Chapter 2
General Overview of the Research Area

2.1 Geographical Location

The researched area is located in the southern part of Republic of Macedonia, in the lower part of Crna Reka drainage basin.

Crna Reka is the second longest tributary to Vardar river (the biggest river and main drainage system in Macedonia) flowing with W–E direction in the southern part of Republic of Macedonia. Karst areas within its basin are located in the upper part in Demir Hisar area, and in the lower part in Mariovo and Tikveš Basins, and also in the basin of its major tributary Raec River (Fig. 1.1).

The lower part of the basin addressed in this research, is mostly hilly to mountainous area dissected by the deep river valleys of Crna Reka and its tributaries. Morphologically comprises parts of two tectonic basins: Mariovo Basin to the south, and Tikveš Basin to the north and north-east, separated by Kozjak Mountain. The north-eastern boundary of the researched area is on Vitačevo Plateau, a sedimentary volcanoclastic plateau; the north-western boundary is the Dren Mountain Massif (Suva Planina, Radobilska Planina and Orle); south-eastern boundary is on Kožuf Mountain and south-western boundary is Satoka River. Central part of the area is the deep valley of Crna Reka, with also deeply incised valleys of tributaries Buturica, Blašnica and Kamenica rivers (Fig. 2.1).

The area is situated on the boundary between the Pelagonian Massif and Vardar Zone, two major geotectonic units in Macedonia, and also comprises parts of two geographical and historical regions: Mariovo and Tikveš. It is mostly a remote area with small and mostly depopulated villages with lack of infrastructure, with rudimentary agriculture and mining as the main economy.

Karst here is found as several separated karst areas, which is a general characteristic of karst terrains in Republic of Macedonia (oasis karst type by Manakovik 1980).

It is developed on Precambrian and Cambrian marbles, Triassic marbly limestones (or marbles) and dolomites, Cretaceous limestones and Pleistocene travertine rocks, without well expressed karst surface, but with well expressed karst underground.

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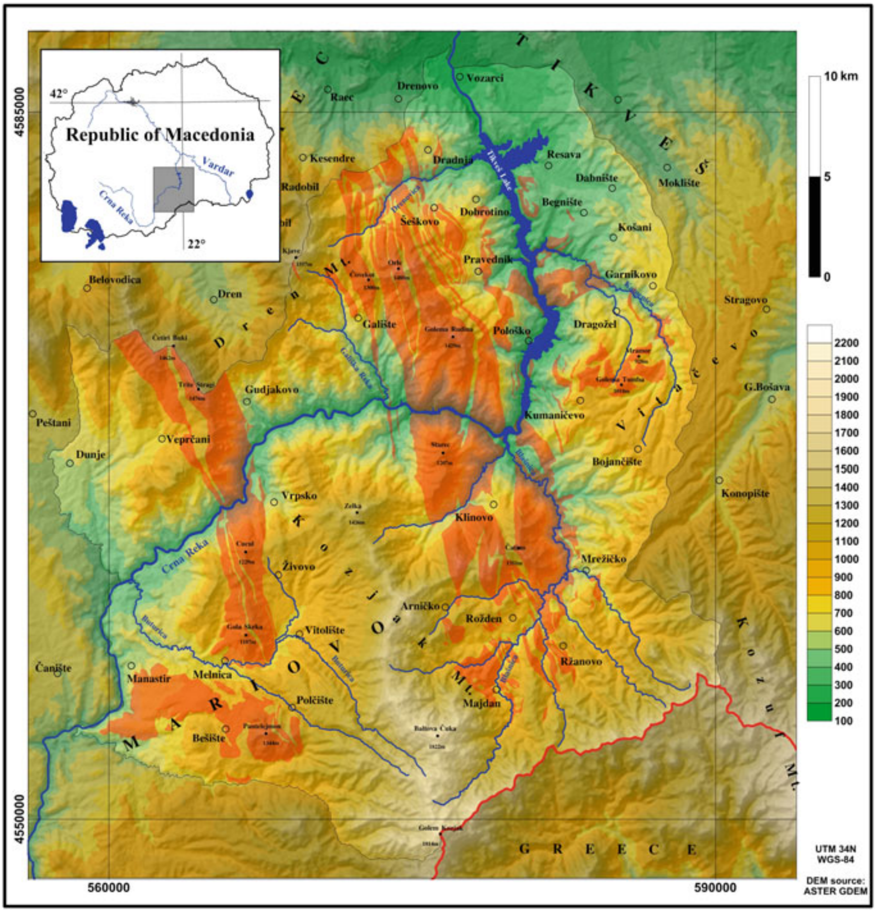

Fig. 2.1 Geographical situation of the research area. Karst rock outcrops are given in *red shade*

2.2 Previous Research

Previous research of karst in this area has been very scarce, mostly due to the generally harsh, hardly accessible and depopulated terrains.

Geological studies of the area included study of the carbonate rocks in the area, determining their spatial distribution, stratigraphy, age, structural characteristics and relations to the other rocks. Although geological research in the area has been conducted since the beginning of the twentieth century, the first comprehensive work is as part of the creation of the basic geological map of former Yugoslavia in scale 1:100 000, presented on sheets Vitolište, Kožuf, Prilep and Kavadarci

(Dumurdžanov et al. 1976; Hristov et al. 1965; Rakičević et al. 1965; Rakićević and Pendžerkovski 1970). The area is also included in the comprehensive work from Arsovski (1997) that gives an overall view to the tectonics and stratigraphy of Macedonia.

