonate

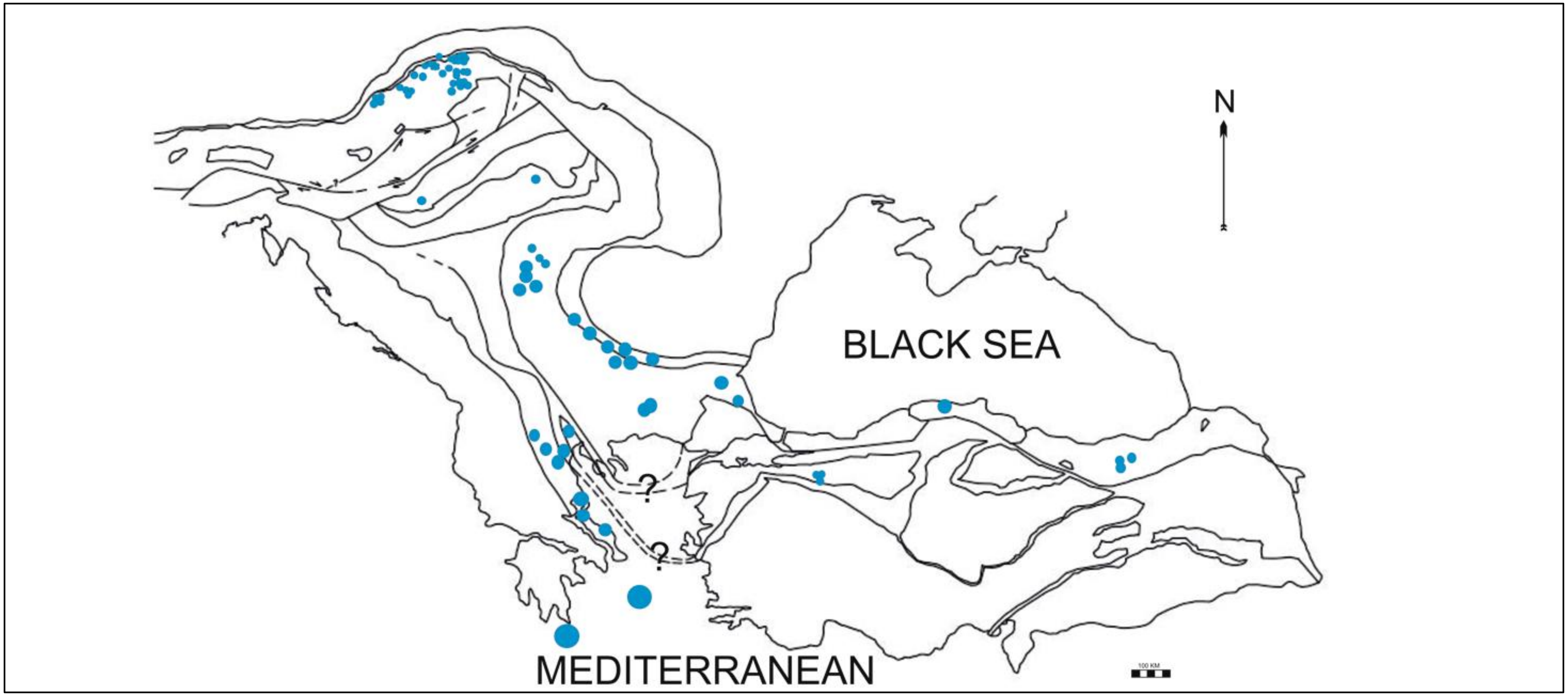

Figure 1.2 : Magmatic rocks represented Carboniferous as an example of step 1

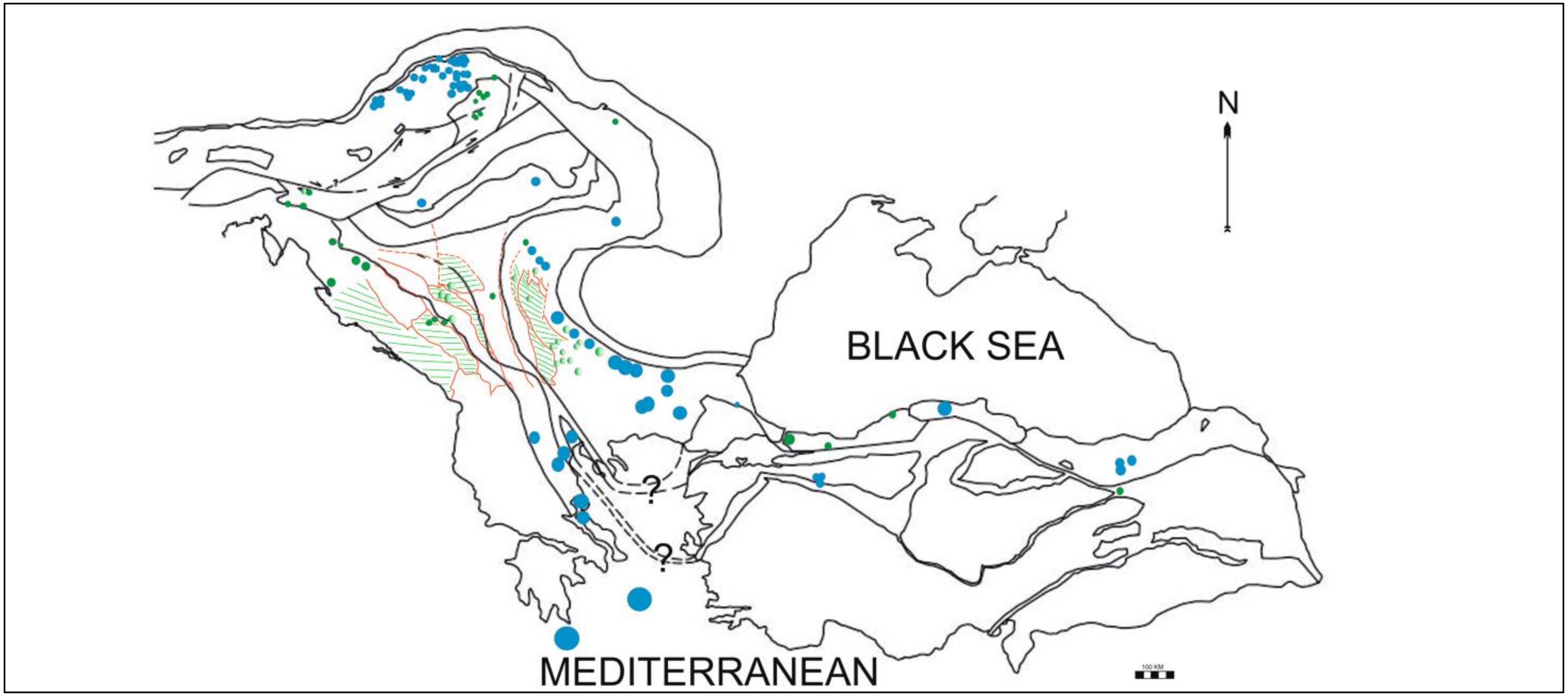

Figure 1.3 : Magmatic rocks and flysches represented Carboniferous as an example of step 2; blue dots: magmatic rocks; green dots: flysches; green lines: flysch zones

deposits as one can guess.

On the other hand, in some instances, marginal basin, which had commonly oceanic signatures like spilites or alkali basalts, could form by splitting pre-existing arcs along the arc axes. Under these circumstances, volcano-sedimentary complexes are indicative for the rifting process of marginal basin.

The third step of this method is to determine all of the organs of orogen by using detailed stratigraphic charts that are explained in the next chapter (Chapter 2). Before the reconstructions of the tectonic zones, drawing the palaeogeographic maps is the fourth step. These maps show the organs of orogen at their present locations. In order to draw these maps, first, skech of the non-palinspastic maps which represent the lithological features of the tectonic zones, are drawn (for example see Fig. 1.4). According to these sketches, palaeogeography of the tectonic zones and therefore the organs of orogen are identified (Chapter 3.1 and App. A.8, A.9, A.10, and A.11).

Final step of this study is the tectonic reconstructions. With the knowledge of the palaeogeographic features of the tectonic zone which were redistributed by later tectonic events, they are repositioned according to their proper positions at that time based on the assumption of the continuity of facies belts along an orogen. First attempt of this final step is Pangaea A2 reconstructions of Van der Voo and French used by Scotese, whose reconstruction is employed as a temporary solution because Pangaea A2 cannot be valid for the Carboniferous-early Permian time (Chapter 3.1 and App. A.12, A.13, A.14, and A.15). For that reason, after Pangaea A2 reconstructions, palinspastic restorations are done for all of the tectonic zones and then the final reconstruction is drawn with these palinspactically restored tectonic zones.

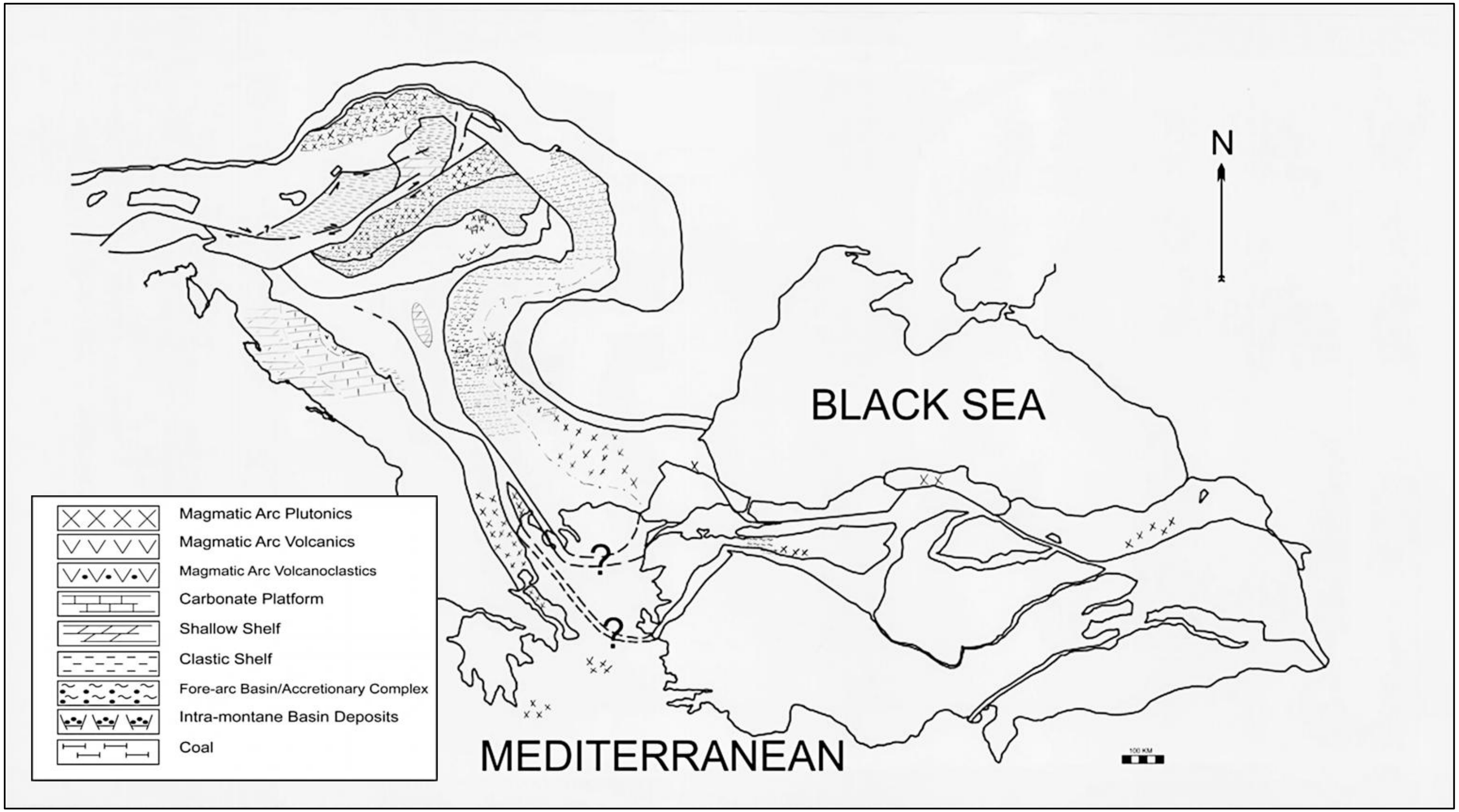

Figure 1.4 : Skech of one of the non-palinspastic maps represented Carboniferous as an example of fourth step

2. GEOLOGY AND STRATIGRAPHY OF THE EASTERN EUROPE

2.1 Introduction

The primary region of interest subjected to this study is the Eastern Europe formed by seven main tectonic units, which are Adriatic-Dinaric System, part of Rhodope-Pontide Fragment, Southern Carpathian, Eastern Carpathians, Tisza Mega-unit, and Alcapa Mega-Unit (Fig. 2.1). Figure 2.1 also shows the Vardar Zone and Turkey. Only Vardar Zone is not included in this study because of that the opening time of the Vardar Ocean is much later than Permo-Triassic (Şengör, 1982). This division is made according to their involvement of the tectonic evolution of the Mediterranean Region in the Palaeo-Tethyan picture. All of them include pre-Hercynian, Hercynian, and post-Hercynian (Alpine) tectonostratigraphic units.

The main focus of this chapter is to unveil the complex geological structures of these tectonics units and identify their implications for the tectonic evolution of the Mediterranean Region. For this purpose, first, magmatic complexes of Carboniferous, Permian, and Triassic age in the Eastern Europe with the Turkey (App. A.1, A.2, A.3, A.4, A.5, and A.6) were determined in order to specify the magmatic arc of the Palaeo-Tethys subduction. Then lithostratigraphic charts of all the main tectonic units were drawn to delineate the palaeogeographic features of the continental places. The whole knowledge used in this chapter is based on published literature (App. A.7). Figure 2.3 shows the legend of all the lithostratigraphic charts.

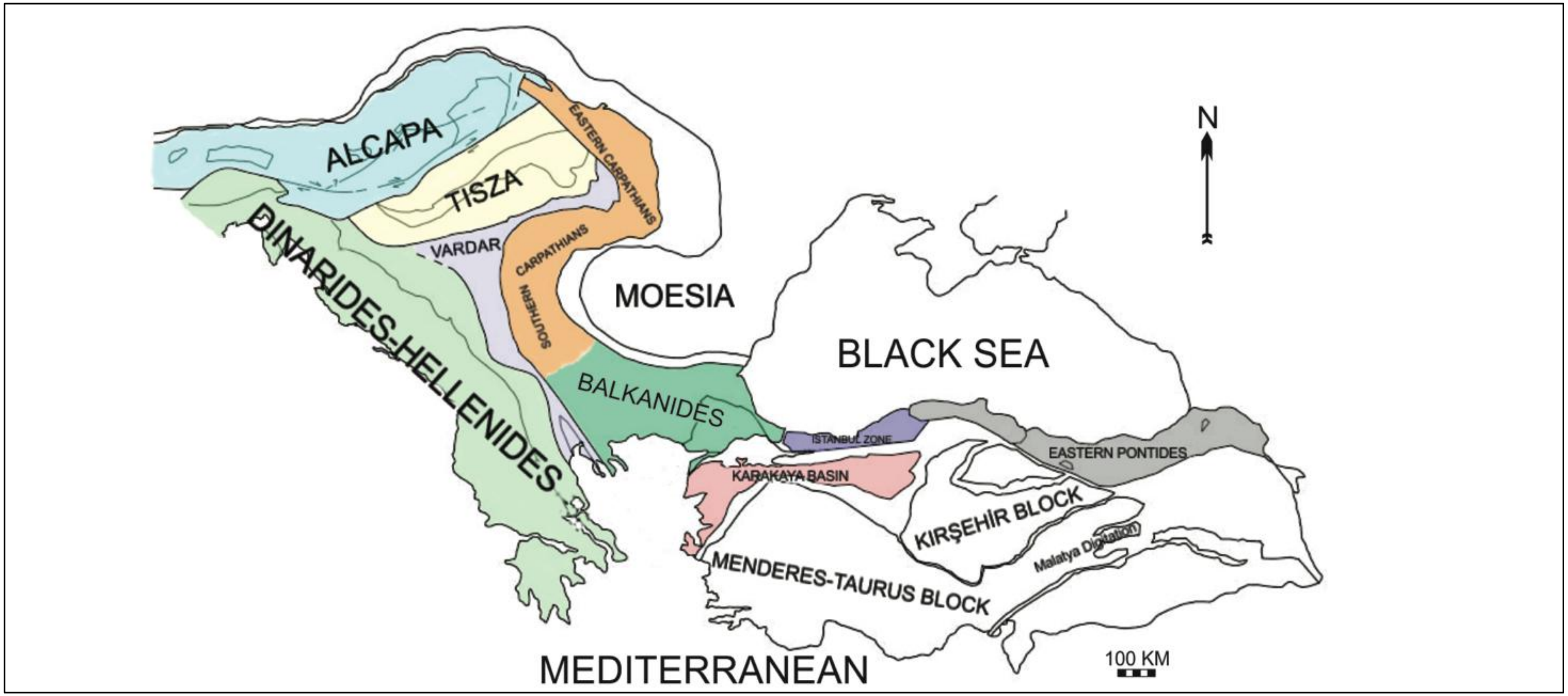

Figure 2.1 : Main Tectonic Units of the Eastern Europe and Turkey

2.2 Dinarides

The tectonic zone which is a mountain chain sytem from the Southern Alps in the NW to the Taurides in the SE, is called Dinarides. However, Cvijič pointed out in 1901 that because of the existence of the Dinaric-Albanian Syntaxis (Dinarisch-Albanesische Scharung), the Dinarides ended in Kosovo and south of it a new mountain system, which he called the Albanian-Greek system, commenced. This is the earliest reference to a "Greek" mountain system independent of the Dinarides. The rationale of this definition is found in Cvijič's teacher Eduard Suess' Das Antlitz der Erde (1909): "*When the syntaxis on the Jhelum was first described, distinguished Indian colleagues admitted the correctness of the facts, for the most part determined by themselves, but they refused to regard the bend in the strike as the principal boundary, in this case the boundary between the Himalaya and the Iranian arc. They pointed to the complete correspondence of the outer, Tertiary, and the resemblance between the structure of the chains of Hazara and Kabul and that of the chains situated to the east of Jhelum. This difference of opinion is fundamental. If we regard the stratified succession and nature of the rocks as determining the connection of mountain chains, then the second interpretation may often be maintained. But when it is a question of searching for the forces, which have built up the mountains, then these characters take a second place, and the direction in which the tectonic forces have found expression will be decisive. Every syntaxis reveals a local opposition between two dynamical influences. It is for that reason that it forms a boundary. For that reason also no name given to a mountain should be carried on beyond a syntaxis.*" (Fig. 2.2; Şengör, 2015, personal communication).

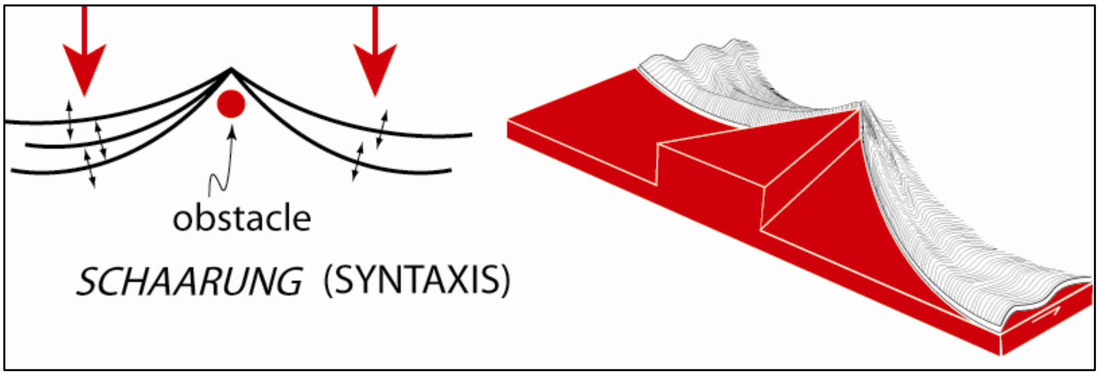

Figure 2.2 : Schematic presentation of Syntaxis

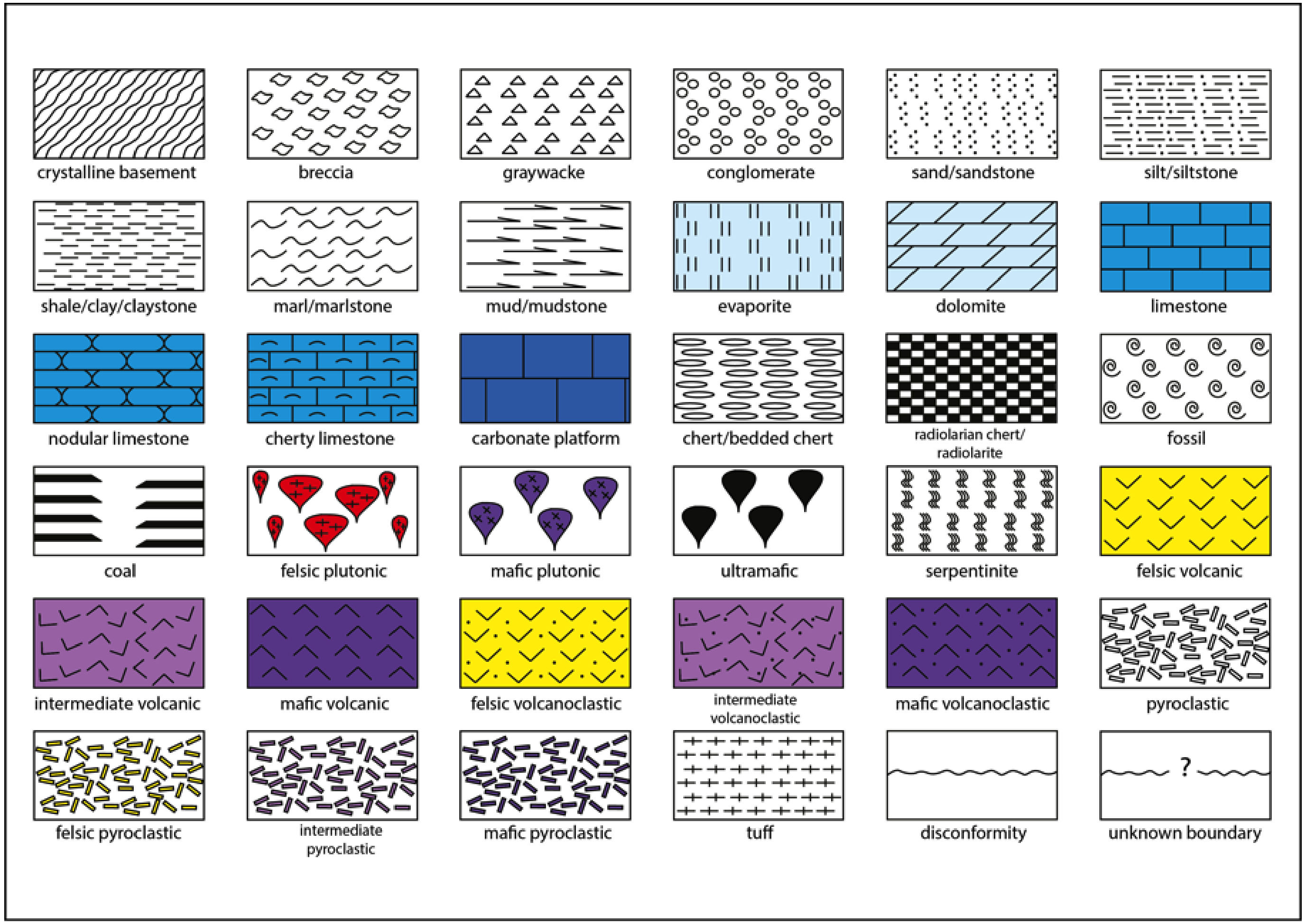

Figure 2.3 : Legend of the lithostratigraphic charts

This tectonic zone comprise four major zone : Internal (Supradinaric), Dinaric, Epiadriatic, and Adriatic Zones from east to west (Vörös, 2000). Drina-Ivanjica Unit in the Internal Zone, East Bosnian-Durmitor Unit, Central Bosnian Unit, and Sana-Una Unit in the Dinaric Zone, Budva Unit and Cukali Unit in the Epiadriatic Zone, and Adriatic-Dinaric Platform in the Adriatic Zone are the main subjects of the following sections.

2.2.1 Drina-Ivanjica Unit

Drina-Ivanjica Unit (Fig. 2.4), west and southwest Serbia, has pre-Mississippian low-grade to anchimetamorphic complexes at its base with the overlying Visean-Early Bashkirian deep-water siliciclastic sedimentary sequences, including olistostrome flysch. Whole Palaeozoic complexes underwent greenschist facies metamorphism are overlain by lower Triassic continental clastic sediments unconformably (Vozárová et al., 2010). Conglomerates, sandstones, graywackes, and siltstones forming lower Triassic are overlain by upper lower Triassic-lower Anisian laminated sandy micrites, massive, dark vermicular micrites, an alternation of dolomites and oolitic limestones-dark bioturbated limestones. Middle Anisian shallow water Steinalm Formation comprising from light, thick-bedded, recrystallized platform limestones, and massive oncolitic light limestones underlie the thin horizon of the Han-Bulog limestones consisting of grey, red, dark red, nodular micrite. In the Ladinian-Lower Carnian, locally preserved grey micrites with thin tuffitic layers at the base and light coloured, reef, back-reef, lagoonal/oolitic limestones form the Wetterstein limestones. The following Carnian-Rhaetian? Dachstein limestones formed by thick masses of limestones underlie the Lias-upper Thorcian biocalcarenite, nodular limestones (Horváth, 2006).

2.2.2 East Bosnian-Durmitor Unit

Palaeozoic sequence of East Bosnian-Durmitor Unit (Fig. 2.5) begins with the Bashkirian deep-water siliciclastic turbidites and olistostromes. Moskovian-Ghezalian carbonate platform includes shallow marine limestones and underlie unconformably the middle-Upper Permian clastics, which pass directly into Lower Triassic clastic with limestones (Vozárová et al., 2010).

