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Preliminary report

SEISMIC DEFORMATION IN BOUNDARY ZONES OF THE ADRIATIC MICROPLATE: THE MODELS FOR THE THREE REPRESENTATIVE ORIGIN ZONES

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SUMMARY: On the basis of reliable fault plane solutions and other geological and geophysical evidence, we defined the three models of the seismic deformation. Each of them is characteristic of the corresponding origin zone. Results and here presented models are in good agreement with existing plate motion models of the Adriatic microplate and the Mediterranean region.

1. INTRODUCTION

Recent geodynamical discoveries are based on the data of geophysical, astronomical and other specific explorations of the Earth. Different approaches provide the keys for the interpretation of the complex aspect and behaviour of the Earth. The new set of data provide precise constraints for the geodynamical modeling of the lithosphere.

The main goal of the geodynamical modeling is determination of the exchange of positions of the points on the Earth's surface and elements of the Earth's gravity field and their physical interpretation. Geodynamical explorations can be divided into (in the space meaning) the global, regional and local ones. As a part of the global investigations the movements of the Earth's crust and general tectonic movements play very important role. Processes of crustal deformations show the "living" aspect of the Earth.

The existing seismological data and other geological evidence are the basis for investigations of recent seismic deformation in the region of the Adriatic microplate.

The Adriatic region resembles, in some ways, relatively stable continental block, caught up within the distributed deformation of the Alpine-Himalayan Belt. On the three sides the Adriatic is bounded by the relatively stable European plate. Its boundary with African plate is short and ill-defined due to seismicity, but is likely to be located in the Southern Adriatic, near the Strait of Otranto.

The Adriatic microplate plays a major role in understanding of the tectonic history of central Mediterranean region and the development of the Alpine system. Position of the Adriatic microplate is specifically defined by the Periadriatic orogeny belt (Apennines, Alps, Dinarides and Helenides). The great density of the earthquake epicenters characterizes some parts of the tectonics deformed orogeny (the Montenegro coastal line, the Friulian arc, the middle and the southern parts of the Appenines).

From the geological point of view, the microplate is composed of the relatively undeformed continental crust of the Adriatic basin surrouded by the orogeny. The crystal basin of the microplate is mostly composed of the phyllites and metamorphic gneisses. Analysis of the geophysical data confirms the existence of the Moho-discontinuity (25-60 kilometers) and different thickness of the lithosphere (80-100 kilometers).

2. SEISMICITY OF THE ADRIATIC MICRPOPLATE AREA

The maps of the epicenters of the earthquakes sketched on the basis of catalogue data, demonstrate specific distribution of the seismicity. The epicenters of the earthquakes are grouped in some characteristic zones. The seismic belt practicaly follows the Appenines belt and with more or less diffuse disposition extends up to the Alps. The intensive seismic activity is characteristic of the Albania and the Adriatic coast in Yugoslavia (Fig. 1). The Valley of the river Po, northern and southern parts of the Adriatic sea basin and Apulia, are seismic regions with weak seismicity, often treated like aseismic in analyses.

The current seismicity of the entire region is characterized by the three strong earthquakes that occured in different parts of the Adriatic microplate, in other words in three separate epicenter areas (Fig. 1) marked by numbers 1, 2 and 3.