There are only few works dealing with the karst in the area. Manakovik (1971) publishes the first information about the caves in Kamenica River. He studied three caves: cave Aramiska Peštera, Buturica Cave and Crkviče Cave, explaining their evolution with the successive draining of Central Macedonian Lake and incision of Kamenica River in the limestone rocks, with Aramiska Peštera considered as the oldest, located in he upstream part with highest elevation of the three, with Buturica and Crkviče considered as younger, at lower elevations downstream along the valley of Kamenica River.

Small notes on the karst in Mariovo are given by Manakovik and Andonovski (1984) as part of the geomorphology of Mariovo. They only address the extension of carbonate rocks, and describe some karst surface features such as karren and dry valleys.

Kolčakovski et al. (2004) published first results about cave Provalata (named Gulabinka in the paper), giving morphometric information and noting the presence of gypsum deposits. Although contributing the presence of gypsum to dissolution of the marble by hydrothermal waters enriched with H_2S, they conclude that the cave is fossil ponor cave.

Speleological work in this area was also done by cavers, locating and mapping generally caves which were previously known to the local population. In the western part (Mariovo area), during the last 10 years, caving clubs SK Zlatovrv from Prilep and Ursus Speleos from Skopje have explored Pešti Cave and caves Melnička Peštera 1 & 2, while SD Peoni from Skopje has explored Provalata Cave and cave Živovska Propast (Propast Provala). In the eastern part, cavers from PSD Orle from Kavadarci have documented a number of caves, mostly in the 1960s and 1970s, describing location, general size and also mapping most of them. SD Peoni from Skopje also located and explored Čulejca Cave, and French cavers (ASBTP from Nice) in collaboration with PSD Orle and SD Peoni worked also in Gališka Peštera and Čulejca Cave.

2.3 Geological Setting

The research area belongs to two major Pre-Cenozoic tectonic structures: Pelagonian Massif and Vardar zone, overlaid by Cenozoic tectonic structures and sediments. It is composed of rocks from various ages from Precambrian to recent (Fig. 2.2).

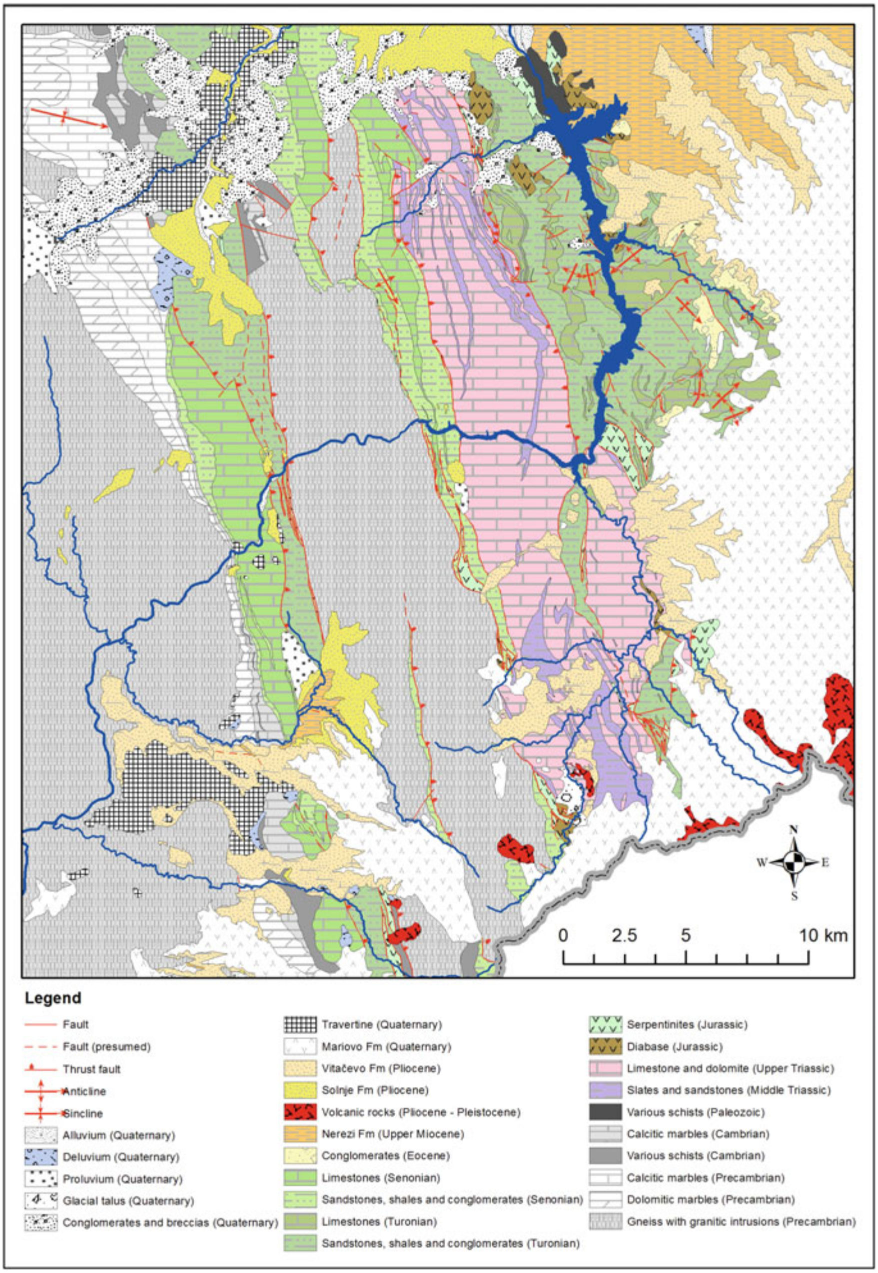

Fig. 2.2 Geological map of the research area, compiled from data after (Dumurdžanov et al. 1976; Hristov et al. 1965; Rakićević et al. 1965; Rakićević and Pendžerkovski 1970; Geološki Zavod—Skopje, unpublished)