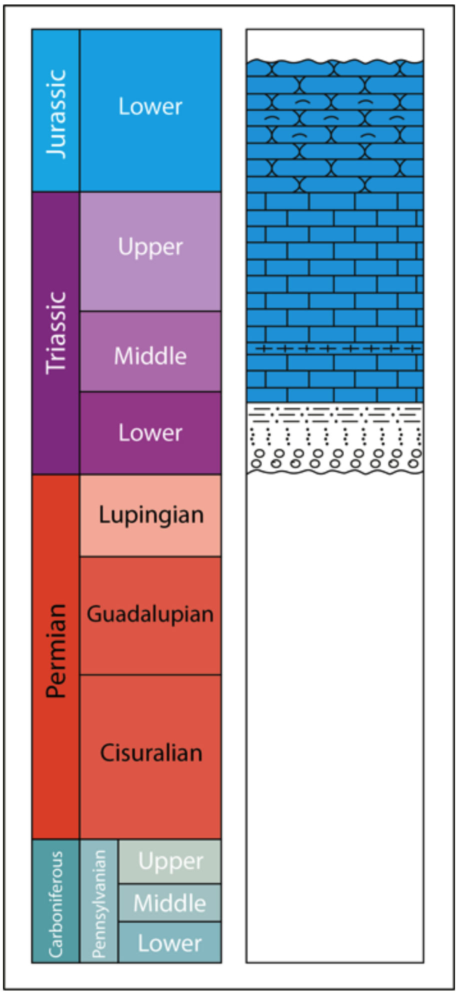

Figure 2.4 : Drina-Ivanjica Unit

In the Lim area, Early-Late Carboniferous represented by metaconglomerates, metasandstones, metasiltstones are overlain by Lower Triassic clastics with limestones. The following middle Triassic is constituted by reef with pelagic carbonate deposits accompanying volcanic successions (Ilić and Pešić, 2007).

In the Prača area, early Carboniferous flysch deposits with late Devonian olistostromes are followed by Permian sequence. The succeeding Early Triassic very low-grade sandstones and shales covered by Anisian-Ladinian massive pelagic limestones and volcanic rocks underlie the Ladinian-Carnian massive carbonates. Intermediate-acid plutonic and volcanic rocks of calc-alkaline affinity dominates the Triassic period (Ilić and Pešić, 2007).

In the northern part of East Bosnian-Durmitor Unit Upper Permian clastics with algal limestone lenses transgress on the Paleozoic metamorphic rocks. Lower Triassic conglomerates, sandstones, oolitic limestones, and dolomites settle down on the upper Permian sediments. Sandy limestones with thick-bedded and massive, light coloured limestones represent the Anisian that is succeeded pelagic limestone with greenish andesite tuffs and cherts intercalation layers of Han-Bulog Ammonitico Rosso-type limestones, greenish andesite tuffs and chert layers, and upper conglomerate horizon. Upper Triassic shallow-water Dachstein Formation incorporating bauxite horizon and more frequently perireef/lagoonal rhythmic limestones is underlain by Ladinian massive reef limestones. Oolitic and crinoidal limestones occupying lower Jura are the indication of platform deepening (Horváth, 2006).

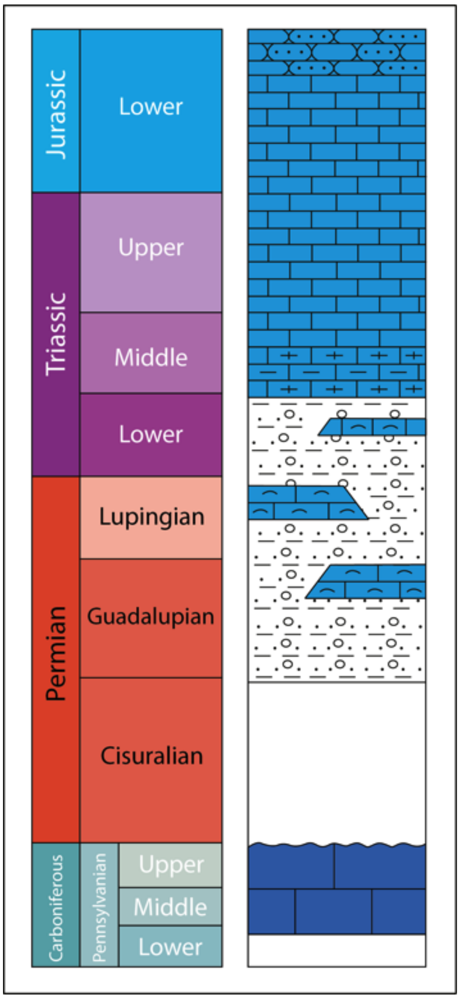

Figure 2.5 : East Bosnian-Durmitor Unit

2.2.3 Central Bosnian Unit

In the Central Bosnian Unit (Fig. 2.6), Late Permian coarse clastics, evaporites and the Bellerophon Formation follow the Famennian-Tournasian pelagic limestones, which is underlain by late Silurian complexes. All levels include bodies, lenses and (?)sills of rhyolites (Ebner et al., 2010). Horváth (2006) claims that the age of Permian sediments is middle-upper Permian. The contact between the Permian and the Triassic sediments is unknown. Upper Scythian-lower Anisian sandstones-siltstones deposits are overlain by upper Anisian-Ladinian pelagic limestones, andesite pyroclastics, and cherty limestones, respectively. These cherty limestones continue conformably until the Pliensbachian (Horváth, 2006).

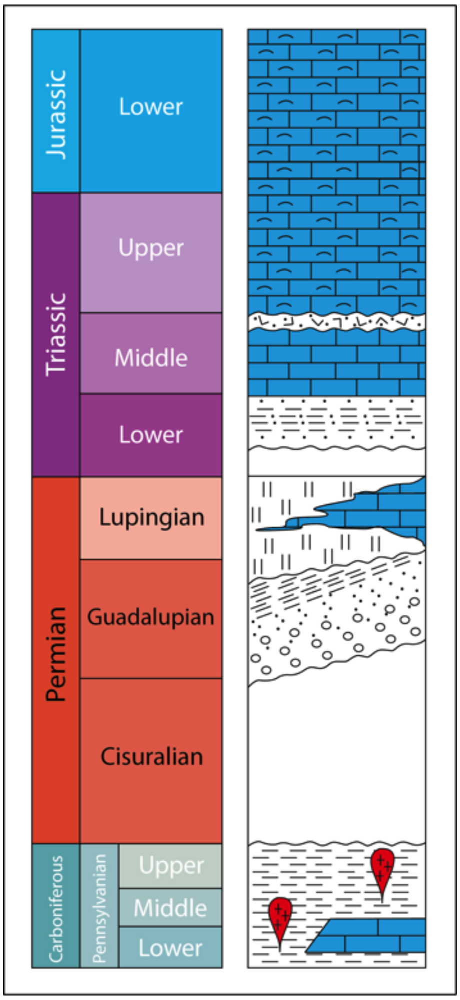

Figure 2.6 : Central Bosnian Unit

2.2.4 Sana-Una Unit

Sana-Una Unit (Fig. 2.7) Palaeozoic sequence starts with the Lower-Middle Carboniferous turbidites known as Javoric Flysch Formation including metasandstones, metasiltstones, and olistostromes. Middle-Upper Permian red breccias, conglomerates, sandstones, shales and evaporates settle down after a considerable hiatus. Transgressive Clastic Formation of lower Triassic age rests on the Permian sediments (Vozárová et al., 2010). Ebner et al. (2010) state; however, that there are different Palaeozoic sequences in the Sana Region and Una Region. In the Sana Region, Carboniferous flysch predominates in the area before Late Visean bedded limestones and the subsequent Bashkirian Shallow-water limestones, namely

Stara Rijeka Formation. Sandy and marly limestones of Eljdiste Formation terminate the sequence.

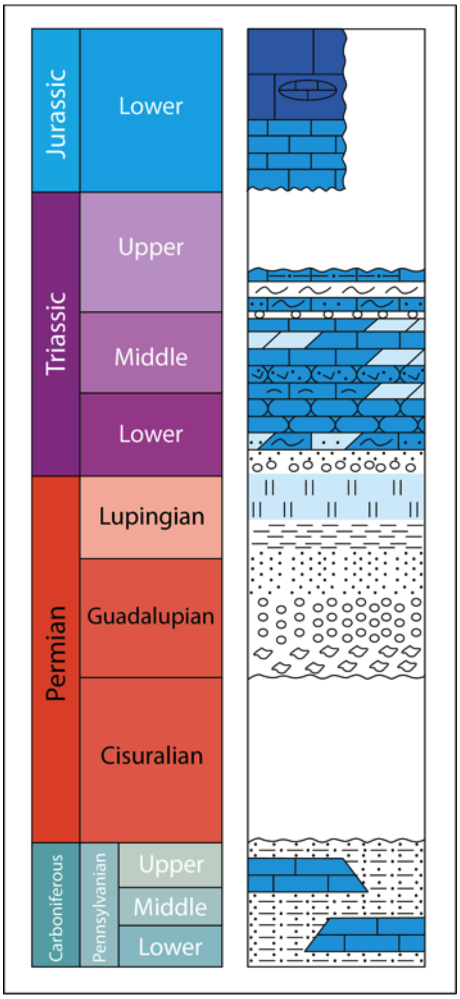

Figure 2.7 : Sana-Una Unit

Mesozoic sequence in the Sana-Una Unit represents platform deposits from the Triassic until the end of Cretaceous (Horváth, 2006). This sequence begins with the Lower Triassic in the order of clastics, sandy-marly-dolomitic limestones and oolitic limestones. On the SW margin of the unit, flysch-like rhythmic terrigenous deposit occur in the Lower Anisian, whereas in the central areas are represented by crinoidal-brachiopodal shallow marine limestones and neritic dolomites. Han Bulog Ammonitico Rosso interbedded with the Aniso-Ladinian andesite tuffs and flows in the upper Anisian which covers the lower Anisian uniformly and continues with the Ladinian reef/lagoonal limestones and dolomites. Carnian coarse clastics, sandy-marly limestones, marls, and silty limestones follow the Ladinian deposits and is overlain by Lower-Middle Jurassic oolitic limestone bars/reefs and black bituminous lagoonal carbonates. Nevertheless, in Khin, Liassic carbonates is underlain by Ladinian unconformably and in Prekarst regions, erosion begins after Triassic dolomites until upper Jurassic limestones.

2.2.5 Budva Unit

Budva unit (Fig. 2.8) is the northwestern continuation of Pindos Zone and rests between the Adriatic Unit at the base and the Dinaric Unit at the top (Horváth, 2006). Mesozoic sequence of this unit includes lower Triassic clastics at the base. Turbidite sanstones, marls and marly limestones of Anisian age cover these clastic rocks with the unknown contact features and underlie the Ladinian tuffs, andesites, bedded cherts, and marls. The rest of the sequence continues with the Ladinian-Upper Cretaceous calcarenites and calcareous breccias, cherts, marls, and clay interlayers in the central parts and well-bedded pelagic cherty limestones and marls in the more distal areas (Horváth, 2006; Robertson and Shallo, 2000).

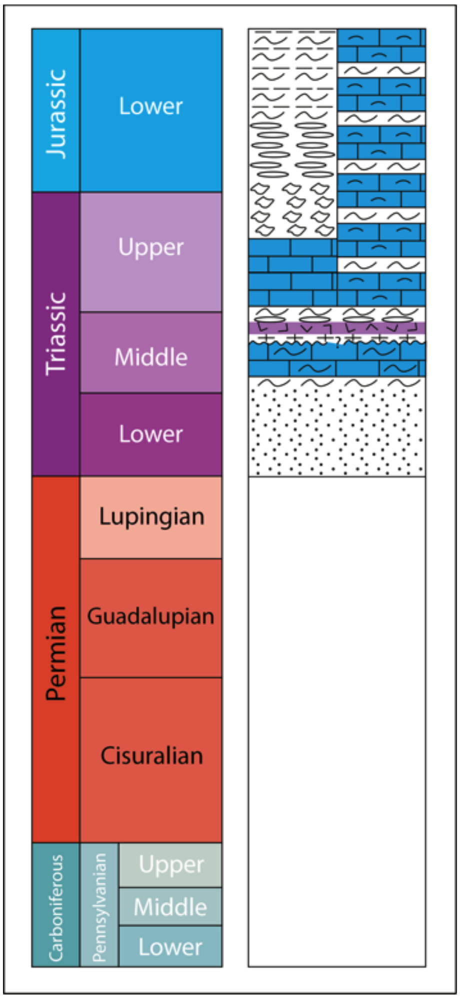

Figure 2.8 : Budva unit

2.2.6 Cukali Unit

Cukali Unit (Fig. 2.9) is the southeastern continuation in the Albania of the Budva Unit. Its Mesozoic series begins with the Anisian-Ladinian extrusives of intermediate to basic composition, shales, limestones, and radiolarian cherts. Jurassic pelagic carbonates, siliceous limestones, radiolarian chert and thinly interbedded shales cover the Ladinian-upper Triassic neritic and pelagic carbonates (Robertson and Shallo, 2000).

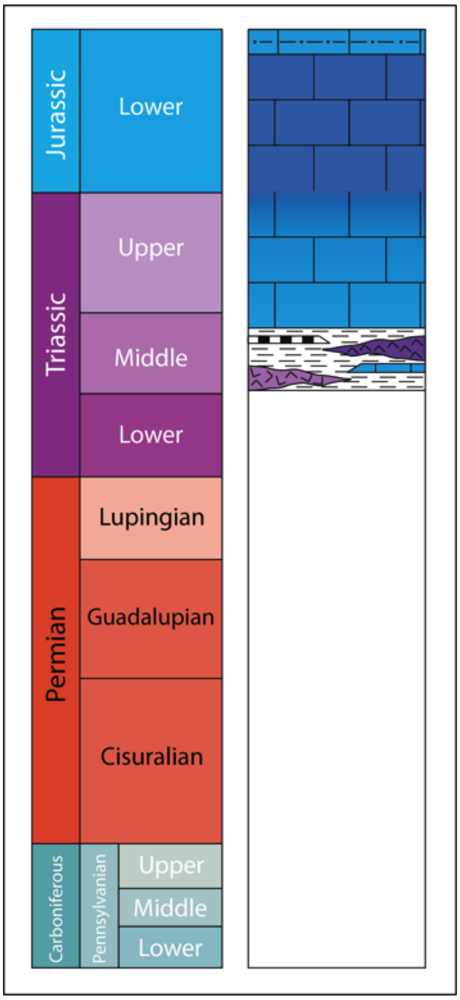

Figure 2.9 : Cukali Unit

2.2.7 Adriatic-Dinaric Platform

Adriatic-Dinaric Platform (Fig. 2.10) represent a Palaeozoic sequence including Moscovian fossiliferous limestones, Kasimovian sandstones, and Gzhelian conglomerates, respectively (Ebner et al., 2010). Upper Cisuralian-lower Guadalupian is the beginning of the Permian sequence which includes two cycles of conglomerate-sandstone-siltstone alternation at the base, dolomites with limestone interlayers, and sandstones at the top (Vozárová et al., 2010). Mesozoic succesion rests direcly on the Permian sediments. Scythian evaporites, sandstones, and cherty/reef limestones underlie Anisian-Ladinian limestones, andesite pyroclastics, and reef limestones. Carnian-Rhaetian reef limestones, dolomites, and brecciated limestones rest on the Anisian-Ladinian sediments directly and are overlain by lower Jurassic sandy platform limestones (Horváth, 2006).

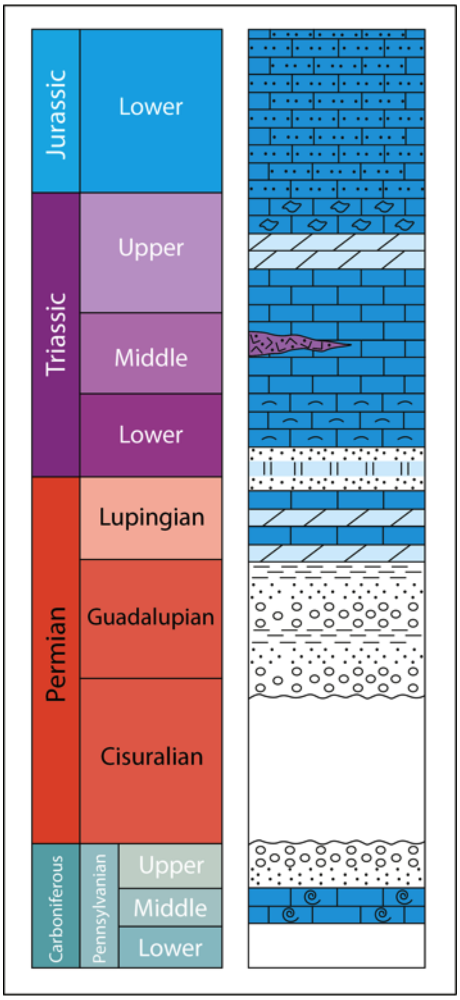

Figure 2.10 : Adriatic-Dinaric Platform

2.3 Hellenides

Jacobshagen (1986) proposed a subdivision for the Hellenides; NNW-SSE trending major tectonic zones of this subdivision consists of Foreland, West Hellenic nappes, Central Hellenic nappes and Median Crystalline belt, Internal Hellenic nappes, and Hinterland from west to east. Pelagonian Zone and Pindos Zone, which are the main subjects of this section, are in the Central Hellenic nappes and Median Crystalline belt.

2.3.1 Pelagonian Zone

Pre-upper Carboniferous crystalline basement of the Pelagonian Zone (Fig. 2.11) overprinted by greenschist facies metamorphism, consists of orthogniesses, augengneisses, amphiolites, micaschists, amphibolic schists and quartzites, and granites (Kastoria and Pieria granites of upper Carboniferous age). Permian-early Triassic sequence is underlain by crystalline basement. Metaarkoses, fine-grained metasandstones, quartzose conglomerates, lenses of recrystallized arenaceous limestones, coarse limestone breccias, calc-schists interbedded with andesites, tuffs, basic and rhyolitic dykes forming the Permian-early Triassic sequence is overlain by Triassic carbonate platform with a contact marked by thrust faces, folding, and mylonization. Transition to Jura limestones is continuous (Mountrakis, 1984, 1986; Jacobshagen, 1986).

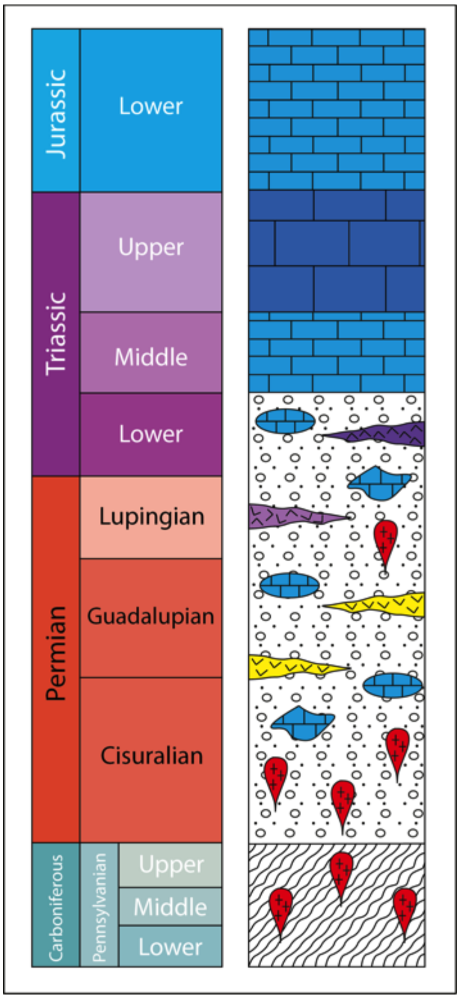

Figure 2.11 : Pelagonian Zone

2.3.2 Pindos Zone

Sedimentation in the Pindos Zone (Fig. 2.12), or generally as Pindos-Olonos Zone, begins in the Meozoic period and pre-Triassic sequences are unknown (Brunn, 1956; Aubouin, 1970; Jones and Robertson, 1991; Degnan and Robertson, 1998; Robertson and Shallo, 2000; Ozsvart et al., 2012).

Brunn (1956) stated that the Mesozoic in the northern Pindos Zone is dominated by ophiolites which are serpentinized peridorites. The middle Triassic limestones underlie this ophiolites and the succeeding upper Triassic fine limestone plates and beds of grey jasper followed by Jurassic-early Cretaceous thin-bedded cherts. He also studied the northern extremity of the southern Pindos Zone started by middle Triassic limestones. In this area, Ladinian is occupied by andesites comrising chloritized augite and big plagioclases (andesine) at the base, massive limestones, and limestones and grey cherts at the top. Upper Triassic basal jaspers and grey Cre taceous radiolarites.

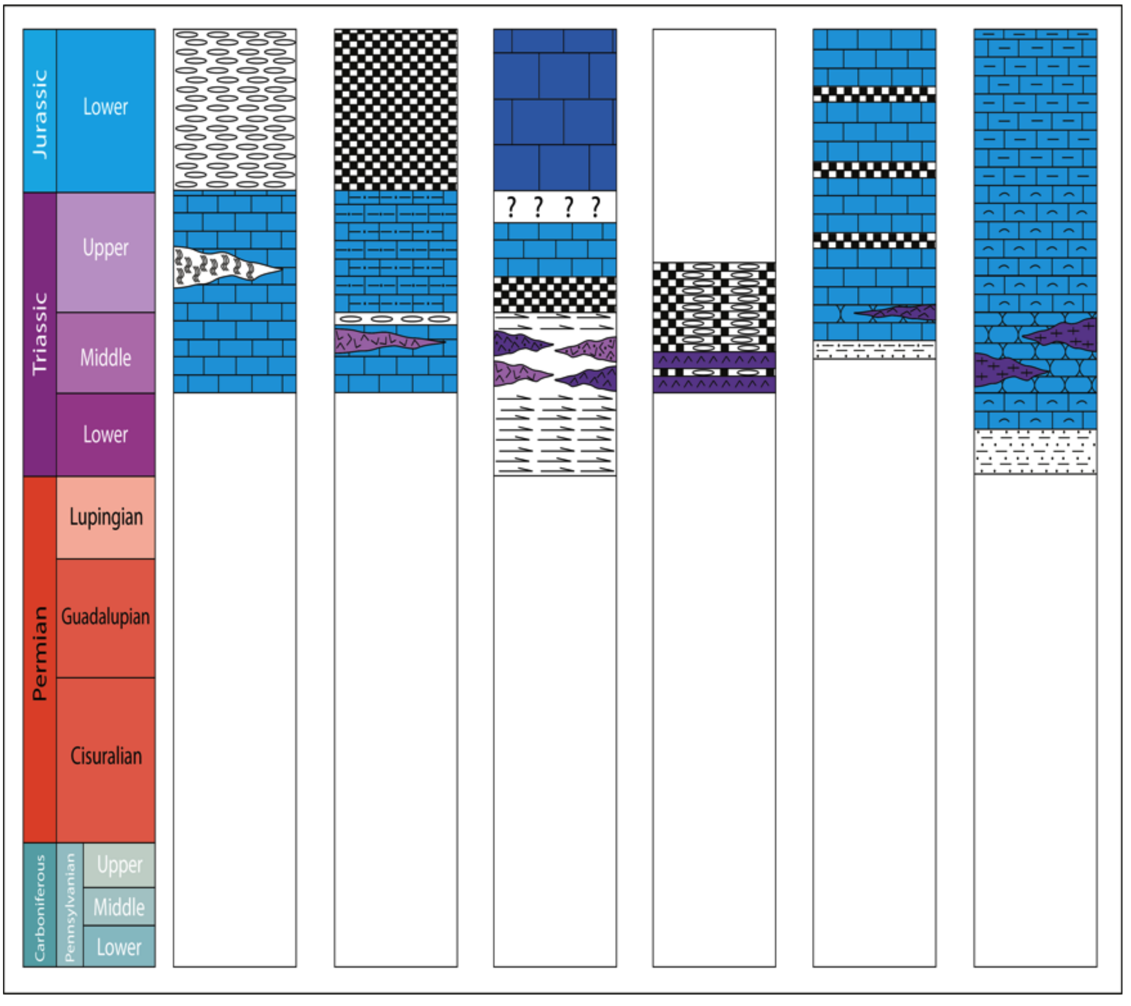

Figure 2.12 : Pindos Zone

In the Vardoussia, the Lower Triassic pelitic sediments (mudstones) appears at the base of succession. The succeeding Anisian-Ladinian rift volcanics and volcanoclastics and mudstones at the top precede the Carnian radiolarites, Norian cherty limestones, and lower Jurassic carbonate platform (Robertson and Shallo, 2000).

In the northern Pindos and also Othris, Ozsvart et al. (2012) found Pelsonian basal pillow basalts starting the Anisian sequence. These pillow basalts have an alternation with ribbon radiolarites and cherts until the end of Anisian. The following Ladinian-lower Norian is formed by only ribbon radiolarites and cherts.

In the NW Peloponnese, Ladinian-early Carnian Priolithos Formation comprising of litharenites, shales/siltstones, and siliceous micrites followed by nodular limetones accompanied by basic volcanics are overlain by uppermost Carnian-lower Jurassic pelagic limestones with bedded radiolarian cherts of Drimos Formation (Degnan and Robertson, 1998).

In the Kastaniotikos, the lower Triassic deposits consist of an alternation of sand-clay followed by cherty limestones. Jurassic siliceous limestones, radiolarites, and pelitic sediments, respectively, follow the middle Triassic nodular limstones associated with the volcanogenic beds including diabasic tuffs and upper Triassic cherty limestones (Aubouin, 1970).

2.4 Southern Carpathians

Southern Carpahians can be divided three main structural units, which are Danubian, Getic, and Supragetic Nappe system. All of these nappe systems are generally composed of Precambrian-Cambrian and low-grade Lower Palaeozoic crystalline complexes, and in Eastern Serbia, of the Tournaisian-Visean flysch to passive continental margin formations which are unconformably overlain by post-Variscan, Pennsylvanian-Cisuralian continental deposits (Vozárová et al., 2010). Triassic sedimentary successions are either incomplete and continue discordantly to the lower Jurassic deposits, or completely lacking, and lower Jurassic deposits are underlain by post-Variscan overstep and metamorphic basement complexes discordantly (Kovács et al., 2010).

2.4.1 Danubian Nappes

Eastern part of Danubian Nappe system corresponds to Lower Danubian Nappes (Fig. 2.13). Sedimentation consisting of Jurassic sediments following the Permian red conglomerates and sandstones with disconformity outcrops in the South Retezat Mts. and in the Tismana-Vâlcan Mts. (Vozárová et al., 2010).