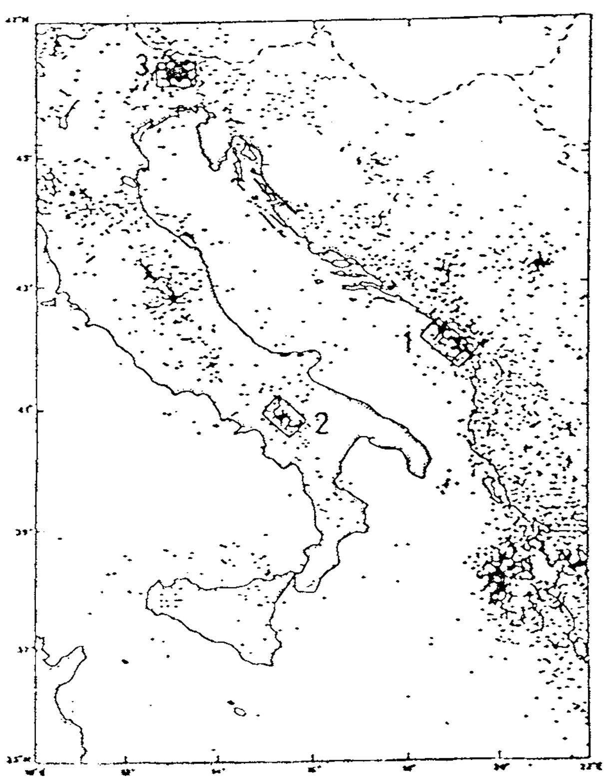

Fig. 1. The seismicity of the Adriatic microplate area generated in the period 1963-1990. (on the basis of USGS data base). The epicenters of all published earthquakes with hypocenter depths less than 50 kilometers are shown. The positions of the epicentral zones 1, 2 and 3 are marked.

Separated epicentral zones have great density of the earthquake epicenters and express greater seismic activity in regard to the other parts of that region. In Fig. 1, the separated epicentral areas are marked respectively as: 1-South Adriatic, 2-Irpinia, 3-Friuli area.

General feature of the seismicity of the whole Adriatic microplate area is the occurence of the seismic sequences with the strongest earthquakes and numerous foreshocks and aftershocs.

In such a way the generation of seismic energy in the case of the epicenter area of the Friuli was followed by more than 20 strong earthquakes with magnitudes greater than 4. 0 (in the period May 06 1976 - December 13 1976.) and a great number of weakly earthquakes (Carulli G.B. *et al.* 1990).

In the case of the South Adriatic seismic sequence (period April 09 1979-January 23 1980) a great seismic energy was generated. In this period 132 strong earthquakes have occured with magnitudes greater than 4.3 and numerous weak earthquakes (Karakaisis G.F. *et al.* 1985).

Seismic activity with similar characteristics was generated in the Irpinia zone in the period between 1980 and 1981.

This type of seismic activities in the frame of separated epicentral zones as parts of one unique geology whole, only confirms the complexity of the recent geodynamic processes in this region and represents the reflexion of the active seismotectonics. Seismotectonic processes are connected with deformations in the earthquake sources. On the basis of data relevant to the occured stongest earthquakes and complex interpretation, it is possible to model different types of seismotectonic deformations. Such models (proposed on the basis of strongest representative earthquakes) are very important for complex geodynamics relations between the Adriatic microplate and the near surrounding and represent a confirmation of the plate tectonic theory applied for this area.

By analysis of seismological and other available data relating to the representative earthquakes for the epicentral zone 1 (April 15 1979., Montenegro earthquake), the epicentral zone 2 (November 23 1980., Irpinia earthquake) and the epicentral zone 3 (May 061976., September 15 1976., Friulian earthquakes), we defined mechanisms of the faulting for each of them and the positions of the dominanat stress axis. In case of epicentral zone 3 we analized two earthquakes, the strongest earthquake (May 06 1976.) and the strongest aftershock (September 15 1976). The mentioned earthquakes occured in the frame of the whole seismic zone but with different faultings in the sources.

3. PLANAR DEFORMATIONS

There are several ways for characterisation of deformations.

Structural analysis can be very well adapted to recent tectonics with possibility for description of the different types of deformation present in the frame of any region, as well as the sequences of the various deformation stages in case of a polyphase deformation.

Microtectonic methods, as an important step in the quantitative analysis of brittle deformation,