2.3.1 Pre-Cenozoic Stratigraphy

Pelagonian Massif consists of Precambrian gneiss and schist rocks, covered by a thick section of dolomitic and calcitic marble in the upper part, and with abundant granitic plutons (Arsovski 1997; Dumurdžanov et al. 2005). Dolomitic marbles are mostly developed in the lower parts of the Precambrian marble series, and grade upwards to calcitic marble. They are found along the eastern border of the Pelagonian Massif, in a NNW–SSE stripe, with dolomitic marble more widespread in the southern parts (south from Crna Reka), and calcitic marble in the northern parts (north of Crna Reka). They are mostly white to gray, small grained to massive, highly fractured, and mostly pure carbonate rocks (Table 2.1) with less than 1 % silicate component (Stojanov 1974; Dumurdžanov et al. 1976).

Dolomitic marbles overlay gneiss rocks and dip to the ENE by 25°–50°, as part of the NNW–SSE oriented Veprčani Monocline. Precambrian gneiss and micaschist rocks, with granitoid plutons are also found in the Vardar Zone, as part of the Kozjak horst.

Paleozoic metamorphic rocks determined as Cambrian are developed in both the exterior and interior part of the Vardar Zone. The thickness of the complex it's not well determined because in most of the area, they are overlaid by Cenozoic deposits, but presumed to be around 1500 m. The Paleozoic complex is presented with different facies (Dumurdžanov et al. 1976): marbles; marbles and cipolin marbles; quartzite-sericite schists and quartzites; amphibolites and amphibole schists; phyllite-micaschists, greenschists and carbonaceous schists. A significantly thick mass of marbles lay along the eastern edge of the Pelagonian massif. At Pantelejmon (1344 m) in the southern parts, the Cambrian complex starts with schist in the lower parts, and through carbonaceous schists and cipolin marbles pass to medium bedded marbles. North of Melnica, the schists are found only as lenses within the Cambrian marbles which lay directly on top of the Precambrian marbles.

Triassic rocks are presented in form of a tectonic block with N–S direction, composed of terrigenous and carbonate sediments. They start with middle Triassic slate and sandstone deposits as the basal unit (Dumurdžanov et al. 1976;

Table 2.1 Chemical analysis of marbles from Pletvar, 20 km NNW from Crna Reka (Stojanov 1974)

	Dolomitic marble (%)	Calcitic marble (%)
CaO	32.50	54.35
MgO	19.63	1.02
SiO_2	0.27	0.50
FeO	0.10	/
Fe_2O_3	0.14	0.21
Al_2O_3	0.33	/
CO_2	49.96	43.80
$CaCO_3$	58.04	97.06
$MgCO_3$	41.05	2.13

Robertson et al. 2012), above which are deposited grey shallow-water Upper Triassic carbonates presented with limestones and dolomites, significantly metamorphosed, mostly platy and thick bedded, rarely massive (Dumurdžanov et al. 1976; Robertson et al. 2012). The upper part of the carbonate platform includes a thin interval of recrystallized chert, shale and thin bedded limestone which pass transitionally upwards into further thick-bedded, recrystallized limestone of possible Jurassic age (Robertson et al. 2012). They are locally highly deformed by isoclinal folding.

Jurassic ophiolitic rocks are found as elongated lenses along many tectonic structures, diapirically emplaced. They are localized in four main tectonic zones, along vertical or thrust faults (Dumurdžanov et al. 1976). The first is along many faults in the Upper Cretaceous rock delineating the west border of Kozjak block; the second is connected to the Galište–Arničko graben along NNW–SSE oriented faults; the third is along the faults forming the west border of Pološko–Ržanovo graben; and the fourth starts from Crna Reka trough Kumaničevo village and to the SSE below the tertiary-quaternary deposits. Lithologically they are composed of serpentinites and peridotites, gabbro and diabase.

Upper Cretaceous sediments are presented with thick section of Turonian and Senonian sediments (Rakićević and Pendžerkovski 1970; Dumurdžanov et al. 1976). Turonian sediments have thickness of around 2000 m and are localized in two zones. The first is on the western edge of the Vardar zone, as a part of the Dren-Vitolište graben. The sediments are overthrusted onto Senonian sediments to the west and have a fault connection with the Kozjak horst to the east. The second zone is in the inner part of the Vardar zone as part of the Pološko–Ržanovo graben. They are covered with pyroclastic sediments to the south, and have fault guided connection with the Triassic rocks. Three facies can be separated (Rakićević and Pendžerkovski 1970; Dumurdžanov et al. 1976): conglomerates and sandstones; sandstones, shales and conglomerates; limestones. The limestones are found in the upper layers of the Turonian sediments, and as layers and lenses inside the clastic sediments. They are massive, platy and thick bedded, micritic, gray to gray–white in color with sandy to marly alternations at places, containing numerous fossil fragments (Rakićević and Pendžerkovski 1970; Dumurdžanov et al. 1976).

In the Senonian sediments several facies are determined (Rakićević and Pendžerkovski 1970; Dumurdžanov et al. 1976): limestones; flysch: sandstones, siltstones, shales and limestones; sandstones, shales and conglomerates; and conglomerates and sandstones. Senonian limestones are found as the topmost formation of the Senonian sediments in the Dren-Vitolište graben and as part of the flysch deposits in the Galište–Arničko graben. They are platy to thick bedded, grey to white, rarely pinky and locally sandy or marly.

