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Source mechanism and source parameters of September 1, 1994 earthquake, Bitola

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Abstract
On September 1, 1994 a moderate size earthquake with local Richter magnitude of M_L5.2 occurred in Bitola region in the south-western part of the Republic of North Macedonia. In this study source mechanism was studied - including P-nodal planes determination for the earthquake, taken separately as fault planes and source parameters. The source parameters of this event were determined using dislocation theory of dynamic faulting from which seismic moment tensor of the earthquake was specified. Furthermore, seismic moment of the earthquake, fault (slip) area and slip vector were estimated using moment magnitude. In this case the fault was defined as plane surface.

Keywords: source mechanics, seismic moment tensor, seismic moment, faulting.

1. 1. Introduction

In the evening of 1 September 1994, a moderate-sized earthquake with magnitude M_L5.2 and intensity I_o=VII-VIII occurred in the southwestern part of the Republic of North Macedonia, located near the town of Bitola (**1**). The earthquake caused significant macroseismic effects. Town Bitola together with many villages in the surrounding area, was severely damaged (**2**). In the following month, 96 earthquakes were felt with magnitude $2.0 \leq M_L \leq 5.0$, which is result of seismic activity of faults in the south-western part of the Bitola region. Most of those faults are borders of active neotectonics structures and thus expected to be seismicity. The hypocenter of the main shock with 598 registered earthquakes until December 1994, was in the granite layer of the crustal model (**3**). The distribution of the epicenter of the mainshock and all located and felt aftershocks is shown in Figure 1. The tectonic conditions in the epicenter area Bitola are a region of confrontation of many tectonic structures, namely Pelister Massif on southwest, Shemnica Massif on west, Selecki Massif on east and the Pelagonia valley between them (**8**). The neotectonic activity is characterized by permanent uplifting of the terrain, whit predominantly vertical movements under regional tectonic stresses approximatively oriented south-southwest (SSW), who is still in progress, causing mainly north-south (N-S) oriented faults and northwest-southeast (NW-SE) oriented faults (**4**). The present situation is given in Fig 2.

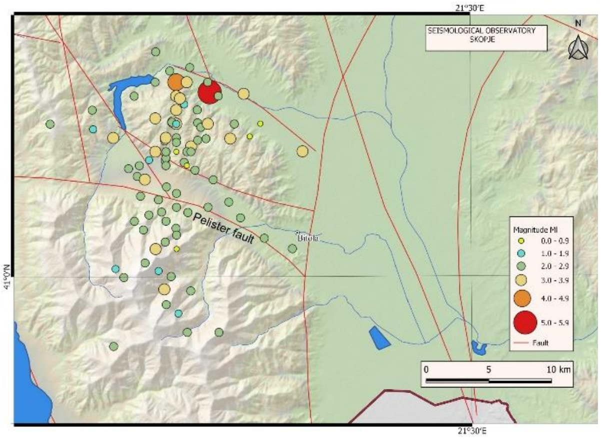

Figure 1. Distribution of felt earthquakes (September 1994 – December 1994)

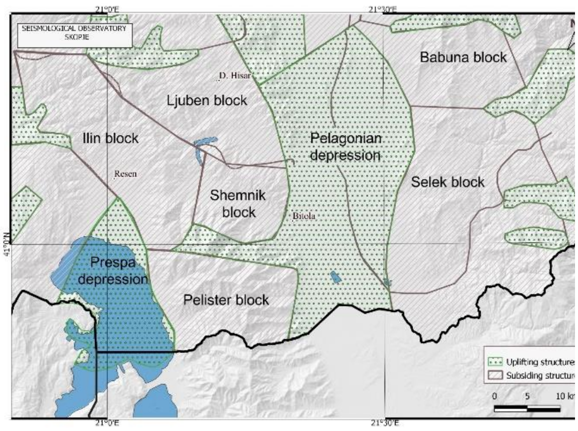

Figure 2. Neotectonic structures in the Bitola region

2. Dislocation theory of dynamic faulting

The most probable source model for the earthquakes is a dynamic faulting – a rupturing with relative slip of rupture's walls that propagates in a short time and with a velocity that increases rapidly, having the *S* wave velocity as upper limit.

The theory of dislocations considers earthquake source mechanism as a dynamic faulting of the Earth's material (faulting whose speed increases until the conditions for its termination are reached), or we could say that, the theory of dislocations considers jump in the displacement field. The orientations of the fault plane and the fault slip (fault walls' relative slip) in the dislocation theory are perpendicular, so-called P nodal planes (5). The method gives a double-valued solution for the source mechanism because it is not possible to recognize the fault-plane between the two P nodal planes. This method is often denoted as P-nodal planes determination, and the resolving of the fault-plane ambiguity is usually done with other seismological or non-seismological considerations. Considering the entire seismic cycle as a part of the far-field of displacement of the main shock, knowing the fault parameters, strike angle Φ, the dip angle δ and the slip angle λ, and the moment magnitude M_W of the main shock, we determined the corresponding seismic moment (M_0), fault (slip) area (Σs), rupturing velocity v, maximal linear dimension L and slip vector $\overline{a^l}$. The next step is determination on seismic moment tensor (7).