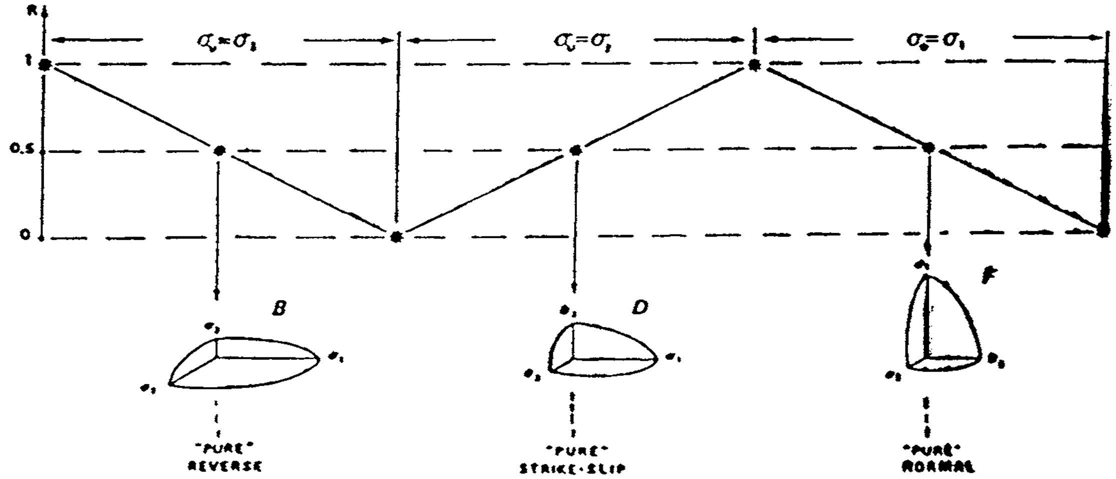

Fig. 2. The three cases of planar deformation: "pure reverse", "pure strike slip" and "pure normal", in terms of the form and orientation of the corresponding stress tensor.

can be also used. These methods rely on microstructural observations (fault planes and microfaults, tension gashes and stylolites) and usually aid the recognition of the types of deformations affecting the region as well as their chronology. Microtectonic methods may also rely on striation measurments on fault mirrors and on their treatment by appropriate methods. This approach allows the inversion of the parameters of an average stress tensor explaining the striations, these parameters being the orientation of the axes and the tensor form.

As a specific approach it is possible to use earthquake focal mechanisms and stress measurements *in situ* for determination of present tectonic activity and state of stress of a region.

The compilation of information from diverse sources demonstrates the overall consistency of the different types of data (geophysical data, geological observations), and their combination defines consistent models of deformation for particular region. More exactly, there is a possibility of reciprocal understanding between present-day phenomena (seismicity, *in situ* stress measurements, geodesy) and recent tectonic phenomena.

Today's deformations which occured under sub-surface conditions can be explained, theoreticaly, by the shape and orientation of the corresponding stress tensor, the form being defined by the value of the ratio R ($0<R<1$). To each particular value of R (0, 1/2, 1) there corresponds a given shape of the tensor which, coupled to the definition of the tensor orientation in space, defines a specific type of deformation.

The three simple cases of planar deformation are defined by Anderson (1951). These three types of deformation have identical tensor forms characterised by the value of the intermediate stress component $\sigma_2=(\sigma_1+\sigma_3)/2$ (i.e. $R=1/2$). Each one of these deformations (Fig. 2) is specified by the orientation of the stress tensor and by the corresponding type of faulting (normal, reverse or strike slip) which can ben observed.

"Pure reverse" deformations are planar ones (vertical plane), the maximum stress axis (σ_1) is horizontal and the minimum stress axis (σ_3) is vertical. The deformation is dominated by reverse faults and by folds.

"Pure normal" deformations are planar deformations in the vertical plane, with the minimum stress axis in the horizontal plane (σ_3) and corresponding maximum stress (σ_1) is in vertical plane. This type of deformation produces only normal faults.

"Pure strike slip" deformations constitute the case with both maximum (σ_1) and minimum stress axis (σ_3) in the horizontal plane. The corresponding deformation involves only strike slip faulting.

These three types of pure planar deformations can be seldom observed in nature, at least not on regional or large scale (they can exist on the microtectonic scale and usually are found near large faults). In fact, on regional scale, the combination of various fault types is most often observed (strike slip and reverse faults or strike slip and normal faults).

4. SEISMIC DEFORMATION MODELS IN THE EARTHQUAKE SOURCES

The determination of seismic deformation in the sources of the studied events is based on two-step investigations.

The first one is the determination of the nodal planes, i.e. fault plane, and the second is the determination of stress field feature.