2.3.2 Main Tectonic Structures in the Pre-Cenozoic Rocks

Pre-Cenozoic rocks within the Vardar zone were strongly deformed in the latest Cretaceous to Paleocene time (Laramide phase), in number of folds and faults with NNW direction (Arsovski 1997; Dumurdžanov et al. 2005).

In Vardar zone we can separate two structural segments: Kozjak-Drenovo and Veles-Klepa-Tikveško Ezero segments (Fig. 2.3). Most of the area is part of the Kozjak-Drenovo segment, a system of horsts and grabens built from different complexes and formations divided by faults (Dumurdžanov et al. 1976; Arsovski 1997):

Kozjak horst extends in sub meridian direction over 30 km, starting from Raec Valley to the north, trough Dren and Kozjak to south, 4–6 km wide. It is settled between Dren-Vitolište graben to the west and Galište–Arničko graben to the east, divided by regional faults (Vrpsko reverse fault to the west and Kozarnički fault to the east), along which small lenses or bigger masses of tectonized serpentinites are found. It is composed of rocks from the gneiss and micaschists series, and granitoides of the Precambrian complex, and represents a cutoff part from the Pelagonian massif.

Dren-Vitolište graben, located to the west of the Kozjak horst, has system of longitudinal reversed faults (Vrpsko reverse fault) as part of the west border fault system of the Vardar Zone. In the middle of the graben the Turonian formation prevails, intensively dislocated, with lenses of serpentinites inserted along the faults. This middle part of the graben is overthursted on the west side over the Senonian flysch (Klen reverse fault), which overlays the Precambrian and Paleozoic complex of the Pelagonian massif.

Galište–Arničko graben lies to the east of the Kozjak horst, as a narrow graben, 2 km wide in the north part, and 1 km wide in the south. This graben is composed of Senonian flysch sediments, intensively folded into isocline folds. From the both sides the graben is isolated by regional faults (Kozarnički and Dračevički faults) alongside which lay elongated lenses of serpentinites.

Rožden horst lies to the east of the former graben. It is built from the Triassic sediments, intensively folded, mainly into isocline folds. In the north part the folds lean to the east, and the whole structure is overthursted trough the cretaceous sediments to the east, along the Smrdeliški fault. The south part of the horst is divided into two parts by the Pološko–Ržanovo graben.

Pološko–Ržanovo graben has N–S direction and is built of Turonian sediments, which form significantly big anticline (Crna Reka anticline) with axis parallel to the direction of Crna Reka. To the south, this anticline is deformed by the Čatenaški fault.

Veles-Klepa-Tikveško Ezero segment (Rakićević and Pendžerkovski 1970; Dumurdžanov et al. 1976; Arsovski 1997) here is presented with couple of folded structures in the Turonian sediments along the north part of the Tikveš Lake, in the

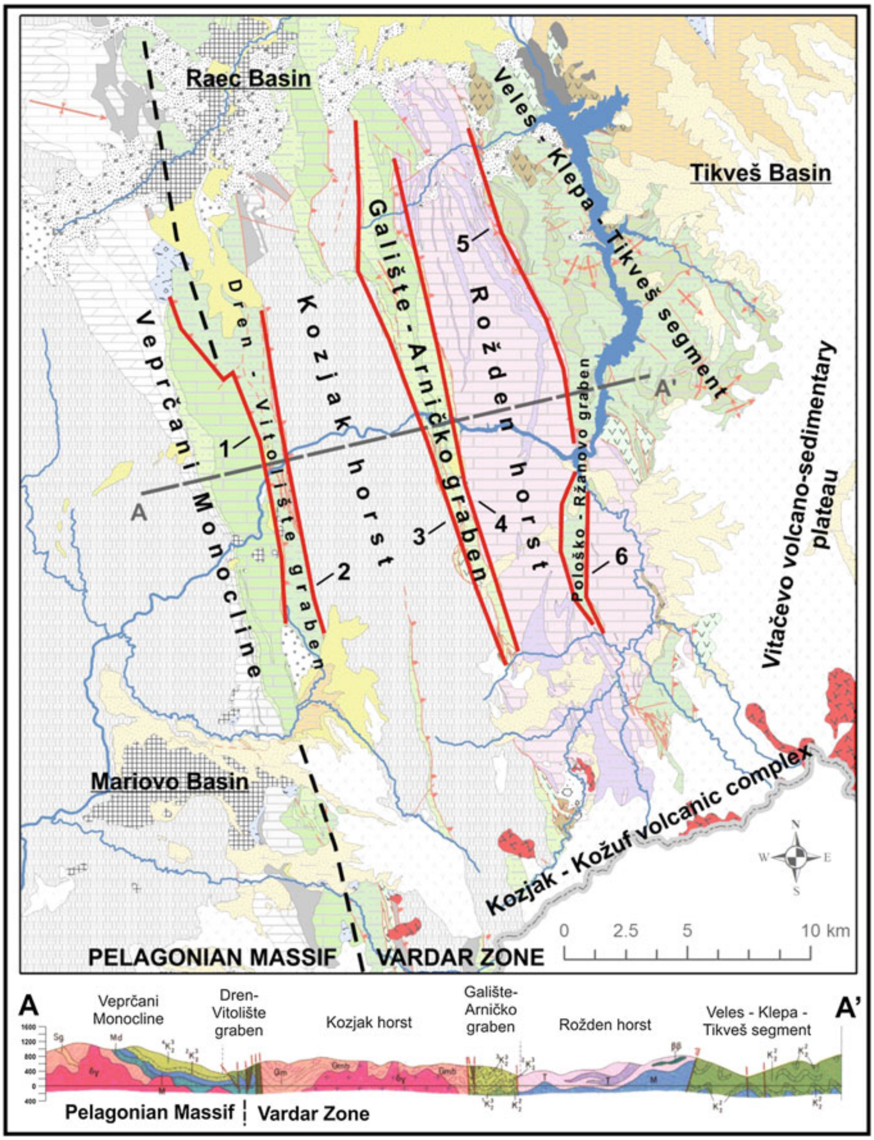

Fig. 2.3 Simplified structural map with main tectonic structures. *1* Klen reverse fault, *2* Vrspsko reverse fault, *3* Kozarnički fault, *4* Dračevički fault, *5* Smrdeliški fault, *6* Čatenaški fault. Note the difference in symbols between map and cross-section, with cross-section represented in original as given by Dumurdžanov et al. (1976)

