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# Recent Tectonic Activity in the Imotsko Polje Area

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**Key words:** Active fault zones, Stress, Structures, Earthquakes, Imotsko polje, Croatia.

## Abstract

Displacements of the Adriatic microplate, particularly of its southern part, are of crucial importance for the understanding of recent tectonic movements. Deformations of the structural fabric and the resulting tectonic activity also encompass the studied area. There are four most active fault zones - Mosor-Biokovo, Zagvozd-Vrgorac-Metković, Trilj-Tihaljina-Čapljina and Imotski-Međugorje-Popovo polje. In the explored area, these zones delimit the Imotsko polje.

The calculated regional stress is oriented in the range between 10-190° and 350-170°. The relationship between the orientation of structural units and stress enables reverse displacements, most frequently in the direction of the south and south-east. The change in stress orientation in the Mt. Biokovo hinterland makes the aforementioned fault zones surrounding the Imotsko polje favourably oriented in respect to the stress, thus enabling dextral horizontal tectonic transport of the structures in different fault blocks.

In the two fault zones - Trilj-Tihaljina-Čapljina and Imotski-Međugorje-Popovo polje, there are 98 outcrops suitable for the structural geology measurements. The obtained data on the local stress orientation and spatial displacement of structures are the most important. The character of faults and the most active fault sections are marked, as well as the local structures that are formed due to strong horizontal component of structural displacement in the studied fault zones. Recent tectonic activity is confirmed by the occurrence of earthquakes. Spatial distribution of the earthquake epicentres depicts zones of seismotectonic activity that are related to the aforementioned most important fault zones. Two of the fault zones - Trilj-Tihaljina-Čapljina and Imotski-Međugorje-Popovo polje are especially well marked by earthquakes occurring at depths of between 3 and 15 km.

## 1. INTRODUCTION

The Imotsko polje is situated in the Dinarides, in the hinterland of the reverse structures among which Mt. Biokovo is the most prominent (Fig. 1). Two facts point to the tectonic activity in the entire area:

- permanent occurrence of earthquakes with a particular concentration of epicentres around Imotski, Makarska and Vrgorac (HERAK et al., 1996);
- geodetic measurements of the marker points near Split, Dubrovnik, Hvar and on the neighbouring islands, performed between 1994-1996 show that horizontal and vertical displacements up to 2 cm per year occurred (ČOLIĆ et al., 1996; CIGROVSKI-DETELIĆ, 1998).

In order to define tectonic movements, it was necessary initially to consider previously acquired knowledge on the structural relations and basic classifications of the structural fabric (e.g. RAIĆ et al., 1976, 1978; MARINČIĆ et al., 1978; MAGAŠ et al., 1979; BIJU-DUVAL & MONTADERT, 1977; HERAK, 1986, 1991; LAWRENCE et al., 1995; GRANDIĆ et al., 1997), together with the data on the structural relations at depth (e.g. ALJINOVIĆ, 1984; ALJINOVIĆ et al., 1984, 1987; LABAŠ, 1987; SKOKO et al., 1987). Especially important are the data on the recent stress field and the possible deformation of structures (RITSEMA, 1974; ANDERSON & JACKSON, 1987; GRÜNTHAL & STORMEYER, 1992; HERAK et al., 1995; MARKUŠIĆ et al., 1998; PRELOGOVIĆ et al., 1999; ALTINER, 1999). The spatial distribution of earthquake epicentres is particularly significant for definition of the most active faults. The most reliable data for description of tectonic movements were collected by structural geological mapping. A total of 98 outcrops were studied in the Imotsko polje area, and the measured data enabled more detailed analysis of the characteristic structural fabric. Emphasis was placed on the definition and classification of structures and faults according to their importance in structural fabric and tectonic activity. The structural fabric characteristics are described in such a way that the most active fault sections and displacements of tectonic blocks are stressed, and that the local structures and their deformations are shown.

## 2. FAULTS, STRUCTURAL RELATIONS AND DISPLACEMENTS

In the area shown in Fig. 1, the principal structural data are given together with the earthquake epicentres. Earthquake foci depict the spatial distribution of the seismotectonically most active zones. These zones are related to the most important faults of the structural fabric.

