4.2.1. GEOTECTONIC, SEISMICITY AND SEISMOTECTONIC OF THE DINARIDES OF BOSNIA AND HERZEGOVINA

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4.2.1.1. Introduction

The aim of this paper is to present geotectonic characteristics of the Dinarides and Bosnia and Herzegovina, and to discuss about their seismicity and seismotectonic.

The geotectonic evolution of the Bosnia-Herzegovina part of the Dinarides has been a matter od research for long time, from Suess (1875) which is considered the Dinaridic «godfather» by proposing name «Dinarische Alpen». At that time, the importance of overthrusts and nappes in the regional structural framework of the Alps, had already been recognized but not generally accepted. Suess concluded that folding and thrusting played the most important role in the development of muntain systems. He also emphasized that orogens consist of fold-and-thrust belts comprising external units overthrusted by internal ones.

These ideas were also applied in the first geotectonic subdivisions of the Dinarides. Kober (1924) was the first to distinguished three geotectonic units in the Dinarides composed of seven large-scale nappes. Later Kossmat (1924), Kober (1924) and Nopcsa (1928) continued to apply the same principles in their research on the evolution of the Dinarides.

After a 30 year break, Kober (1952) presented in his monograph. His concept, which was generally accepted by most of the former Yugoslavia formed the basis a for further research (Petković, 1961; 1958; Bešić, 1954; Sikošek and Medwenitsch, 1955 Miljuš, 1973; Grubić, 1980: Dimitrijević, 1982; Anđelković 1982; Herak, 1986; Lawrence et all., 1995; Grandić et al., 1997; Pamić et al. 1998; Tari, 2000). In the sixties and seventies under the guidance of J. Aubouin, the group French geologists carried out during the sixties and seventies several PhD Thesies covering the entire Dinarides and Northern Hellenides. Results of these valuable studies were synthesized by Aubouin et al. (1970).

Several papers treating relation between tectonic and seicmic activity followed (Dragašević&Andrić, 1980, Sikošek, 1983, 1985, 1994, 1999, 2000, Trkulja, 1997, Oluić, 2005, Prelogović et al., 1997, Janković, 1987, Vidović et al., 1972, Hrvatović, 2005).

4.2.1.2. Regional seting

- ### Position of the Dinarides within the Alpine-Himalaya orogenic belt

In the framework of classical but abandoned geosynclinal concept, Kober (1911) distinguished «two branches» within the Alpine-Himalaya belt and included the Dinarides, together with the Apennines, Southern Alps and Hellenides, in the «southern branch» whilst his «northern branch» embraced the Western-Eastern Alps, Carpathians and Balkan.

Continuation of the Dinarides toward the Alps is not clearly defined. As a matteh of fact, the External Dinarides, e.g. the Adriatic-Dinaridic carbonate platform continue, paleogeographically, in the Southern Alps, although some geologists (Carrulli et al., 1991, Placer, 1998) their structural boundary put along the Southalpine Front, e.g. thrust which is in its eastern prolongation joined with disconnected fragments of the Internal Dinaridic lithologies occur in frontal parts of the Sava-Vardar Nappe that can be traced westwards to the Slovenia-Italy frontier.

Recently, in the Alps/Dinarides adjoining area is separated a transitional zone named Mid-Trans-Danubian Zone (Fulop et al., 1987), Zagorje-Mid-Transdanubian Zone (Pamić & Tomljenović, 1998) or Sava Zone (Haas et al., 2000). The zone is composed of mixed blocks from both the Alps and Dinarides and is the results of Tertiary (Oligocene-Miocene) lateral extension tectonics (Kazmer, Kovacs, 1985, Ratschbacher et al., 1991).

The relationship between the Dinarides and Hellenides is much clearer. This is shown in the fact that all paleogegraphic and structural units of the Internal Dinarides continue southeastward into the Helenides (under different names) suggesting that they must have originated from one and the same oceanic domain, i.e the Dinaridic-Hellenidic Tethys (Pamić, 2002) or the Vardar Ocean (Dercourt, 1972, Stampfli, 2000).

The south-western boundary between the External Dinarides and Adria Microplate is covered by Adriatic Sea. The Adriatic-Ionian Zone is positioned between them as foredeep zone. It does not outcrop along the Adriatic shore but south-eastward of the Skadar-Peć fault it represents the most external zone of the Hellenides (Fig. 4.2.1.1.).

The best outcrops of Paleozoic and Mesozoic tectonostratigraphic units of the Dinarides are found on the territory of Bosnia and Herzegovina. In the present structure of the Dinarides the Alpine distinctly predominates tectonostratigraphic units over the Paleozoic ones in an approximate relation 4:1. Both Paleozoic and Alpine tectonostratigraphic units originated in the Tethys as proposed by Suess (1893). According to current of the geodynamic ideas on the evolution of the Alpine-Himalaya belt the Paleozoic formations originated in the Paleotethys, i.e., by the convergnece of the Laurassia in the north and Gondwana in the south (Ziegler, 1990, Matte, 1991, von Raumer&Neubauer, 1993, von Raumer, 1998 and other). On the other hand, the Alpine tectonostratigraphic units of the Alpine-Himalaya belt, including the Dinarides, originated in the Neotethys, or simply Tethys by the convergence of Euroasia in the north and Africa in the south (Dercourt, 1970; Dewey et al., 1973, Dercourt et al., 1993 and other).

At the present erosional level, the Dinarides and Carpathians are not in direct conatct; mountains of the northernmost Dinarides are about 400-500 km far from the southernmost Carpathian mountains with the Pannonian Basin in the between. However, its basement is composed broken of from the Carpathians during the Berriasian (Marton, 2001). Virtual boundary between the Dinarides and South Tisia (e.g. Carpathians) coincides approximately with the northern marginal fault of the Sava Depression. Based on field observation and refraction seismic data southwrn Tisia dips to the southwest beneath the Dinarides at an angle of about 10-15 (Tari and Pamić, 1998).

The area of Bosnia and Herzegovina is included in the middle parts of the Dinaridic Mountain System and it is positioned between Apulia (Adriatic Microplate) in the south and the Panonian and South Tisia, respectively. Evolution of the Dinarides was

genetically related to the Tethys which existed during the Mesozoic and Early Palaeogene between two supracontinents – Euroasia or its Moesian fragment in the north and Africa or its Apulian fragment in the south. The Dinarides represent a typical orogenic system included in the Alpine – Himalaya belt. Main large lithofacies associations of the Dinarides originated during the Alpine orogenic cycle. However, there are also large lithological units which originated during the Variscan orogenic cycle (the Paleozoic complex of the Una-Sana area, Mid-Bosnian Schist Mts., Southeast Bosnia and North Bosnia) and the postorogenic ones originated during the Oligocene – Neogene (marine to fresh-water sediments of the South Panonian Basin) and Neogene intramontane fresh-water basins: Sarajevo-Zenica, Tuzla, Ugljevik, Kamengrad, Bugojno, Livno, Duvno, Gacko, Bihać-Cazin, Drvar, Mesići, Miljevina and others.