western part of Vitačevo plateau. Main folds are the Kamenica Anticline and Dragozel Syncline, with NW oriented axis, cut by the NW–SE Dragozel fault, and several second order folds having NE oriented axis.

2.3.3 Cenozoic Stratigraphy and Tectonics

Cenozoic evolution is connected with two phases of basin development in late Eocene to recent time and reflects two major periods of extensional deformation separated by a short period of shortening (Dumurdžanov et al. 2004, 2005).

During the first period of extension in late Eocene, Tikveš-Ovčepole basin was formed as a forearc basin lying to the west of the regional magmatic arc. Five litozones are separated within the Paleogene sediments, of which basal conglomerates with fragments originating from Turonian sediments are found in the vicinity of Dragožel, Garnikovo and Kumaničevo villages (Rakićević and Pendžerkovski 1970; Petrov et al. 2010).

In the late Oligocene-Early Miocene, the strata in Tikveš basin were deformed as a result of two short periods of shortening (Pyrenian and Savian phases). These short periods of deformation were followed by a period of erosion that reduced the landscape to low relief and separated the first and second major periods of extension (Dumurdžanov et al. 2004, 2005; Petrov et al. 2010).

The second period of extension started in late early Miocene and became the dominant mode of deformation within Macedonia to the present. Basin formation in Macedonia during the second period is described in five cycles by Dumurdžanov et al. (2004, 2005). Tikveš and Mariovo Neogene grabens, which are located in the researched area, were formed during the second cycle (late Miocene: late Sarmatian —Meotian), partially controlled by N–S and NE–SW trending faults.

Mariovo Basin is located in the western part of the research area, and is filled with lacustrine and pyroclastic sediments deposited from Upper Miocene to Pleistocene (Dumurdžanov et al. 2004):

- ***Nerezi Formation*** (Upper Miocene)—gravel and sandstone; siltstone and silty claystone that grades upward into claystone and coal; and siltstone and sandstone followed by a hiatus.
- ***Solnje Formation*** (Pliocene)—poorly stratified gravel and sandstone, overlain by:
- ***Vitačevo Formation*** (Pliocene)—stratified tuff overlaid by sandstone and gravel interbedded with beds of diatomite, tuff, and sandy claystone; travertine deposits, tuff-agglomerate and sandstone.
- ***Mariovo Formation*** (Pleistocene)—pyroclastic rocks with nine travertine layers and a 20-m-thick travertine deposit on top.

Tikves Basin is bounded on its western side by normal faults of N–S and NW–SE strike, while two NE-striking parallel faults bound its northwestern and southeastern sides. Three formations are recognized in the central and southern part of the basin (Dumurdžanov et al. 2004):

- ***Nerezi Formation*** (Upper Miocene)—lies unconformably on Eocene rocks, starting with (the basal unit) basal conglomerate with gravel, sandstone, and brown claystone overlain by sandstone and mottled claystone; interbedded grey claystone, coal-bearing claystone and coal beds overlain by marl and marl-rich (the middle unit); interbedded sandstone, siltstone, and silty claystone (upper unit).

- ***Vitačevo Formation*** (Pliocene)—sandstone overlain by tuff and agglomerate with diatomite and tuff at the top; overlain by interbedded yellow sandstone, tuff, and agglomerate, locally containing travertine; with tuff agglomerate and tuff as the topmost part.
- ***Mariovo Formation*** (Pleistocene)—strata deposited in a lacustrine environment that was terminated during Pleistocene time by deposition thick beds of breccia conglomerate with volcanic material, above which lies agglomerate, tuff, volcanic breccias, and locally travertine.

Remnants of Pliocene deposits (Solnje Formation) as well as Pleistocene travertines (Mariovo Formation) are also found along the valley of Crna Reka, indicating possible connection of the Mariovo Lake with the Central Macedonian Lake (Dumurdžanov et al. 2003, 2004).

Dumurdžanov et al. (2004, 2005) interpret the evolution of the Neogene basins in Macedonia in 5 cycles, with Mariovo and Tikveš basins forming in cycle II (late Miocene: late Sarmatian-Meotian), with total hiatus at the end of cycle III (Pontian). In Pliocene—cycle IV (Solnje Formation and Vitačevo Formation in Mariovo; Vitačevo Formation in Tikveš) a transgression occurs, accompanied with volcanic activity in Kožuf and Kozjak Mts., which continued through Early Pleistocene (Mariovo Formation). With the draining of the lake system in central Macedonia (which started probably as late as Middle Pleistocene; Dumurdžanov et al. 2005) as a result of general uplift in Macedonia and subsidence in the Aegean Sea, Mariovo Lake also drained, thus Crna Reka established its fluvial basin.

