Studies and Geodetic Solutions for Future Evaluations and Monitoring Crustal Movements in Banat County

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Abstract: *The main purpose of the paper is to offer an overview of the situation existing in Banat county, regarding crustal deformation and propose solutions for future monitoring. Taking into consideration the history of the field movements in this area, causes, intensity, propagation, it would be interesting to establish a permanent solution for their evaluation using accurate geodetic technologies. It is planned to obtain 3D realistic models of seismic faults from Banat and also to estimate their seismogenic potential and improving the seismotectonic models. The faults will be investigated also by complementary seismic measurements. It is anticipated the transfer and the applicability of the results for initiation of other projects about the natural precursory phenomena of the earthquakes. The experiment to be achieved within this project has real chances to be a permanent and viable component of a "Natural pilot laboratory", and could be developed for a multidisciplinary and interdisciplinary research of earthquakes from the western part of Romania, several groups of active areas being implied: Arad-Sinnicolau Mare, Vinga-Varias, Masloc-Buzias, Jimbolia - Sinmihai, Sag-Parta, Mosnita-Recas, Banloc-Voiteg and small areas along the border of Romania with Serbia and Hungary.*

Keywords: *crustal deformation, permanent solution, geodetic technologies, evaluation.*

1. Introduction

The accumulation of tectonic stress leads to earthquakes whose occurrence, in turn, results in the accommodation and release of such tectonic stress. These can be investigated in relation to an earthquake cycle defined by preseismic, coseismic, post seismic, and inter seismic phases. During each of these phases the crustal deformation exhibits a characteristic behavior. However, neither the spatial extent of strain release near the source and at the surface nor the time frame of corresponding deformation signatures is fully understood. Ground motions resulting from an earthquake are recorded by seismographic instruments on the Earth's surface, yielding seismograms, or waveform records, spanning a broad temporal spectrum from below 1s for body waves to over 300s for surface waves. Free oscillation data for large earthquakes also may be obtained from the very-long-period instruments. The various seismic waveform data are analyzed in order to characterize the earthquake source process as a series of displacements on a given number of fault surfaces.

The amount of coseismic strain release, corresponding in large part to the strain accumulated during an interseismic period, can be estimated using the relations between displacements, seismic moments and strain energy. Displacements observable at the Earth's free surface can be computed by numerical integration of the Green's function which describes the displacements, caused by a finite earthquake source, over space and time for a given medium.

The Green's function depends on the source and observation (receiver) coordinates and time, and satisfies boundary conditions on the fault surface, which are specified by the particular problem. Waveform data from an earthquake source usually are more complex than predicted from a simple fault model. Many seismologists have developed methods to model a complex earthquake source using body waveforms. The seismic moment released during an earthquake is the predominant portion of the strain energy accumulated since the previous earthquake in the source region. The seismic slip rate can be estimated from the total released moment. However, the slip adjustments may be aseismic, in which case the ratio of seismic to tectonic slip would be too small. Seismic slip rates are estimated from the accumulated seismic moment release assuming typical fault parameters for events in the area of interest. The depth extent of a fault generally may be ambiguous, determined in gross by the average crustal thickness or earthquake sequence source depths. Repeated slip dislocations, or fault displacements, lead to the accumulation of surface deformation, and hence to the evolution of geomorphologic features.

With the rapid developments of geodetic techniques and the accuracy and reliability in geodetic measurements, the geodetic methods have gained importance for monitoring crustal deformation on earthquake researches. Microgeodetic networks which are designed for detecting crustal movements in seismically active areas are capable of monitoring 3-D position changes within a few mm. Crustal deformation induced by the motion of tectonic plates produces a wide variety of landforms at the surface of the Earth and their size depends on the duration of the process involved in their formation. Deformation monitoring is conducted for the purpose of detecting and interpreting small changes in the geometric status of the earth. With the rapid developments of modern geodesy, and with the unprecedented accuracy achievable in geodetic measurements using advanced techniques, the geodetic methods have gained world-wide acceptance for monitoring crustal dynamics for earthquake studies. It is important to measure both the long-term rate of deformation and the short-term deformation associated with the seismic activity along individual faults. The first type of measurement requires accurate topographic maps to quantify the cumulative displacement of surfaces. The second type of measurements requires the capacity of estimating displacements of the ground at millimeter level of precision over short time intervals. Contrary to the geological research, the studies of crustal deformation are based on the analysis of repeated geodetic measurements, and their combination with results of other geophysical investigations. Geodesy provides facilities to investigate the Earth's crust movements and shares these data with other disciplines.