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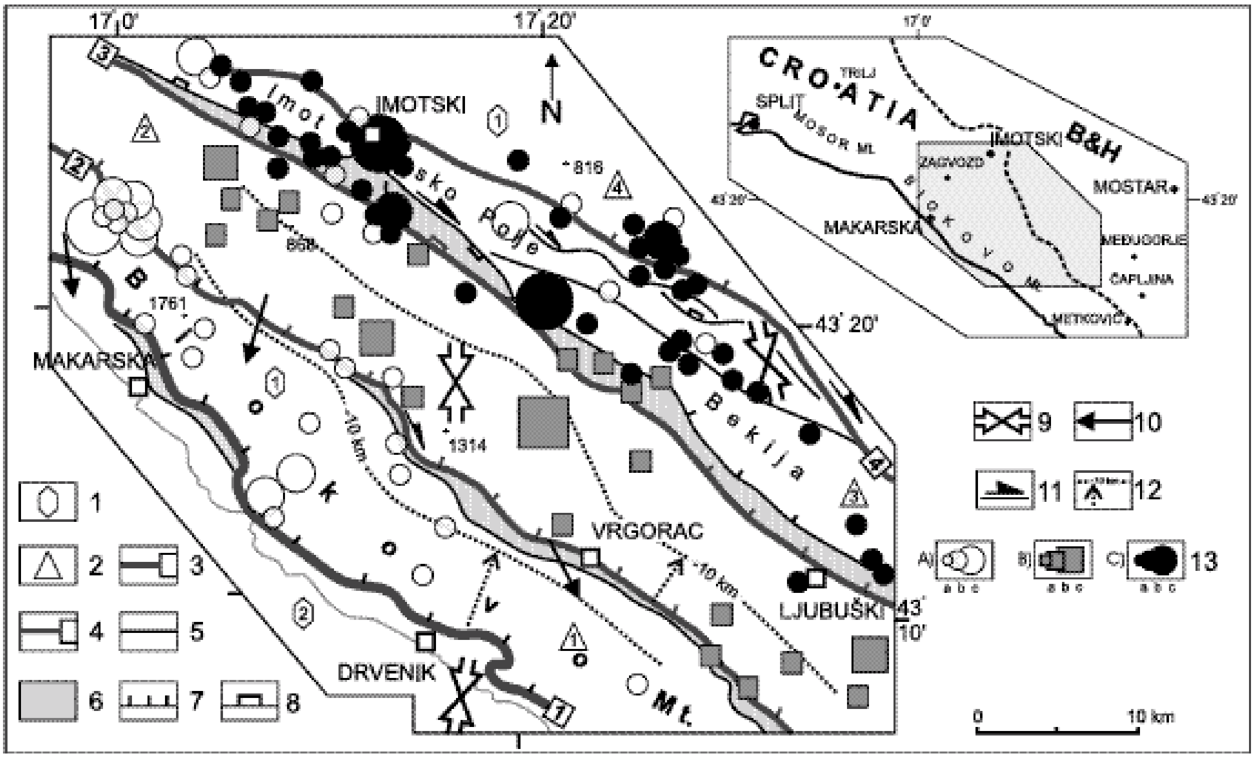


Fig. 1 Structural fabric and zones of seismotectonic activity. Legend: 1) regional structural units: Dinaricum (1), Adriaticum (2); 2) structural units: Biokovo (1), Biokovska Zagora (2), Imotski-Bekija (3), Trebistovo-Posušje-Mostar (4); 3) the most important fault of the structural fabric, contact between the regional structural units: Mosor-Biokovo fault (1); 4) faults delimiting structural units: Zagvozd-Vrgorac-Metković fault (2), Trilj-Tihaljina-Čapljina fault (3), Imotski-Međugorje-Popovo polje fault (4); 5) faults within the fault zones and branches of more important faults; 6) fault zones; 7) reverse faults; 8) normal faults; 9) regional stress orientation; 10) direction of tectonic transport close to the surface; 11) fault sections with horizontal displacement of tectonic blocks; 12) projection of the seismotectonically active zones at a depth of 10 km; 13) earthquake epicentres (magnitudes: a<4, b=4-5, c>6) marked for the following fault zones: Mosor-Biokovo (A), Zagvozd-Vrgorac-Metković (B), Trilj-Tihaljina-Čapljina and Imotski-Međugorje-Popovo polje (C).

Earthquake foci concentrations that are connected to the Mosor - Biokovo fault (1) and the Zagvozd - Vrgorac - Metković fault (2) depict the relatively steeply inclined zones of tectonic activity (65° in average) to a depth of approximately 10 km. The biggest concentration of foci is in the zone that is related to the Mosor - Biokovo fault (1); this zone acquires a mild inclination only at depths greater than 10 km (Fig. 1); the earthquake foci in the vicinity of Imotski are located at depth in the range of 18 to 20 km. In the area between the Trilj - Tihaljina - Čapljina fault (3) and the Imotski - Međugorje - Popovo polje fault (4) earthquakes occur at depth between 3 and 15 km, within a subvertical zone (around 80°).