New information regarding the Pliocene deposits invokes different interpretation to the evolution of the basins along the Vardar valley during the end of Miocene and in Pliocene time. A Gilbert-type fan delta, the postponed signature of the Messinian Salinity Crisis (MSC), has been documented in the Pliocene sediments southward of Skopje at Dračevo (Clauzon et al. 2008). It follows a previous phase of incision of deep valleys due to the lowering of base level as a result of almost complete desiccation of the Mediterranean Sea. Such results demonstrate that the MSC impacted the region of Skopje as it did for the northern Aegean region (Thessaloniki) and Western Dacic Basin (Turnu Severin). Hence, a marine gateway is considered to have connected the Aegean Sea and the Dacic Basin (Eastern Paratethys) through the Balkans Chain, replacing the generally suggested corridor in the present-day Bosphorus Strait area (Fig. 5.76).

Considering the location of the Tikveš Basin along the Vardar Zone between Skopje and Thessaloniki, MSC event must have impacted this area as well, with the hiatus at the end of Nerezi Formation (Upper Miocene) to be considered as a result of this event. The Pliocene deposits along the Crna Reka Valley also indicate valley incision prior to the Pliocene deposition, which might be connected to the MSC. Consideration of the possible MSC impact on the evolution of the area is of great importance, since such event would have had significant effect on the general relief formation, and also on karst development.

2.4 General Geomorphology

The base of the relief in the area is constituted by structural forms: horsts and grabens formed as part of the South-Balkan extensional system. The horst structures are Kozjak and Dren Mountains, and the grabens are Mariovo and Tikveš basins. Overprinted onto these macro-relief forms, as a result of fluvial-denudation, coastal, and karst erosion processes, are meso and micro-relief forms, different in shape and size.

Dren Mountain massive (Kjave, 1557 m) has a W–E direction and is composed of three morphological units. This is due to the lithology and older tectonic structure influencing the relief. To the west is the Suva Planina mountain with NW direction, built of Precambrian, Cambrian and Cretaceous rocks. In the middle is the main ridge of Dren Mountain, composed of Precambrian gneiss and Cretaceous sediments, and to the east lies Orle Mountain, containing Triassic and Cretaceous rocks.

Kozjak Mountain (Baldova Čuka, 1822 m) continues to the south of Dren Mountain and has an N–S general direction. It is composed of Precambrian to Cretaceous rocks. To the west it is highly eroded as part of the small Vitolište basin and Buturica valley, and borders the Mariovo basin. To the east it is separated from Vitačevo plateau by the valley of Blašnica.

Neogene lakes of Tikveš and Mariovo basin have left traces of lacustrine terraces. In Mariovo Manakovik and Andonovski (1984) determined two lacustrine terraces, at 1100–1150 m and at 1000–1050 m. Traces of the terrace at 1100–1150 m are found on the slopes of Pantelejmon, west side of Kozjak and on the ridge of Cucul (1229 m), Šipka (1182 m) and Gola Skrka (1187 m). The second terrace at 1000–1060 m is more pronounced in the area, and traces are found around Pantelejmon, Polčiško Pole, on the west side of Kozjak where it is more pronounced, also around Cucul (1229 m), Šipka (1182 m) and Gola Skrka (1187 m). The best preserved remnants are on Polčiško Pole. This terrace is considered as the central lake plain during Upper Pliocene by Manakovik and Andonovski (1984). In Tikveš, Manakovik (1971) found four lacustrine terraces, at 900 m, at 740–800 m (due to the pyroclastic sediments), at 660–700 m and at 600–620 m representing the former central lake plain. The biggest remnant of the lacustrine environment are the thick sediments, sands, clays, conglomerates, that are filling the Mariovo and Tikveš basins, which in Mariovo end with 20 m thick travertine deposit. They are deeply incised by valleys, and in the higher areas completely eroded.

The interpretations of the evolution of the Tikveš and Mariovo basins (Manakovik 1968; Manakovik and Andonovski 1984) should be revised, due to the new data on the sedimentation of the basins and age of sediments (Dumurdžanov et al. 2004, 2005). Also data (from south of Skopje) suggesting marine environment in upper Miocene, possible influence of the MSC and Pliocene marine transgression connecting the Aegean sea with the Dacic basin (Clauzon et al. 2008), which contradicts to the previous explanation of continuous lacustrine environment in the basins in Macedonia, events that surely influenced the valley of Crna Reka and Tikveš and Mariovo basins.

Fluvial relief covers most of the area, presented with the drainage of Crna Reka. The main form is the valley of Crna Reka that has gorge characteristics. It cuts through the area in W–E direction with a deeper valley segment separating Dren and Kozjak mountains. The upper parts of this gorge (on Dren and Kozjak Mountains) are wider and are remnants of old valley of Crna Reka, while at several locations along the valley in the lower parts Pliocene deposits are found, indicating Miocene age of the paleo Crna Reka Valley (Manakovik and Andonovski 1984). From the confluence with Blašnica, Crna Reka continues to the N, and also has gorge-like characteristics until Vozarci village where Crna Reka has formed a wider alluvial plain, continuing to the confluence with Vardar River.

Her tributaries have smaller drainage basins and smaller discharge than Crna Reka, so most of them did not managed to adjust its long-profile to the base level of Crna Reka. In the valley of Crna Reka, Manakovik and Andonovski (1984) determined fluvial terraces at different relative elevations (380–400 m, 310–340 m, 230–240 m, 200–210 m, 130–140 m, 115–120 m, 65–70 m, 40–55 m, 15–20 and 5 m).

2.5 Climate

As a result of the morphological configuration the area is characterized with local climate, with modified Mediterranean influence coming from downstream valley of Crna Reka (from the Aegean Sea, through the valley of Vardar River), and temperate continental influence coming from upstream valley of Crna Reka (from Pelagonian Basin). Of the climate parameters only temperature and precipitation will be presented.