During recent years remote sensing and geospatial information tools and techniques, including numerical modeling, have advanced considerably. These tools offer a greater understanding of the Earth as a complex system of geophysical phenomena, that, directly and through interacting processes, often lead to natural earthquake hazards. Fusion of satellite and in-situ geophysical measurements together with numerical modeling enable a better probable location of a particular hazard event with a significant socioeconomic impact. Space-based geodetic measurements of the solid Earth with the Global Positioning System, combined with field seismological measurements provide the principal data for modeling lithospheric processes as well as for accurately estimating the distribution of potentially damaging strong ground motions, critical for earthquake engineering applications. Seismic and in situ monitoring, geodetic measurements, high-resolution digital elevation model and imaging spectroscopy are contributing significantly to seismic hazard risk assessment.

Romania is a moderate to high seismic area and its history reminds of frequent disasters caused by earthquakes. Of all its seismic zones, the most important and well known is the Vrancea zone, in the Carpathians Arc Bend. This area is characterized by (i) intermediate deep and crustal earthquakes, (ii) seismic high rate (4 to 5 destructive earthquakes per century) and (iii) intensive looses on large areas, surpassing Romanian borders. For the Vrancea seismogenic Region (VSR) the historical records of subcrustal earthquake occurrences are fairly more than a millennium. The earliest event in those catalogues is an earthquake occurred during the year 984. During this time period at least 37 strong events, that is with maximum intensity VIII (MSK) or more are gathered into file. In fact that intensity is the level/threshold at which the tremors are damage. The earthquakes of 10 November 1940 (M=7.4), and of 4 March 1977 (M=7.2) were the largest in this century. It is believed that the great earthquake of 1802 may have reached M=7.7. The upper limit of magnitudes for Vrancea earthquakes is in the region of M=8.0. Other source zones (in the Fagaras Mountains and Banat) are crustal, and generate lower magnitudes - seldom exceeding M=6.0.

Seismological information for Vrancea earthquakes is plentiful, primarily due to their high frequency of occurrence. Assuming that the data are complete for large magnitudes for the last 600 years, this time interval shows 3 earthquakes / century with Mw > 7.2 and 6 events/century with Mw > 6.8 in good agreement with the Gutenberg/Richter relation.

In Romania there are several significant areas of seismicity with earthquakes at normal depths (less than 60 km). The most active zones are in the western part of Romania near the city of Timisoara (Banat and Danube Seismogenic Zones), in the central part near Sibiu (FC) and in the north western part at Baia Mare.

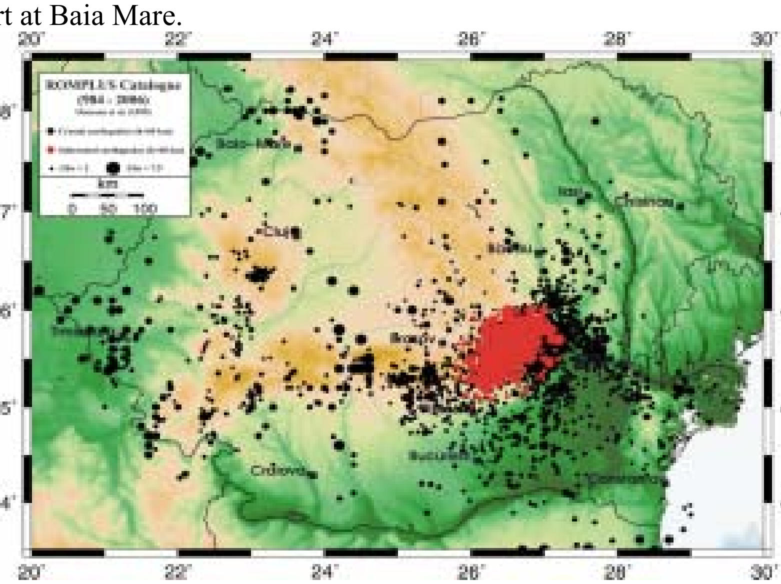

Fig. 1 Seismicity in Romania (www.infp.ro)