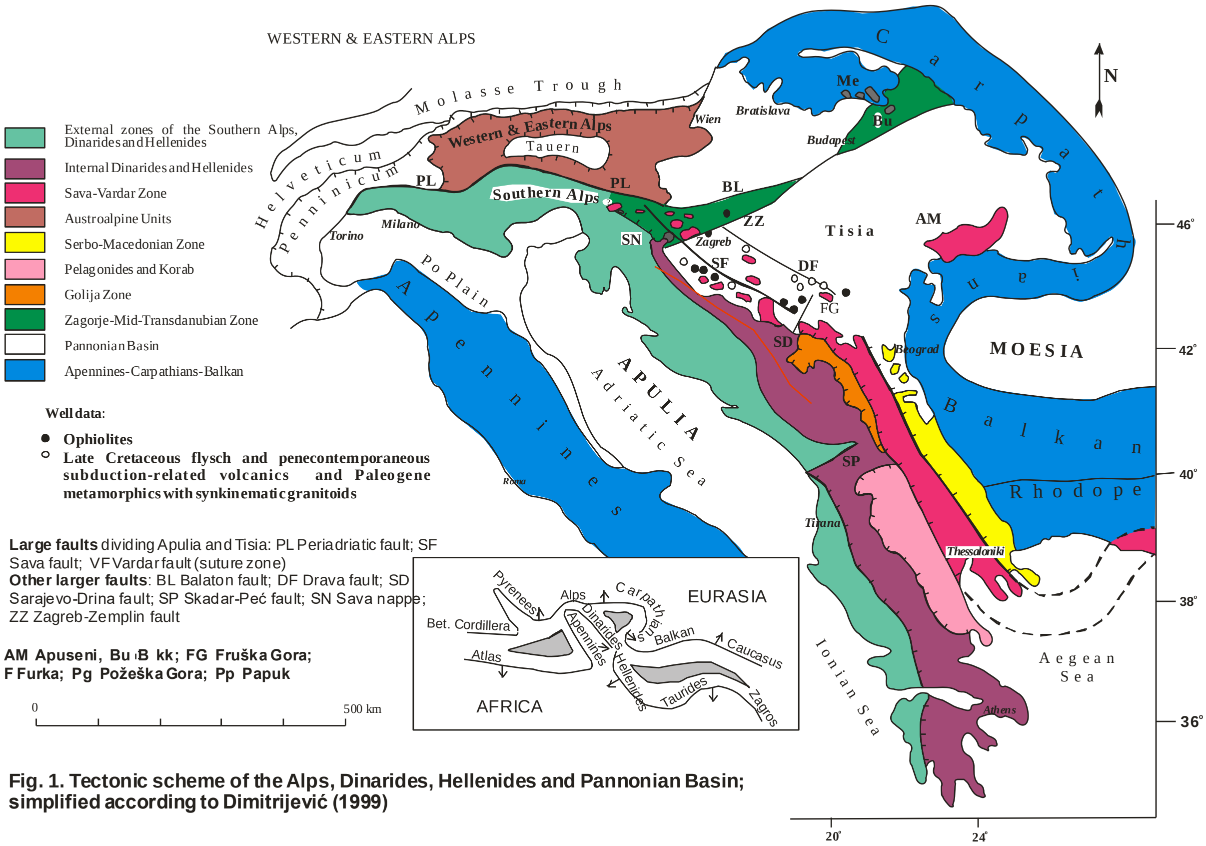


Fig. 1. Tectonic scheme of the Alps, Dinarides, Hellenides and Pannonian Basin; simplified according to Dimitrijević (1999)

Numerous papers have been published on geotectonic evolution of the Dinarides and they are summarized alsewhere (Herak, 1991). Based on modern plate tectonics ideas, the Dinarides can be subdivaided into several large structural-paleogeographic units as first proposed by the Frenche geologist (Aubouin et al., 1970) for the whole Dinaride-Hellenide area.

Despite their complex, imbricate thrust structure, in the Dinarides is preserved distinct zoned pattern in the spatial distrubution of large tectonostratigraphic units, reflecting their paleogeographic evolution. From the southwest (Apulia) to the northeast (Moesia), the following tectonostratigraphic (paleogeographic) units can be separated (Pamić, 1993): 1) Dinaric carbonate platform (External Dinarides); 2)Bosnian Flysch; 3)Dinardie Ophiolite Zone; 4)Sava-Vardar Zone.

The units 2 to 4 define the Internal Dinarides. This regular pattern in the distribution of tectonostratigraphic units is disturbed by allochtonous Paleozoic-Triassic masses (5) which are thrust onto the units of the Internal Dinarides and onto the northeastern margin of the External Dinarides (Fig. 4.2.1.2.), in many areas, the Dinarides are disconformably overlain by postorogenic Oligocene, Neogene and Quarternary sediments (6).

The Dinarides are characterized by fold, imbricate and thrust structures striking NW-SE with distinct southwestern vergences. Alpine tectonostratigraphic units mentioned above are thrust each to other with the External Dinarides at the base and the Sava-Vardar Zone at the top (Fig. 4.2.1.2.). As distinguished from the whole Central Dinarides the northernmost parts of the Sava-Vardar zone are characterized with northern vergences which are recognized in the northern parts of the Mts. Majevica, Motajica and Prosara.

Geological map (Fig. 4.2.1.2.) shows geology of the pre-Quarternary. This map is compiled on the basis of numeorus sheet Geological Map of Bosnia and Herzegovina, scale 1:100 000.

4.2.1.3. Main tectonostratigraphic units of the Dinarides

The central parts of the Dinarides, which were not strongly affected by the Tertiary deformations are characterized by a regularly zoned pattern of tectonostratigraphic units derived from different oceanic (Dinaridic Tethys) and continental (Adriatic-Dinaric carbonate platform) palegeographic realms (Pamić et al., 1998). From the SW to the NE, i.e. from the Adriatic microplate to the Pannonian Basin (Tisia-Moesia), the following units can be distinguished (Fig. 4.2.1.2.).