According to the thermal regime (and the climate in general) the area has three different parts (Stankoski 1984): the narrow belt along the valley of Crna Reka, starting from Tikveš and up to around 600 m elevation (Manastir Village), has modified Mediterranean thermal regime with mean annual temperature of 12.4 °C and maximal rainfall in May (68.1 mm); the areas of the valley of Crna Reka above 600 up to 900 m, with the hilly terrains in Mariovo and Tikveš have almost same thermal regime as in the Pelagonian Basin, with mean annual temperature 11.3 °C. Summers are warm, and winters cold with more rainfall in autumn, giving temperate continental characteristics to the thermal regime; mountain areas of Kožuf, Kozjak and Dren mountains have mountain climate with mean annual temperatures from 6 °C at the summits and ridges to 8–10 °C on the slopes. Absolute temperatures in the area are maximum of 40.1 °C in July and minimum of −19.8 °C in December.

Annual distribution of precipitation in the area is very irregular as a result of the complexity of the relief, winds, and the position regarding the Aegean Sea. The area has modified Mediterranean pluvimetric regime with maximum in spring (May) and second maximum in autumn (November) and minimum in August and July. The precipitation is mainly influenced by the relief, resulting in precipitation of up to 500 mm in the valley of Crna Reka, to 600–700 mm on the hilly terrains of Mariovo and Tikveš, and 800–1000 mm on the mountain areas. Most of the precipitation comes in spring (32 %), autumn has 28 %, winter 22 % and summer 18 %. Average precipitation is 570 mm with maximum in May (102.9 mm) and minimum in August (30.5 mm). Of the overall annual precipitation, snow takes from 9 % in the valley of Crna Reka up to 30–40 % above 1500 m. In average snow starts in the middle of December (14.XII) and lasts until middle of March (10.III) Special characteristic of the pluviometric regime in the area are the continuous no-rain days—draughts. They are most common in summer, when continuous no-rain days reach up to 58 days in some years, and every year there is period of almost one month with drought (Stankoski 1984).

If we summarize, the area has three climate zones: modified Mediterranean climate along the valley of Crna Reka (in narrow belt along the valley downstream to Tikveš) with maximum precipitation in spring (May) and autumn (November), and minimum in summer; temperate continental climate occupying the hilly and plateau parts of the area, with maximum precipitation in November and secondary in May, and minimum in July and August; mountain climate in the area of Kozjak, Dren and Kožuf mountains.

Overall the area has average annual precipitation of 570 mm, most of it precipitated in spring and autumn, except the mountain parts that have higher precipitation up to 1000 mm and more even annual distribution. The average annual temperatures range from 6 to 10 °C in the mountains to 12.4 °C in the lower parts in valley of Crna Reka, with maximum of 40.1 °C and minimum of −19.8 °C (Stankoski 1984).

2.6 Hydrography

The area occupies the lower part of the drainage basin of Crna Reka, starting from the confluence of its right tributary Satoka River, to the confluence of its biggest tributary, Raec River. In this area Crna Reka has number of tributaries of which the right tributaries are characteristically bigger and with bigger discharge, draining the mountainous areas of Nidže, Kozjak and Kožuf mountains. Main tributaries in the area are: Buturica, Blašnica and Kamenica to the right, and Gališka and Drenovica to the left.

Crna Reka is the second longest tributary to Vardar River, the biggest river and main drainage system in Macedonia. It starts in Demir Hisar area, to the west of Pelagonian Basin, with the Železnec springs considered as the source. From the source to the confluence with Vardar River it has a length of 207 km, with vertical difference of 631 m between the source and the confluence elevation, and average slope of the longitudinal profile of 3 ‰, which in Mariovo is higher at 5.9 ‰, and at some sections even 11 ‰. Average annual discharge, measured at the measurement station in Skočivir at the entrance to Mariovo area (prior to the research area, so without the water coming from the later described tributaries), is 19.3 m^3/s, with the highest discharge in March (71 m^3), and lowest in September with 0.10 m^3 (Gaševski 1984).

Buturica River, in the upper part called Vitoliška Reka, emerges on Kozjak Mountain at 1600 m in the area called Vlaški Kolibi. It has a number of smaller right tributaries which come from east from a more forested part of its basin. Before Vitolište Village, Buturica flows in NE direction where receives a right tributary coming from the area of Živovo Village. After this confluence, Buturica has W direction down to Melnica, where it receives its biggest tributary Polčiška Reka. Downstream from here, Buturica takes NW direction and before the confluence to Crna Reka turns to N direction. Buturica River is 20 km long and has basin of 102 km^2. Its valley is mostly gorge like (Gaševski 1984).

Blašnica River is the biggest tributary to Crna Reka in the research area. Begins on Kozjak at 1700 m close to the river head of Buturica and confluences to Crna Reka near Tumba (384 m), having length of 28 km, drainage area of 210 km^2 and average drainage elevation of 980 m. It has more developed drainage than the other tributaries in the area. Bigger tributaries are Krusta, Kozarik, Dabov Dol, Topli Dol, and Mrežička Reka. Blašnica has gorge like valley, with some smaller parts where its profile has smaller gradient, mostly due to the different lithology (Gaševski 1984).

Kamenica River is 14 km long, starting from its head near Bojančište village at about 940 m until its confluence to Tikveš Lake. It has several tributaries, of which Dragoželska Reka is the biggest (Manakovik 1971).

There are two bigger left tributaries of Crna Reka in the area. One is Gališka Reka that emerges at 1110 m below Kjave (1557 m) on Dren Mountain, with length of 9 km and SE direction connecting with Crna Reka on the beginning of the Tikveš Lake. The other is Drenovica, also 9 km long, and emerging below Kjave (1557 m) at 1100 m on the eastern slopes of Dren Mountain, flowing in NE direction to the Tikveš Lake near the dam.