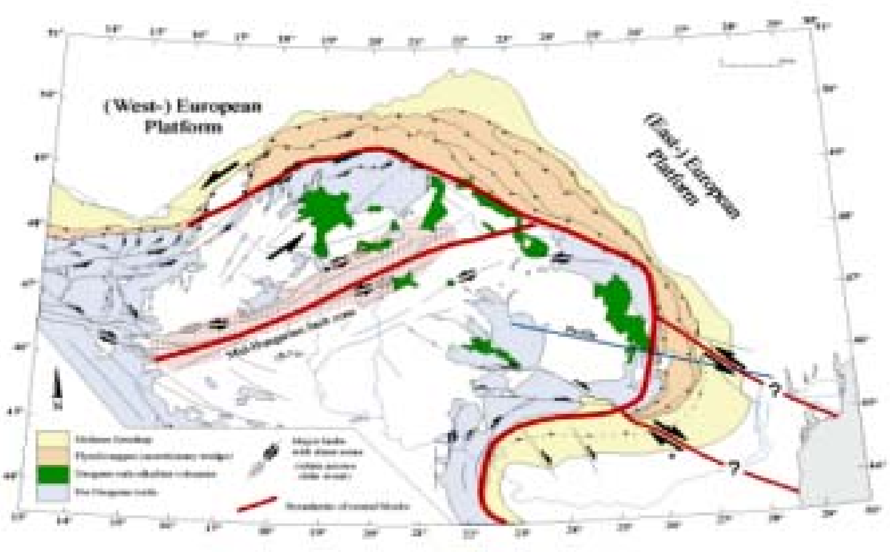

Fig. 2 Tectonic overview map of the Carpathian region

2. Seismological characteristics of the Banat Region

The western and south-western part of Romania, often called the Banat Seismic Region (BSR), lies on the complex tectonic contact area between i) the Carpathian orogen (South Carpathians and Apuseni Mountains) and ii) the subsidence structures of the south-eastern border of Pannonian Depression (grabens, intra-mountains depressions). Banat Seismic Region is the most important seismic region of Romania when we refer to the seismic hazard determined by crustal earthquakes sources (focal depth smaller than 60 km). The seismicity studies accomplished for defining the seismic hazard sources from BSR define two main seismogenic zones: Banat Seismogenic Zone and Danube Seismogenic Zone (e.g. Radulian et al. 2000) that correspond to the main regional morphological units developed in the region, the Western Plain of Romania and South Carpathians mountain ranges, respectively.

The geology and tectonics of this zone is very complex: two major grabens elongated in NW-SE direction, prevail in the zone: Sinnicolau Mare, Caransebes. Between these structures an uplifted tectonic block extends from Buzias to Hungary (Battonya-Buzias horst). In the South, the Caras graben is developed.

The historical earthquake epicenters distribution reveals a very good spatial with the principal faults from the region. The current seismicity emphasizes three clusters around Timisoara. The first one occurred in October 199 about 15 km NNW from Timisoara and the fault plane solution of the main event show a normal faulting on a NE oriented plane. The other cluster is located about 30 km NE from Timisoara.