Traditionally, source mechanisms have been determined using first-motion data to constrain a single double-couple mechanism. The nature of the data set means that such mechanisms describe the early part of the source. This may or may not be representative of the whole source process for large earthquakes. A new access to determination of the nodal planes is the CMT-method which offers the possibility for studying the spatio-temporal pattern of released stress. In modern seismology, CMT method has a dominant role. Numerous digital seismic networks, i.e. digitalized seismic data, make possible the automatic process. CMT method is a nonlinear inversion of digital waveforms data for the retrieval of the centroid and six independent components of the moment tensor. The usual representation in terms of six components of the zero-degree moment tensor is adequate for point source at given location.

4.1. South Adriatic origin zone – the April 15 1979, Montenegro earthquake

The Montenegro earthquake (15. April 1979, M_l=6.9, M_s=7.1) is the strongest recent earthquake occured in the Adriatic region and surroundings. In the past 15 years this seismic event was the main source of the necessery information for fundamental and applied seismological, seismotectonics and engineering investigations.

The basic parameters of this event are specified by:

- origin time: T_0=06:19:40.8;
- epicenter location: latitude λ=41.061 N, longitude ϕ=19.015 E;
- focal depth: h=11 km;
- local magnitude of the earthquake: M_l=6.9.

The CMT method was applied to the 15 April 1979, Montenegro earthquake (the event was registered by more than 227 seismological stations, including more than 10 digital seismological stations).

The needed parameters (azimuths of the principal stress axes and elements of the nodal plane) are defined as:

The stress axis: T-axis azimuth 31°;
P-axis azimuth 222°.
The nodal plane: strike 127°;
dip 77°.

The illustration of the assumed seismic deformation model is shown in the Figure 3.

The similar type of the fault mechanisms was characteristic of other strong events generated in the frame of this seismic sequence (the strongest foreshocks and aftershocks). On the basis of that information it is possible to suppose that the proposed model of seismic deformation can be relevant to the whole epicentral area of the Adriatic coast of Yugoslavia.

4.2. Irpinia origin zone – the November 23 1980, Irpinia earthquake

The Irpinia earthquake is the best documented strong earthquake in the whole Adriatic region. This earthquake was registered at teleseismic, regional and local distances on analog and digital media. This event was the greatest earthquake in the Apennine mountains for the past 50 years.

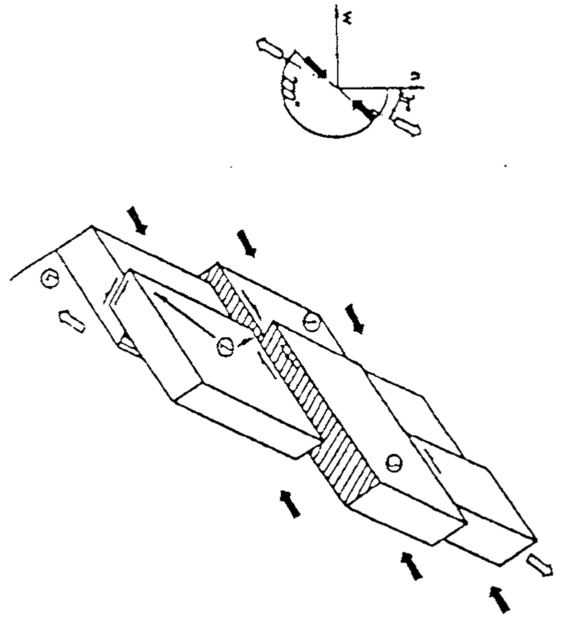

Fig. 3. The model of possible seismic deformations in the source of the 15 April 1979 Montenegro earthquake. The black arrows illustrate the pressure axis, and the white one the tension axis. The reverse faulting with a considerable strike-slip motion along the active fault is marked with number 2, and practically present part of the eastern margin of the Adriatic microplate. The other marks are the Adriatic microplate (1) covered by external Dinarides (3), i.e. the contact zone with considerable seismic deformation. These deformations are, in the spatial sense, grouped in the frame of seismic layer marked by earthquake foci. In the deeper parts (4) there are probably aseismic deformations.

There are several research works and solutions, but the basic parameters of this event can be defined as:

- origin time: T_0=18:34:53.8;
- epicenter location: latitude λ=40.9 N, longitude ϕ=15.4 E;
- focal depth: h=10 km;
- local magnitude of the earthquake: M_l=6.5.