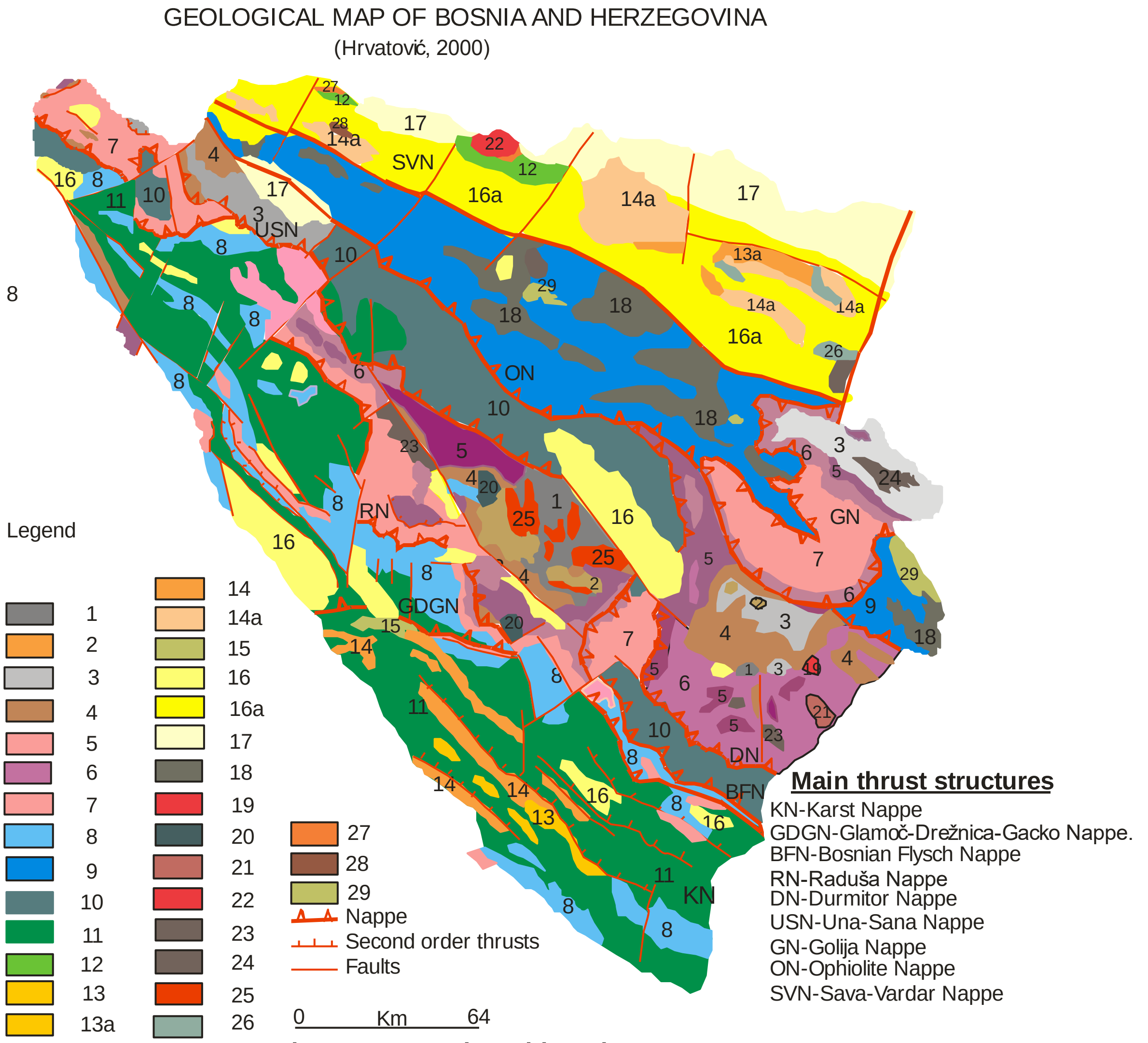
- ### The Dinaric carbonate platform

In the present structure of the Dinarides, the Dinaric carbonate platform is included in External Dinarides. Its southwestern marginal parts overlaying the Apulia are covered by the Adriatic Sea, whereas its northeastern margin is thrust by allochthonous Paleozoic-Triassic formations. The Dinaric carbonate platform largely composed of a) an Upper Paleozoic sequence composing Late Carboniferous-Early Permian clastics and carbonates, b) a Late Permian to Norian sequence of clastics and platform carbonates and associated synsedimentary igneous rocks deposited during the initial rifting stage of the Alpine cycle. In some areas the carbonates are interlaxered with chert, shale, pyroclatic and volcanic rocks, which accumulated in platform depressions, particularly during the Ladinian. Middle Triassic formations are confromably overlain by Carnian limestone and associated volcanics and by Norian limestone and dolomite. During the Norian conditions for long-lasting carbonate platform sequences were finally established, and c) the Norain-Lutetian carbonate platform, which begins with the Norian-Rhetian «Hauptdolomit», which only in some areas overlies the Carnian Raibls Beds (Pamić et al. 1998). Stable shallow-marine environments prevailed during Jurassic-Cretaceous and lasted until the Lutetian temporairly interrupted by several pelagic incursions.

Platform carbonate deposits, besides their significant thickness (4000 to 8000 m) they are characterized lateral and vertical alternations of different facies, mostly associated with shallow marine environments. Environments are from peritidal through low-energy shallow subtidal-lagoons, restricted inner platform shallows, high-energy tidal, beach and shoreface.

- **The Bosnian Flysch**

Jurassic-Cretaceous formations of the Apulian passive continental margin originated along slope of the Adriatic-Dinaridic carbonate platform and on its foot (Pamić, Jurković, 1997). These formations are most widespread in the area between



Main tectonostratigraphic units

Dinaridic carbonate platform: 7. Late Triassic dolomites, limestones and marlstone, 8. Jurassic limestones and dolomites, 11. Cretaceous limestones, 13. Paleocene limestones, 14. Eocene limestones and calcarenite,
Flysch bosniaque :
10. Tithonian to Barriasian siliciclastic flysch (Vranduk group); Late Cretaceous-Lower Paleogene carbonate flysch(Ugar group)
Dinaridic ophiolite zone : 18. Late Jurassic ophiolitic melange or wildflysch"; 9. Ultramafic massifs;
29. Overstep formations (Pogari formation and platform limestone);
Allochthonous Paleozoic and Triassic formations :Metamorphyc rocks:
1. Silurrian greenchist and epidote-amphibolite facies ; **Sedimentary rocks:** 2. Devonian limestones and dolomites;
3.Carboniferous siltstones, shales, sandstones, limestones (with turbiditic character);
4. Late Permian siliciclastics, limestones and evaporites; 5. Early Triassic siliciclastics and limestones;
6. Middle Triassic (limestones, chert, tuffite, dolomites); 7. Late Triassic limestones and dolomites; **Volcanic rocks**:
25.Paleozoic rhyolite group; 20. Middle Triassic basalt group; **Plutonic rocks**: Middle Triassic19. Alkaly-feldspar syenite,
20. Gabro group, 21. Granodiorite-diorites group. **Sava-Vardar Zone :** 13a. Paleocene limestones and siliciclastics,
14a. Eocene siliciclastics, 26.Late Cretaceous limestones and siliciklastics; 12. Non-metamorphosed to Greenschist-amphibolite facies Late Cretaceous-Paleogene flysch (Prosara and Motajica),
22. Eocene granite group(Motajica), 24. Andesite i dacite (Srebrenica); 27. Orto and Paragneiss (Prosara and Motajica);
28. Mafic and ultramafic magmatites N-Kozara
Post-orogenic Oligocene, Neogene and Quarternary sediments
15 Oligocene (Promina formation); 16. Miocene intramontain fresh-water sediments, 16a Miocene South Pannonian Basin
17. Pliocene-Quarternary sediments