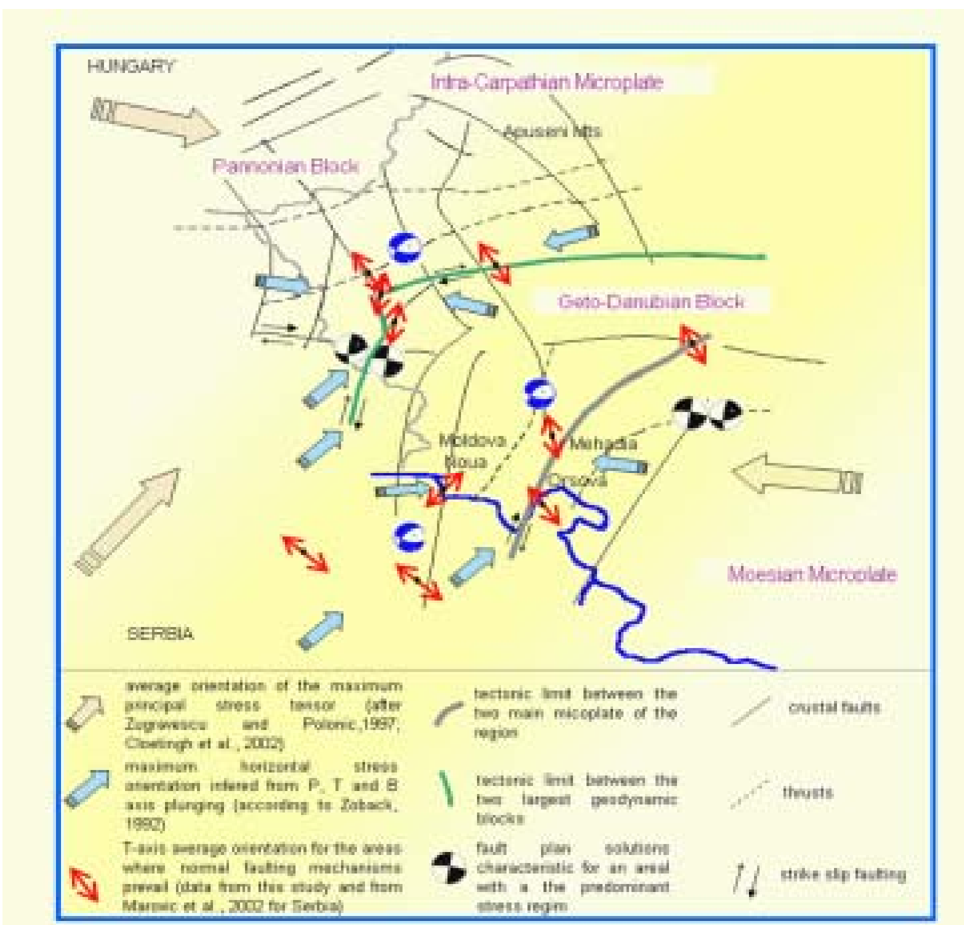

Fig. 3 Sketch of maximum principal stress tensor

The earthquake potential of the known local seismic sources has been confirmed either by the maximum intensities/magnitudes observed in the historical period (1443-1970): IMAX=8 degree on European Macroseismic Scale (EMS) /Ms=5.7, and the frequency of occurrence of the earthquakes (over seven thousands events are catalogued between 1443 and 2007 in the region; since 1880 the events with I>6 EMS occurred with an annual average frequency of 0.4).

The epicentre are scattered all over in the Banat Seismogenic Zone (Western Plain of Romania), but they cluster into small source zones that form several groups of active areas: Arad-Sinnicolau Mare, Vinga-Varias, Masloc-Buzias, Jimbolia-Sinmihai, Sag-Parta, Mosnita-Recas, Banloc-Voiteg and small areas along the border of Romania with Serbia and Hungary.

The maximum magnitude/intensity observed in the region is Ms=5.7/8EMS (Banloc-Voiteg, 1991).

The focal depth of the local earthquakes do not exceed 25 km.

The last stong earthquakes occured in the Banloc-Voiteg area. This seismic source prolongs to the NNE up to South-South-East of Timisoara and continues uncertain to the North of Buzias (the Banloc-Recas Fault). Between 1915 and 1991 it generated three strong earthquakes, 19.09.1915, Io=VII-VIIIOMSK/Mw=5.4; 12.07.1991, Io=VIIIOMSK/Mw=5.6 and 02.12.1991, Io=VIIIOMSK/Mw=5.5.