On the basis of the teleseismic observations, focal mechanism has been obtained (CMT method). The needed parameters (azimuths of the principal stress axes and elements of the nodal plane) are defined as:

The stress axis: T-axis azimuth 39°;
P-axis azimuth 163°.
The nodal plane: strike 317°;
dip 62°.

The illustration of the assumed seismic deformation model is shown on Figure 4.

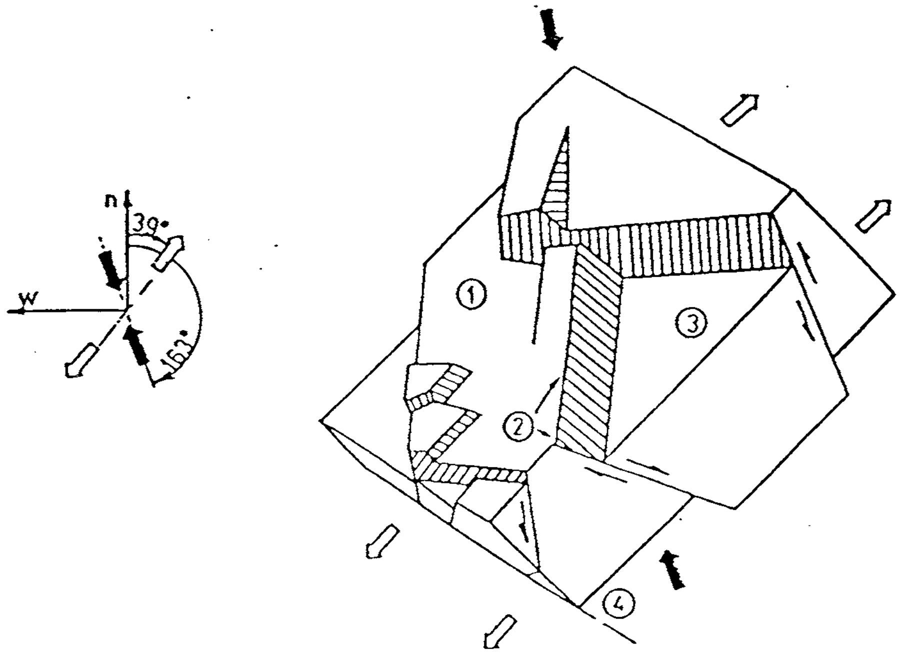

Fig. 4. The model of possible seismic deformations in the source of the 23 November 1980, Irpinia earthquake. The pressure axis and the tension axis are illustrated with the black and the white arrows. Pure normal faulting is a consequence of the radial extension. Because of that faulting, one part of the Adriatic microplate (3) is relatively brought down in relation to the Appenninic limestone platform (1). The faulting zone (2) with brightly vertikal motion is characteristic of the western margin of the microplate. Seismic deformations are grouped in the seismic layer marked by earthquake foci. In the deeper parts (4) there are processes of aseismic deformations.

4.3. Friulian origin zone – the May 06 1976, Friulian earthquake and the September 15 1976, Friulian earthquake

The Friulian origin zone is a contact one between the Alps and the Dinarides. High level of seismicity is characteristic for this part of the Adriatic microplate. We analized two strong earthquakes because different faulting is the distinctive feature for the whole epicenter area. In case of the strongest earthquake (May 06, 1976; M_l=6.4) the focal mechanism was generally reverse, while in case of the strongest aftershock (September 15, 1976; M_l=6.1) the focal mechanism was strike-slip, i.e., there were two available mechanisms of faulting in the frame of the Friulian epicenter area.

The focal mechanisms of the Friulian earthquakes have been obtained using the polarities of the P-waves, i.e., first-motion data.