Fig. 4.2.1.2. Geological map of Bosnia and Herzegovina (Hrvatović, 2000)

the Mid-Bosnian Schist Mts in the south and the Dinaride Ophiolite Zone in the north and northeast. In the geological literature these formations were included in the geotectonic and paleogeographic zones by different names by diferent authors: Durmitor flysch (Bešić, 1952), Flysch bosniaque and zone prekarstique (Aubouin et al., 1974), Sarajevo-Banja flysch zone (Mojičević, 1975), Flexure zone (Grandić, 1974) and zone of passive continental margin formations (Pamić et al., 1998).In the Bosnian Flysch, which attains a total thickness of about 3000 m, two subunits can be distinguished (Olujić, 1980).

a) The «Vranduk Subgroup» is characterized by an alternation of non-flysch, «paraflysch» and subordinate turbidite series composed mainly of micrites, arenites, shales, in some areas interlayered by radiolarites reflecting several pelagic incursions. This series ranges in age from Early Jurassic to Berriasian.

b) The «Ugar Subgroup» is a typical carbonate flysch series from the carbonate shelf margin. It ranges in age from the Albian to the Senonian and rarely contains Early Paleogene microfossils.

- ## The Dinaride Ophiolite Zone (DOZ)

The Dinaride Ophiolite Zone, which is the most important geotectonic unit of the Internal Dinarides, can be traced along stike from the area south of Zagreb in the northwest through Borje, Ozren, Konjuh up to the Višegrad area in the southeast. The zone continues without a break through southwest Serbia and Kosovo, and further southward as the Mirdita Zone in Albania (Fig. 4.2.1.1.).

The Dinaride Ophiolite Zone (DOZ) covers the most of the Internal Dinarides and it is composed of the following units (Pamić 1982; Pamić et al., 2002.

a) The «Radiolarite Formation», Middle / Late Triassic to Early Cretaceous in age, is a bed-to-bed sequence in which radiolarites predominate over shales, micritic limestones and basalts.

b) The «Olistostrome Ophiolite Mélange» is a chaotic complex largely composed of shaley-silty matrix with fragments of graywackes, ophiolites and subordinately chert, amphibolite, clastics, as well as Middle Triassic to Tithonian limestone exotics. The original interlayering of shales and graywackes with occasional slumps and basalt flows is preserved only in some areas. Microfossil assemblage indicates a Jurassic age of this mélange.

Ophiolites, dismembered to various degree, are mainly peridotites with subordinate basalt-diabase and gabbro. K-Ar mineral ages ranging between of 178-160 Ma were obtained on amphibolities and accompanied rocks of peridotite metamorphic soles (Lanphere et al., 1975; Majer et al., 1979) together with Sm-Nd age of 136 Ma obtained on peridotite tectonites Lugović et al., 1991). The ophiolites have probably MORB characteristics (Lugović et al., 1991; Pamić et al., 2002).

c) The Berrisian to pre-Albian sequence i.e. the «Pogari Formation», which unconformably overlies the ophiolite mélange is composed of conglomerates, breccias and lithic sandstones containing re-deposited ophiolite fragments in its basal parts. These clastics sediments of the Pogari Formation are conformably overlain by limestones of Albian to Senonian age.

- ## The Sava-Vardar Zone

The formations of the active continental margin of the Dinaridic Tethys are included into the Vardar geotectonic zone of the Dinarides. The Vardar Zone sensu stricto, as defined by Kosmat (1924), was separated in Macedonia as 40-70 km wide zone sendwiched between the Pelagonides and the present Serbo-Macedonian Massif. Afterwards it was extented further to the north and northwest as the Vardar Zone sensu lato (Aubouin, 1974), which can be traced along strike for about 900-1000 km from Thessaloniki in Greece along NNE direction. In deffects south of Belgrade to WNW direction and extends south of the Sava River in Bosnia up to the Zagreb – Zemplen Line in the northwest. For that reason it would be more appropriate to be called the Sava-Vardar Zone.

Based on recent data (Pamić, 1993; 2000), the Bosnia part of the Vardar Zone consists of the formations as follows: 1) Cretaceous-Early Paleogene flysch. In some areas, the lower parts of the flysch are interlayered with coeval subduction-related basalts and rhyolites intruded by comagmatic A-type granites; 2) Tectonized Ophiolite Mélange which differs from the Jurassic olistostrome mélange of DOZ by a higher degree of tectonization of its matrix by ophiolite fragments of Cretaceous/Early Paleogene age, and coeval limestone exotics; 3) Late Paleogene regionally metamorphic sequences originated from surrounding Late Cretaceous flysch; 4) Synkinematic granitoids and 5) Post-orogenic volcanics. The Vardar Zone, particularly its northern parts are strongly by Neogene sediments of the South Pannonian Basin.

- ## The allochthonous Paleozoic-Triassic units

In the geological structures of the Dinarides of Bosnia and Herzegovina are also included Paleozoic complexes which represented basement on which strated Mesozoic-Paleogene evolution of the Dinaridic Tethys. The Paleozoic complexes, together with frequently accompanied Triassic formations are allochthonous and occur in the areas as follows: Sana-Una, Mid-Bosnian Schist Mts., Southeastern Bosnia (Foča-Prača area) and East Bosnia (Drina-Ivanjica area).

The Allochthonous Paleozoic-Triassic units of the Internal Dinarides which disturb the regularly zoned distribution pattern of Dinaridic tectonostratigraphic units. These units consist mainly of Late Paleozoic (Devonian-Carboniferous) metasediments and metavolcanics, which are covered by Permian and Triassic sediments and rhyolites, Early Paleozoic metasediments and magmatic rocks. These pre-Alpine formations are accompanied with abundant Triassic limestones and dolomites, with subordinate clastic and volcanic rocks. Field relationship and the most recent analytical data indicate that the these allochthonous Paleozoic-Triassic units were probably derived from the South Eurasia margin (Pamić et al., 1998; Pamić, 2003).

Incorporation of all these tectonostratigraphic units into the present structure of the Dinarides can be explanied by the following steps of the Alpine orogeni cycle (Pamić et al., 1998, 2002), a) Middle/Late Permian to early Norian rifting; b) (?)Late Triassic/Middle Jurassic opening of the Dinaridic Tethys; c) Late Jurassic/Early Cretaceous SW-directed obduction of ophiolites on the Adriatic margin, followed by the emplacement of the allochthonous Paleozoic-Triassic units by SW-directed thrusting. This gave rise to first Alpine metamorphic overprint, as indicated by radiometric data (Pamić et al. 2004), and d) Mid-Eocene collisional crustal shortening during the main Dinaridic deformational phase. This was accompanied by the second phase of ophiolite emplacement, synkinematic granitoid plutonism, and the second Alpine regional

metamorphic overprint recorded in Paleozoic formations. A more detail discussion on the evolution of the Dinarides is presented in Pamić et al., (1998, 2002).