3. Seismological investigations for source mechanism and source parameters

Firstly, we obtained the P-nodal solution for the studied earthquake. We used polarities of 42 first far field P seismic motions for the main earthquake. At the seismological station in Skopje (SKO), the electromagnetic seismometer recorded the amplitudes of the ground motion (Fig. 3). The corresponding P-nodal solutions of the 1994 Bitola earthquake with local magnitude M_L5.2 and moment magnitude M_W5.18, source mechanism and "beach ball" diagram (6) is presented in Table 2.

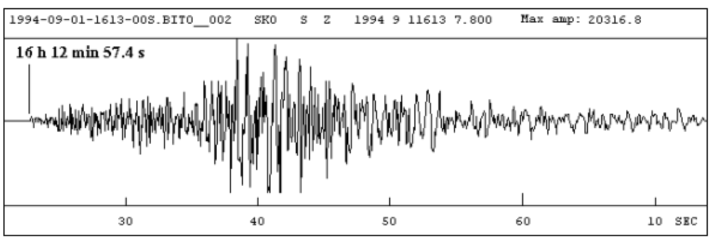

Figure 3. Digital record of the 1994 September 1 M_L 5.2 Bitola earthquake at the Seismological Observatory in Skopje (SKO)

According to the comparison with the macroseismic data and tectonic data, the earthquake had been caused by a normal right lateral motion of the hanging wall of a fault plane striking toward 289^0 WNW and dipping under an angle of 21^0 NNE, that fault plane can be associated with the north-east border of the Pelister mountain – Pelister fault. The whole aftershock activity is due to this fault (**6**). In Table 1 we represent location and P-nodal solution (beachballs), for main earthquake were ϕ and λ – epicentral latitude and longitude, M_W, M_L –moment and local magnitude, Φ_s, δ and λ – strike azimuth, dip angle and hanging wall slip angle; n-l-l – normal left lateral fault, n-r-l - normal-right-lateral fault**;** H and h-hypocentral time and depth.

In Table 2 we represent the main source parameters on faulting were M_0 –seismic moment, Σ_L– fault surface, L_L– maximal linear dimension, ν– sliding speed of the blocks and $\overline{a^l}$ – slip vector or displacement of the blocks.

Table 1. Location and P-nodal solution for the 1 September 1994 M_L5.2 Bitola earthquake

Main shock parameters		P-nodal plane I				P-nodal plane II				"Beach–balls" diagram
Data (DMY) Time H/GMT (h:min:s UTC)	φ(°N), λ(°E); M_L, M_W, $h(km)$	Φ_s (°)	δ (°)	λ (°)	Fault type	Φ_s (°)	δ (°)	λ (°)	Fault type	
01.09.1994., 16:12:40.6	41.13, 21.25; $M_L = 5.2$, $M_W = 5.18$; $h = 16.1$	114 ESE	69 SSW	-88	(n-l-l)	289 WNW	21 NNE	-95	(n-r-l)	

Table 2. Source parameters of the 1994 Bitola M_L5.2 earthquake

Data, (DMY) Time H/GMT (h:min:s UTC	φ(°N), λ(°E); M_L, M_W, $h(km)$	$M_0(N*m)$	$\Sigma_L(km^2)$	$\overline{a^l}(m)$	$L_L(km)$	$\nu\ (km/s)$
01.09.1994., 16:12:40.6	41.13, 21.25; $M_L = 5.2$, $M_W = 5.18$; $h = 16.1$	$8.3 \cdot 10^{16}$	17.68	0.14	4.38	1.024

4. Conclusion

The comparison of the parameters from possible fault planes (P-nodal solution) with parameters from seismic source can be define dynamic faulting of the earthquake. In this case, the seismologically confirmed source mechanism is a normal right lateral faulting, which is striking toward WNW (dipping toward NNE). The fault surface had a maximal linear dimension of ≈ 4 *km*, fault (slip) area ≈17 km^2, rupturing velocity ≈1 *km/s*, slip vector ≈0.14 *m* and seismic moment valued with M_0 = 8.3·1016 *N·m*.

It was found that this faulting is associated with the neotectonic Pelister fault, which is a contact between the uplifting Pelister block (Baba Mountain) and the western branch of the subsiding Pelagonian depression. The comparisons of the P-nodal solution with the observed aftershocks epicenters distribution and macroseismic data brought separately the same result.

5. References

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