The basic parameters of those events are:

THE STRONGEST FRIULIAN EARTHQUAKE (May 06, 1976; M_l=6.4):

- origin time: T_0=20:00:11.6;
- epicenter location: latitude λ=46.36 N, longitude ϕ=13.27 E;
- focal depth: h=10 km;
- local magnitude of the earthquake: M_l=6.4

Needed parameters (azimuths of the principal stress axes and elements of the nodal plane) are defined as:

-The stress axes: T-axis azimuth 04°;
P-axis azimuth 156°.
-The nodal plane: strike 076°;
dip 75°;

THE STRONGEST FRIULIAN AFTERSHOCK (September 15, 1976, M_l=6.1):

- origin time: T_0=09:21:19.0;
- epicenter location: latitude: λ=46.23 N, longitude ϕ=13.09 E;
- focal depth: h=9 km;
- local magnitude of the earthquake: M_l=6.1.

Needed parameters (azimuths of the principal stress axis and elements of the nodal plane) are defined as:

-The stress axis: T-axis azimuth 48°;
P-axis azimuth 171°.
The nodal plane: strike 061°;
dip 68°.

Figure 5 illustrates the model of assumed seismic deformation for the whole origin zone (marks A and B designate the respective origin zones of the strongest Friulian earthquake and the strongest aftershock from the same seismic sequence).

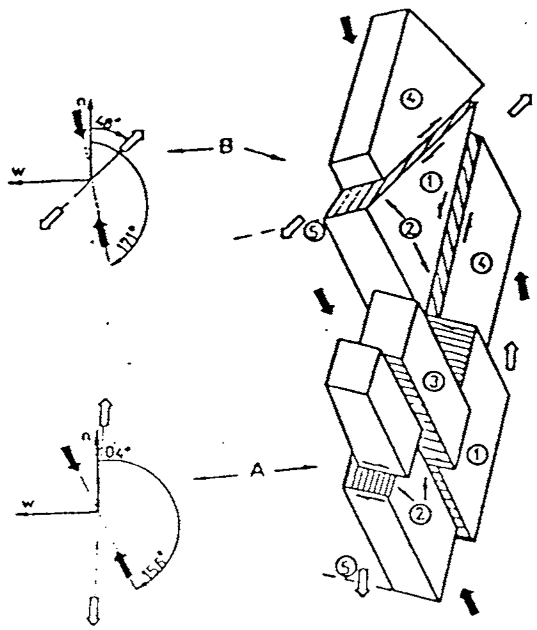

Fig. 5. The model of possible seismic deformations in the sources of the Friulian earthquakes (seismic sequence May-September 1976).

Fig. 5A illustrates possible deformations in the source of the strongest Friulian earthquake (May 06 1976, M_l=6.4) caused by complexity of faulting with dominant reverse motion of the fault blocks and parts of the Adriatic microplate (1) underlined below peripherial parts of the Southern Alps (3).

Fig. 5B illustrates possible deformations in the source of the strongest aftershock (September 15 1976, M_l=6.1) caused by complexity faulting with dominant strike-slip movements of the parts of the microplate and the contact parts of the Southern Alps (4). The azimuths of the stress axes (the black and the white arrows) defined on the basis of fault plane solutions, clearly manifest the trend of the stress field around that part of the Adriatic microplate. The result of such stress field is the genesis of combined seismic deformations along the faults in the seismic layer marked by earthquake foci. In deeper parts (5) there are probably active processes of aseismic deformations.

5. CONCLUSION

The models of seismic deformations presented here rely on the analysis of fault mechanisms as a basis for defining dominant stress fields. Normal faulting mechanisms are typical of earthquakes in peninsular part of Apennines, while combined mechanisms characterise earthquakes of the North Italy. Yugoslav coast is characteristic of reverse faulting. Slip vectors orientations of the fault planes confirm anticlockwise rotation of the Adriatic microplate around the pole in the North Italy.

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СЕИЗМИЧКЕ ДЕФОРМАЦИЈЕ У ГРАНИЧНИМ ЗОНАМА ЈАДРАНСКЕ МИКРОПЛОЧЕ: МОДЕЛИ ЗА ТРИ РЕПРЕЗЕНТАТИВНЕ ЖАРИШНЕ ЗОНЕ

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Претходно саопштење

На основу поузданих решења механизама раседања и других геолошких и геофизичких доказа, дефинисали смо три модела сеизмичких деформација. Сваки од њих карактеристичан је за одговарајућу жаришну зону. Резултати и овде приказани модели сагласни су са већ постојећим моделима тектонике плоча за област Јадранске микроплоче и Медитерана.