After the last orogenic pulse the Dinarides were uplifted and eroded in conjunction with Oligocene/Neogene strike-slip faulting due to continued Adria indentation and westward transport of Moesia (Márton, 1993; Kázmer & Kovács, 1985; Ratschbacher et al., 1991). Within the uplifted Dinarides elongated transpresional depressions developed in a form of intramonatne basins where Neogene continental and lacustrine, sporadically coal-bearing sediments were deposites.

4.2.1.4. Main tectonic structures and discontinuities

The Central Dinarides, which were not disrupted by Oligocene-Miocene strike-slip faulting are characterized by imbricated fold-and-thrust structures that display a distinct southwest vergence. Apart from small-scale tectonic complications, the tectonostratigraphic units presented above were thrusted one on top of the other, with the External Dinarides unit and Sava-Vardar Zone, corresponding to the lowest and the highest unit, respectivelly. This large-scale fold-and-thrust imbricationof the Dinarides formed since Late Jurassic up to Eocene collisional deformational phases.

Deep refraction seismic data that the top of the allochthonous basement is located at depths of 8 to 13 km beneath the external parts of the Central Dinarides and at about 8-10 km beneath the Bosnian Flysch and the Dinaride Ophiolite Zone. By contrast, sediment thickness are of order of 3-5 km in southern parts of the Pannonian Basin. Similarly, the crust- mantle boundary rises from about 40-45 km beneath the External Dinarides to 30 km beneath the Dinaride Ophiolite Zone and to less than 25 km beneath the South Pannonian Basin (Fig. 4.2.1.3. - Dragašević, 1977, Pamić et al., 1998).

Within the Dinarides the following main large structures can be distinguished (Fig. 4.2.1.2.):

1) The Karst thrust, is the largest thrust sheet of the Dinarides, comprises the entire Dinaridic karst region, and is largely composed of Mesozoic to Early Paleogene carbonate platform sequences. Depeding on authors and regions, this thrust sheet has been referred to by different names. It was thrusted southwestward over the Ionian Zone. However, its sole thrust is largely concealed (Grandić et al., 1997). To the northeast the Karst thrust sheet is overvide by Una-Glamoč-Drežnica-Gacko and Bosnia Flysch Nappes. In the southeasternmost Dinarides, the Karst thrust sheet overlies the Budva Zone which continues into Hellenides as the Cukali Zone (Albania).

2) Una-Glamoč-Drežnica-Gacko thrust sheet is thrusted over the Karst thrust sheet (Fig. 4.2.1.1.) and more specifically its Dinaricum part, and, in turn, is covered mainly by the Bosnia Flysch Nappe. In the northwest, the Glamoč-Drežnica-Gacko (part of the Una-Kuči Nappe), which is overridden by the Raduša Nappe, continues further northwestward to Una River.

The Una-Glamoč-Drežnica-Gacko thrust sheet corresponds, at least partly, to the «zone pre-karstic» of the French geologists (Aubouin et al., 1970) and thus it has a transitional position between the External Dinarides. This unit consists largely of Triassic formations in which dolomites and limestones predominate over clastics and igneous rocks.

The Una-Glamoč-Drežnica-Gacko thrust sheet corresponds, at least partly, to the «zone pre-karstic» of the French geologists (Aubouin et al., 1970), that has a transitional

position between the External and the Internal Dinarides. This thrust sheet consists largely of Triassic formations in which dolomites and limestones predominate over clastics and igneous rocks. Only in some areas it is composed of Early Jurassic sediments and this subordinate Paleozoic clastics and carbonates, whilst Mesozoic Internal Dinaridic lithologies such as Triassic carbonate and siliciclastics, are distinctly missing.

3) The Bosnia Flysch Nappe is entirely composed of the Bosnian Flaysch sequences derived from Adriatic passive margin. To the southeast it is underlain by the Una-Glamoč-Drežnica-Gacko thrust sheet. Its southeastermost parts includes the Vermoshi Zone in NW Albania, which is cut by the Skadar-Peć fault to the southeast. Lateral equivalent of the Bosnia Flysch Nappe in the central and southern Hellenides are the Krasta Zone (Albania) (Meco & Aliaj, 2000; Aubouin, 1973). The Bosnia Flysch Nappe can be traced along the entire length of the Dinarides and is best exposed in the Central Dinarides between Vareš and Banja Luka, where it is overriden by the Ophiolite Nappe (Mojičević, 1978).

4) The Ophiolite Nappe is the largest Internal Dinaridic thrust sheet. In the northwestern Dinarides, the Ophiolite Nappe wedges out in the area west of the Zagreb-Zemplin Line. Its frontal parts can be traced from the Vareš area towards the northwest in the area Nemila-Mts. Borije-Uzlomac up to Banja Luka. In all this area the Ophiolite Nappe is thrust onto the Bosnian flysch Nappe. In the Central Dinarides, the Ophiolite Nappe is the best exposed whereas further southeastward it is tectonically covered by the Golija Nappe. In the southeasternmost Dinarides, the Ophiolite Nappe extends into the Mirdita Zone and the Subpelagonian Zone of the Albanides and the Hellenides (Fig. 4.2.1.1.).

Within the Ophiolite Nappe numerous faults were recorded, as for example, along the northern margin of Mt. Kozara, in the areas of Vrbas-Teslić, Banja Luka-Kotor Varoš, Teslić-Zavidovići with its extension to the Olovo-Sokolac-Rogatica fault. Along some of these faults springs of mineral and thermomineral waters occur.

5) The Sava-Vardar Nappe forms the northeastern thrust sheet of the Dinarides, which can be tracced along the strike for about 700 km, and continues further southeastward into Hellenides. In the north, the Sava-Vardar Nappe overlies the Ophiolite Nappe. Its northern part is largely covered by the Neogene fill of the South Pannonian Basin. To the north, the Sava-Vardar Nappe is bounded by the South Tisia Block. Field relations and geophysical data indicate that South Tisia dips under the Sava-Vardar Nappe at a very low angle (Pamić, 1998, Tari, Pamić, 1998) as a result of a back-thrusting, involving north-directed tectonic transport during the Pliocene (Pamić et al., 1998).