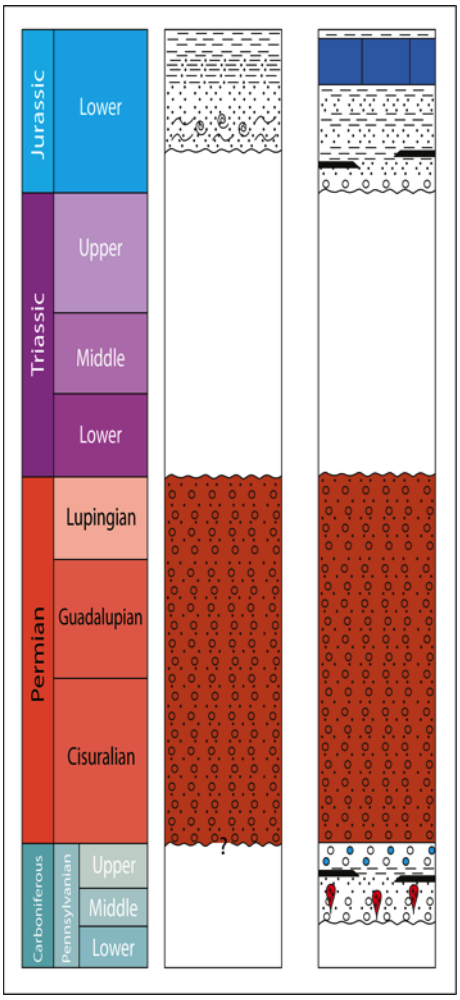

Figure 2.13 : Lower Danubian Nappes

On the other hand, in the Vrška Čuka and Miroč, sequences begin with the Precambrian-Cambrian greenschists followed by an unconformity. Kasimovian-Gzhelian period that is underlain by grenschists contains polymict alluvial conglomerates containing rock debris from underlying schists, granites and metaquartzites in its basal part. After this basal part, there are fluvial sandstones and shales with scarce thin coal seams, in 230 m total thickness. Conglomerates, which contain limestone cobbles, appear in the uppermost part of this sequence. However, after Kasimovian-Gzhelian sequence, while red-beds occupies the Permian period and there is a hiatus during Triassic in the Vrška Čuka, sedimentation did not occur during the Permian and Triassic period in the Miroč. Both sequences continue with the Jurassic sediments (Vozárová et al., 2010).

Upper Danubian Nappes (Fig. 2.14) are the western part of the Danubian Nappes and tectonically overlie the Lower Danubian Nappes. In Romania, Presacina Zone in the east and Sirinia Zone in the west; in Serbia, Porec Zone and Stara Planina Region were selected.

In the Presacina Zone, Carboniferous sediments and older rocks are unconformably overlain by Cisuralian deposits which have red-beds sequence including conglomerates/sandstones in its lower part and sandy-clayey member in its upper part (Vozárová et al., 2010). Permian deposits are overlain by Liassic Gresten-type formation because there is no Triassic sequence (Haas et al., 2010).

Rather more detailed stratigraphic sequence presents in the Sirinia Zone than in the Presacina Zone. Sequence begins with the lower part of Upper Moscovian-Kasimovian deposits that contains grey-blackish detrital sequences with coal beds, sedimentary breccias and polymict conglomerates with the crystalline rock detritus. In the middle part, locally basic phyroclastics and lava flows (basalts, basaltic andesites, rarely andesites) are intercalated while in the upper part, sandstones, sandy shales and shales end the Carboniferous sequence with a stratigraphic hiatus atop of it. In Cisuralian, basal part consists of red alluvial and lacustrine conglomerates, sandstones and shales with the lenses of limnic limestone with a few basic volcanics. Lower/Povalina Formation and Upper/Trescovat Formation involved in the middle part that generally contains rhyolite-dacite volcanics and their pyroclastic rocks. Mixed dacitic conglomerates and microconglomerates, alternating with red sandstones, shales, sporadical limestones with the ignimbritic rhyo-dacitic bodies occupy Povalina Formation whereas there are only rhyolitic ignimbrites in the Trescovat Formation. Red-beds with conglomerates, sandstones and shales in the upper part terminate the whole Palaeozoic sequence (Vozárová et al., 2010). Hettangian (?)-Sinemurian Gresten-type deposits involve in the region after Permian succession because of the lack of Triassic sediments (Haas et al., 2010).

In the Poreč Zone, sedimentation starts with the Tournaisian-Visean flysch sequence followed by an unconformity and Late Bashkirian-Moscovian fluvial-lacustrine sediments. These fluvial-lacustrine sediments are overlain by Moscovian and Permian deposits, respectively, which they both have a lower and an upper parts.

Polymict conglomerates with the gneiss, greenschist and metaquartzite pebbles (braided river or fan delta deposits) constitute the lower part of Moscovian, which is over 300 m in thickness. Lacustrine sandstones and shales, which contain macroflora following the lower part form the upper part of Moscovian and are overlain by Permian deposits. The lower part of Permian is a terrigene horizon composed of conglomerate breccia, sandstone and shale, red sandstone and shale intercalated with freshwater limestones sequentially. On the other hand, the upper part of Permian is a volcano-sedimentary horizon composed of red sandstone, shale, volcanic breccia, tuffs and rhyolite/dacite extrusion (Vozárová et al., 2010). Triassic sediments are completely missing in this zone and sequence continues with the Liassic coal-bearing Gresten-type formation (Horváth, 2006).

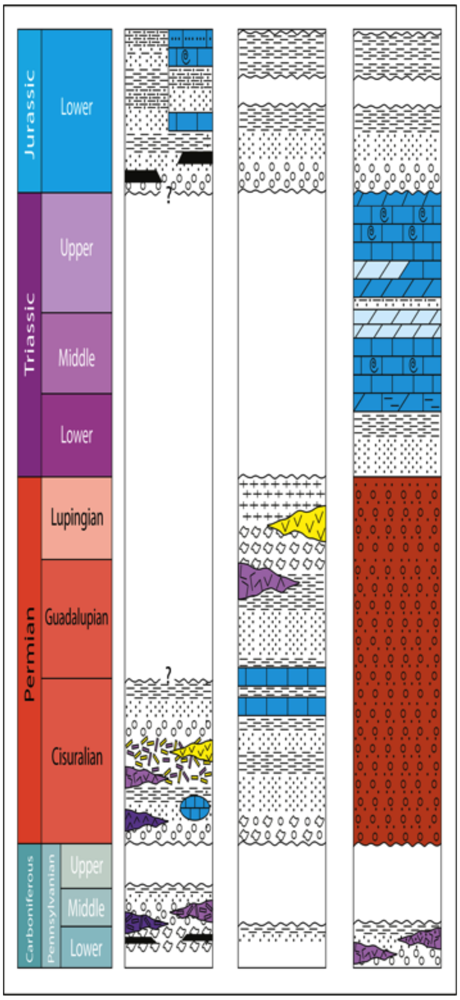

Figure 2.14 : Upper Danubian Nappes

In the Stara Planina Region, Moscovian volcano-sedimentary limnic sediments (dacite-andesite and their volcanoclastics mixed with siliciclastic sediments) and thin coal seams within dark shales are unconformably underlain by Devonian sediments, basic and acid magmatites with Proterozoic greenschists. After a stratigraphic hiatus, Permian continental red-beds end the Palaeozoic sequence (Vozárová et al., 2010). Among the Upper Danubian Nappes, Triassic sedimentation presents only in the Stara Planina Region. In the lowermost Triassic, megasequence of fluvial deposits including siliciclastic sediments forms Temska Formation. Marine siliciclastics involve in the formation of the lower Scythian Zavoj Formation, which is overlain by upper Scythian micaceous sandstones, partly clayey and dolomitic shelly limestones. The following lowermost Anisian includes platy, folded limestones. In the Pelsonian there are thick-bedded brachiopod limestones. The overlying uppermost Illyrian composed of crinoid limestones with crinoid calyces and stems, and calcareous algae which is overlain by massive, slightly dolomitic Ladinian limestones in about 15 m thickness. Siltstones, sandstones and sandy and dolomitic limestones occupy Carnian sediments that is underlain by 250 m thick Anisian sequence. In the Norian, dolomites, dolomitic limestones and limestones are followed by biosparites, oolite and dolomitic limestones and algal limestones of Rhaetian age. However, red series including terrigenous siliciclastics form the transition from Rhaetian to Liassic (Kovács et al., 2010).

2.4.2 Getic Nappes

Getic Nappes (Fig. 2.15) occur structurally as an intermediate nappe sheet between Danubian Nappes at the base and Supragetic Nappes at the top. Sedimentary sequence in Braşov Nappe, in its eastern part, represents 350 m thick, Permian or lower Triassic conglomerates and quartzitic sandstones containing rhyolite intrusions, which are underlain by crystalline basement. The following Triassic deposites are composed of lower Triassic bituminous marls and dark limestones (50 m), Anisian black Guttenstein limestones with black shale interlayers (75-250 m) followed by an unconformity, and Ladinian crinoidal limestones whose transition to lower/middle Jura Coaliferous Formation including dark sandstones, clays with occasional trachyte and alkaline syenite dykes marked with an unconformity (Horváth, 2006).

Westward, in Resita Zone, Doman Beds (300 m) lie at the base of the Moscovian-

Cisuralian sequences. It comprises from basal conglomerates, which are massive and with no obvious bedding, and breccias with the blocks and pebbles of crystalline rocks. Doman Beds pass gradually into upper Moscovian-Kasimovian Lupacu-Batrân Beds (200-400 m) containing siliciclastic fluvial conglomerate and sandstone complex, which prograde into sandy shales with paleoflora remnants and coal beds. Kasimovian Lupac Beds (150-300 m) underlain by Lupacu-Batrân Beds consists of lacustrine sediments, black shales and argillaceous sandstones with ferruginous concretions and coal intercalations. At the top of the whole sequence, Cisuralian deposits appear without any disconformities. Lower part of Cisuralian sediments (150-300) is known as Black Clay Formation having black argillaceous rocks with intercalations of fluvial sandstones, conglomerates and occasionally lacustrine limestones inside of it. Upper part of Cisuralian sediments (1000-1500 m) known as Red-Sandy Conglomerate Formation represents a sequence of conglomerates, sandstones and red clays (Vozárová et al., 2010). In some localities, this formation is overlain by Bathonian-Callovian microconlomerates, calcareous sandstones and marly limestones (Horváth, 2006).

In Eastern Serbia, Getic Nappes outcop in Kučaj Zone. Succession starts with Tournaisian-Visean thick, low-grade metamorphosed flysch succession and is followed by an unconformity before Kasimovian-Gzhelian continental, fluvial-lacustrine deposits. This fining-upward sequence involves polymict conglomerates, graywackes and shales with scarce coal seams and occasionally siderite nodules and passes gradually into the Permian red-beds (Vozárová et al., 2010). In some areas, the Triassic deposits are missing and middle Jura sediments, which are clastic basal layers, sandy carbonates, well-bedded limestones with ammonites unconformably overlie the Precambrian metamorphics and diverse Palaeozoic rocks (Horváth, 2006). On the contrary, some areas unconformably underlain by Permian terrestrial rocks represent Triassic deposits. Starting with the Scythian basal quartz conglomerate and white or pink sandstones passing upwards into subarkosic rocks, the Triassic sequence is complete concordant. After continental sediments, there are shallow marine deposits involving sandstones of graywacke and subgraywacke types. Sandy dolomites or dolomites and limestones with bioturbations known as Krepoljin Formation are last members of Scythian period. Ždrelo Formation of Anisian age underlain by Scythian deposits consist of lowermost Anisian light coloured dolomitic limestones with crinoid calyces and stems, Pelsonian grey, bedded, nodular limestones and shales, Upper Pelsonian white limestones, and Illyrian black, bedded micrites and sparites, respectively. The following lowermost Ladinian dark-grey to black micrite, microsparite and platy (mm-thick) dark marlstone, fine-grained dolomites, ferruginous platy, dark-grey to black marlstones, and dark marly limestones occupy the Wetterstein Formation. In the Carnian-Norian there are Rapatna Formation and Golubac Formation and they are lateral equivalent of each other. Golubac Formation contains sporadically sandy and dolomitic limestones with oncoids, while Rapatna Formation consists of micrites, microsparites, and quartz sandstones. On the top of this sequence Dachstein Formation represented by Carnian-Norian shallow water platform and Rhaetian limestones and dolomites, respectively, terminates the sequence (Kovács et al., 2010). Bajocian basal clastics and oolitic limestones overlie Dachstein Formation transgressively (Haas et al., 2010).

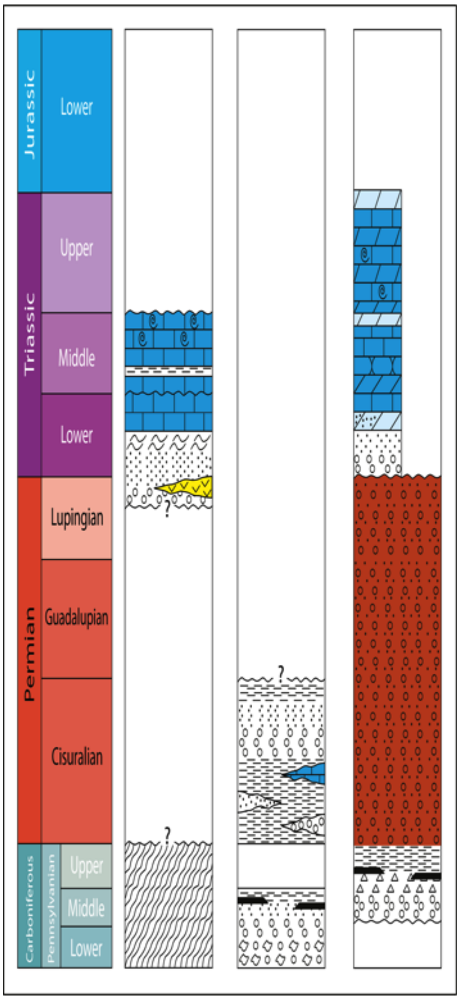

Figure 2.15 : Getic Nappes

2.4.3 Supragetic Nappes

Supragetic Nappes (Fig. 2.16) lie atop of Getic Nappes structurally and are the last studied units in the Southern Carpathians in this research. In Făgăraş Nappe, upper Carboniferous-Permian molasse deposits consisting of red conglomerates and siltites are directly underlain by crystalline basement. The succeeding Triassic sediments are composed of lower Triassic yellow and violet sandstones and upper lower Triassic-Anisian dolomites followed by an unconformity that underlie the Aptian conglomerates, calcareous breccias, reef limestones and Orbitolina limestones, intruded by granitic rocks of 102-145 Ma (Horváth, 2006).

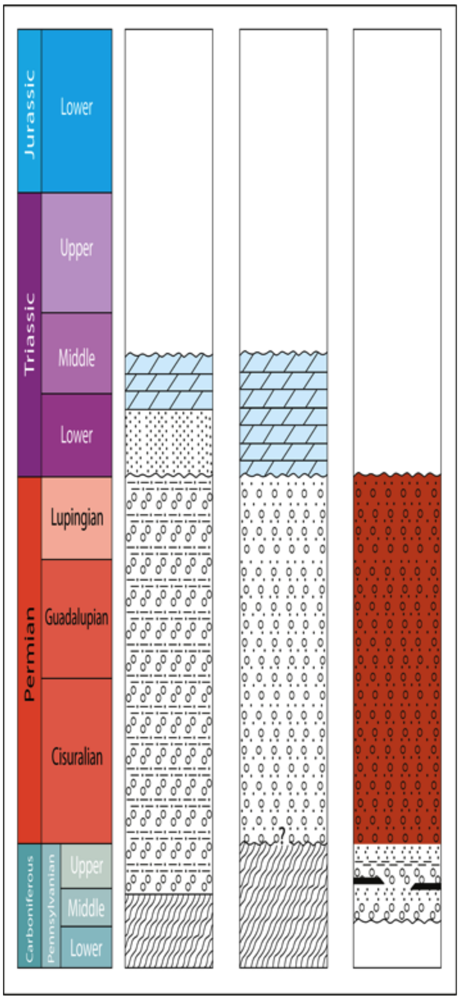

Figure 2.16 : Supragetic Nappes

In Bîrşa Fierului Nappes, crystalline basement underlie the Permian conglomerates and sandstones followed by an unconformity. Triassic deposits underlain by this unconformity represent the lower Triassic-Anisian dolomites. After Triassic deposits there is an unconformity again and Aptian calcareous-clasitic series overlie this unconformity (Horváth, 2006).

In the Ranovac-Vlasina-Osogovo Region, East Serbia, sequence begins with low-grade Palaeozoic complex (Ordovician? -Visean?) underlying unconformably the Kasimovian-Gzhelian terrestrial, fluvial and lacustrine sediments that contain polymict conglomerates and coarse-grained sandstones alternating with microconglomerates and shales with occasional thin coal seams. These sediments pass upward into Permian red-beds conformably (Vozárová et al., 2010).

2.5 Eastern Carpathians

Precambrian continental crust of Eastern Carpathians metamorphosed into greenschist facies during Variscan metamorphic stage is overstepped by late- and post-orogenic Variscan sequences (Vozárová et al., 2010). These sequences are preserved only in some areas of Eastern Carpathians, which are Pentaia, Pietriceaua, Poleanca and Iacobeni Nappes of Infrabucovinian Nappes, Subbucovinian Nappes, and Rarău Synclines, Haghimaş Synclines and Perşani Mountains of Bucavinian Nappes.

2.5.1 Infrabucovinian Nappes

In the late Pennsylvanian-Cisuralian, the lowest unit of Eastern Carpathians, Infrabucovinian Nappes (Fig. 2.17), generally represent first grey sandstone and microconglomerates, and then reddish conglomerates with scarce intercalations of sandstones and siltstones. However, in the Poleanca Unit of the Northern Maramureş and Rahov Mountains, there are also rhyolites and basalts of Cisuralian age (Vozárová et al., 2010).

Lower Triassic quartzitic sandstones of Pentaia Nappe are underlain by these general upper Pennsylvanian-Cisuralian deposits. The following lower Triassic-Anisian bituminous limestones, dolomites with andesite and basalt dykes underlie lower Jura black quartzitic sandstones and shales unconformably (Horváth, 2006).

In the Pietriceana Nappe, upper Pennsylvanian-Cisuralian sediments are followed by Guadalupian-Lopinghian reddish conglomerates which prograde into the lower Triassic siliciclastics (Vozárová et al., 2010). Anisian? massive dolomites and middle-upper? Triassic light massive limestones and dolomitic lenses follow the lower Triassic quartzites. There are red limestones between Anisian? and middle-upper? Triassic sediments (Horváth, 2006).

As mentioned above, Poleanca Nappe comprises Permian sequences of several hundred meters underlain by late Pennsylvanian sequences, which are different from the other Infrabucovinian Nappes. In these Permian sequences thick, dark, clastic sequence including dark siltstones, sandstones and clays are followed by continental red clastic deposits including sandstones, silts, conglomerates with intercalations of basalt and rhyolite flows and pyroclasitcs concordantly. The succeeding lower Triassic? white quartzitic sandstones underlie the Anisian deposits (200 m). These deposits are formed by a lower part involving bituminous dolomites, limestones and an upper part involving lighter-colored massive dolomites (Horváth, 2006).

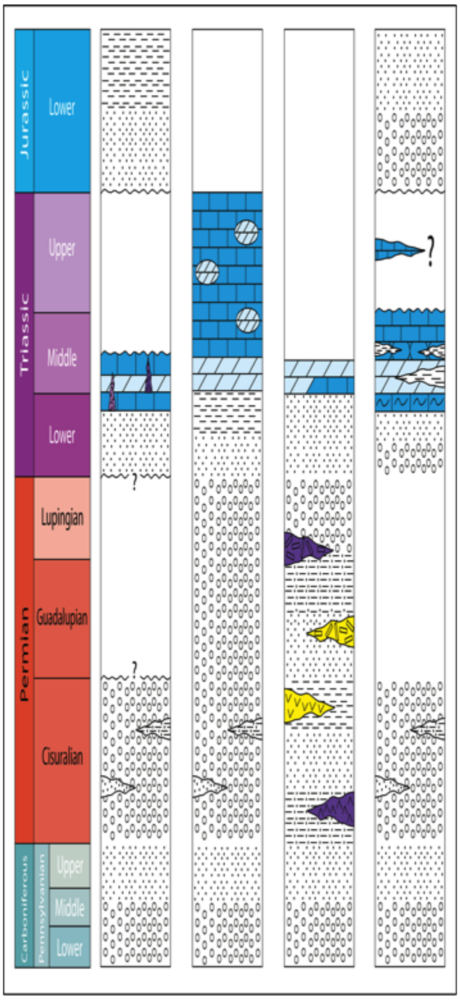

Figure 2.17 : Infrabucovinian Nappes

Upper Pennsylvanian-Cisuralian deposits are overlain by lower Triassic conglomerates and quartzitic sandstones in the Upper Infrabucovinian Nappe, namely Iacobeni Nappe. After thin-bedded marly limestones, a Gutenstein-type formation (100-200 m) of Anisian age including well-bedded bituminous dolomites or dolomarls with shaley interlayers appears. A Ladinian? series of red nodular limestones with red or green shaley interlayers and a Ladinian? series of light marbles follow each other respectively, and are underlain by Anisian Gutenstein-type formation. Lower Jura dark sandy, conglomeratic and coaliferous sediments follow Ladinian? deposits unconformably (Horváth, 2006). Moreover in some regions of Iacobeni Nappe, upper Triassic? light marmaraceous limestones are reported (Kovács et al., 2010).

2.5.2 Subbucovinian Nappes

In the Subbucovinian Nappes (Fig. 2.18), crystalline basement directly underlie Permian continental red siliciclastics (Kovács et al., 2010). The following lower Triassic clastic series are overlain by uppermost lower Triassic-Anisian carbonate platform consisting of massive, dolomitic or rarely well-bedded bituminous calcareous facies.

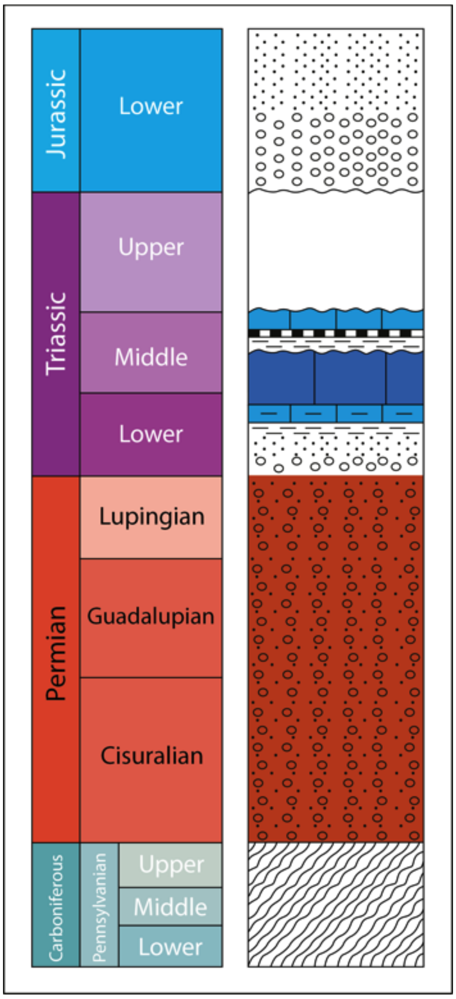

Figure 2.18 : Subbucovinian Nappes

The stratigraphic level between lower Triassic and uppermost lower Triassic-Anisian is occupied by dark, shaley, bituminous limestones. The unconformably succeeding Ladinian red shales with radiolarites (10-30 m) and grey limestones are followed by thin, limonitic marine sandstones and quartzite-conglomerates with a disconformity (Horváth, 2006).

2.5.3 Bucovinian Nappes

The upper units of Eastern Carpathians, Bucovinian Nappes (Fig. 2.19), consist of crystalline basement overlain by continental clastics in the Rarău Synclines, Haghimaş Breccia in the Haghimaş Synclines, and overstepped by Triassic series in the Perşani Mountains (Vozárová et al., 2010).

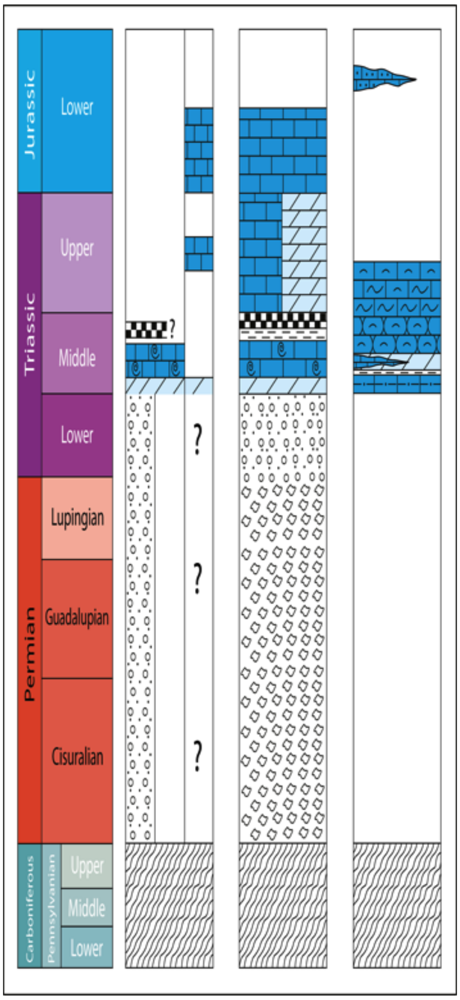

Figure 2.19 : Bucovinian Nappes

In the Rarău Synclines, Triassic series start with the basal part of Scythian age including conglomerates and quartzose sandstones with intercalations of red shales and continue Lower Anisian massive dolomites, locally platy and fossiliferous in its basal part. In some places, these dolomites lie directly on the crystalline basement. After lower Anisian, Steinalm-type algal limestones preserved locally appears in the Pelsonian-Ladinian. There is an uncertain evidence of radiolarites of Ladinian age. Middle Jura Tătarca Breccia follows Ladinian after erosion (Vozárová et al., 2010). In some places, the Anisian massive dolomites are overlain by the Norian massive limestones and the Hettangian-Sinemurian thin hematitic oolitic limestones, respectively (Horváth, 2006).

In the Haghimaş Synclines, the Triassic series are the same with the Triassic series of Rarău Synclines until lower Ladinian. Shallow-water *dasycladacean*-bearing limestones occupy the lower Ladinian succeeded by Ladinian red silts and radiolarites, upper Triassic limestones and dolomites, and Hettangian-Sinemurian thin hematitic oolitic limestones, sequentially (Horváth, 2006).