The Mosor - Biokovo fault zone (1) is the most important in the structural fabric. It marks the contact between the two regional structural units - Dinaricum (1) and Adriaticum (2). Within the Dinaricum, the aforementioned faults delimit the following structural units: Biokovo (1), Biokovska Zagora (2) and Imotski-Bekija (3). The most important faults and structural units have the following characteristics:

- Mosor - Biokovo fault (1) - different dip angles were measured, in the 28-80° range, but most frequently between 55 and 75°; the parallel faults of this zone are found in the flysch sediments and along Mt. Biokovo; within the Biokovo unit (1) there are a number of parallel faults, mostly reverse ones, that are either satellite or branching faults of the main zone; there are also frequent signs of tectonic transport along the bedding planes, and retrograde rotation on the steeply inclined fault planes; the faults mostly have the diagonal displacement in the direction of the S-SE, occasionally S-SW;
- Zagvozd - Vrgorac - Metković fault (2) - the zone is 300 - 1,300 m wide on the surface and is composed of a sequence of parallel faults and branching faults; the measured dips are in the 46-70° range, only occasionally between the 32-40° and slightly more frequently between 78 and 84°; the Biokovska Zagora unit (2) is characterised by sequences of local reverse structures and faults; rotation of structures is observed as well as displacements in S-SW direction, most frequently in direction of S-SE and SE, together with occasional dextral horizontal displacements;
- Trilj - Tihaljina - Čapljina fault (3) - mostly normal faults are found in the 2,000 m wide zone, but there are also reverse faults of opposite vergence, measured dip angles are in the range between 56 and 86°; some of the fault sections are characterised by dextral hori-