6) The Dinarides include four nappes derived Paleozoic-Mesozoic terrane. The Paleozoic-Triassic Nappe has a very important role in structure of the Dinarides. Its importance reflects in its dimensions, various stratigraphy and lithology, from and mode of thrusting and others. These are: a) Sana-Una, b) Golija, c) Durmitor and d) Raduša nappes.

a) In the northwestern Internal Dinarides is located Sana-Una Nappe (Maksimčev&Jurić, 1974). The Sana-Una terran represmet part of the unique segment of Earth's crust, which has been later dismembering by Late Cretaceous-tertiary strike-slip movements The Una-Sana Paleozoic complex comprises the area of Bosanski Novi, Prijedor, Kozica, Sanski Most, Budimlić Japra, Ključ and Mrkonjić grad (Fig. 4.2.1.1.).

This allochthonous complex is included in the Pannonian Nappe (Miladinović, 1974) which stretches here from Mt. Petrova Gora in Banovina up to Broncani Majdan. Paleozoic formations are thrust onto various Triassic formations which occur as milonitic zones, tectonic windows and klippes. Within the same thrust system in also included the Sanski Most thrust composed of Triassic formations, which crops out beneath the Sana-Una Nappe. The Sana-Una Paleozoic area is bounded to the north by the Sava Zone from which is separated by the Kozara-Spreča fault.

b) In the Central-Eastern Dinarides (East Bosnia) it is represented by the Golija Nappe, which is composed of the Drina-Ivanjica Paleozoic formations (Fig. 4.2.1.2.). East Bosnian Paleozoic formations represented the northwesternmost parts of the large Drinja – Ivanjica Paleozoic complex, also reffered to as the Golija Zone (Aubouin et al., 1974) which is thrust onto the Dinaride Ophiolite Zone. The Paleozoic formations are accompanied by Triassic formations which form the large ravna Romanija thrust stretching southeastward up to Sokolac and Višegrad. Below this thrust crop out tectonic windows composed of rocks of the underlying Dinaride Ophiolite Zone (areas of Žepa and Rogatica).

c) The Durmitor which is characteristic for the southeastern Dinarides, is largely composed of Triassic carbonates accompanied by subordinate clastics, siliceous and igneous rocks. However, it also includes the Foča-Prača Paleozoic complex of southeast Bosnia, the Lim Paleozoic-Triassic complex of Montenegro, and its southeastern extension in Albania (Pamić, Jurković, 2002, Meco, Aliaj, 2000). The frontal parts of the Durmitor Nappe, which tectonically overlies the Bosnia Flysch Nappe (Fig. 4.2.1.2.), can be traced southeastward up to the Skadar-Peć fault. Further in Albania the Durmitor-Gashi (Hrvatovi&Pamić, 2005). Nappe continues into the Gashi Zone. Triassic formations of the Durmitor Nappe are internally folded and imbricated. A century ago Kittl (1904) found that Mt. Trebević near Sarajevo represents a large imbricate structure composed of several second order nappes.

d) The Raduša Nappe, has an ambigous structural position (Fig. 4.2.1.2.), and can be traced along its strike for ca. 150 km. Along its northeastern margin it is ocerthrust by the Bosnian Flysch Nappe, while in turn it override the Una-Glamoč-Drežnica-Gacko thrust sheet along its frontal part. The southwestern part of the Raduša Nappe is largely composed of Triassic carbonates and subordinate coeval clastic and igneous rocks, and scarce Permian sediments. Middle/Late Permian evaporites which probably lubricated its basal thrust plane commonly crop out along its frontal parts. In the northern part the Raduša Nappe is in contact with the Paleozoic complex of the Mid-Bosnia Schist Mts. This contact is marked by Voljevac strike-slip fault which is an older thrust fault reactivated as a strike-slip fault during the Tertiary.

<u>Vrbas-Voljevac fault</u> defines the southwestern part the Mid-Bosnian Schist Mts. This very significant dislocation stretches from Prozor in the southeast towards the northwest in the Vrbas Valley and in the area south of Banja Luka it terminates jointing the northwesternmost part of the Busovača fault. The Vrbas-Voljevac fault zone, strecthing NW-SE, is a few hundred wide as recognized by satellite and aerophotos. The dislocation separates Paleozoic formations of the Mid-Bosnian Schist Mts. from surrounding Mesozoic, mainly carbonate rocks. The fault zone is partly covered by post-orogenic Neogene sediments of the fresh-water Bugojno Basin. In Triassic sediments spatially related to the Vrbas-Voljevac fault zone, volcanics of Triassic spilite-keratophyre association are very common. In these Triassic formations the mineralizations of barite, tetrahedrite, Au, Hg, Cu and quartz are found. It is very

probable that this large dislocation originated by Oligocene transpressional strike-slip faulting, and it is also probable that it was reactivated during the subsequent Neogene tectonic phases.

Busovača fault defines spatially the northwestern boundary of the Mid-Bosnian Paleozoic complex toward the Neogene Sarajevo-Zenica Basin. This large fault located between these two different geological units is easily detectable on satellite images and aerophotos. The Busovača fault can be traced along strike from Ilidža nearby Sarajevo to the Travnik area where is partly covered by the Mt. Vlašić thrust parth of the Bosnia Flysch Nappe); in the northwest it terminates at Mrkonjić Grad.

Along this fault numerous mineral and thermomineral water spring occur as wellas various mineralizations (quarzt, barite, Cu, Fe, Au). The fault predisposed the generation of the intramontane Sarajevo-Zenica neogene Basin. It is characterized both by vertical and horizontal movements. Along the margin of the Sarajevo-Zenica Basin vertical movements up to 1500-1700 m were registred. These vertical movements were accompanied by significant horizontal movements, when longiotudinal transpressional faults originated. Comparatively mild diagonal long folds found in the Miocene fresh-water Sarajevo-Zenica Basin might have originated due to dextral movements of the basinal flank of the Buusovača fault by horizontal strain activity (Hrvatović, 1997).

In the area between Busovača and Kiseljak the existence of the Busovača fault was suported by geophisical prospecting data (magnetism and gravimetry). These data indicate that the Busovača fault represents a dislocation zone dipping towards the axis of the Neogene Sarajevo-Zenica Basin. In the area of Ilidža, Kiseljak area and Klokot spatially related to the Busovača fault, in basement were penetrated by deep wells Triassic limestones and dolomites, and pre-Devonian metarhyolites and metaclastics. In most of the deep-wells flow-fluxes of gas and thermomineral water were registered.

Sarajevo fault stretches in NE-SW direction which is perpendicular to the NW-SE strike of the Dinarides. It can be traced from Konjic on the Neretva River in the southwest up to Mt. Sarajevo Ozren in the northeast were covered by the Paleozoic-Triassic nappe. It is very probable that it joins the Drina fault in the northeast and the Neretva fault in the southwest. The Sarajevo fault runs along the southeastern boundary of the Mid-Bosnian Schist Paleozoic-complex. Combined creation of this fault and the Busovača fault predisposed the generation of the Sarajevo-Zenica intramontane depression susequently filled by Neogene fresh-water formations. The Sarajevo fault also disrupted surrounding Triassic formations and the formations of the passive continental margin.