The subsequent seismic activity on a complex system of faults, triggered by the 1991 strong earthqaukes, lasted many years, the area being actually one of the most active area from the region.

The seismic activity level recorded during the last years recommend this seismic source area for a multidisciplinary study and monitoring to know and better understand the seismogenic processes in the region.

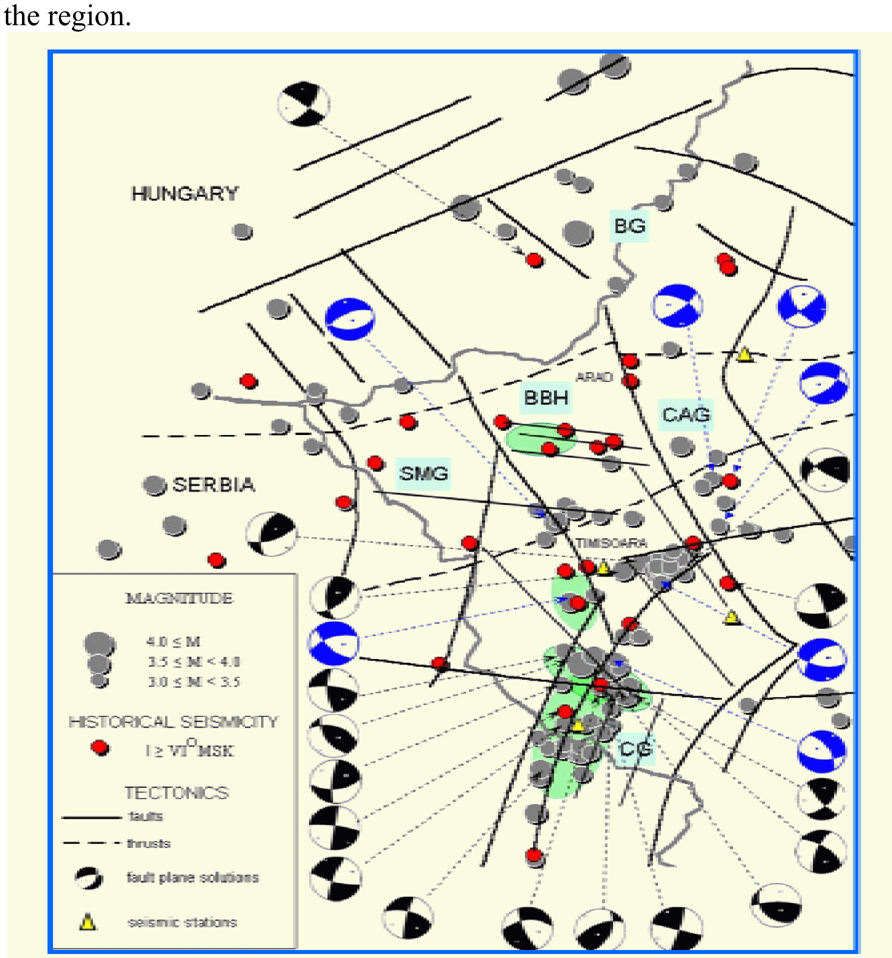

Fig. 4 Banat seismogenic zone:tectonics and seismicity

3. Global Positioning Systems – tool for crustal movements evaluation

The key to understand the Earth's dynamics and system complexity is to integrate satellite observations at local, regional and global scales, over a broad portion of the electromagnetic spectrum with increasingly refined spectral resolution, spatial resolution and over times scales that encompass phenomenological lifecycles with requisite sampling frequency. Recent advances in computational science and numerical simulations are allowing the study of correlated systems, recognition of subtle patterns in large data volumes, and are speeding up the time necessary to study long-term processes using observational data for constraints and validation. Integrating remotely sensed data into predictive models requires measurements at resolutions substantially superior to those made in the past when the observational systems and the discipline of natural hazards research were less mature than they are today. Furthermore, assimilation of data and model outputs into decision support systems must meet operational requirements for accuracy, spatial coverage and timeliness in order to have positive impact on disaster risk management.