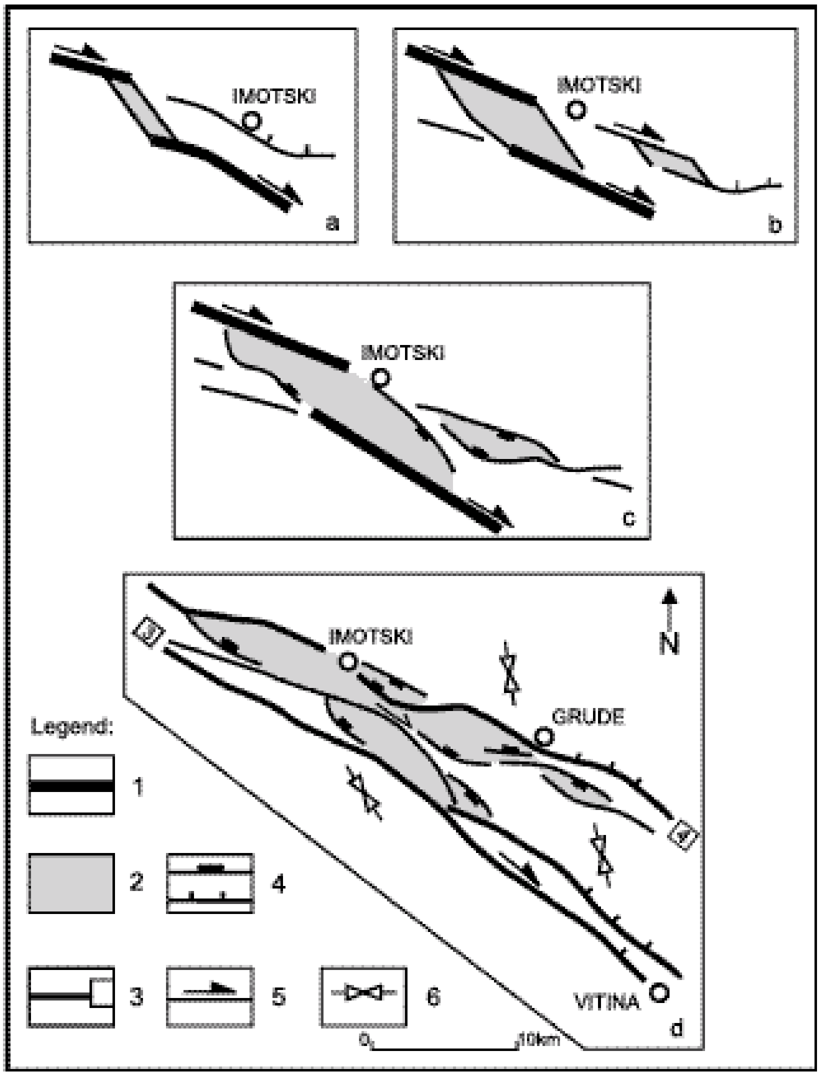


Fig. 2 Reconstruction of possible formation of extensional structures in the Imotsko polje area (a, b, c, d - succession phases). Legend: 1) primary fault; 2) extensional zones; 3) fault zones in the recent structural fabric: Trilj-Tihaljina-Čapljina (3) and Imotski-Međugorje-Popovo polje (4); 4) normal and reverse faults; 5) direction of horizontal displacement; 6) generalised stress orientation in the studied fault sections.

zontal displacement of tectonic blocks; the change in character of displacement is observable in direction of Ljubuški, where the reverse fault sections appear;

- Imotski - Međugorje - Popovo polje fault (4) - reverse faults prevail in this zone, apart from the Imotski area, where there are normal faults; the zone is 200 - 1,000 m wide; dip angles are in the 60-80° range; the faults within the Imotski-Bekija (3) structural unit have the same characteristics as the boundary faults; this means that the unit actually represents a relatively wide fault zone with a spatial arrangement of the most important, boundary faults and their differently inclined branching faults in between.

The observed dextral horizontal displacements enable the conclusion to be drawn that the formation of Imotsko polje is connected to the spatial extension in conditions of favourable (diagonal) stress orientation in respect to the strike of the initial, primary fault. Possible formation of the extensional structures in the Imotsko polje is illustrated in Fig. 2. The Pliocene and mostly Quaternary sediments that were deposited indicate the time of formation. Fault characteristics, local structures and movements or tectonic transport of blocks are illustrated by showing parts of the fault zones Trilj - Tihaljina - Čapljina (3) and Imotski - Međugorje - Popovo polje (4).

The Trilj - Tihaljina - Čapljina fault zone (3) is shown in Fig. 3. An example is given in the area of Zmijavci, south of Imotski (Fig. 3a), where the existence of the faults that branch from the boundary fault is at first observable. In addition, the secondary strike-slip faults ($R_1$ and $R_2$ systems) appear within the zone, with either dextral or sinistral horizontal displacement of tectonic blocks. Gradual bending of the entire zone is also observed, which makes the fault zone section around Zmijavci favourably oriented in respect to the stress action. This causes the additional extension in this area and formation of the local pull-apart structure.

The stress orientation is not the same along the entire studied fault zone. Therefore tectonic blocks are rotated in some places and the fault traces are bent along the strike. Local pop-up structures were formed (Fig. 3b). The margins of these structures are marked by the steeply inclined reverse faults of opposite vergence. In these cases, the displacement of hanging