In the Perşani Mountains, crystalline basement is overstepped by the Anisian platform sediments. These sediments involve Early Anisian grey-bluish, silty or micritic limestones and silty shales, Pelsonian-Lower Illyrian dolomites which alternate or interfinger with Steinalm-type massive limestones, and Latest Anisian-Ladinian variegated, nodular limestones with cherts (Kovács et al., 2010). Carnian red marly limestones and thin-bedded cherty limestones cover Anisian platform sediments. In some areas, oolitic limestones occupy the Aalenian (Horváth, 2006) and in some areas, Upper Pliensbachian transgressive, reddish-yellowish sandy oolitic limestones appear (Haas et al., 2010). Nonetheless, frequent gaps dominate the Jurassic succession.

2.6 Tisza Mega-unit

Complex internal structure of Tisza Mega-unit has different pre-Alpine basements of different Alpine Zones as it has different origin from surroundings that is European plate origin. These crystalline complexes are the Kungságia (Mórágy Unit and Kőrős Unit), Slavonia-Dravia (Babócsa Unit and Baksa Unit), Békésia (Kelebia Unit and Battonya Unit) Complexes, and Bihor Autochthon in Apuseni Mountains. Mecsek Unit, Villány-Bihor Unit, and Codru Nappe System with the Alpine sequence of Bihor Autochthon occupy the Alpine Zones of Tisza Mega-unit.

2.6.1 Mecsek Unit

Mórágy Unit constitutes the basement of Mecsek Unit (Fig. 2.20) (Kovács et al., 2000) and consists of pre-Variscan quartz phyllites and gneisses, Variscan quartz phyllites and gneisses-amphiboles-quartz phyllites and gneisses alternation, and Carboniferous migmatites. These deposits are intruded by Carboniferous acid magmatic rocks, followed by a hiatus. Pennsylvanian? Nagykőrős Sandstone Formation underlain by intrusive rocks, aggregates grey, sometimes organic-matter-rich, fossil-free, non-metamorphic, medium and fine-grained molasse-type sandstones. The succeeding Cisuralian Korpád Sandstone is formed by a cyclicity of polymict conglomerates and red, coarse-grained sandstones with red-brownish mudstone intercalations. Following an erosional surface Gyürüfü Rhyolite (277±45 Ma) that is reddish-brown or reddish-lilac volcanic body, accompanied by lava flow alternating with ignimbrites composes the basal part of the Guadalupian-Lopingian Series. After repeated erosion, transgressive Cserdi conglomerate occurs. This cyclic red-beds sequence in which conglomerates, sandstones, and siltstones alternate gradually passes upward into the Boda Siltstone comprising from thick, monotonous, reddish-brown siltstones with scarce intercalations of fine-grained sandstones and dolomitic marls, and is followed by Kövágószölös Sandstone Formation including well-bedded fluviatile coarse- to fine-grained sandstones and a lacustrine-paludal siltstones. Transition from the Kövágószölös Sandstone Formation to the Early Triassic so-called Jakabhegy Sandstone Formation is marked by a hiatus (Haas et al., 2001). Three lithological units form Jakabhegy Sandstone Formation; there are coarse conglomerates with pebbles of quartzite, rhyolite, granite and shales at the base, fining-upward cycles including thin conglomerates, cross-bedded sandstones capped by siltstones at the middle, siltstones and fine-grained sandstones with palaeosol horizons, intercalations of Aeolian dune sands at the top. Siliciclastic-carbonate ramp system dominates the Early Anisian. It begins with three cycles of sandstones-greenish red siltstones-dolomites. Anhydrite and gypsum level is succeeded by dolomitized peritidal carbonates. In Bithynian-Pelsonian period flaser-bedded limestones and marlstones with tempestites form the mid and outer ramp deposits. Laminated organic carbon-rich calcareous marls follow the basal bituminous oncoidal packstones and bivalve shell beds of backshoal origin in the Ladinian-lower Carnian. Upper Triassic arkoisic sandstones and siltstones constitute

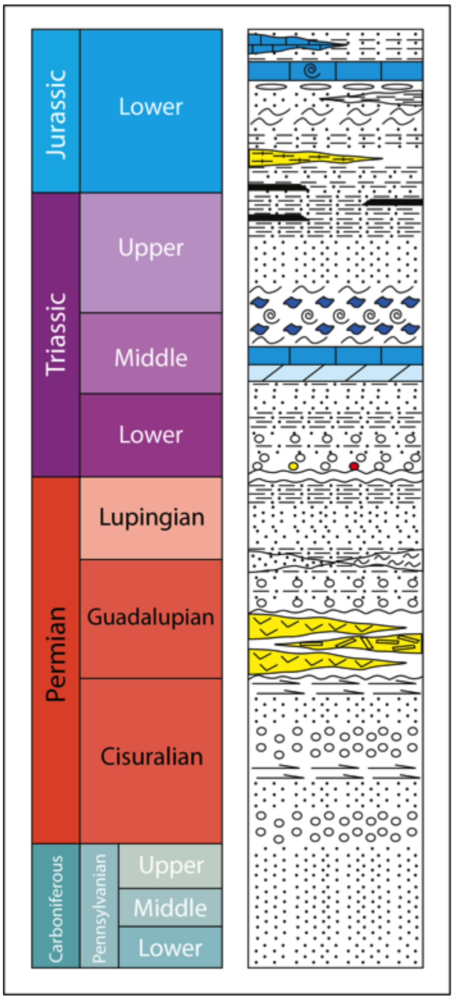

Figure 2.20 : Mecsek Unit

Karolinavölgy Sandstone Formation, which passes into Jura Gresten-type sequence continuously (Kovács et al., 2010). Gresten-type sequence comprises of cyclic alternation of arkosic sandstone, siltstone, claystone and coal layers at the base of the Hettangian-Lower Sinemurian period. These coal layers appears in the upper Triassic series thinly and are known as “Mecsek Coal” together with the Hettangian-Lower Sinemurian thin rhyolitic tuffite interlayers and the upper member of Mecsek Coal Formation (Haas et al., 2010).

2.6.2 Villány-Bihor Unit

Basement of the Villány-Bihor Unit (Fig. 2.21) is the Kőrős Unit of Kungságia Complex (Kovács et al., 2000) except the basement of Villány Mountains which is the Baksa Unit of Slavonia-Dravia Complex (Haas et al., 2001). Bihor Autochton in the Apuseni Mountains also involved in the Villány-Bihor Unit.

Pre-Variscan Kőrős Unit comprises from quartzphyllites and gneisses. Variscan period is marked by two cycles of quartz phyllites and gneisses alternating with amphibolites. In the Carboniferous, quartz phyllites and gneisses, migmatites, acid magmatic rocks, and Kistoronya Sandstone Formation following a hiatus succeed the Variscan period in some places, respectively, whereas sheared, dark grey carbonate-phyllite with quartz, sericite and graphitic phyllite intercalations appears as Late Carboniferous Tázlár Phyllite Formation in other places (Haas et al., 2001). The whole sequence ends with Kistoronya Sandstone Formation which is overstepped by Cisuralian red sandstones forming Korpád Sandstone Formation and thin rhyolite lava flows (Vozárová et al., 2010).

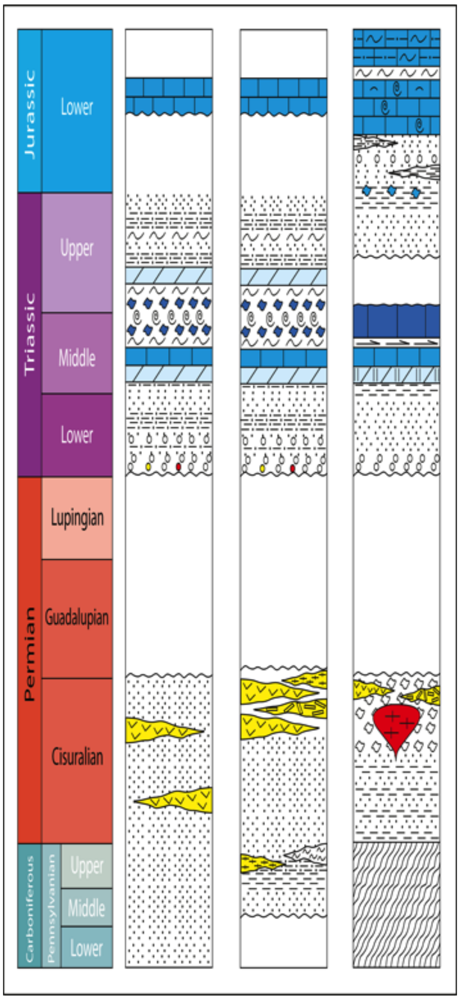

Figure 2.21 : Villány-Bihor Unit

Baksa Unit is constituted by quartz phyllites and gneisses with Görcsöny Eclogite Formation with Gyód Serpentinite Formation at the base, amphibolites at the middle, and quartz phyllites and gneisses at the top. The following Variscan period comprises from 3 cycles of quartz phyllites and gneiss-amphibolite alternation with intercalation of meta-dolomite between first and second cycles and of metalimestones and marbles between second and third cycles. Carboniferous deposits composed of quartzphyllites and migmatites, respectively, succeed the Variscan period. Upper Moscovian-Kasimovian Téseny Sandstone Formation settles down on the Carboniferous series unconformably (Haas et al., 2001). Thick coal-bearing grey coloured sandstone-claystone sequence forms Téseny Sandstone Formation. Kasimovian-Gzhelian formation is occupied by complex of violet-brown siltstone and fine-grained sandstone with several thin rhyolite tuffs and dolomitic marl intercalations and passes progressively into the Cisuralian thick and complete red-beds formation known as Korpád Sandstone Formation. Gyürüfü Rhyolite Formation terminates the Cisuralian series with the thick acidic volcanic and volcano-sedimentary rock complex including rhyolitic lava complex & related pyroclastics (ignimbrites, tuffs) (Vozárová et al., 2010).

After erosion and a noticeable gap, Triassic sequences of the Villány-Bihor Unit begin with the same lithological features of the Mecsek Unit except the evaporitic "Middle Muschenkalk" event occurs in the Illyrian, while it is completely missing in the Mecsek Unit. Furthermore, instead of Karolinavölgy Sandstone, coastal-continental succession forms the upper Triassic series that follows the Ladinian conformably. Upper Triassic alternation of yellowish-grey dolomitic marl and dolomite, brownish- or greenish-grey sandy siltstone and greyish-white quartzarenite with disappearing of dolomites and becoming predominant of greenish-reddish siltstone in the upper part (Kovács et al., 2010), underlie unconformably the Pliensbachian thick limestones (Haas et al., 2010).

Crystalline complex of Bihor Autochthon is known as NE continuation of the Kőrős Unit. Pre-Variscan stage is occupied by Somes Terrane Crystalline basement made up of paragneisses, micaschists, leptyno-amphibolite sequence and migmatites. Variscan period is overprintted by retrogressive greenschist facies metamorphism of 316-306 Ma. Permian sediments overstep pre-Variscan and Variscan sequences. These overstep sequences have argillaceous silty shales and locally vermicular sandstones at the base and quartzitic breccia containing metamorphic basement fragments, scarce bodies of rhyolites and acid welded pyroclastics at the top. Muntele Mare granitoids (278 Ma) intrudes into the whole sequence in the upper Cisuralian (Vozárová et al., 2010). After this granitoids penetration, the sedimentation continues with the Scythian continental red-beds including fluvial and deltaic, partly limnic siliciclastic with coarse conglomerates at the basal level. Evaporitic dolomites following red, sometimes green shales of tidal flat and shallow marine facies occurs in the lowermost Anisian. Mixed shallow ramp facies dominates the lower Anisian. The end of the lower middle Anisian includes lower and upper dolomite sequence with thick, dark vermicular limestones and dolomites in between. Illyrian is characterized by Lugaş Formation consisting of basinal limestones with calcarenitic and coquina storm-beds, slumps and mud-flows and siliciclastic sediments, while upper Illyrian-Cordevolian is characterized by Wetterstein-type carbonate platform succeeded by a paleokarst. Fine-grained siliciclastic continental-shallow marine succession represents The Carpathian Keuper-type Scărita Formation which settles down on this erosional gap (Kovács et al., 2010). The only known Jurassic succession of Bihor Autochthon is in the Pădurea Craiului Mountains in which Wetterstein-type Ladinian sequence underlie unconformably the basal member of the Hettangian continental sequence that is formed by red argillaceous-silty shale locally including breccia with boulders of Triassic limestones (Haas et al., 2010).

2.6.3 Codru Nappe System

Békésia Complex made up of Kelebia Unit and Battonya Unit forms the basement of Codru Nappe System (Fig. 2.22) or Békés-Codru Unit as in Kovács et al. (2000). Quartz phyllites and gneisses undergone Variscan low, medium and high-grade metamorphism occupy the pre-Variscan, Variscan and Carboniferous in Kelebia Unit (Haas et al., 2001). In the north Serbian area known as Kelebia locality, Cisuralian Gyürüfü Rhyolite Formation settled down on an erosional surface following metamorphic basement, represents rhyolite lava with small erosive remnants of Korpád Sandstone Formation (Vozárová et al., 2010).

On the other hand, pre-Variscan and Variscan Battonya Unit consists of 3 cycles of quartz phyllites and gneisses alternating with amphibolites and are terminated by quartz phyllites and gneisses. In Carboniferous migmatites followed by acidic intrusive rocks occurs. Pre-Variscan, Variscan and Carboniferous migmatites are also overprinted by Variscan low, medium and high-grade metamorphism (Haas et al., 2001). These metamorphic complexes are intruded by a broad granitoid body including biotite-muscovite granodiorite with enclaves of medium- and high-grade metamorphic rocks. Pre-Triassic Gyürüfü Rhyolite Formation overlie these sequences with an erosional surface between them (Vozárová et al., 2010).

Jakabhegy Formation consisting of grey and lilac continental sandstones starts the lower Triassic. The succeeding middle-upper Triassic includes lower Anisian Werfen-type variegated or red shale, upper Anisian-Ladinian shallow marine, lagoonal dolomites, and upper Ladinian-Norian grey shallow marine marls and limestones with calcareous algae and light grey dolomites (Kovács et al. 2010). A volcanic event also took place at 240±45 Ma (Vozárová et al., 2010). Lower Jurassic red limestones cover the Triassic sequences (Haas et al., 2010).

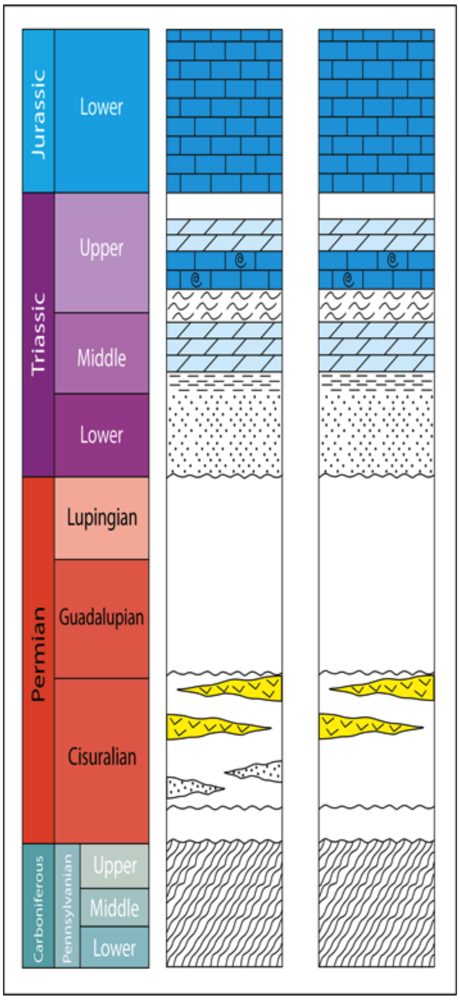

Figure 2.22 : Kelebia and Battonya Unit of Codru Nappe System

Codru Nappe System in Apuseni Mountains has Pre-Variscan basement named Codru Complex. It includes polymetamorphic ortho-amphibolites, paragneisses, micaschists and quartzites of 405 Ma amphibole age and 373 Ma muscovite age and integral parts of pegmatite and intrusive bodies of trondhjemite, quartz-diorite and orthoclase granite, microcline and muscovite granites known as Codru granitoids of

356 Ma muscovite age. Retrogressive Variscan deformational event is greenschist metamorphism. Permian post-Variscan overstep sequence consists of varicoloured sediments, locally associated with acid and basic volcanic rocks in the Finiş Nappe, Arieseni Nappe, Moma Nappe, and Dieva Nappe (Vozárová et al., 2010) explained in the sequent section.

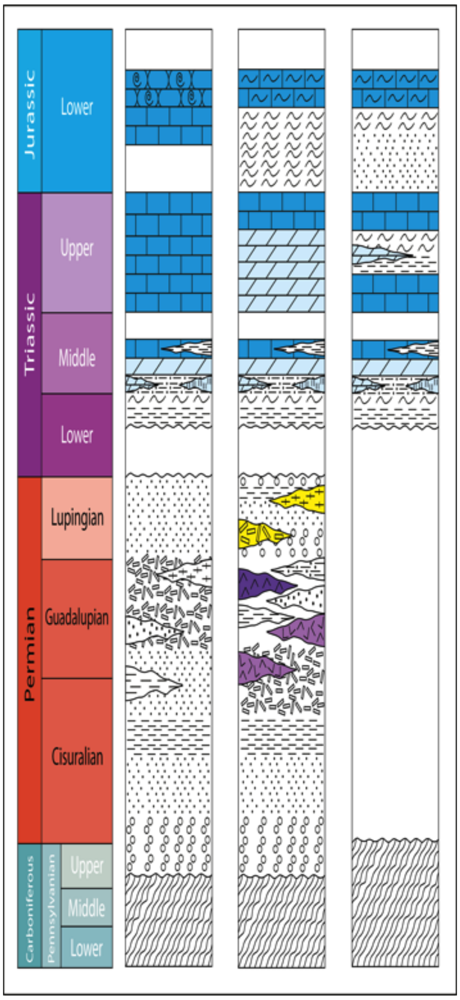

Figure 2.23 : Valani, Finiş, and Dieva Nappes of Codru Nappe System

In the Finiş Nappe (Fig. 2.23) latest Pennsylvanian-Cisuralian Laminated Conglomerate Formation made up of oligomictic metaconglomerates associated with laminated metasandstones and purplish metapelites followed by Vermicular Sandstone Formation comprising from red lithic sandstones with bioglyphes (burrow fillings) interbedded with shales and sandy shales, Rhyolitic Formation comprising from mainly ignimbrites, locally interbedded tuffs and tuffaceous sandstones, and Feldspathitic Formation comprising from feldspathitic sandstones, respectively (Vozárová et al., 2010).

In the Arieseni Nappe (Fig. 2.24) Vermicular Sandstone Formation following

Laminated Conglomerate Formation is succeeded by an equivalent of the Rhyolitic Formation mentioned above. This formation has detrital feldspathitic sediments and subsidiary ignimbrites/rhyolites and sporadic occurences of basalt as its compound. Oligomictic Formation occurs the last level of this sequence before Triassic series (Vozárová et al., 2010).

In the Moma Nappe (Fig. 2.24) and Dieva Nappe (Fig. 2.23) Laminated Conglomerate Formation precedes Volcanic Formation which contains Lower Rhyolite Member, Mafic Member, and Upper Rhyolite Member. First member is occupied by mainly ignimbrites in which the dacitic rocks are associated towards the upper part. In the Moma Nappe cinerites also accompany this member. Basalts, andesite-basalts, spilitic rocks and anamesite flows with intercalations of basaltic tuffs, interbedded with shales, silty shales, siltstones and fine reddish-violet sandstones form the Mafic Member. Upper Rhyolite Member in which conglomerates, feldspathitic and arkosic sandstones and shales, levels of rhyolitic ignimbrites and acid tuffs crosscuts the Mafic Member. Only in the Dieva Nappe Oligomictic Formation occurs with decreasing of volcanic materials (Vozárová et al., 2010).

Codru Nappe System of Apuseni Mountains can be divided into two units by Lower and Upper Codru Nappes in Mesozoic period. Lower Codru Nappes begin with the uppermost Scythian-lowermost Anisian shales, marls and siltstones with evaporitic and dolomitic interlayers known as Werfen Shales. The succeeding Anisian dolomites is followed by uppermost Anisian basinal and pelagic well-bedded, dark, cherty limestones with few shale intercalations, namely Roşita Limestones. In the Carnian sedimentation shows diversity in the different units of Lower Codru Nappes. Finiş Nappe is represented by Roşita limestones, whereas Dieva Nappe is represented by dolomites. On the other hand Valani Nappe (Fig. 2.23) in the north shows Wetterstein limestones. In the Norian Dachstein limestones passes through into platform dolomites and Keuper-type shales and sandy marls with thin dolomitic interlayers, respectively, towards to north. Dark, slightly bituminous marly limestones with occasional oolitic, brachiopod- or coral-rich layers appear in the Rheatian and are succeeded by Hettangian-Sinemurian rather uniform grey sandy marls. However, in the north Hettangian Gresten-type sandstones settle down on the Rheatian series unconformably (Horváth, 2006).

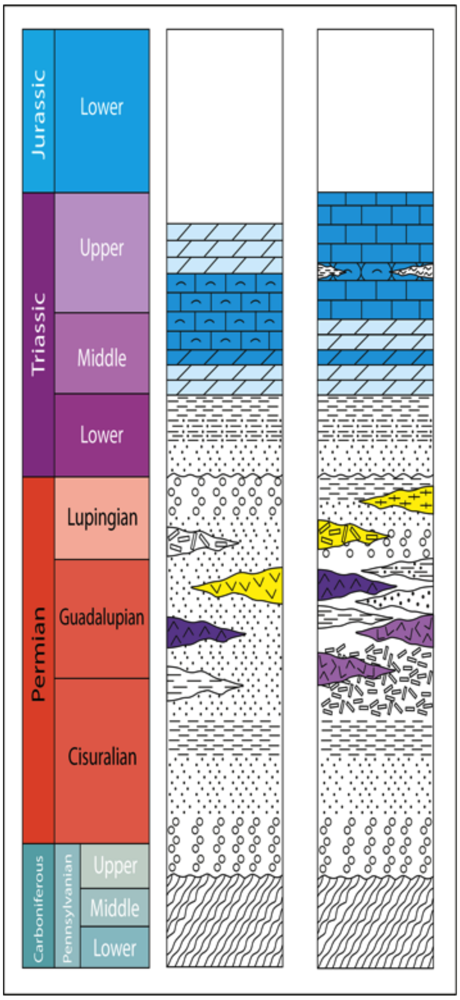

Figure 2.24 : Arieseni and Moma Nappes of Codru Nappe System

Werfen-type Scythian series including in the order of coarse-grained sandstones, fine-grained siltstones, and shales, comes after Permian sequences unconformably in the Upper Codru Nappes. Anisian shallow marine carbonate platform formed by massive dolomites, evaporitic dolomites and dolomitic limestones precedes pelagic limestones which represent varied affinity in the Arieşeni Nappe and Moma Nappe. In the Arieşeni Nappe the upper Carnian is dominated by grey to black micritic limestones following the upper Anisian-lower Carnian dark grey, well-bedded cherty limestones. Sequence is terminated by the uppermost Carnian-Norian thick, massive dolomites. In the Moma Nappe the upper Anisian-Carnian redeposited, platform-derived dolomitic and limestone layers start the series with the subsequent cherty and nodular limestones with shaly-marly intervals and complete them with the Norian-Lower Rhaetian Dachstein limestones containing lenses of pelagic limestones with thin-shelled bivalves. Jurassic deposits are completely missing in these areas (Horváth, 2006).

2.7 Alcapa Mega-Unit

Alcapa Mega-unit is composed of three units: Eastern Alps Units, Inner Western Carpathians Units, and Pelsonia partial unit in the Pannonian Basin (Vörös, 2000). In this section, general lithological features of Tatricum, Hronicum, and Veporicum units of Central Western Carpathians, Gemeric Unit of Inner Western Carpathians, and Bükk Unit of Pelsonia are explained.

2.7.1 Central Western Carpathian Zone

In the Tatricum unit (Fig. 2.25) Variscan medium- to high-grade crystalline basement intruded by granitoids is overstepped unconformably by Permian conglomerates and coarse-grained sandstones that are proximal to distal braided-alluvial sediments and restricted in the High Tatra, Low Tatra, and Malé Carpathy Mountains (Vozárová et al., 2010). The following Scythian deposits have transgressive terrigenous sediments, which are basal member of coarse but relatively thin conglomerates, sandstones, and variegated clays and shales containing dolomite intercalations, respectively. These sediments prograde by gradually decreasing into lower Anisian Gutenstein-type limestones formed by a carbonate platform having well-bedded, grey, bioturbated limestones at the base. Ladinian is marked by massive dolomites and green tuffitic clays. In High Tatra these massive dolomites includes thicker (200 m) well-bedded limestones and dolomites on the top of Ladinian. After Ladinian sedimentation is exposed to the important changes. Yellow to violet sedimentary complex of sandstones with intercalations of shales and thin dolomite layers dominate from the Carnian to the Norian. Rhaetian Kössen-type development is formed by alternating sandstones and shales / alternation of fossiliferous and oolitic limestones and clays. However in a noticeable part of this unit Ladinian dolomites settle down on the Jurassic levels unconformably, while in the High Tatra and Low Tatra Anisian limestones are followed by Jurassic levels unconformably. Śipruń group occurs in the Hettangian-Aptian generally although ridge development takes place in the High Tatra and Low Tatra in this very period (Horváth, 2006).