Global Positioning System measurements can be used as reference to satellite remote sensing results, being necessary to interpolate deformations between the GPS points. By combining these data sets can be improved also the temporal resolution of the deformation. In remote sensing field, synergy use of data provides means to combine satellite multispectral and multitemporal data.

GPS is a very important tool for crustal displacements assessment and surface kinematics occurring in response to active crust-lithosphere dynamics of Banloc area. In figure 5 and 6 is presented a sketch of the seismotectonic features that support the GPS network (consisting 4 permanent stations: Baia Mare, Deva, Bucureşti, Oros – Ungaria and 4 points of the national network: Moşniţa, Gomila Mare, Grăniceri, Partoş) draft proposed for monitoring the faults system developed in the Banloc-Voiteg seismogenic area.

Fig. 5 EUREF Permanent network

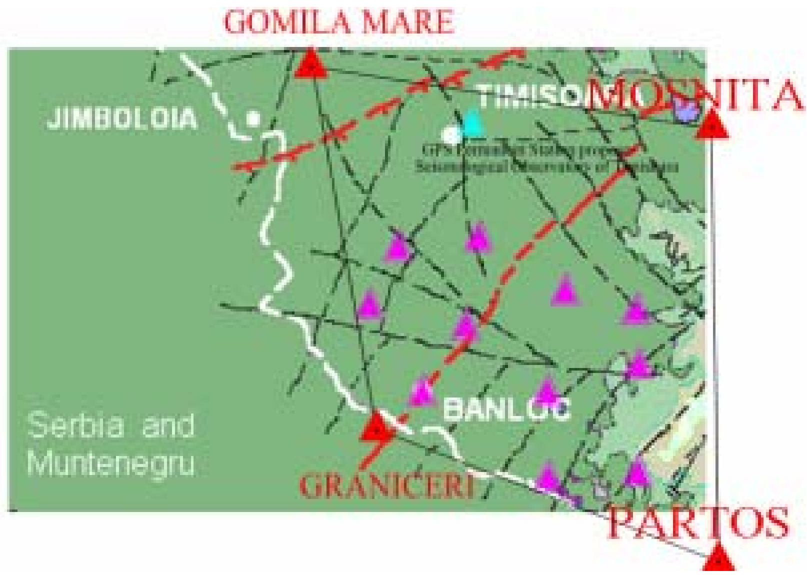

Fig. 6 GPS monitoring network (proposal) of the Banloc seismogenic area

The idea of the project consists of combining the satellite information from EUREF permanent stations with data collected periodically from proposed interest points shown before.

It is also proposed the installation of a permanent station inside the yard of the seismologic observatory in Timisoara which, together with the other 4 points(Mosnita, Gomila Mare, Graniceri, Partos – all of the first order in the national geodetic network), will generate a control network for measurements in the Banloc area.

Starting from this control network it will be developed a secondary network of detail points on the direction of the estimated faults.

Integration of these data with crustal seismicity, surface geology, and topography through a Geographic Information System (GIS) approach places critical constraints on the geodynamic settings for identifying the distribution, geometry, and type of active crustal faults, for elucidating the spatial relationship between the crustal structures and mantle seismicity. The long-wavelength geodetic strain rate field has been computed with the strain field obtained from the analysis of earthquake focal mechanisms. Significant coherence, in terms of style of deformation, between geodetic and seismic strain fields have been obtained in most of the study area.

With GPS geodesy can be recognized times and locate areas of increased geophysical activity by mapping crustal deformation, seismicity, and other factors.

4. Conclusions

The permanent development and application of broad spectrum of satellite remote sensing systems and attendant data management infrastructure will contribute needed baseline and time series data, as part of an integrated global observation strategy that includes airborne and in situ measurements of the solid Earth. Seismic hazard modeling capabillities, will result in more accurate forecasting and visualizations for improving the decision support tools and systems used by the international disaster management community.

The experiment to be achieved within the proposed project can become a permanent and viable component of a “Natural pilot laboratory”, with the possibility of being developed for an interdisciplinary research of earthquakes from the western part of Romania.

It is anticipated the transfer and the applicability of the results for initiation of other projects about the natural precursory phenomena of the earthquakes.

5. References

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