2.7 Karst Extension

In the before defined general borders of the research area, karst rocks cover 187.67 km^2, which is 22.36 % of the area (total area of 839.42 km^2). Karst rocks are represented with carbonate rocks with various degrees of diagenesis and metamorphosis, with marbles, limestones, dolomites and travertines, having ages from Precambrian, Cambrian, and Cretaceous to Pleistocene time. Important characteristic of the Precambrian formation is that most of the marbles are dolomitic marbles (Table 2.2).

Table 2.2 Surface area of karst rock outcrops in the research area

Age	Rock type	Surface area (km^2)	Percentage of karst rocks
Precambrian	Dolomitic marble	8.53	4.55
Precambrian	Calcitic marble	2.08	1.11
Cambrian	Calcitic marble	6.62	3.53
Triassic	Metamorphosed limestone and dolomite	97.93	52.18
Turonian	Limestone	23.90	12.74
Senonian	Limestone	32.46	17.30
Pleistocene	Travertine/tufa	16.15	8.61
Total		187.67	100

The Upper Triassic carbonate formation has the largest extent, with little more than half of the karst rock surface area, having both dolomites and limestone, partly metamorphosed. The calcitic Precambrian marbles have the smallest surface area, together with the Precambrian dolomitic marbles and Cambrian calcitic marbles, although their thickness is quite significant, with most of these rocks covered by younger sediments (Fig. 2.4).

Spatially carbonate rocks here are generally located in three NNW–SSE oriented stripes, with tectonic or sedimentary borders to the west and east, transversely cut in segments separated by river valleys or Neogene-Quaternary deposits.

The western stripe is located along the eastern edge of the Pelagonian Massif, composed of Precambrian and Cambrian marbles, separated by a thin clastic section from the overlying thick Senonian limestones. The western border is sedimentary with the underlying Precambrian gneiss formation, while the eastern border is represented by an overthrust fault along which Turonian clastic formation is overthursted onto the Senonian limestones.

The middle stripe is mostly composed of Upper Triassic limestones and dolomites, with tectonic borders to the west and east; with small Senonian limestone stripe to the west, and Turonian limestones to the east. The eastern stripe is composed of Turonian limestones which continue from the Turonian limestone in the central stripe, with western border defined by contact with the underlying clastic formation or by faults, while to the east they are buried by the Neogene-Quaternary Tikveš Basin deposits. To the north and south these carbonate rocks are generally buried by Neogene-Quaternary lacustrine, fluvial and pyroclastic deposits. Travertine rocks represent generally the topmost formation of Mariovo Basin deposits.

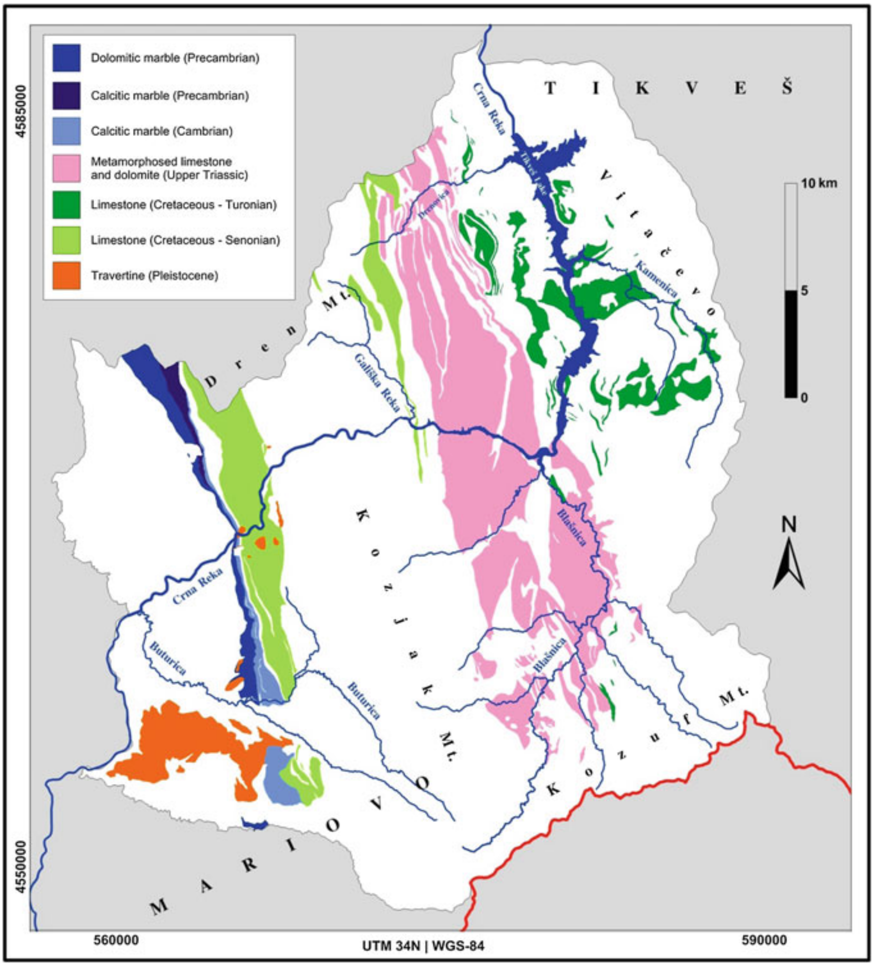

Fig. 2.4 Extension of karst rock outcrops in the research area

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