Upper Pennsylvanian Nižná Boca Formation which is a regressive clastic sequence intruded by granitoids, preceedes conformably the Cisuralian succession that is an alternation of conglomerates, sandstones, and shales with lenses of dolomite and locally occurrence of gypsum and calcrete/caliche horizons in the Hronicum unit

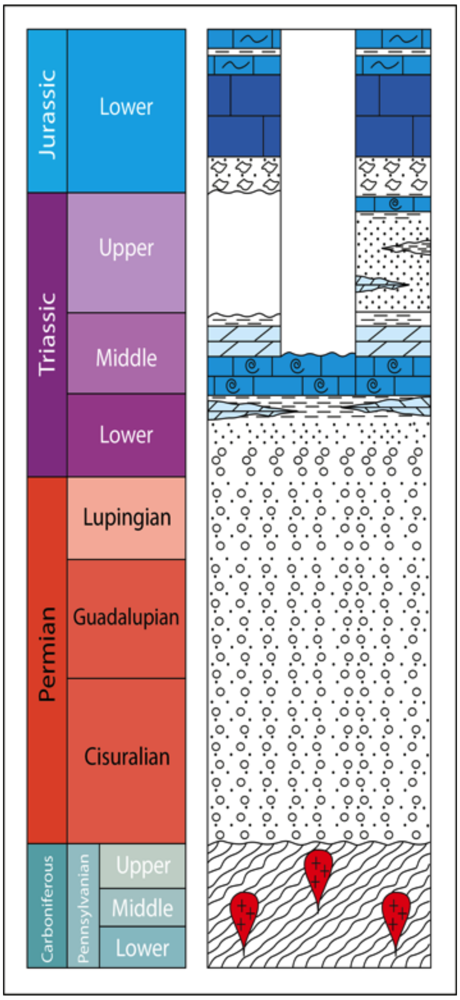

Figure 2.25 : Tatricum unit

(Fig. 2.26). The most essential event in this period is the rift-related andesite-basalt volcanism with a continental tholeiitic magmatic trend (Vozárová et al., 2010). Permian deposits prograde transgressively into Scythian sediments that is composed of in the order of conglomerates, sandstones, and shales, and rarely preserved basic volcanic rocks in some places. Anisian is represented by pure carbonates made up of shallow water Gutenstein-type limestones, and well-bedded, grey, sometimes bioturbated (vermicular) limestones. Upper Anisian-Ladinian shows different sediments in the north and in the south. Massive platform dolomites and subsequent dolomite platforms form in the northern units. Pelagic, basinal limestones and subsequent massive Wetterstein-type limestones occur in the southern unit. Later, Carnian-Norian sandy, silty, terrigenous Lunz beds followed by carbonate platform and Rhaetian Kössen-type fossiliferous limestone beds alternating with black clays settles down on the northern and southern units. The succeeding Sinemurian-Pliensbachian crinoidal and cherty limestones are unconformable with the Rhaetian deposits (Horváth, 2006).

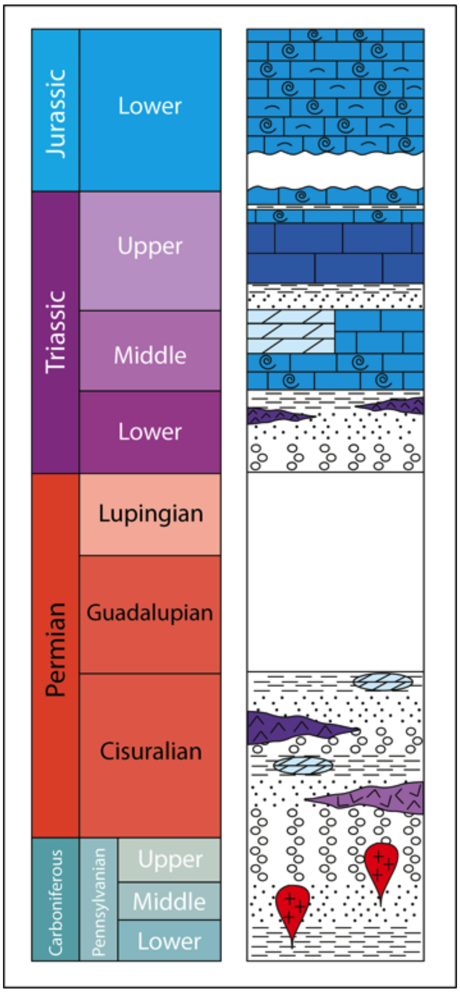

Figure 2.26 : Hronicum unit

Veporicum unit (Fig. 2.27) has a discrete evolution for Carboniferous-Permian period, which separates the unit into two subunit as the Northern Veporicum and the Southern Veporicum.

In the Northern Veporicum, lower Permian sediments directly overlie the crystalline basement intruded by granitoids unconformably. Arkosic fluvial sandy sediments, calc-alkaline dacite effusions with ignimbrites and epiclastic deposits, rare andesite/basalt and their volcanoclastics constitute the Brusno Formation which is overlain disconformably by Predajna Formation including micaschiscts, paragneisses, micrograntes and reworked Brusno volcanites (Vozárová et al., 2010). Permian deposits pass transgressively into the Scythian sediments that are acidic (quartzporphyry) volcanites and conglomerates-sandstones, claystones, and shales of basal member. Anisian-Ladinian carbonate platform and subsequent massive dolomites are overlain by Carnian sandstones and shales of Lunz Beds and thin dolomites. Shales, dolomites, and sandstones form a Keuper-type formation in the Norian. Hettangian-Sinemurian sandy crinoidal limestones rest on an erosional surface following Norian deposits (Horváth, 2006).

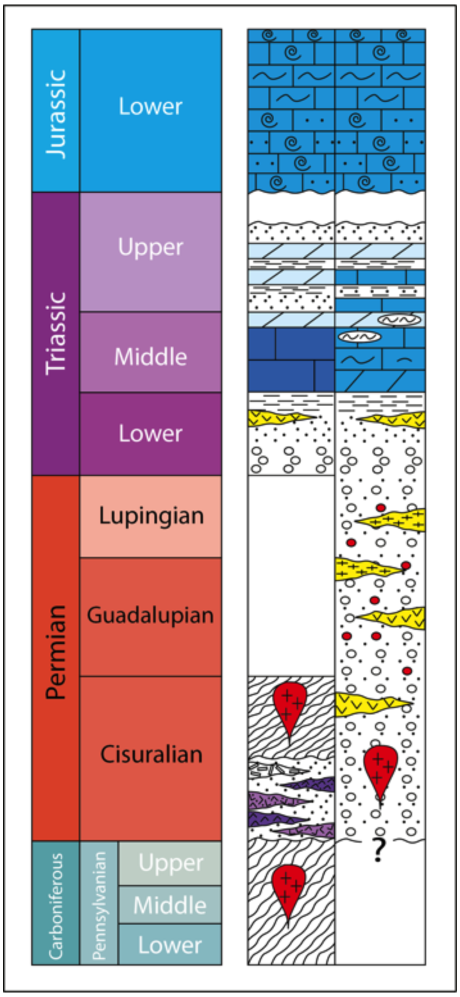

Figure 2.27 : Veporicum unit

In the Southern Veporicum, Kasimovian-Gzhelian post-orogenic Slatviná Formation underlie the Permian sediments which are coarse-grained arkosic metasandstones and rare metaconglomerates with abundant granitic detritus, occasional lava flows of calc-alkaline rhyolites with their tuffs (Vozárová et al., 2010). Scythian conglomerates-sandstones, claystones, and shales of basal member and acidic (quartzporphyry) volcanites settle down transgressively on Permian sediments. Gutenstein-type sometimes-dolomitic limestones and deep-water marly and cherty limestones dominate the Anisian. Ladinian thick massive limestones and dolomites with marly lenses are overlain by Carnian marly and cherty limestone sequence accompanied by black shales with sandstone layers. After Carnian period, Northern Veporicum and Southern Veporicum have the same affinity (Horváth, 2006).

2.7.2 Gemeric Unit

Gemeric unit (Fig. 2.28) is subdivided into the Northern Gemeric Zone and Southern Gemeric Zone, which have diverse lithological features.

In the Northern Gemeric Zone, lower Permian sequence is underlain by Carboniferous deposits disconformably. Basal part of the Permian sequence known as Knola Formation consists of poorly-sorted conglomerates and breccias, followed by coarse clastic sediments with bimodal andesite/basalt-rhyolite volcanism. The succeeding Petrova Hora Formation comprised from clastic sediments, bimodal volcanics and volcanoclastics with rhyolite tuff (278±11 Ma), and Artinskian-Kungurian microflora in the upper part, underlies sandy-conglomeratic horizon. Middle-upper Permian represented by siliciclastic-evaporitic sequence with anhydrite-gypsum and salt breccia, preceedes the lower Triassic siliciclastic-carbonate sediments (Vozárová et al., 2010).

In the Southern Gemeric Zone Lower Permian continental Rožňava Formation overlies the thick lower Palaeozoic volcanogenic flysch basement named Gelnica Terrane. Two cycles of Rožňava Formation has conglomerates interfingering with rhyolite-dacite subaerial volcanoclastics and rare lava flows at its base alternating sandstones and mudstones at its top. Rhyolites in the volcanogenic horizons (~276±25 Ma) of these cycles are calc-alkaline to alkaline magmatic type. The succeeding Guadalupian-Lopingian Stitnik Formation is formed by two cycles of sandstones-siltstones and shales followed by lenses of calcareous sandstones and dolomitic limestones with intercalations of shales on the top. S-type granites with different ages also appear: 276±13 Ma and 263±28 Ma (Finger and Broska, 1999; Finger et al. 2003), 263.8±0.8 Ma and 262.2±0.9 Ma (Kohút and Stein, 2005), 250±18 Ma (Poller et al., 2002). Lower Triassic is represented by Nová Ves and Kobeliarovo Formation consisting of variegated sandstones and shales with bodies of evaporites, and the subsequent marlstones and limestones at the top. Mainly Gutenstein-type dolomites and limestones, partly with light (recrystallized) limestones occupy the middle Triassic (Vozárová et al., 2010).

2.7.3 Meliata Unit

Meliata Unit (Fig. 2.29) is associated with the middle Triassic Meliata Ocean although it has also Permian thin continental crust metasediments. These me-

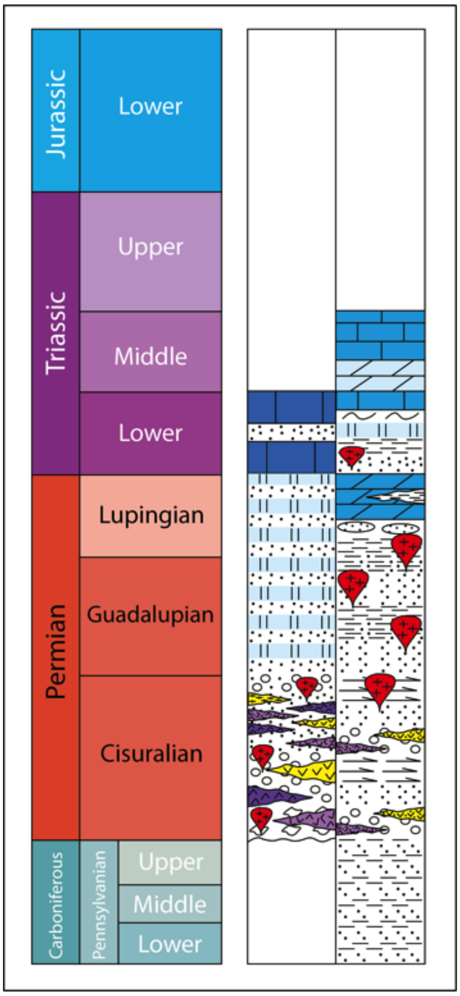

Figure 2.28 : Gemeric unit

tasediment series consist of Jasov Formation and Bucina Formation. Basal member of Jasov Formation includes siliciclastic quartzose metasediments with rare acid volcanics and volcanoclastics. Conglomerates and metasiliciclastic fragments follow the basal member and are overlain by felsitic rhyolite-dacites and their volcaniclastics with non-volcanic quartzose detritus of Bucina Formation (Vozárová et al., 2010). Permian-Triassic boundary, lower Triassic, and upper Triassic are unknown. Middle Triassic in the Meliata Unit known as Darnó-Tornakápolna Zone occupied by oceanic basement with rift or ocean floor related basalts, intrusives and ultramafics overlain by thin disturbed sedimentary sequence. There are also serpentinites with lherzolitic-harzburgite origin, spilites from pillow lavas, gabbros and dolerites, and MORB tholeiitic basalts. In the Ladinian thin red and black clays, shales or radiolarites occur between the lava flows. Jurassic series begin with the upper Lias-lower middle Jurassic dark shales with sandstone or limestones lenses and radiolarite lenses in the central of the unit known as Brusnik, Szarvaskő and Honce

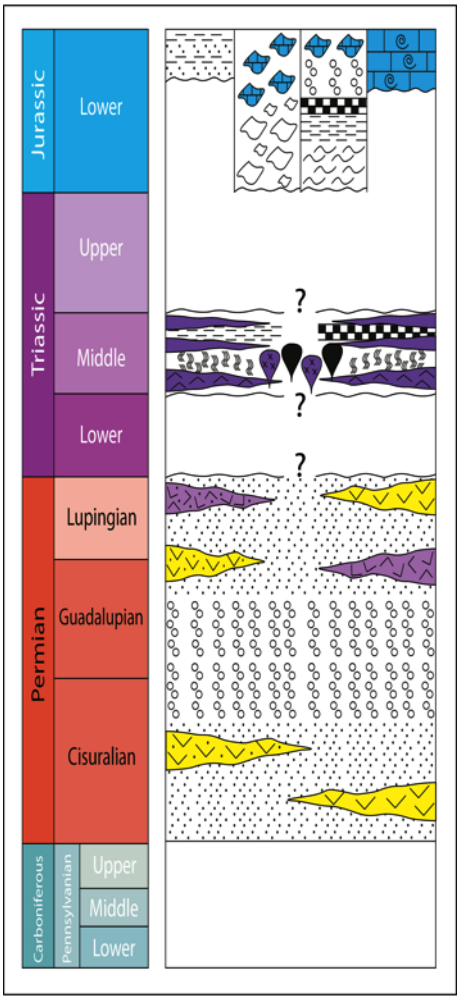

Figure 2.29 : Meliata unit

Series, the lower-middle Jurassic wildflysch containing larger/smaller olistoliths and cherty/pelagic limestones clasts of redeposited olistostromes, and rhyolites and andesites in the Teleskoldal Series, the Lias variegated marls, clays, radiolarite levels, fine-grained sediments enclosing conglomerates and limestone olistoliths in the Telekesvölgy Series, the upper Lias-lower middle Jurassic allodapic crinoidal limestones, cherty limestones with dark marly/shaly interlayers in the Oldalvölgy Series (Horváth, 2006).

2.7.4 Bükk Unit

Pre-Upper Moscovian Szilvásvárad Fmormation represented by distal turbiditic shale-sandstone sequence and the following Late Moscovian-Ghzelian Málwritten Formation represented by fossiliferous limestones and siliciclastics of the shallow-marine sequence are restricted in the Bükk Mountains (Fig. 2.30) although upper parts of Mályinka Formation is truncated by erosion substantially (Ebner et al., 2010).

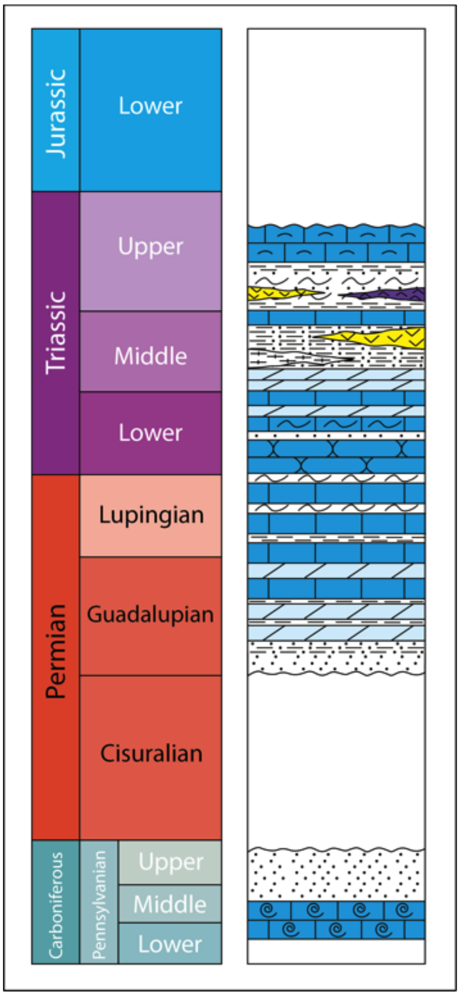

Figure 2.30 : Bükk unit

Therefore Guadalupian Szentlelek Formation rests directly on the upper Moscovian sediments. Whitish-grey and variegated sandstones at the base, the subsequent lilac to reddish siltstones with fine-grained sandstones and violet and brownish-red sandstones with increasing amounts of clastic muscovite, and alternation of greenish-grey claystones, dolomites, gypsums and anhydrites at the top form the Szentlelek Formation. Latest Guadalupian-Lopingian Nagyvisnyó limestones consists of limestones and dolomite layers at the lower part prograded into medium-bedded, dark grey to black limestones with thin black shale layers, by decreasing trend of dolomitization, and alternation of limestones and marl layers-marls with calcareous nodules at the upper part (Vozárová et al., 2010). Lower Triassic nodular limestones, sandstones, marly limestones, dolomites, and limestones pass through middle Triassic dolomites, siltstones intercalated with rhyolites and tuffs, and limestones directly. Upper Triassic shales, sandstones, and marls interfingering with rhyolite and basalt lava flows followed by cherty limestones terminate the Triassic sequences and are covered by middle Jurassic sediments unconformably (Horváth, 2006).

3. TECTONIC EVOLUTION OF THE MEDITERRANEAN REGION DURING PERMO-TRIASSIC PERIOD

The Mediterranean Region remained mainly under the influence of the Palaeo-Tethys until the Jurassic and after which the Neo-Tethys and the Atlantic Ocean influences became the controlling factors (Şengör and Yılmaz, 1981). Until now, there are a few studies undertaken to explain the late Palaeozoic-early Mesozoic evolution of the Palaeo-Tethyan Realm (e.g. Şengör, 1982). The major purpose of this research was to shed light on the Permo-Triassic tectonic evolution of the Mediterranean Region by revealing the geology of its continental fragments in terms of plate tectonics, and to see what the geometry of the Hercynian orogen might have been at its completion.

The succeeding sections include the identification of sutures and the tectonic units involved in the evolution of the Mediterranean Region and their reconstruction using a palinspastic restoration. Finally, I shall represent the tectonic evolutionary history of the Mediterranean Region.

3.1 Tectonic Units and Sutures of Palaeo-Tethys involved in the evolution of the Mediterranean Region

Since Staub (1928) it has been known that the Hercynian Orogenic System and eastern Palaeo-Tethys Ocean had formed as a consequence of the collision of Laurasia in the north and Gondwanaland in the south and the demise of the Palaeozoic oceans between them. Because of the Palaeozoic-Mesozoic transition witnessed events of high mobility in the oceanic realm, Permo-Triassic period plays a key role in the evolution of the Mediterranean realm.

When the tectonic units are examined acording to their lithological features at that time based on the transition between the continental assemblages and the oceanic assemblages, the oldest suture zone of the Tethyan evolution can be traced in the present positions of units form Turkey to Austria, namely Palaeo-Tethyan Suture which is the trace of the Palaeo-Tethyan subduction zone.

In the eastern Pontides, Carboniferous-Permian characterized by metaquartzites, pink to brown meta semi-pelitic and pelitic rocks, recrystallized limestones (Yılmaz et al., 1997), and granitoid complex (App. A.1, A.2, A.3 & A.4) represents a magmatic arc. The succeeding unconformable middle-upper Permian quartzitic sandstones, marbles, and recrystallized limestone horizons interbedded with the metasandstones and shale-siltstone-micritic limestone alternations (Yılmaz et al., 1997) show features of a clastic shelf of an oceanic environment. Therefore, one can observe the oceanic assemblages over the continental assemblages in the unit.

In the Sakarya Continent, pre-Permian metamorphic complexes underlying arkosic sandstones and conlomerates, neritic limestones (Genç and Yılmaz, 1995), and granitoid complexes (App. A.1, A.2, A.3, A.4, A.5, and A.6) represent a magmatic arc and Permian shallow-water deposits as a clastic shelf form the same transition in the eastern Pontides, only more rapidly.

In the Rhodope-Pontide Fragment, Carboniferous-Permian conglomerates, sandstones, siltstones, interbedded coal layers, unconformable limestone layers or blocks, breccias at the top of lower Permian, upper Permian laminated sandstones, unconformable limestones with volcanics and volcanoclastics in some places (Yanev 2000), and granitoid complexes (App. A.1, A.2, A.3, and A.4) in the Balkan Terrane, and almost the same deposits which are affected by metamorphism (Turpaud, 2006) and orthogneiss complexes (App. A.1, A.2, A.3, and A.4) in the Rhodope indicate that the unit was probably a magmatic arc.

As described in the previous section from the viewpoint of lithological features of the eastern European tectonic units, this transition can be seen in the Pelagonian Zone, in the Tisza Mega-unit, and in the Western Carpathians in the Carboniferous, and also in some places of the Southern Carpathians in the Permian (App. A.8, A.9, A.10, and A.11).

Palaeo-Tethys suture extends from eastern Pontides to the Western Carpathians, by passing through the Pelagonian Zone, Rhodope-Pontide Fragment, Southern-Eastern Carpathians, and Tisza on the palaeogeographic maps (App. A.8, A.9, A.10, and A.11). However, when the tectonic zones are repositioned according to Pangaea A2 reconstruction one can see that the subduction zone extends from eastern Pontides and Sakarya Continent to the Rhodope-Pontide Fragment by passing through the

Pelagonian Zone, Western Carpathians, Tisza, and Southern-Eastern Carpathians (App. A.12, A.13, A.14, and A.15).

The other, relatively minor compared to the former suture, is that of the Karakaya (in Turkey)-Meliata (in the Western Carpathians)-Hallstatt (in Austria) Basins appear as a Permo-Trassic marginal basin of the Palaeo-Tethys (Sağdıç et al., 2015, App. A.9, A.10, and A.11). The opening time of this marginal basin by rifting is identified as Permo-Triassic with the indicative rift rocks at that time and indicative oceanic crust rocks in the middle-late Triassic.

In Turkey, in the Yenişehir-İnegöl-Bilecik Triangle of the Karakaya Basin, Permo-Triassic basal conglomerates and sandstones accompanying arkose, lithic arenite and rare orthoquartzite with the Carboniferous-upper Permian limestone blocks and olistostrome, dark grey siltstones-marl alternation, and overlying partly spilitic basalts and pyroclastic rocks with tuffs and agglomerates, greywackes, quartz-rich sandstones, micaceous siltstones, shales and limestones overlain by Middle-Upper Triassic red mudstones, shales, micritic limestones, radiolarites, ribbon cherts and pillow basaltic lavas (Genç and Yılmaz, 1995) are the indication of the rifting and the subsequent ocean openning events. In the Biga Peninsula, the rifting and ocean opening events are represented by Karadağ Unit including Lower Permian thin to medium bedded, dark grey, black, beige recrystallized limestones and the overlying white, thickly bedded/massive limestones followed by calciturbidite horizon, Uppermost Permian-Lower Triassic slightly metamorphosed fine-grained green shales, siltstones, calciturbidites, pelagic cherty limestones and limestones with the basic volcanic rock olistoliths, and Permo-Triassic Denizgören Ophiolite (Okay et al., 1991). In the Central Sakarya, between Bilecik and Nallıhan, Permian-Triassic transition is absent. However, limestones blocks of Permian age and spilitic bassaltic volcanism appears in the Middle-Upper Triassic (Yılmaz, 1981). Moreover, Tokat Massif of the Eastern Pontides (Yılmaz et al., 1997) and Malatya Digitation in the SE of Turkey (Yılmaz et al., 1987), Permo-Triassic and Middle-Upper Triassic successions are characterized by the rifting and the ocean openning events. In the Tokat Massif, Lower Triassic sequence overlying the Permian deposits with an angular unconformity consists of an alternation of dark lavas-siltstones-quartzites-metatuffs associated with the ignimbrites and light grey, fossiliferous recrystallized limestones interbedded with the metagreywackse and metasiltstones, and the succeeding purple shales, greywackes and red mudstone-limestone-chert alternation, and metaflysch sequence in which grey, dark grey phyllites of alternating metasiltstone and sandstone origin with rare metabasite lenses included. The sequence ends with the green foliated metalavas accompanying with the white calcschists at the top. In the Malatya Digitation, Permian dolomites underlie the Middle-Upper Triassic shallow-marine clastics and magmatic occurences comprising from in the order of reddish shales, blackish-green shales with quartzite interlayers, carbonated shale and limestone layers, coarse-grained sandstones-pebblestones, blackish-green siltstones-shales, reddish-black silexite and silicified mudstones, nodular argillaceous limestones, quartzite added black shales from bottom to top, and also spilitic basic lavas and diabases, basalts, and hypabyssal basic? rocks.

The continuation of Karakaya-Meliata-Hallstatt suture in the eastern Europe extends from the Pelagonian Zone to the Western Carpathians by passing through the Internal Dinarides (App. A.9, A.10, and A.11). Hallstatt Zone in Austria is the terminal zone for this suture and it begins with the Haselgebirge Series including basal salt-clay rocks, red-white salt and green and red salty-clay with the primary intercalations of melaphyres, diabases, and tuffs, the following green clay rocks, red salt rocks, and grey salt rocks, respectively (Tollman, 1976). The succeeding Scythian Werfen-type quartzites, shales, and limestones, Lower Anisian rauhwacke, limestones, and dolomites and limestones, and Upper Anisian limestones, namely Hallstätterkalk (Hallstatt Limestones) (Tolmann, 1976) respresent the deepening of the area in an oceanic realm.

3.2 Palinspastic Restorations of Tectonic Units

The word of palinspastic has an Ancient Greek origin : "*pálin"* for the word "again" or "back again" and "*spastikós*" for the word "drawing", meaning the restoration of its original form by retrieving of any deformation. The pioneer of these studies is Arnold Heim (1882-1965), who is a Swiss geologist and had made this kind of restoration for the Alps (Şengör, 2015, personal communication).

The reconstructions of the Mediterranean Region which have been hitherto made, encountered various difficulties for the Permo-Triassic evolution within the Pangaea. The major complication is the lack of knowledge of the original shapes of the continental fragments involving in the tectonic evolution of the Mediterranean

Region at that time because all of them have been highly deformed by subsequent tectonic events. However, with the help of present knowledge about the deformation amounts, the tectonic units can be restored back to the original states and reconstructed with more confidence.

This section deals with the palinspastic restoration of the tectonic unit to the pre-Alpide state for the purpose mentioned above. Figure 3.1 shows the schematic presentation of the process. In addition to the eastern European tectonic units, whose geological features and present locations are explained in the third chapter and previous section, and Turkey, which is briefly sketched in the previous section in terms of suture zones, the adjacent areas which are the Alps, Italy and its islands, North Africa, and Iberian Massif restored palinspastically by the reason of their involement of the tectonic evolution of the Permo-Triassic period.