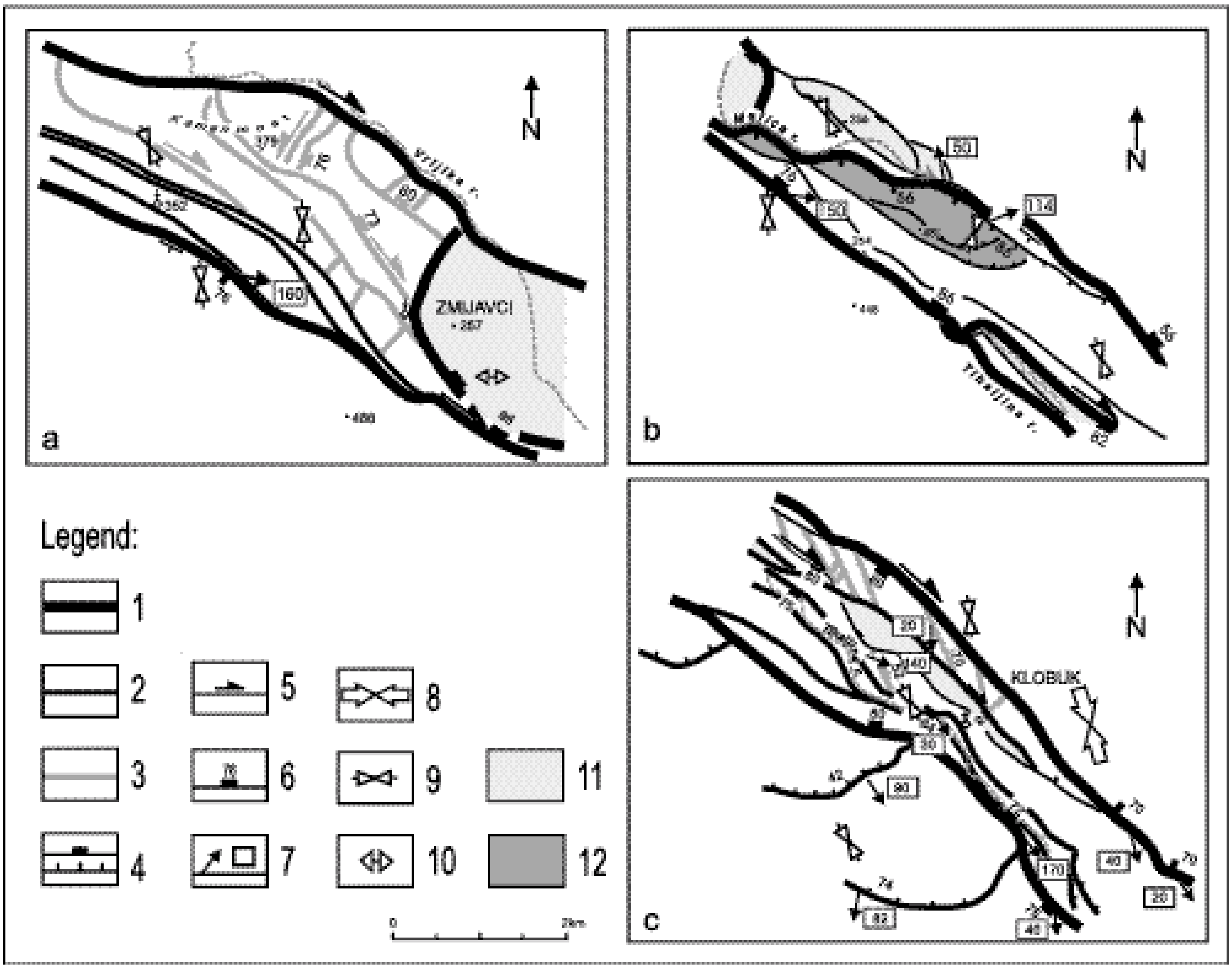


Fig. 3 Trilj-Tihaljina-Čapljina fault zone. Legend: 1) traces of the most important faults in this zone; 2) secondary and branching faults within the zone and the reverse faults in the structures S of the zone; 3) secondary strike-slip faults; 4) normal and reverse faults; 5) direction of horizontal displacement of tectonic blocks; 6) fault dip angle; 7) direction and angle of the hanging wall displacement; 8) generalised stress orientation in this part of the zone; 9) local stress; 10) local extension; 11) pull-apart structures; 12) pop-up structures.

walls can be either sinistral or dextral, and with the diagonal tectonic transport that can even be in a direction opposite to the general direction of horizontal displacement. Boundary faults, together with other faults of the structural fabric, form the fault zones. Within these zones, fault splays frequently appear, consisting of faults that differ in dip angle and sometimes also in the character of displacement. A good example is found in the incised Tihaljina valley that was formed due to horizontal displacement in the boundary fault zone.

Apart from being bent in the direction of the strike, some faults can be curved in the dip direction. This causes change in the character of displacement. For instance, in the area of Klobuk, along the boundary fault of the studied zone, reverse faults are found, which have oblique to subhorizontal dextral displacement (Fig. 3c). This fault zone section is characterised by steeply inclined faults. A number of parallel faults are observed, with formation of the local pull-apart structures in their additional fault zones near Klobuk. The reverse structures SE of Tihaljina are relatively unfavourably (almost perpendicularly) oriented in respect to the stress action and reverse displacements prevail. Parts of the structures have different directions of tectonic transport, and the fault traces are strongly curved in the vicinity of the Trilj - Tihaljina - Čapljina fault zone (3). This is interpreted as the rotation of structures that was aided by horizontal displacement along this fault zone.

The Imotski - Međugorje - Popovo polje fault zone (4) is shown in Fig. 4. Near the Bekijsko polje that lies between Imotski and Grude two characteristics are discerned. The section towards Imotski is favourably oriented in respect to the stress action. Therefore, the fault zone is broadened and the local pull-apart structures are formed. A different stress orientation in the vicinity of Grude makes the observed fault zone unfavourably (almost perpendicularly) oriented. This means that only the reverse deformations of structural fabric are possible here, which causes the local narrowing of the Bekijsko polje area. The same features explain why a local pop-up structure was formed along the faults on the southern margin of the polje.