Neretva fault which approximatelly has N-S direction, transects the complete Mesozoic carbonate platform sequences that are perfectly exposed in the Neretva valley. This is a few kilometre deep fault as indicated by the occurence of Scythian clastics detached from basement.

Drina fault stretches along the Drina Valley area where subsided rocks of its western flank.

Spreča-Kozara fault represents the northern boundary of the Dinaride Ophiolite Zone which predisposed generation of the South Panonian margin. In parts of the dislocation konwn as the "Spreča Depression" in the area between Doboj and Živinice, it is morphologically characterized by a system (sub) parallel faults forming, as a whole, a the regional fault zone. On satellite images the zone can be traced from Doboj to

Derventa and the Slavonija Mts. in the west and along the margins of the Mts. Javor and Romanija in the east and further eastward up to Drina and Užice in Serbia.

Along this fault vertical displacement up to 2000 m were registered. Along its strike occur numerous mineral and thermomineral water springs and various kinds of mineralization (Cu, Pb, pyrite and others).

Una fault , first described by K. Šikinić (1964) and Chorovicz (1969), was at the beginning identifed in the Una River Valley where is easily recognozable in relief in the Martin Brod-Ripač-Bihać area. This is a deep fault which reflects in structure of this part of the Dinarides. Along its strike geological formations spanning between late Permian and Late Cretaceous with spring of the mineral and thermomineral waters can be found. Its eastern block was affected by younger tectonism.

Banja Luka fault stretches along the Vrbas River Valley towards the sava River in the north and further northward transects the Slavonian Mts. and continues in Hungary and, thus it has a regional significance. In River Vrbas Valley parts its western block subsided which gave rise to the creation of the Quaternary Lijevče Polje Depression. The Banja Luka seismogenic zone is apparently related to these tectonic movements.

Other faults comprise a large number of faults identified both in the field and aero-photos. In the carbonate platform (External Dinarides) occur NW-SE striking reverse faults which mark Paleogene structutres of the area of Posušje, Široki Brijeg, Bileće and Trebinje. In this group are included longitudinal faults which predisposed generation of Tertiary depression, i.e., the intramontane basins, as well as the transversal faults in the area of Drvar, Glamoč, Čapljina, Mostar, Ljubinje and Trebinje. In North Bosnia along the northern margin of Mt. Majevica is important a fault with E-W direction which controlls uplift of this mountain. Fault structures are of a particular interest from the point of view of seismic activity. Based on seismic and seismotectonic data (Janković, 1987) concluded that, among tectonically active faults, seismologically the most active are the Banja Luka fault and Spreča-Kozara fault, particularly the parts of their mutual crossing.

4.2.1.5. Seismicity

Acording to the representation of the seismicity status event (historical, instrumental from 1901 to 2004) and to the 4 categories of focal depths, the earthquakes are grouped in Table 4.2.1.1.

Table 4.2.1.1. Earthquakes epicentres from 1901 to 2004 years

Earthquakes epicentres from 1901 to 2004 years					
		Foacl depth (km)			
Number of event	Magnitude	0-10	11-20	21-30	>30
2	>6		1	1	
10	5,6-6,0	3	4	2	2
14	4,6-5,0	6	4	2	2
78	4,6-5,0	48	16	10	3
162	4,1-4,5	125	29	13	3
406	3,6-4,0	363	38	4	1
118	3,1-3,5	108	6	2	22
Total:790		653	92	34	11

Acording to the classification of epicentres earthquakes, there are a few epicentre areas:

- **The area of North Bosnia with Banja Luka is characterized by intensive seismic activity (magnitude 6,4), followed by area of Tuzla, Derventa and Skelani.**
- **The area of Central part of the Dinarides (Jajce, zenica-Žepče, Sarajevo, Treskavica and Prača. The most intense earthquake is registred on Mt. Treskavica (magnitude 6,0).**
- **The area of External Dinarides (carbonate platform) where is a series of epicentres earthquakes in areas: Ljubinje-Stolac-Mostar-Široki Brijeg; Trebinje-Hutovo Blato-Ljubuški –Tihaljina; Trebinje-Bileća-Gacko and Tomislavgrad-Livno.**

Sesmic activities are associated with deep faults; strikie-slip faults and reverse faults (Figs. 4.2.1.2., 4.2.1.3)

4.2.1.6. Seismotectonic activity

The area of Bosnia and Herzegovina is located NE from active compressional geotectonic contact between the Adriatic mass and the Dinarides. The Adriatic mass, as part of Africa, is impressed between Apenines and Dinarides along strike-slip active faults. Earthquakes recorded in the part of the Dinarides of Bosnia and Herzegovina is originated by relase of energy from subduction of Africa and Evropa plates. This energy, as a primary source of the tectonic energy, are delivered as a seismic energy over the seismogene structures (Fig. 4.2.1.3., Table 4.2.1.2.).

According to the activities during tha last 100 years, the Bosnia and Herzegovina was divided into 5 seismogene zones and 57 potential seismoactive structures (Fig. 4.2.1.3., Table 4.2.1.2.). Their lengths are between 6 km to 40 km.

Comparing the tectonic data with recorded epicentres of earthquakes, it is obvious that there ia a mutual between tectonic structures and earthquakes. On the basis data it can concluded that the stronger seismic activity occurs at the boundaries of geotectonic units (directions NW-SE), then along the longitudinal dislocation (directions NW-SE), at the intersections of transversal faults (directions NE-SW and N-S).

Table 4.2.1.2. Seismoenergetical capacity of the seismogenetical structures

Nr.	Name	Length(km)	Magnitude (M)	Depth of focus-h (km)	Intensity in epicentre I_o-MCS°
1	Banja Luka	40	6,6	18	9,0
2	Laktaši	40	6,5	10	9,0
3	Dragočaj	38	6,4	10	9,0
4	Banja Luka-Prijedor	36	6,3	15	8,5
5	Bastasi	8	4,5	20	5,0
6	Laktaši II	19	5,5	10	8,0
7	Prijedor	5	4,0	10	5,5
8	Kozara	9	4,7	15	6,55
9	Sanski Most-Vrhpolje	11	4,92	10	6,55
10	Mrkonjić Grad	25	5,9	10	8,3
11	Bosanski Petrovac	9	4,5	10	6,1
12	Bosanska Krupa	8	4,5	10	6,25
13	Cazin	8	4,5	10	6,25
14	Bihać	12	5,0	10	6,25
15	Klokot	13	5,0	10	7,15