Pfiffner (1993) restored the massifs of the Central Alps and the study of him with some adjustments form the beginning point and the anchor of the palinspastic restorations of this report. The Penninic Zone is reclosed due to the fact that the Penninic Ocean did not exist in the Permo-Triassic. The eastern and southern Alps are restored by comparing the facies continuation and geological cross sections of the Northern Calcareous Alps (Tolmann, 1976) and by opening the Austroalpine nappe structure through pulling the overriding nappe back.

Predicted shortening rate for Italy, Sicily, Dinarides is 100%, i.e. somewhat less than the shortening in the Alps (Şengör, 2015 personnal communication). In order to take back this deformation, the nappe fronts are determined according to facies continuity on the structural map of Şengör (1982) which represents the thrusts. For Italy and Dinarides, western coast of Italy is taken as fixed. The distance between this fixed reference and the first nappe front was measured at some points on the coast so that the angle between measured distance and vertical axes is 90-degrees. Then, the nappe front is shifted with all the other nappe fronts from points at which the measurements taken, twice as much as the former distance because of the 100% shortening. Later the distance was measured at the same points between the first nappe front and the second nappe front by taking the shifted first nappe front as fixed. The rest of all nappe fronts were gone through the same processes until the last nappe front between the Pelagonian and the Vardar Zone. Also in Sicily, the shorthening was measured and the deformation was taken back with the same process according to the thrust fronts. In this manner, all deformations derived from compressional events were withdrawn and the original shapes of the tectonic units were achieved.

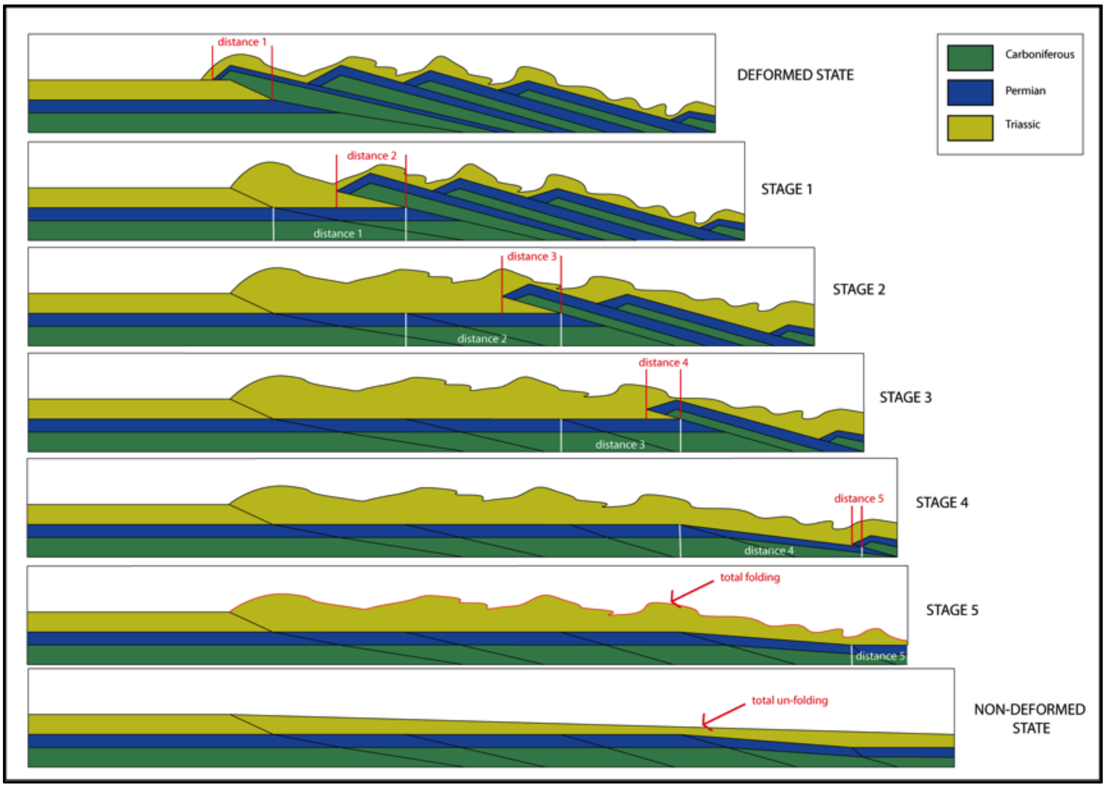

Figure 3.1 : Schematic presentation of the palinspastic restoration

A slightly different process was done for Turkey whose compressional deformation amount were identified by Olivier Monod (2015, personal communication). For its Menderes-Taurus Block and the eastern continuation of it, and the Sakarya Continent, the same process which is used for Italy, Sicily, and Dinarides, was applied except with the 50% shortening. However, there was another deformational story of the Kırşehir Block. It has been known that the former eastern part of the Kırşehir Block is folded on top of its former western part with the compression by forming the present structure. To restore its original shape, the present structure was divided into two pieces horizontally and upper part of it was rotated to its believed original position. By placing the eastern Pontides to the north of the Kırşehir Block on the map plane, the restoration of Turkey was completed.

The compressional deformation rate in the north Africa was calculated by using the geological cross sections of Wildi (1983). In these geological cross sections, first, the beginning points of the nappe fronts were determined and the lengths of them were measured, then scaled to the original distances. Then, these distances were applied on the map from the beginning points backwards for determining the former beginning points of the nappe fronts. Finally, the lower nappe was shifted with the all overriding nappes to its former position by taking the underriding layer as fixed and the nappe just above it were shifted as much as the distance measured for it by accepting the new position of the lower nappe as stable. This process was done for all the nappes and at the end the former external border of the north Africa was determined with its original shape.

The Western Carpathians and the Eastern Carpathians have undergone the same process which is used for the North Africa with the geological cross sections of (Săndulescu, 1975).

The nearly former shape of the Iberian Massif was determined by closing of the Bay of Biscay according to stable western coast of France (Şengör, 2013) and the original position of the northern border of the North Africa. The southern border of the Iberian Massif with its continental shelf border had to be in contact with the original northern border of the north Africa because of the collision between Laurussia and Gondwanaland already happened during Permo-Triassic. The restoration of the Corsica was made based on Jolivet et al. (1991).

3.3 Reconstruction of Tectonic Units of the Mediterranean Region in the framework of Pangaea

Final step after the palinspastic restorations is the reconstruction of the tectonic units which shows where these continental fragments with the associated orientations in the Pangaea. The usual procedure to accomplish this mission is that of the usage of the available evidences of palaeogeography, palaeontology, palaeomagnetism, and regional geology. The most rational starting point in this case is the closing of the Balearic and Ligurian Sea after fixing the western and southern coasts of France and placing the Iberian Massif by closing the Bay of Biscay. In order to achieve this, the Balearic Islands and Corsica-Sardinia Islands with their continental shelf are positioned against the Iberian Peninsula and Provence, respectively, with the counter-clockwise rotation (Alvarez, 1974). The next clear step is to close Tryhhenian Sea by juxtaposing the Italian Peninsula against the Corso-Sardinia block with a nearly 10-degree counter-clockwise rotation. Nevertheless, this step can only be made possible by shifting the North Africa right laterally according to the stable Europe. The critical point required serious attention of this shifting process is that the facies in the Rif Region have to continue into the Betic Cordillera by turning to the east. Only then, Italy can be positioned in its former position. When the connection between the North Africa and the toe of the Italy is completed by placing Sicily between them and the Palaeozoic part of the Calabria-Peloritani is situated between the Balearic block and the Corso-Sardinia block, the former location of the Alboran Sea occurs automatically like a missing piece of a puzzle and the North Africa and Europe with the mentioned adjacent blocks are reconstructed into their positions before the opening of the Atlantic Ocean.

Once the whole western part of the Mediterranean Basin is reconstructed during the Permo-Triassic, the problem about the position of Turkey arises because for the Permo-Triassic Italy, Dinarides with the Pelagonian Zone, and Turkey are connected to each other based on their lithological features. Dinarides with the Pelagonian Zone play the key role in this issue due to its connection with the Central Alps through Southern Alps and with the Turkey. Thus, first, the Alps are placed into their present position, then shifted to the east so that only the Helvetic Zone stays with "stable" Europe. Then, the southern Alps are located in the gap between the Central Alps and the Dinarides with some clockwise orientation because of the facies continuity from the southern Alps to the Dinarides. The Eastern Alps are positioned to the north of the Sothern Alps, and theWestern Carpathians, namely Tatricum, Hronicum, the Gemeric Unit, and the Bükk Unit, are placed against the Eastern Alps. The continuation of the Austroalpine Units, Northern Calcareous Alps, and part of the southern Alps is Tatricum, Hronicum, Gemeric Unit and part of the Bükk , and other part of the Bükk, respectively. With the knowledge of the Karakaya-Meliata-Hallstat Suture Zone, Turkey is juxtaposed against the Dinarides and the Pelagonian Zone so that suture continues from the Karakaya Basin to the Meliata Basin by passing through the Pelagonian Zone.

The final step of this reconstruction is to determine the eastern European tectonic units which are related to stable Europe. The Veporicum which has the continental margin features in terms of its lithology, is considered as the eastern continuation of the Helvetic Zone. According to facies continuity, the subunits of Tisza Mega-Unit, Moesia, Eastern and Southern Carpathians, and the Istanbul-Zonguldak part (the

Istanbul Zone) of the Rhodope-Pontide Fragment are aligned, respectively, along the northern coast of the Palaeo-Tethys Ocean with the Veporicum.

3.4 Permo-Triassic Tectonic Evolution of the Mediterranean Region

As mentioned in this chapter before, the Permo-Triassic tectonic evolution of the Mediterranean Region was dominated by two major activities, which are the on-going subduction of the Palaeo-Tethys and the opening of the Karakaya-Meliata-Hallstatt marginal basin (App. A.10). The Mediterranean Region was characterized by the continental to marine environment during the Permo-Triassic period. Regions east of the Tunisia and Corso-Sardinia Block as far as the coast of the Palaeo-Tethys Ocean were represented by a transition between the terrigenous deposition to a shallow-water deposition. The major tectonic event is the continued closing activity associated with the prograde of the subduction at the margin of the Palaeo-Tethys, which is indicated by the decreasing of the magmatic activity and increasing of the subsidence along the shore of it from the Permian to the Early Triassic.

The intermediate-mafic volcanism and the later transition between neritic to pelagic in the Middle Triassic in the Karakaya Basin, Pelagonian Zone, Meliata Zone, and Hallstatt Zone represented the second major tectonic events: the opening of a marginal basin complex. This marginal basin used the weak zones of Hercynian subduction margin by disrupting the shallow shelfs in the Karakaya Basin and Hallstatt Zone and the magmatic arc in the Pelagonian Zone and Meliata Zone. Before the opening of the Neo-Tethys, Karakaya Basin closed (Şengör and Yılmaz, 1981), thus the closing time of Meliata and Hallstatt Zone also is considered as almost the same time period, although somewhat delayed.

Within the neritic carbonate platform behind the magmatic arc of the Palaeo-Tethys, two pelagic basins formed in the Middle Triassic which were Pindos-Budva and Lagonegro Basins related to the opening of the Mediterranean Sea in the east and the Atlantic Ocean in the west (Şengör, 2015, personal communication). These were the continuations of the same marginal basin opening activity as earlier.

The resulting framework of the Permo-Triassic tectonic evolution in the Mediterranean Region shows the transition from the stable continent in the west to the marine domain in the east by passing through the shallow shelf predominated by a marginal basin. This tectonic evolution has its analogue in the central western Pacific Ocean. Behind the westward facing subduction arc of the ocean, the continental shelf between Taiwan and Japan is disrupted by the extensional forces and the Okinawa Basin is opening as a consequence of this tectonic activities.

4. CONCLUSIONS

In the previous section, the tectonic events took place in the evolution of the Mediterranean Region during Permo-Triassic have briefly explained by discussing the geological structures and palaeogeographical environments of the major continental fragments involved in this evolution. I have prevented much of the geological description and details for the sake of clarity of the text and install these information into the App. A.5 and A.10 for the readers.

From the Carboniferous to the Triassic period was the scene of the on-going subduction and consuming of the Palaeo-Tethys, the opening of a marginal basin right behind the margin of it, and prepared the scene for the Middle Triassic tectonic events such as the opening of the pelagic basins on the carbonate platform of the Palaeo-Tethys.

Palaeo-Tethys' subduction activity dominated the Carboniferous-early Permian single-handedly with the widespread magmatic events in the northeast-east of the present Dinarides. From late Permian on, marginal basin opening activity entranced to the picture under the control of the Palaeo-Tethyan hegemony. Although this opening activity began in the early Permian, it reached its maturity during the late Permian-early Triassic. Magmatic occurrences of this rifting event lie in the Karakaya Basin (possibly began from the Malatya Digitation), Pelagonian Zone and Western Carpathians up to the Northern Calcareous Alps. The other extensional magmatic occurrences of the Tisza Mega-unit and Southern-Eastern Carpathians, which aligned in the northern margin of the Palaeo-Tethys, were related to the intra-continental separation originated from the prograde subduction of the Palaeo-Tethys.

The following Middle-Triassic period was highly mobile in terms of opening several pelagic basins and maturity of the Karakaya-Meliata Ocean. One of these pelagic basins was the Pindos-Budva Basin whose maturity had a role of the evolution of the Mediterranean Sea. The other basin was the Lagonegro Basin. While it made a contribution of the opening of the Mediterranean Sea, its opening also is considered as the first sign of the opening of the Atlantic Ocean. However, I shall restore of the reconstruction of this basin in the forthcoming studies.

As a consequence, I want to emphasize that the Triassic rifting events and the Jurassic rifting events are independent of one another relatively. The general thoughts about this matter are that the Triassic rifting events were the preparations of the ones in the Jurassic. However, the Jurassic rifting phase differed from the Triassic rifting phase both in time and also in space and showed distinctive plate kinematics.

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APPENDICES

A.1: Carboniferous igneous rocks of the Eastern Europe and Turkey

A.2: Carboniferous igneous rock distribution of the Eastern Europe and Turkey

A.3: Permian igneous rocks of the Eastern Europe and Turkey

A.4: Permian igneous rock distribution of the Eastern Europe and Turkey

A.5: Triassic igneous rocks of the Eastern Europe and Turkey

A.6: Triassic igneous rock distribution of the Eastern Europe and Turkey

A.7: Lithostratigraphic charts of the tectonic units in the Eastern Europe

A.8: Carboniferous palaeogeography map

A.9: Early Permian palaeogeography map

A.10: Middle-Late Permian palaeogeography map

A.11: Early Triassic palaeogeography map

A.12: Carboniferous Pangaea A2 reconstruction

A.13: Early Permian Pangaea A2 reconstruction

A.14: Middle-Late Permian Pangaea A2 reconstruction

A.15: Early Triassic Pangaea A2 reconstruction

A.16: Permo-Triassic reconstruction of the tectonic evolution in the Mediterranean Region

Table A.1 Carboniferous igneous rocks of the Eastern Europe and Turkey

#s	Zone	Formation/Location	Rock Type	Age	Error	Method	Reference
1	Pelagonian	Skotini	granite	316,1	1,3	U/Pb	Vavassis et al. 2000
1	Pelagonian	Skotini	granite	315,3	0,8	U/Pb	Vavassis et al. 2000
2	Pelagonian	Edipsos	granodiorite	308,3	0,4	U/Pb	Vavassis et al. 2000
2	Pelagonian	Rovies	granite	319,6	0,7	U/Pb	Vavassis et al. 2000
3	Pelagonian	Veria	granite	307	11	U/Pb	Anders et al. 2007
3	Pelagonian	Veria	granite	300	2	SHRIMP	Anders et al. 2007
4	Pelagonian	Pilion Peninsula	mylonitic orthogneiss	309	13	U/Pb	Anders et al. 2007
5	Pelagonian	Evia Island	orthogneiss	303	2	SHRIMP	Anders et al. 2007

6	Pelagonian	Verdikoussa	granite	302,9	2,4	Pb/Pb	Reischmann et al. 2001
7	Pelagonian	Kastoria	granite	302,4	5/15	U/Pb	Mountrakis 1984
8	Pelagonian	Pieria	granite	302	5	U/Pb	Yarwood & Aftalion 1976
9	Gavrovo-Tripolitsa	Kithira Island	orthogneiss	324	2	U/Pb	Xypolias et al. 2006
9	Gavrovo-Tripolitsa	Kithira Island	orthogneiss	323	3/-3.1	U/Pb	Xypolias et al. 2006
9	Gavrovo-Tripolitsa	Kithira Island	orthogneiss	320	1,2	U/Pb	Xypolias et al. 2006
10	Attic-Cycladic	Paros Island	granitic gneiss	325	4	Pb/Pb	Engel and Reischmann 1998
10	Attic-Cycladic	Paros Island	granitic gneiss	302	2	Pb/Pb	Engel and Reischmann 1998

10	Attic-Cycladic	Paros Island	granitic gneiss	317	1	Pb/Pb	Engel and Reischmann 1998
10	Attic-Cycladic	Paros Island	granitic gneiss	314	3	Pb/Pb	Engel and Reischmann 1998
10	Attic-Cycladic	Paros Island	granitic gneiss	315	2	Pb/Pb	Engel and Reischmann 1998
10	Attic-Cycladic	Paros Island	granitic gneiss	319	2	Pb/Pb	Engel and Reischmann 1998
11	Vardar	Pigi	orthogneiss	319	4	SIMS-SHRIMP	Anders et al. 2005
12	Balkan Terrane	San Nikola	granite	311,9	4,1	HR-SIMS U-Th-Pb	Carrigan et al. 2005
13	Balkan Terrane	Petrohan	granodiorite	304,6	4	HR-SIMS U-Th-Pb	Carrigan et al. 2005
14	Sredna Gora	Smilovene	granite	304,1	5,5	HR-SIMS U-Th-Pb	Carrigan et al. 2005
14	Sredna Gora	Korprivshtitsa	granite	312	5,4	HR-SIMS U-Th-Pb	Carrigan et al. 2005

15	Sredna Gora	Hisara	granite	303,5	3,3	HR-SIMS U-Th-Pb	Carrigan et al. 2005
16	Sredna Gora	Poibrene pluton	diorite	302,9	1,4	40Ar/39Ar Hornblende	Velichkova et al. 2004
17	Stara Planina	Klissura	granite	329,7	7,6	U-Pb single zircon	Malinov et al. 2004
18	Rhodope	Central Rhodopean Dome	metagranite	300	11	U-Pb single zircon	Peytcheva et al. 2004
18	Rhodope	Central Rhodopean Dome	metagranite	331	10	U-Pb single zircon	Peytcheva et al. 2004
19	East Srednogorie	Strandzha	intrusive (granitic rock)	301,26	0,97	ID-TIMS	Georgiev et al.2012
20	Balkan Terrane	Vejen	granodiorite	314	4,8	U-Pb single zircon	Kamenov et al. 2002
21	Rhodope	Byala Reka	granite	301	4	Ion-microprobe U-Pb	Carrigan et al. 2003
22	S.Carpathians	Poniasca pluton	diorite	311	2	SHRIMP (U-Pb)	Duchesne et al. 2008
23	Apuseni Mts.	Someş-Codru Moma	granite	350,5	4,9	LA-ICP-MS zircon U-Pb	Balintoni et al. 2007

24	S.Carpathians	Cherbelezu	granite	311	10	K-Ar	Soroiu et al. 1970
25	S.Carpathians	Sfirdinu	granite	339	12	K-Ar	Soroiu et al. 1970
26	Kucaj Terrane	Brnjica	granitoids	304	-	-	Balintoni et al. 2009
27	Kucaj Terrane	Neresnica	granitoids	304	-	-	Balintoni et al. 2009
28	Kucaj Terrane	Gornjani	granitoids	304	-	-	Balintoni et al. 2009
29	Kucaj Terrane	Beljanica	granitoids	304	-	-	Balintoni et al. 2009
30	Tisia Terrane	Moragy Unit	monzogranite	350	6	Pb-Pb	Klötzli et al. 2004
30	Tisia Terrane	Moragy Unit	monzogranite	352	14	Pb-Pb	Klötzli et al. 2004
31	W.Carpathians	Bratislava Massif	granodiorite	355,4	4,7	SHRIMP U-Th-Pb	Kohút et al. 2009
31	W.Carpathians	Modra Massif	tonalite	346,8	4,1	SHRIMP U-Th-Pb	Kohút et al. 2009

31	W.Carpathians	Tatric Unit	granodiorite	355	18	Electron-microprobe (monazite)	Finger et al. 2003
31	W.Carpathians	Tatric Unit	granodiorite	345	22	Electron-microprobe (monazite)	Finger et al. 2003
32	W.Carpathians	Tatra Mts.	granite	347	14	U-Pb	Poller et al. 2000
32	W.Carpathians	Tatra Mts.	granite	357	16	U-Pb	Poller et al. 2000
32	W.Carpathians	West-Tatra	granite	360-350		U-Pb single zircon	Poller et al. 2001
32	W.Carpathians	High-Tatra	granite	314	4	U-Pb single zircon	Poller et al. 2001
32	W.Carpathians	High-Tatra	diorite	341	5	U-Pb single zircon	Poller et al. 2001
32	W.Carpathians	Tatric Unit	leucogranodiorite	347	24	Electron-microprobe (monazite)	Finger et al. 2003
32	W.Carpathians	Tatric Unit	tonalite	327	28	Electron-microprobe (monazite)	Finger et al. 2003
32	W.Carpathians	Tatric Unit	leucotonalite	317	15	Electron-microprobe (monazite)	Finger et al. 2003

33	C.W.Carpathians	Northern Veporic Unit	granitic gneiss	356	11	SHRIMP U-Pb	Gaab et al. 2005
33	C.W.Carpathians	Northern Veporic Unit	granite	359	6	SHRIMP U-Pb	Gaab et al. 2005
34	C.W.Carpathians	Northern Veporic Unit	granitiod	329	+72-34	U-Pb single zircon	Gaab et al. 2005
34	C.W.Carpathians	Northern Veporic Unit	felsic gneiss	334	19	U-Pb single zircon	Gaab et al. 2005
35	W.Carpathians	Low-Tatra Mts.	granite	330	10	U-Pb single zircon	Poller et al. 2001
35	W.Carpathians	Veporic Basement	metadiorite	346	1	U-Pb	Putis et al. 2001
35	W.Carpathians	Veporic Unit	granite	357	21	Electron-microprobe (monazite)	Finger et al. 2003
35	W.Carpathians	Veporic Unit	granite	352	13	Electron-microprobe (monazite)	Finger et al. 2003
35	W.Carpathians	Veporic Unit	leucogranodiorite	321	18	Electron-microprobe (monazite)	Finger et al. 2003
35	W.Carpathians	Veporic Unit	leucogranite	359	17	Electron-microprobe (monazite)	Finger et al. 2003

36	W.Carpathians	Nizke Tatry Mts.	orthogneiss	349	17	Electron-microprobe (monazite)	Petrik 2006
36	W.Carpathians	Nizke Tatry Mts.	orthogneiss	340	8	Electron-microprobe (monazite)	Petrik 2006
36	W.Carpathians	Nizke Tatry Mts.	orthogneiss	354	15	Electron-microprobe (monazite)	Petrik 2006
36	W.Carpathians	Nizke Tatry Mts.	orthogneiss	322	8	Electron-microprobe (monazite)	Petrik 2006
37	W.Carpathians	Tatric Unit	granodiorite	326	31	Electron-microprobe (monazite)	Finger et al. 2003
38	W.Carpathians	Tatric Unit	granite	348	22	Electron-microprobe (monazite)	Finger et al. 2003
39	W.Carpathians	Fatra	granite	310	8	U-Pb single zircon	Poller et al. 2001
39	C.W.Carpathians	Tatric Unit (Fatra)	granite	304.4	7.5	U–Pb single zircon	Poller et al. 2005
39	C.W.Carpathians	Tatric Unit (Fatra)	granodiorite	305	17	U–Pb single zircon	Poller et al. 2005
39	W.Carpathians	Tatric Unit	granodiorite	342	18	Electron-microprobe (monazite)	Finger et al. 2003

39	W.Carpathians	Tatric Unit	granite	336	9	Electron-microprobe (monazite)	Finger et al. 2003
39	W.Carpathians	Tatric Unit	granodiorite	333	24	Electron-microprobe (monazite)	Finger et al. 2003
39	W.Carpathians	Tatric Unit	granodiorite	348	21	Electron-microprobe (monazite)	Finger et al. 2003
39	W.Carpathians	Tatric Unit	granite	348	18	Electron-microprobe (monazite)	Finger et al. 2003
39	W.Carpathians	Tatric Unit	leucogranite	343	12	Electron-microprobe (monazite)	Finger et al. 2003
39	W.Carpathians	Tatric Unit	tonalite	308	30	Electron-microprobe (monazite)	Finger et al. 2003
40	W.Carpathians	Tatric Unit	granite	348	22	Electron-microprobe (monazite)	Finger et al. 2003
41	W.Carpathians	Tatric Unit	leucogranite	342	13	Electron-microprobe (monazite)	Finger et al. 2003
42	W.Carpathians	Tatric Unit	leucotonalite	323	22	Electron-microprobe (monazite)	Finger et al. 2003
42	W.Carpathians	Tatric Unit	granodiorite	357	13	Electron-microprobe (monazite)	Finger et al. 2003

42	W.Carpathians	Tatric Unit	tonalite	352	17	Electron-microprobe (monazite)	Finger et al. 2003
42	W.Carpathians	Tatric Unit	leucogranite	331	22	Electron-microprobe (monazite)	Finger et al. 2003
43	Strandja Massif	Üsküp	metagranite	309	24	Pb-Pb	Okay et al. 2001
44	Central Sakarya Basement	Borçak	granodiorite	319,5	1,1	SHRIMP	Ustaömer et al. 2012
44	Central Sakarya Basement	Küplü	granitoid	324,3	1,5	SHRIMP	Ustaömer et al. 2012
44	Central Sakarya Basement	Çaltı	granodiorite-tonalite	327,2	1,9	SHRIMP	Ustaömer et al. 2012
45	Kastamonu Belt-Central Pontides	Sivrikaya granite	tonalite	303	0,54	U-Pb	Cameroon 2008
45	Kastamonu Belt-Central Pontides	Sivrikaya granite	granodiorite	304	1,2	U-Pb	Cameroon 2008