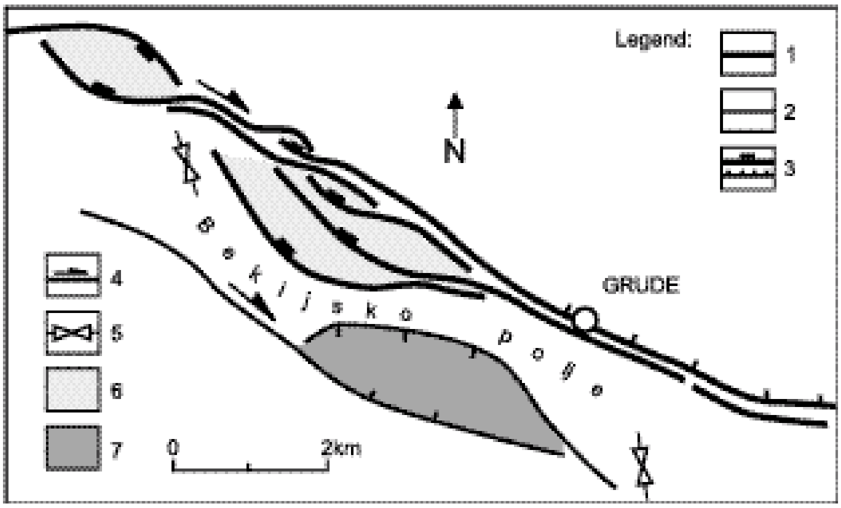


Fig. 4 Imotski-Međugorje-Popovo polje fault zone. Legend: 1) traces of the most important faults in this zone; 2) faults along the borders of the Bekijsko polje; 3) normal and reverse faults; 4) direction of horizontal displacement of tectonic blocks; 5) generalised stress orientation in the parts of this zone; 6) pull-apart structures; 7) pop-up structures.

## 3. CONCLUSION

Recent tectonic activity in the surroundings of the Imotsko polje is marked by the horizontal component of structure displacement in the Trilj - Tihaljina - Čapljina (3) and Imotski - Međugorje - Popovo polje (4) fault zones. This activity is inevitably dependable on the position of Imotsko polje in the regional structural fabric.

Of crucial importance for the recent tectonic movements are displacements of the Adriatic microplate, particularly of its southern part. Within the Dinarides, there are rock masses of variable density, different size and spatial position that resist the microplate movements. In this way the stress regime is formed that influences deformations of structural fabric and the activity of faults.

In this part of the Dinarides the calculated regional stress is oriented between 10-190° and 350-170°. The relationships between the strike of structural units and orientation of recent stress indicate two facts: there is active compression in the area which is most expressed in Mt. Biokovo, and there is a possibility for the reverse displacements in the S and SE direction. Most of the measurements taken in the fault zones delimiting structural units have shown the oblique displacement of tectonic blocks. This means that parts of the structural fabric are in rotation and that displacements of structures are formed in reaction to the primary movements of the Adriatic microplate.

The change in orientation of the action of regional stress from the coastline in direction of Imotski is an important fact. This change is a consequence of the displacement and rotation of structural units that led to formation of new relationships between the rock masses. In this way, the structures and faults within the Imotski-Bekija structural unit (3) are mostly positioned favourably (oblique) inclined in respect to the stress orientation. This implies the possibility of dextral horizontal displacement of structures. It is especially well marked along the Trilj - Tihaljina - Čapljina (3) and Imotski - Međugorje - Popovo polje (4) fault zones. The biggest spatial extension is observed in the Imotsko polje area, in the vicinity of Tihaljina and Klobuk and also in the Bekijsko polje. Alternatively, oblique displacement of tectonic blocks was frequently observed, mostly with an angle of 20-40°, but also 50-75°. This means that there is variable orientation of the local stress. These variations are causing formation of local extensional or compressional structures, bending of fault planes both in the direction of strike and dip as well as the formation of fault splays and reverse faults of opposing vergence in some places.

From the position of the Trilj - Tihaljina - Čapljina (3) and Imotski - Međugorje - Popovo polje (4) fault zones in the regional structural fabric the following conclusions can be drawn:

- the area bounded by these faults is an active zone with prevailing dextral horizontal tectonic transport;
- earthquakes in this subvertical zone happen at depths in the range of 3-15 km;
- the most active component of the regional structural fabric is the frontal part of the Dinarides, which is dominated by the seismotectonically active zone of the Mosor - Biokovo fault (1).

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