16	**Ključ**	**15**	**5,3**	**10**	**7,45**
17	**Grahovo**	**15**	**5,1**	**15**	**7,2**
18	**Osječenica**	**19**	**4,8**	**15**	**6,55**
19	**Dinara**	**40**	**4,8**	**15**	**6,75**
20	**Kupres**	**10**	**4,8**	**10**	**7,0**
21	**Duvno**	**13**	**5,1**	**15**	**7,5**
22	**Livno**	**10**	**5,1**	**10**	**7,3**
23	**Buško jezero**	**10**	**5,0**	**10**	**7,2**
24	**Posušje**	**10**	**4,6**	**15**	**6,4**
25	**Tihaljina**	**10**	**6,0**	**15**	**8,0**
26	**Ljubuški**	**27**	**6,0**	**10**	**8,8**
27	**Široki Brijeg**	**8**	**4,5**	**10**	**6,5**
28	**Hutovo**	**10**	**5,0**	**15**	**7,0**
29	**Stolovi-Slano**	**15**	**4,8**	**10**	**7,0**
30	**Trebinje**	**15**	**4,5**	**10**	**6,5**
31	**Ravno**	**10**	**4,8**	**17**	**6,0**
32	**Stolac**	**27**	**6,0**	**17**	**8,5**
33	**Nevesinje**	**10**	**4,8**	**6**	**7,6**
34	**Gacko**	**11**	**4,9**	**10**	**7,0**
35	**Zelengora**	**11**	**4,9**	**7**	**7,0**
36	**Foča**	**10**	**4,8**	**7**	**7,0**
37	**Treskavica**	**27**	**6,0**	**19**	**8,0**
38	**Han Pijesak**	**20**	**5,6**	**6**	**8,5**
39	**Milići**	**10**	**4,8**	**6**	**7,0**
40	**Skelani**	**22**	**5,7**	**6**	**8,5**
41	**Žepče**	**10**	**4,8**	**4**	**8,0**
42	**Zenica**	**10**	**5,0**	**10**	**7,0**
43	**Travnik**	**10**	**4,8**	**10**	**7,0**
44	**Derventa**	**8**	**4,6**	**17**	**6,0**
45	**Modriča**	**15**	**5,3**	**8**	**7,7**
46	**Gradačac**	**15**	**5,3**	**8**	**7,7**
47	**Usora**	**18**	**5,5**	**10**	**7,7**
48	**Vučkovci**	**10**	**4,8**	**7**	**7,2**
49	**Maoča**	**15**	**5,3**	**7**	**7,9**
50	**Tinja-Moluhe**	**12**	**5,0**	**10**	**7,0**
51	**Srebrenik**	**11**	**4,9**	**10**	**7,0**
52	**Duboštica**	**7**	**4,4**	**7**	**6,1**
53	**Bijeljina**	**20**	**5,6**	**10**	**7,9**
54	**Sapna**	**12**	**5,0**	**10**	**7,0**
55	**Kalesija**	**18**	**5,5**	**10**	**7,7**
56	**Živinice**	**15**	**5,5**	**10**	**7,4**
57	**Tuzla**	**11**	**4,9**	**10**	**6,8**

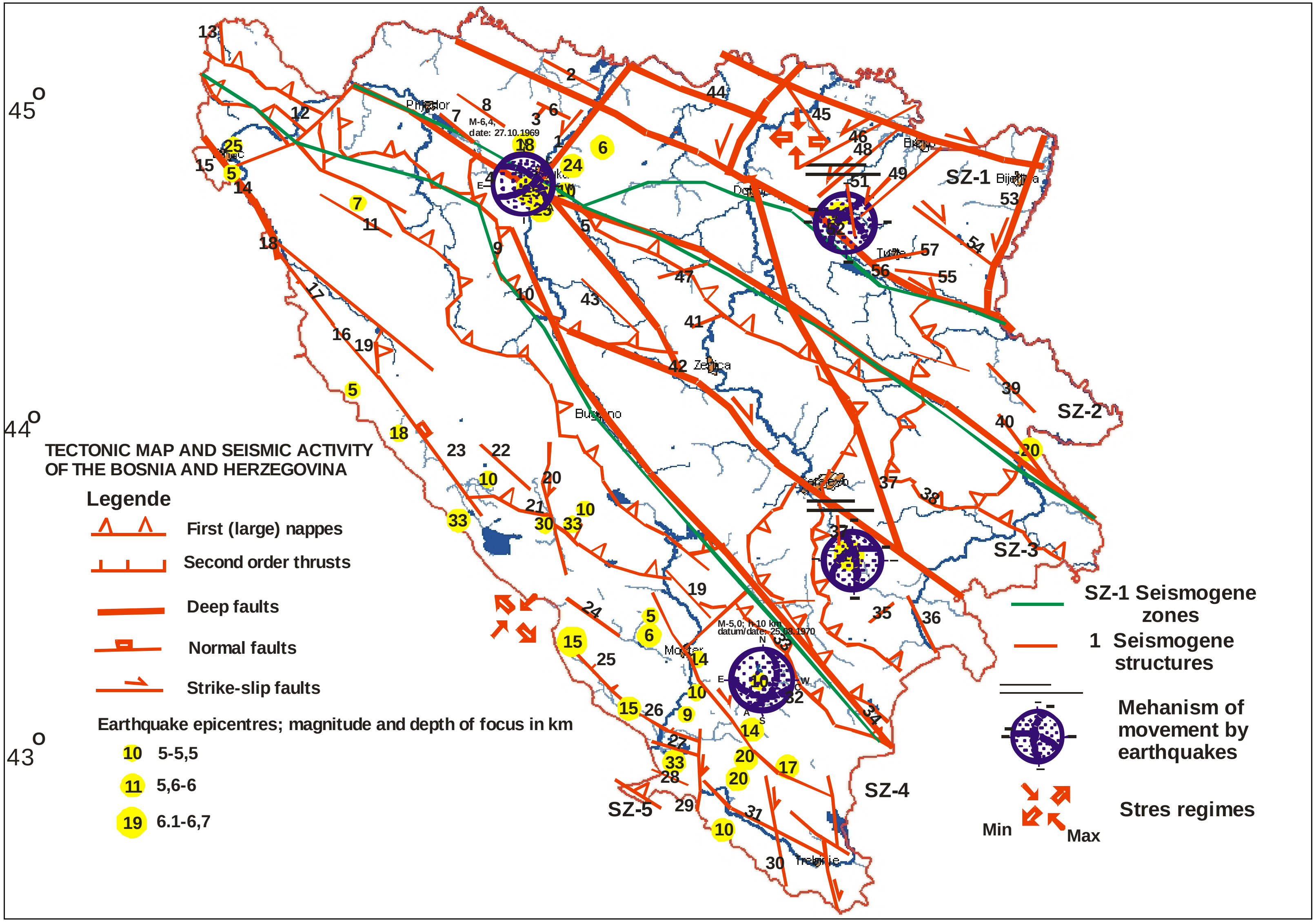


Fig. 4.2.1.3. Tectonic map and seismic activity of the Bosnia and Herzegovina

4.2.1.7. References

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