45	Kastamonu Belt-Central Pontides	Sivrikaya granite	granodiorite	317	16	Pb-Pb	Cameroon 2008
46	Eastern Pontides	Gümüşhane Pluton	granite to granodiorite	316,8	2.9-3.6	Ar-Ar	Topuz et al. 2010
46	Eastern Pontides	Gümüşhane Pluton	granite to granodiorite	318,3	3.4-4	Ar-Ar	Topuz et al. 2010
46	Eastern Pontides	Gümüşhane Pluton	granite to granodiorite	316	2.3-3.9	Ar-Ar	Topuz et al. 2010
46	Eastern Pontides	Gümüşhane Pluton	granite to granodiorite	316,5	3.8-4.3	Ar-Ar	Topuz et al. 2010
46	Eastern Pontides	Gümüşhane Pluton	granite to granodiorite	341,4	5,4	conventional U-Pb	Topuz et al. 2010
46	Eastern Pontides	Gümüşhane Pluton	granite to granodiorite	329	6	LA-ICP-MS U–Pb	Topuz et al. 2010
46	Eastern Pontides	Gümüşhane Pluton	granite to granodiorite	319	5	LA-ICP-MS U–Pb	Topuz et al. 2010

Figure A.2 Carboniferous igneous rock distribution of the Eastern Europe and Turkey

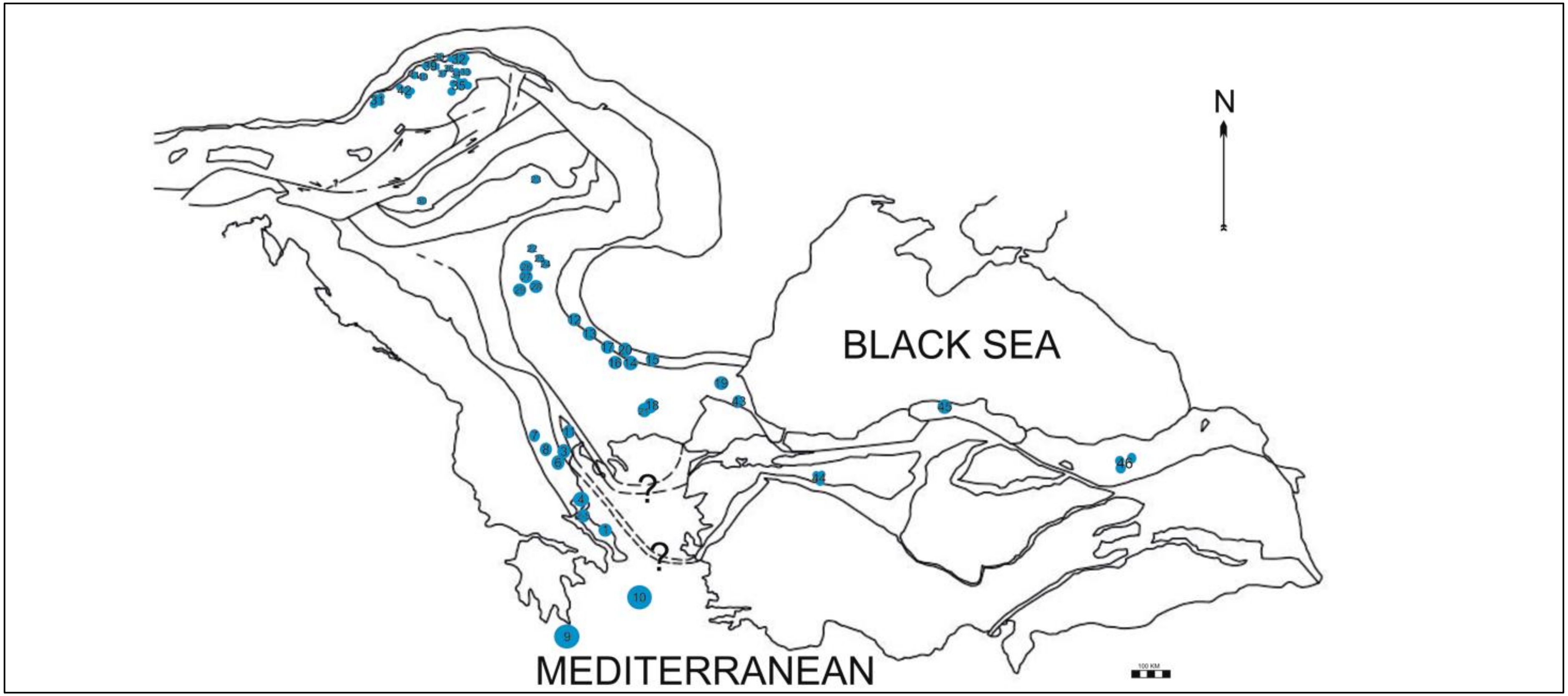

Table A.3 Permian igneous rocks of the Eastern Europe and Turkey

#s	Zone	Formation/Location	Rock Type	Age	Error	Method	Reference
1	Pelagonian	Skiathos Island	orthogneiss	289	14	U/Pb	Anders et al. 2007
1	Pelagonian	Skiathos Island	orthogneiss	287	11/-12	U/Pb	Anders et al. 2007
1	Pelagonian	Skiathos Island	orthogneiss	264	14	U/Pb	Anders et al. 2007
2	Pelagonian	Pilion Peninsula	orthogneiss	279	14	U/Pb	Anders et al. 2007
2	Pelagonian	Pilion Peninsula	orthogneiss	281	3	Pb/Pb	Anders et al. 2007
3	Pelagonian	Mavrovouni	orthogneiss	280	2	U/Pb	Anders et al. 2007
4	Pelagonian	Verdikoussa	granitic rock	283,6	4	Pb/Pb	Reischmann et al. 2001
4	Pelagonian	Verdikoussa	granite	284,8	4,2	Pb/Pb	Reischmann et al. 2001
4	Pelagonian	Elassona	granite	283,9	3,9	Pb/Pb	Reischmann et al. 2001

4	Pelagonian	Olympiada	diorite	283,3	7,1	Pb/Pb	Reischmann et al. 2001
4	Pelagonian	Olympos-Ossa Unit	granodiorite	271,6	3,3	Pb/Pb	Reischmann et al. 2001
5	Pelagonian	Verdikoussa	orthogneiss	279	2	U/Pb	Anders et al. 2007
6	Pelagonian	Varnous Mts	granodiorite	298	7	Pb/Pb	Anders et al. 2005
6	Pelagonian	Kastoria	granite	292	5	Pb/Pb	Anders et al. 2005
6	Pelagonian	Varnous Mts	mafic rock	282	8	Pb/Pb	Anders et al. 2007
6	Pelagonian	Varnous Mts	mafic rock	296	6	Pb/Pb	Anders et al. 2007
6	Pelagonian	Varnous Mts	felsic rock	289	8	Pb/Pb	Anders et al. 2007
6	Pelagonian	Varnous Mts	intermediate rock	294	4	Pb/Pb	Anders et al. 2007
6	Pelagonian	Varnous Mts	intermediate rock	282	1	U/Pb	Anders et al. 2007

6	Pelagonian	Varnous Mts	intermediate rock	290	6	Pb/Pb	Anders et al. 2007
6	Pelagonian	Florina	granite	258-268	7	K/Ar	Mountrakis 1984
7	Pelagonian	Voras Mts	orthogneiss	285	2	U/Pb	Anders et al. 2007
7	Pelagonian	Kaimakchalan	granite	276	9	Pb/Pb	Anders et al. 2007
8	Serbo-Macedonian	Mt. Athos-Gregoriou	granite	292,6	2,9	SHRIMP	Himmerkus et al. 2011
9	Rhodope	Pangeon Unit	augen gneiss	275,5	3,6	Pb/Pb	Turpaud 2006
9	Rhodope	Pangeon Unit	bt gneiss	282,7	3	Pb/Pb	Turpaud 2006
9	Rhodope	Pangeon Unit	augen gneiss	286,4	4	Pb/Pb	Turpaud 2006
9	Rhodope	Pangeon Unit	bt gneiss	278,7	7,7	Pb/Pb	Turpaud 2006
9	Rhodope	Pangeon Unit	augen gneiss	282,9	4,8	Pb/Pb	Turpaud 2006

9	Rhodope	Pangeon Unit	augen gneiss	289,5	7,6	Pb/Pb	Turpaud 2006
9	Rhodope	Pangeon Unit	leucocratic gneiss	269,7	9	Pb/Pb	Turpaud 2006
9	Rhodope	Pangeon Unit	leucocratic gneiss	281,1	6,44	Pb/Pb	Turpaud 2006
9	Rhodope	Pangeon Unit	augen gneiss	291,2	8,8	Pb/Pb	Turpaud 2006
9	Rhodope	Pangeon Unit	augen gneiss	275,8	3,9	Pb/Pb	Turpaud 2006
10	Rhodope	Byala-Reka	leucocratic gneiss	278	26	Pb/Pb	Turpaud 2006
10	Rhodope	Byala-Reka	augen gneiss	289,7	6,5	Pb/Pb	Turpaud 2006
11	East Srednogorie	Strandzha	intrusive (granitic rock)	293,8	7,6	LA-ICPMS	Georgiev et al.2012
11	East Srednogorie	Strandzha	intrusive (granitic rock)	274,1	4,5	LA-ICPMS	Georgiev et al.2012
12	Sredna Gora	Strelcha	granite	289,5	7,8	HR-SIMS U-Th-Pb	Carrigan et al. 2005

13	Sredna Gora	Poibrene pluton	diorite	263	0,69	40Ar/39Ar Biotite	Velichkova et al. 2004
14	S.Carpathians	Ogradena	granite	260	9	K-Ar	Soroiu et al. 1970
15	S.Carpathians	Synorogenic Granites	gneissic granite	296	12	K-Ar	Soroiu et al. 1970
16	S.Carpathians	Muntele Mie	granodiorite	264	10	K-Ar	Soroiu et al. 1970
16	S.Carpathians	Vîrful Pietrei	granite	280	9	K-Ar	Soroiu et al. 1970
17	Apuseni Mts.	Highiş (Cladova)	diorite	266,7	3,8	U-Pb	Pana et al. 2002
17	Apuseni Mts.	Highiş (Jernova)	microgranite	264,2	2,3	U-Pb	Pana et al. 2002
17	Apuseni Mts.	Paiuşeni	diorite	267	-	-	Balintoni et al. 2009
17	Apuseni Mts.	Paiuşeni	granite	264	-	-	Balintoni et al. 2009
18	Apuseni Mts.	Muntele Mare	granite	278,4	2,1	U-Pb	Pana et al. 2002

18	Apuseni Mts.	Muntele Mare	granite	291,1	1,1	LA-ICP-MS zircon U-Pb	Balintoni et al. 2009
19	W.Carpathians	Gemeric Unit	granite	263	28	Electron-microprobe (monazite)	Finger et al. 2003
20	W.Carpathians	Gemeric Unit	granite	272	11	Th-U-Pb (monazite)	Finger&Broska 1999
20	W.Carpathians	Gemeric Unit	granite	276	13	Th-U-Pb (monazite)	Finger&Broska 1999
20	W.Carpathians	Gemeric Unit	granite	273	13	Th-U-Pb (monazite)	Finger&Broska 1999
20	W.Carpathians	Gemeric Unit	leucogranite	255	22	U-Pb single zircon	Poller et al. 2002
20	W.Carpathians	Gemeric Unit	biotite granite	273	30	U-Pb single zircon	Poller et al. 2002
20	W.Carpathians	Gemeric Unit	granite	270	64	Rb-Sr	Kovach et al. 1986
20	W.Carpathians	Gemeric Unit	granite	290	40	Rb-Sr	Kovach et al. 1986
20	W.Carpathians	Gemeric Unit	granite	272	47	Rb-Sr	Kovach et al. 1986

20	W.Carpathians	Gemeric Unit	granite	251	16	Rb-Sr	Kovach et al. 1986
21	W.Carpathians	Veporic Unit	leucogranite	263	19	Electron-microprobe (monazite)	Finger et al. 2003
21	W.Carpathians	Veporic Unit	granite	266	16	Electron-microprobe (monazite)	Finger et al. 2003
21	W.Carpathians	Veporic Unit	granite	269	22	Electron-microprobe (monazite)	Finger et al. 2003
22	C.W.Carpathians	Tatric Unit (Fatra)	orthogneiss	281	14	U–Pb single zircon	Poller et al. 2005
23	W.Carpathians	Tatric Unit	granite	273	17	Electron-microprobe (monazite)	Finger et al. 2003
24	Strandja Massif	Kırklareli	metagranite	271	2	Pb-Pb	Okay et al. 2001
24	Strandja Massif	Kula	metagranite	271	11	Pb-Pb	Okay et al. 2001
24	Strandja Massif	Kırklareli	metagranite	257	6,2	Pb-Pb	Sunal et al. 2006
25	İstanbul	Sancaktepe	granite	253,7	1,75	SHRIMP	Yılmaz Şahin et al. 2010

25	İstanbul	Sancaktepe	granite	255	5	Rb-Sr	Yılmaz 1977
25	İstanbul	Sancaktepe	granite	254	-	K-Ar (biotite)	Yılmaz 1977
26	Bolu Massif	Sünnice Group	meta-granitic rock	262	19	single zircon	Ustaömer et al. 2005
27	Kastamonu Belt-Central Pontides	Deliktaş leucogranite	Monzogranite	294,3	1,1	U-Pb	Cameroon 2008
27	Kastamonu Belt-Central Pontides	Deliktaş leucogranite	Monzogranite	291	5,1	U-Pb	Cameroon 2008

Figure A.4 Permian igneous rock distribution of the Eastern Europe and Turkey

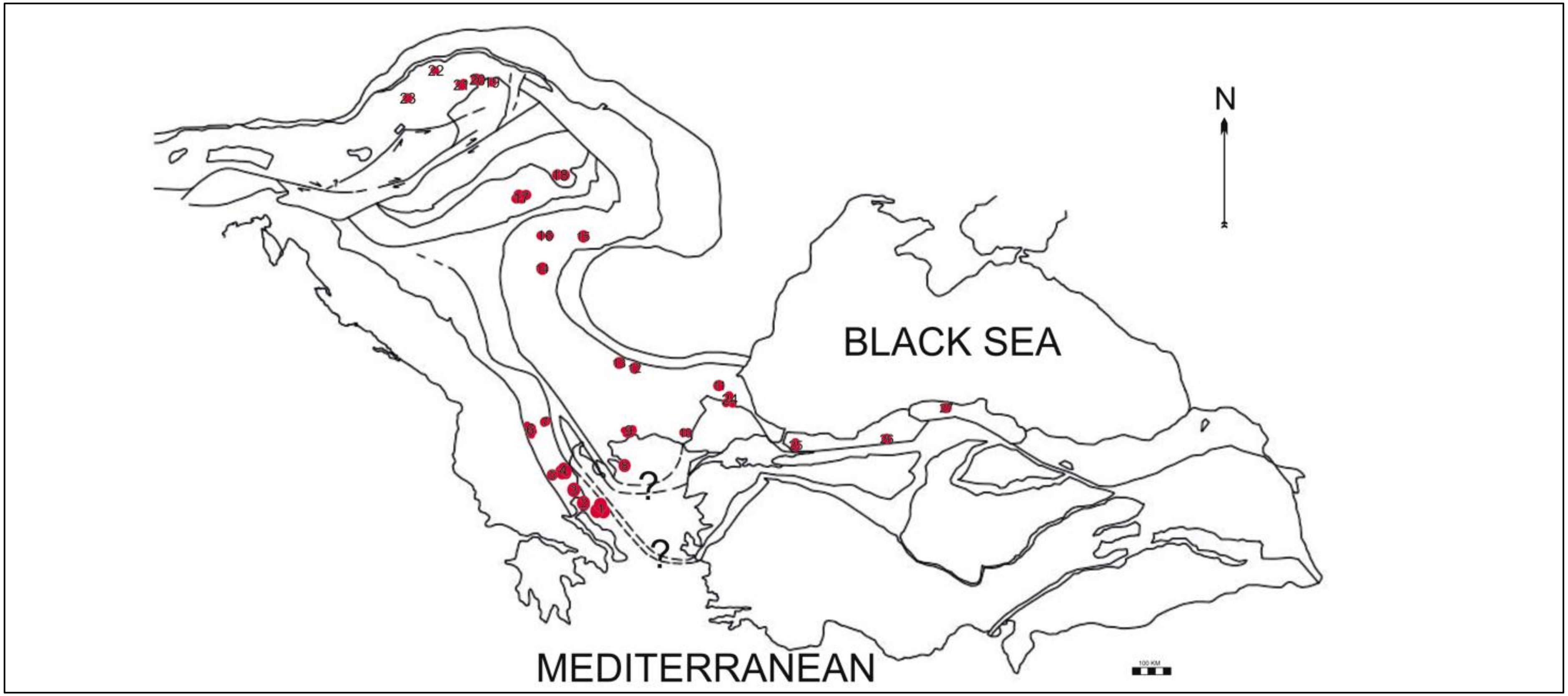

Table A.5 Triassic igneous rocks of the Eastern Europe and Turkey

#s	Zone	Formation/Location	Rock Type	Age	Error	Method	Reference
1	Pelagonian	Mt. Olympos	orthogneiss	245	8	U/Pb	Anders et al. 2007
2	Serbo-Macedonian	Igralishte (Ograzden)	granite	240	+13/-9	U-Pb single zircon	Zidarov et al. 2004
2	Serbo-Macedonian	Skrut (Ograzden)	granodiorite	248,85	0,7	ID-TIMS	Peytcheva et al. 2005
3	S.Carpathians	Muntele Mie	granodiorite	249	10	K-Ar	Soroiu et al. 1970
4	W.Carpathians	Gemeric Unit	leucogranite	245	18	U-Pb single zircon	Poller et al. 2002
4	W.Carpathians	Gemeric Unit	granite	246	5	U-Pb single zircon	Poller et al. 2002
4	W.Carpathians	Gemeric Unit	granite	246	25	Rb-Sr	Kovach et al. 1986
5	C.W.Carpathians	Tatric Unit (Fatra)	leucogranite	231	17	U–Pb single zircon	Poller et al. 2005
6	Bornova Flysch Zone	Karaburun Granitoid	quartz-diorite	247,1	2	U-Pb	Akal et al. 2011

7	Menderes Massif	Ödemiş-Kiraz Submassif	orthogneiss	245,7	4,6	Pb-Pb	Koralay et al. 2001
7	Menderes Massif	Ödemiş-Kiraz Submassif	orthogneiss	241,1	5,2	Pb-Pb	Koralay et al. 2001

Figure A.6 Triassic igneous rock distribution of the Eastern Europe and Turkey

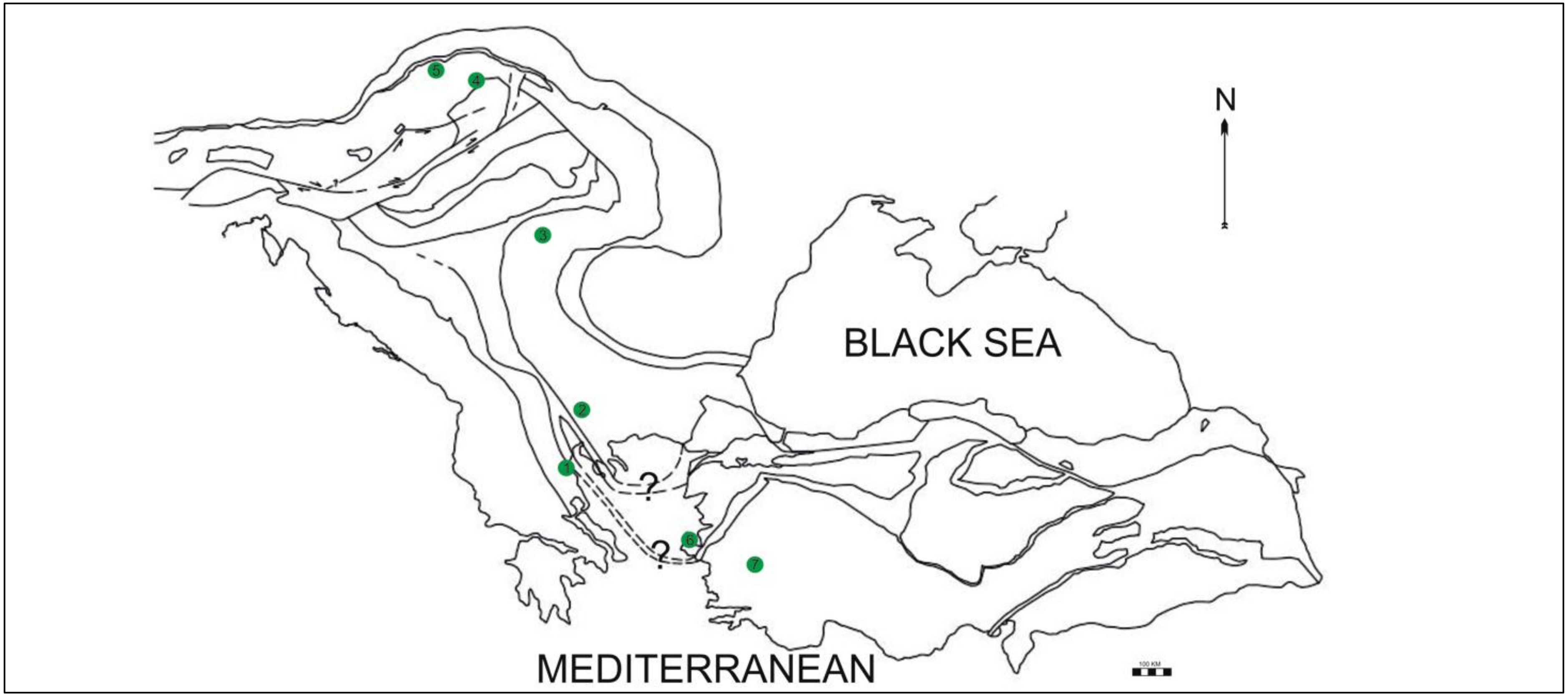

Figure A.7 Lithostratigraphic charts of the tectonic units in the Eastern Europe

Figure A.8 Carboniferous palaeogeography map

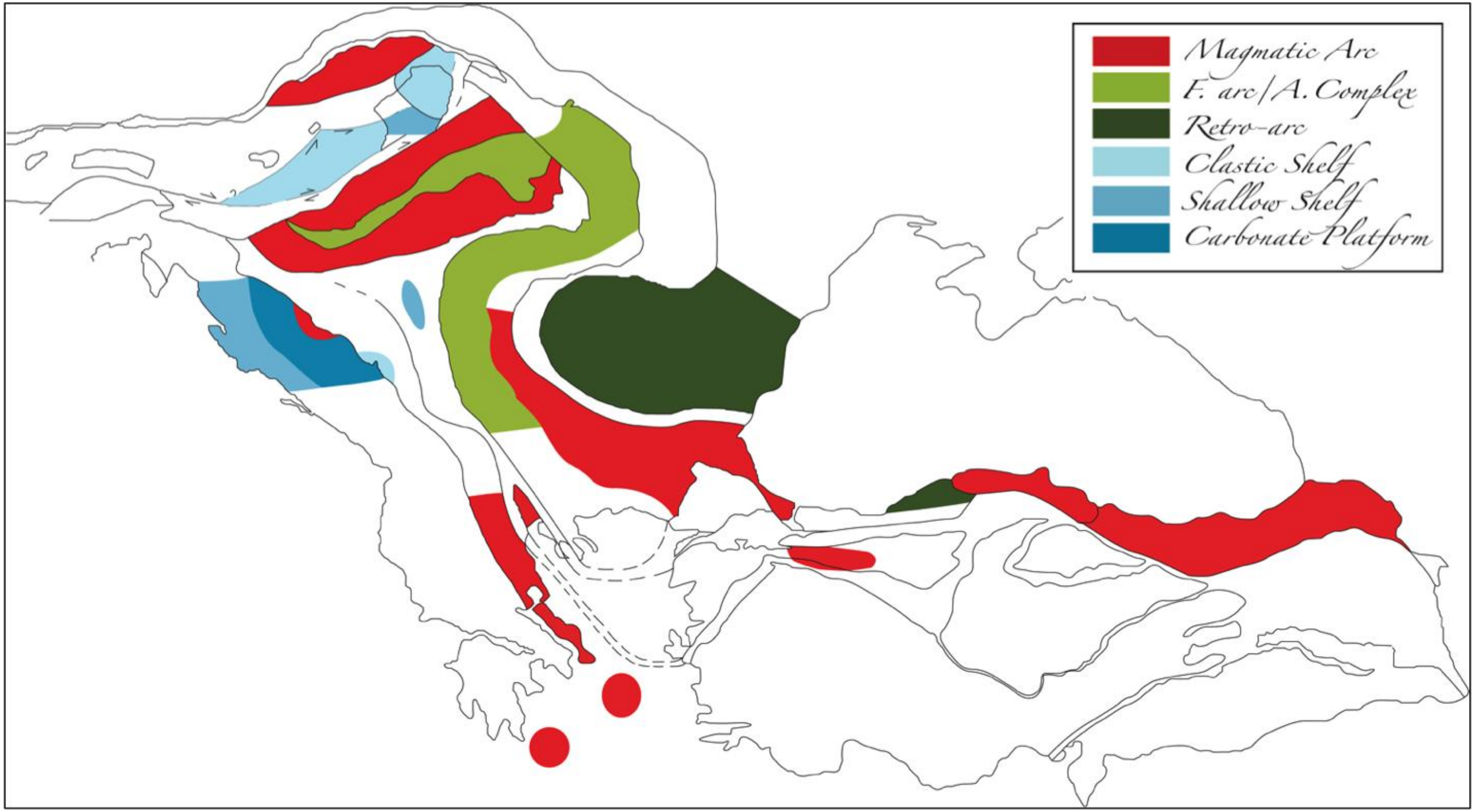

Figure A.9 Early Permian palaeogeography map

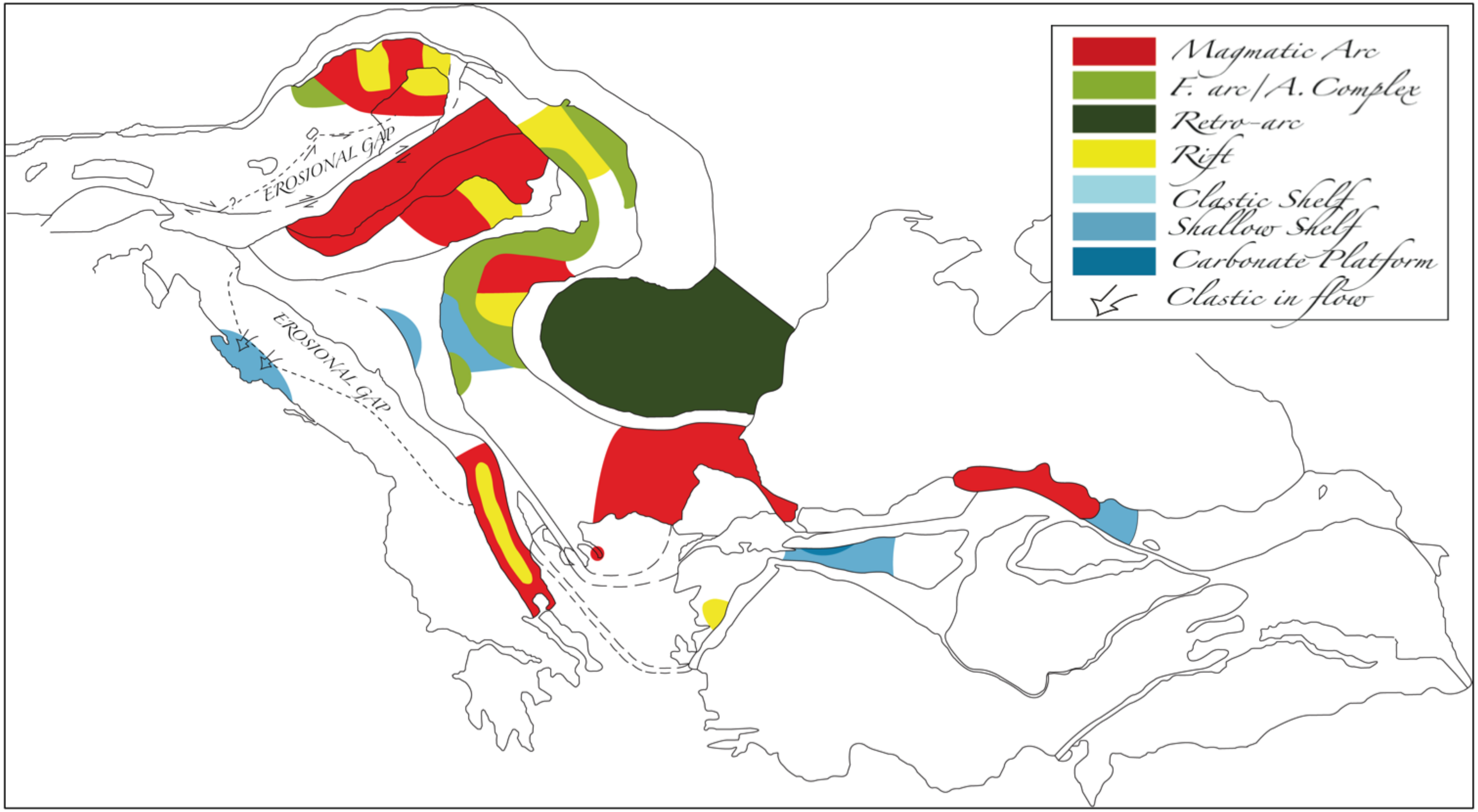

Figure A.10 Middle-late Permian palaeogeography map

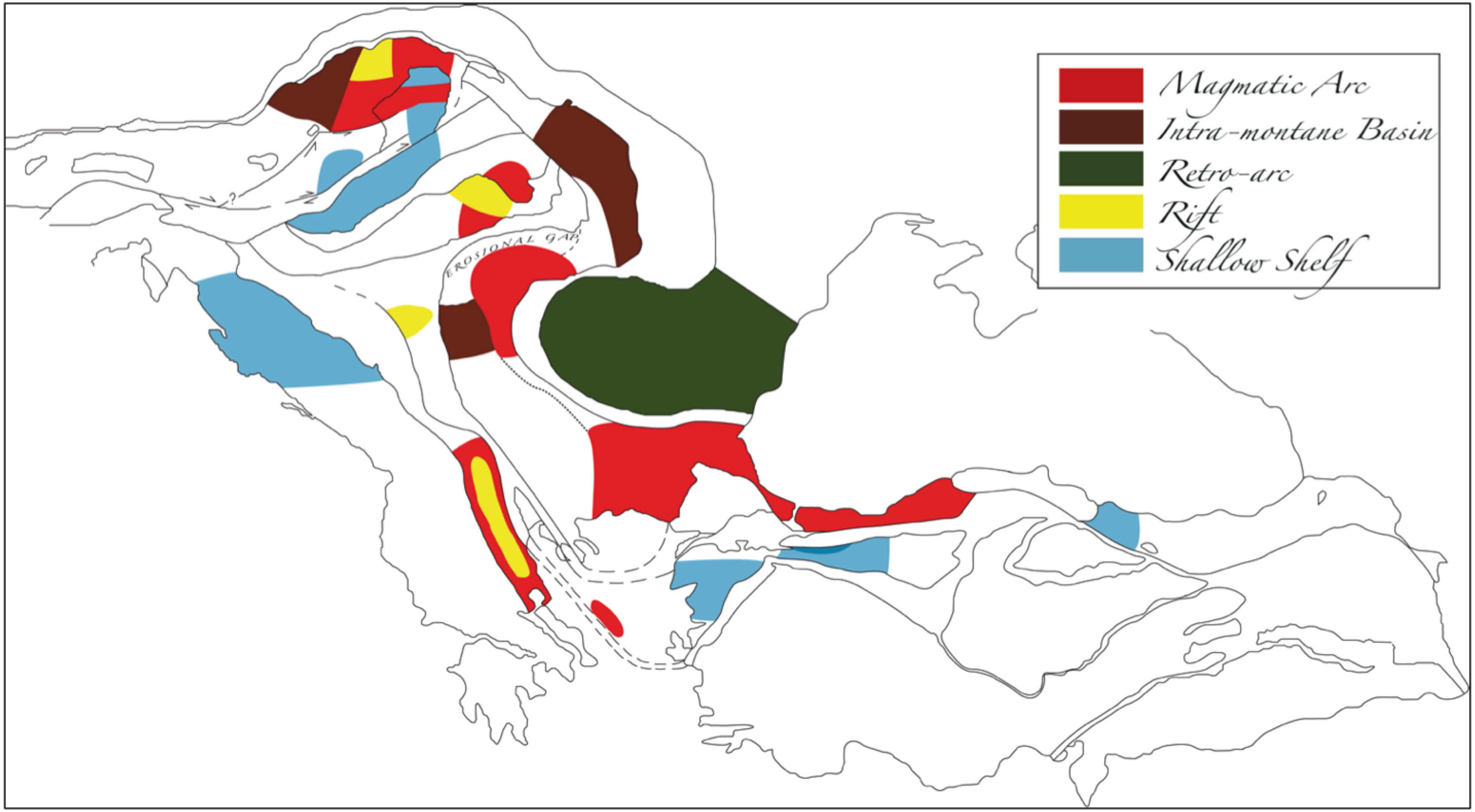

Figure A.11 Early Triassic palaeogeography map

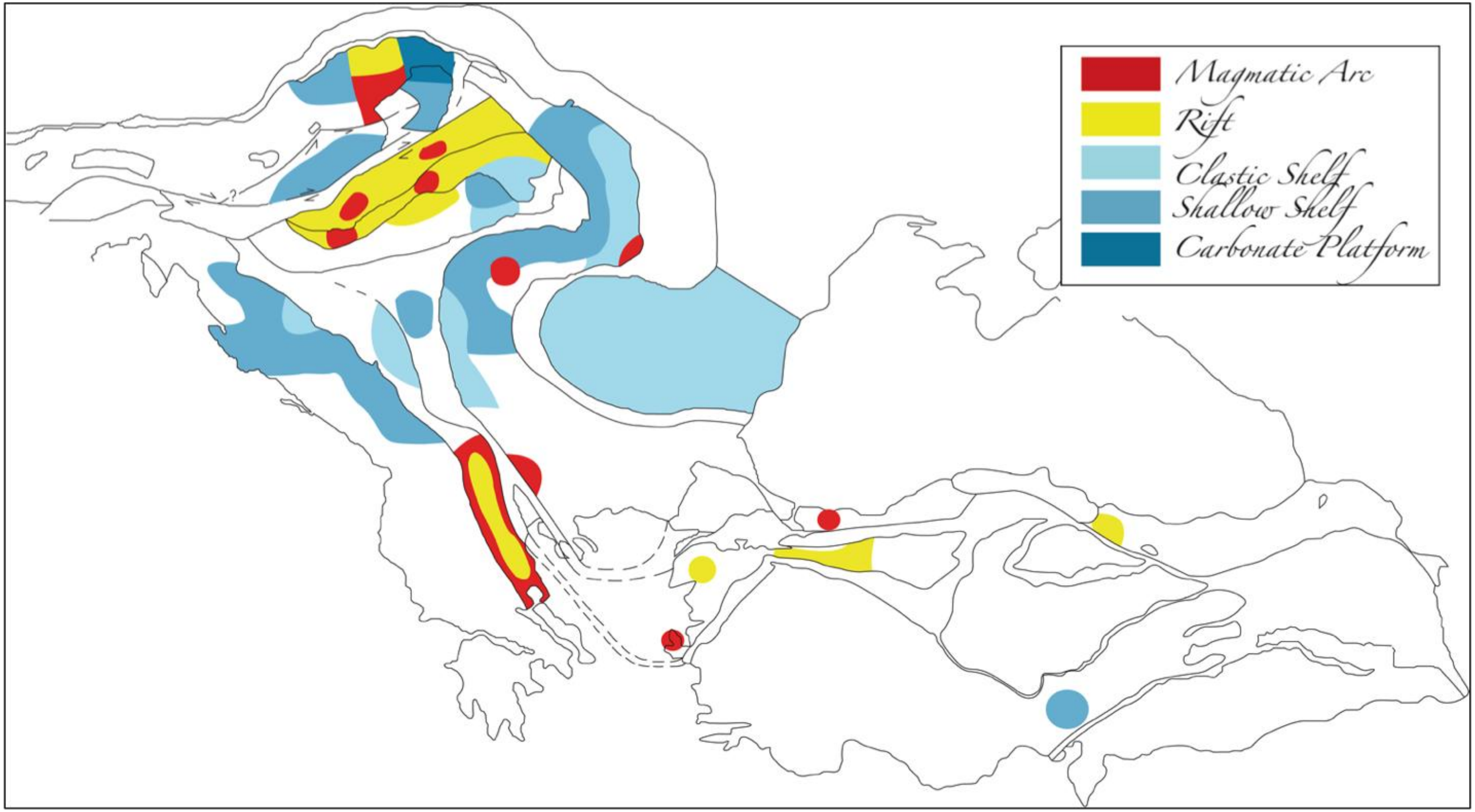

Figure A.12 Carboniferous Pangaea A2 reconstruction

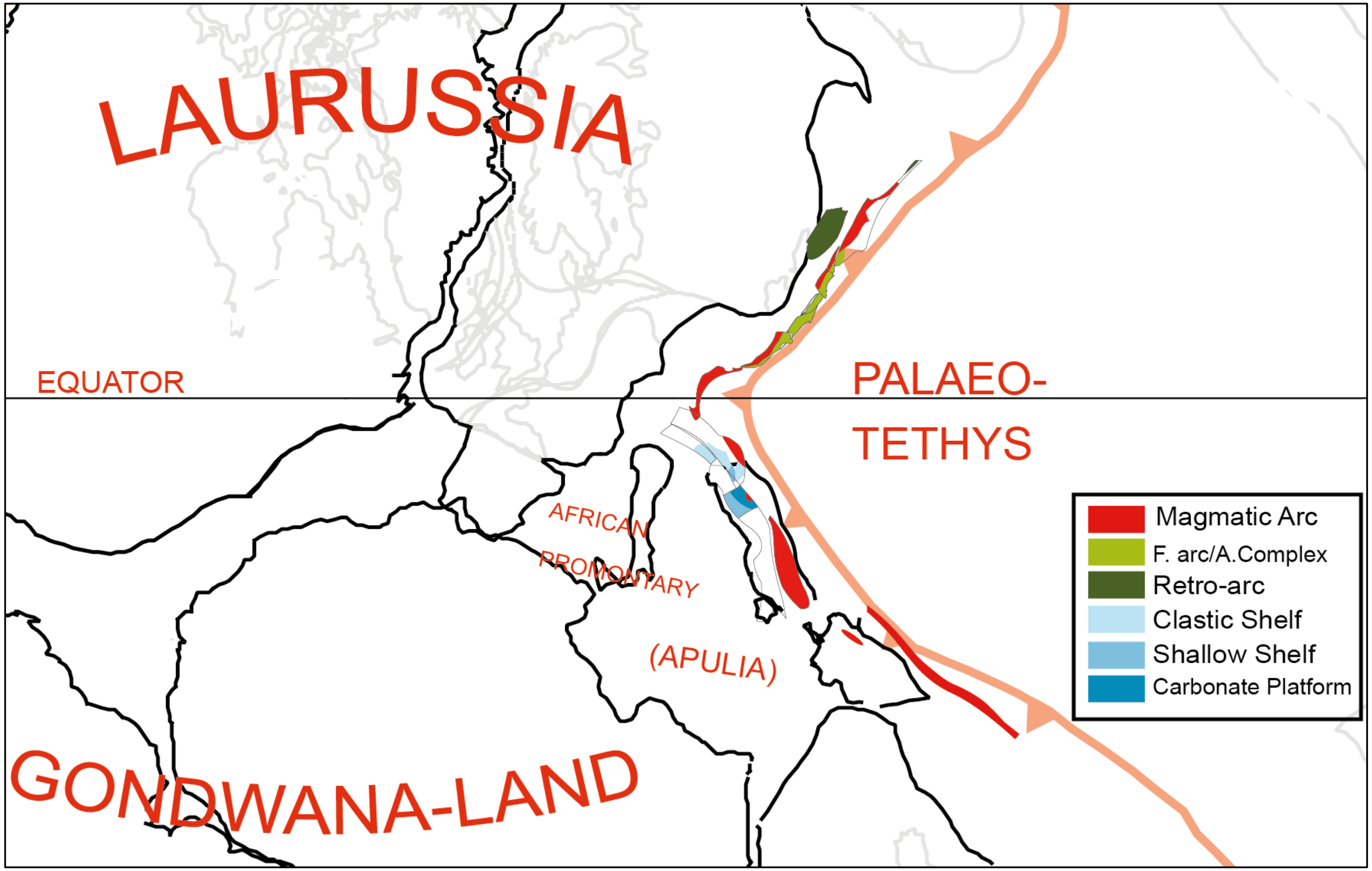

Figure A.13 Early Permian Pangaea A2 reconstruction

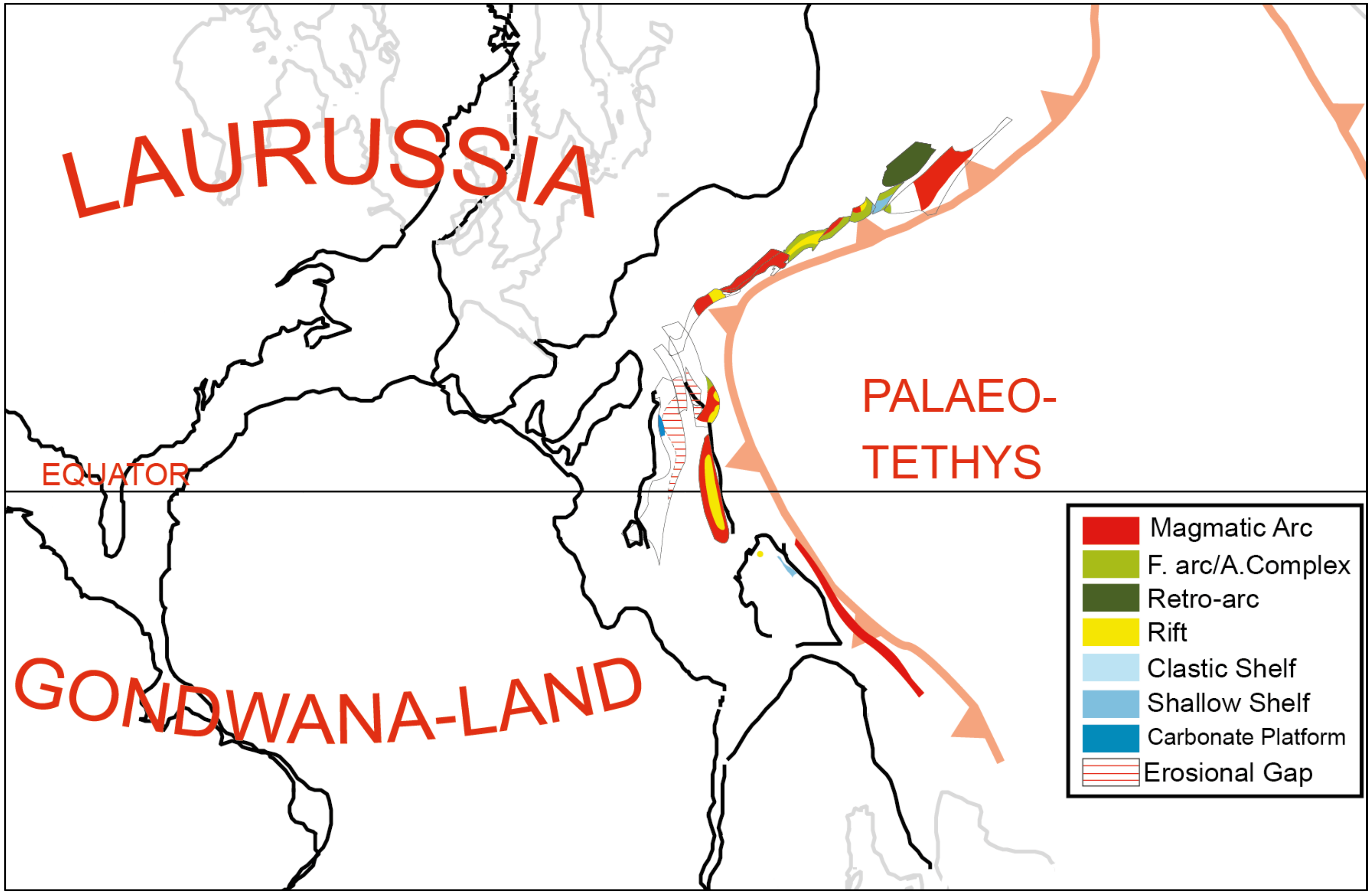

Figure A.14 Middle-Late Permian Pangaea A2 reconstruction

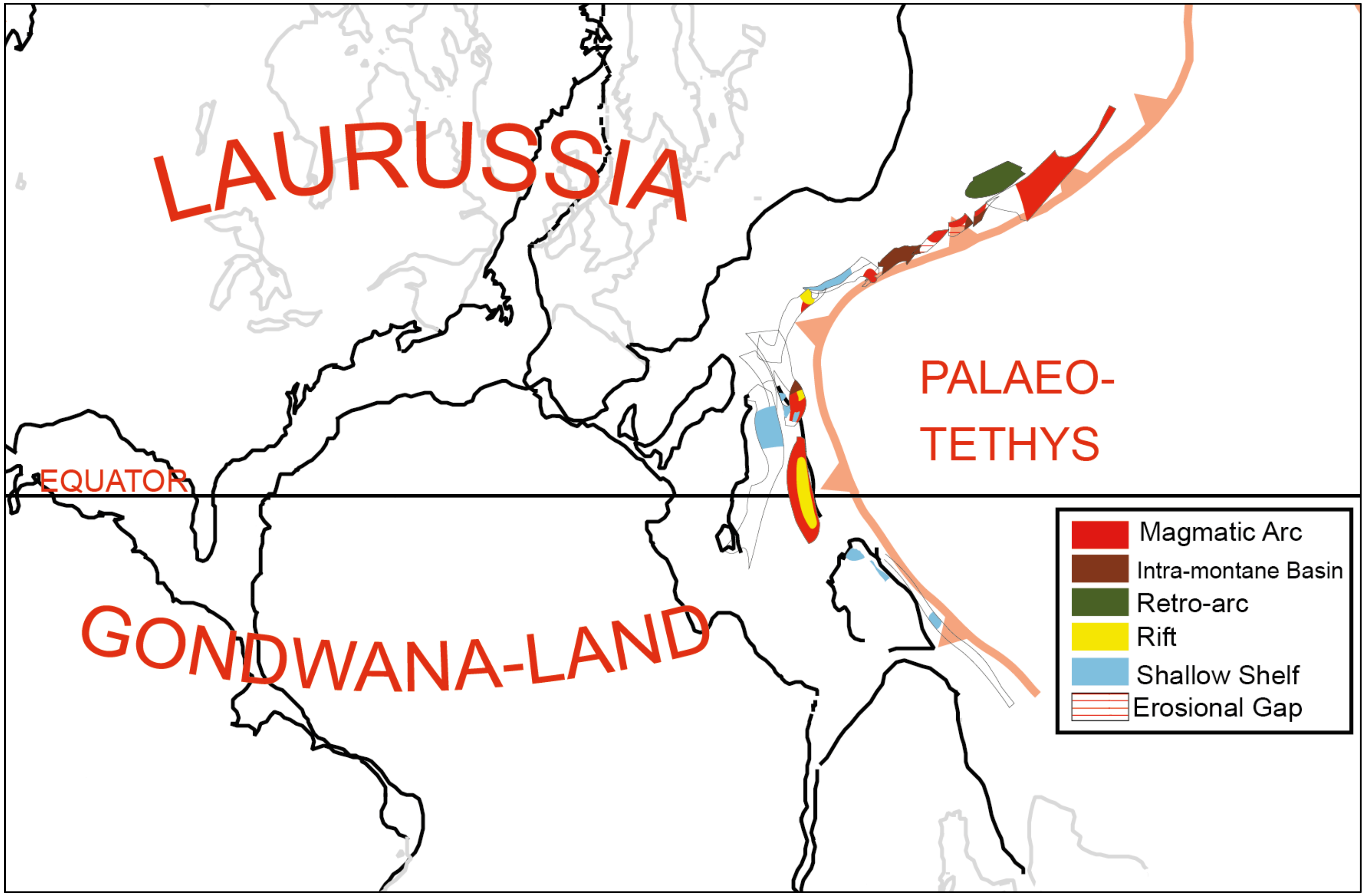

Figure A.15 Early Triassic Pangaea A2 reconstruction

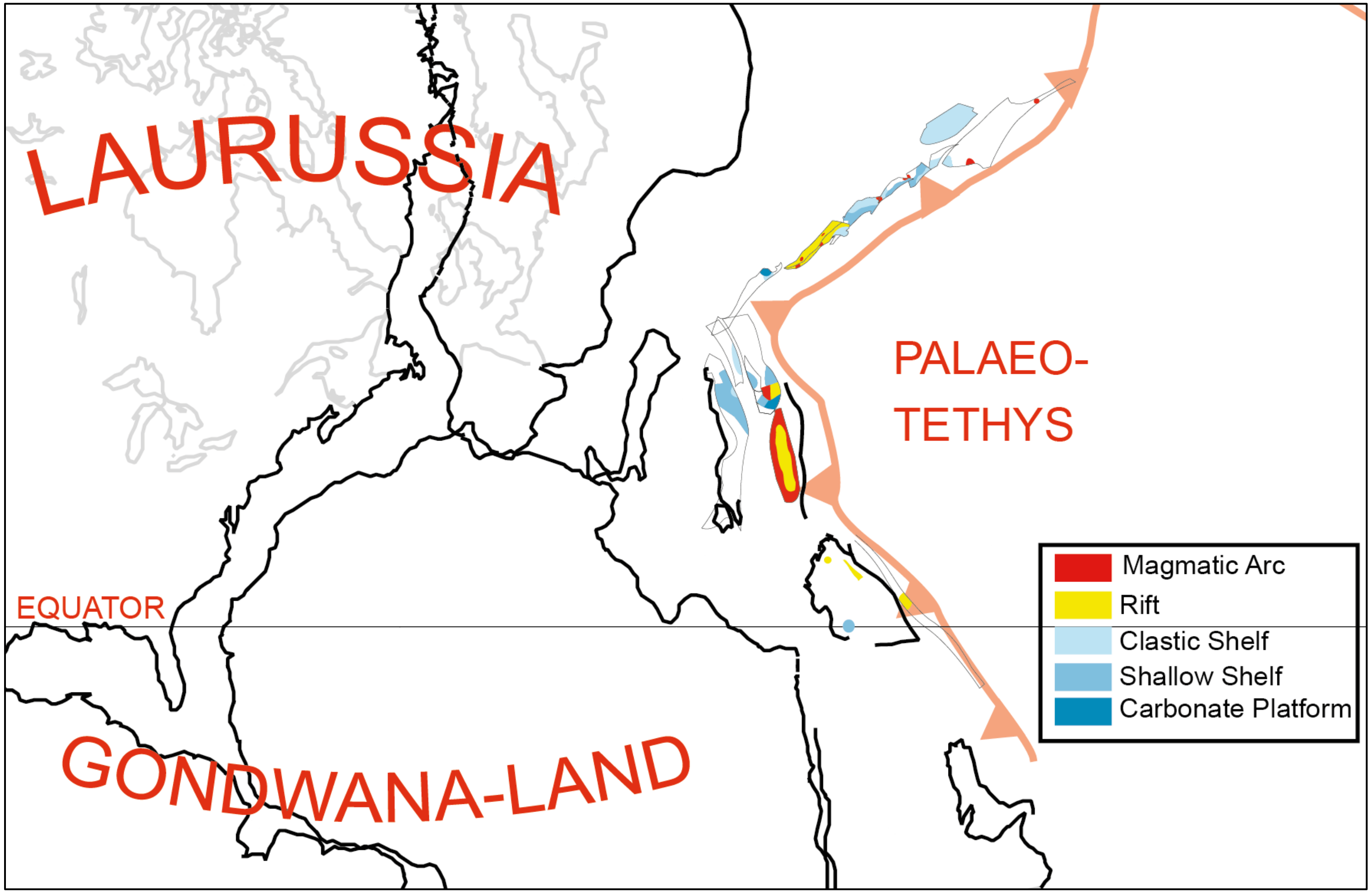

Figure A.16 Permo-Triassic reconstruction of the tectonic evolution in the Mediterranean Region

CURRICULUM VITAE

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- **Sağdıç, N.G.,** Sunal, G., and Şengör, A.M.C., 2014. Hercynian And Post-Hercynian Events In The Balkan/Carpathian/Anatolian Area High Mobility In The Core Of The Pangaea, *Geophysical Research Abstracts,* **16,** p. 14186.
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