Chapter 2
Active Fault Systems and Their Significance for Urban Planning in Bucharest, Romania

Dumitru Ioane, Mihail Diaconescu, Florina Chitea and George Garbacea

Abstract In urban planning activities, besides a detailed seismic zonation, knowledge of the areal distribution of active faults, and particularly of faults crossing the city in heavily built districts, may be valuable in numerous cases. This chapter aims to identify active faults or fractures in Bucharest, a large city developed over thick layers of Quaternary unconsolidated sediments. To achieve this goal, the research is based on an integrated analysis of all existing relevant data coming from geology, geomorphology, geophysics and seismology. Another purpose is to understand the role of faults in the spatial variability of seismic damaging effects on buildings in view of a better future urban planning. The N-S fault system seems to be involved in neotectonics, affecting the geomorphology between Bucharest and Ploieşti cities. It could represent an active transcrustal fault, the deepest seismic event recorded within Bucharest at subcrustal depth being located on its southern prolongation. Within Bucharest the presence of faults affecting Pleistocene sediments was previously illustrated using borehole data, shallower vertical displacements of Quaternary formations along faults being interpreted in this study. The existing seismic reflection data recorded within Bucharest was used to interpret shallow faults considered as active or capable faults crossing Quaternary sedimentary deposits.

Keywords Tectonics · Neotectonics · Geomorphology · River network · Romania

2.1 Introduction

Active fault systems may have significant influences in slow ground displacements during neotectonic vertical or/and horizontal movements, or sudden ones, as a consequence of high magnitude earthquakes.

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M. Bostenaru Dan et al. (eds.), *Earthquake Hazard Impact and Urban Planning,*
Environmental Hazards, DOI 10.1007/978-94-007-7981-5_2,

In large cities such as Bucharest, Romania, developed over quite thick sequences of Quaternary unconsolidated sediments, there were no real possibilities of geologically mapping faults or fault systems, the geological structures being deeply buried. Due to their specific structure, the unconsolidated sediments do not preserve traces of active faulting due to neotectonic processes or seismic events. In geotechnical and hydrogeological wells or in the city subway tunnels such tectonic features are not easily observed by specialists, the resulting geological cross sections representing many times only changes in geological facies and no faults or fractures.

An integrated analysis of all existing relevant data coming from geology, geomorphology, geophysics and seismology may represent a first stage of a study aiming at locating active/capable faults or fractures in the Bucharest city area and understanding their role in the spatial variability of seismic damaging effects on buildings in view of a better future urban planning.

2.2 Geographic Location, Geomorphology and Rivers Network

2.2.1 Geographic Location

Bucharest, the capital of Romania, is located in the northern part of the Romanian Plain (Fig. 2.1), between the Danube River (60 km southward), the Carpathian Mountains (100 km northward) and the Black Sea shore (250 km eastward).

The city covers an area exceeding 20 km in diameter; its geographical coordinates may be roughly considered as 44°43, in latitude and 26°10, in longitude.

2.2.2 Geomorphological Data

The topography in the Bucharest area is quite flat, the relief decreasing gently southeastward, toward the Danube. The difference in relief elevations within Bucharest ranges from 50 m (SE) to 100 m (NW), following the main topographic regional trend from river Danube to the Carpathians.

Geomorphological data in the area where Bucharest is situated show that starting from the city northern limit there is a sudden change of about 10 m in the topographic elevations on a lineament trending N–S, between Bucharest and Ploieşti cities. The area located west of this lineament is characterized by higher altitudes as compared to that situated eastward.

At the regional scale, the geomorphological boundary between the southern plain and the northern hilly region follows two main trends, as shown by the digital terrain model (http://srtm.csi.cgiar.org 2011), displayed in Fig. 2.2: (1) NE–SW from the East Carpathians bend zone to Ploieşti city and then again, from Bucharest toward Danube river; (2) N–S between Ploieşti and Bucharest cities.

Fig. 2.1 Geographic location of Bucharest city, Romania

The high topography area located especially in the western part of Bucharest is considered to represent a remnant of uplifted Middle Pleistocene rocks, affected by erosion processes due to both Dâmboviţa and Argeş rivers (Lacatusu et al. 2008).

As an interesting geomorphological feature, the Dâmboviţa riverbanks are asymmetrical, the south-western riverbank being much higher (15 m) as compared to the north-eastern one (2 m). Within Bucharest, this asymmetry was also observed at the Colentina riverbanks.

2.2.3 Rivers Network

Palaeohydrological studies showed that during Middle Pleistocene-Lower Holocene the rivers and their tributaries modeled the relief of this area, by both erosion and sediments deposition processes.

The main rivers crossing Bucharest are Dâmboviţa and Colentina. Their river courses trend NW–SE and display the same asymmetry regarding tributaries—both

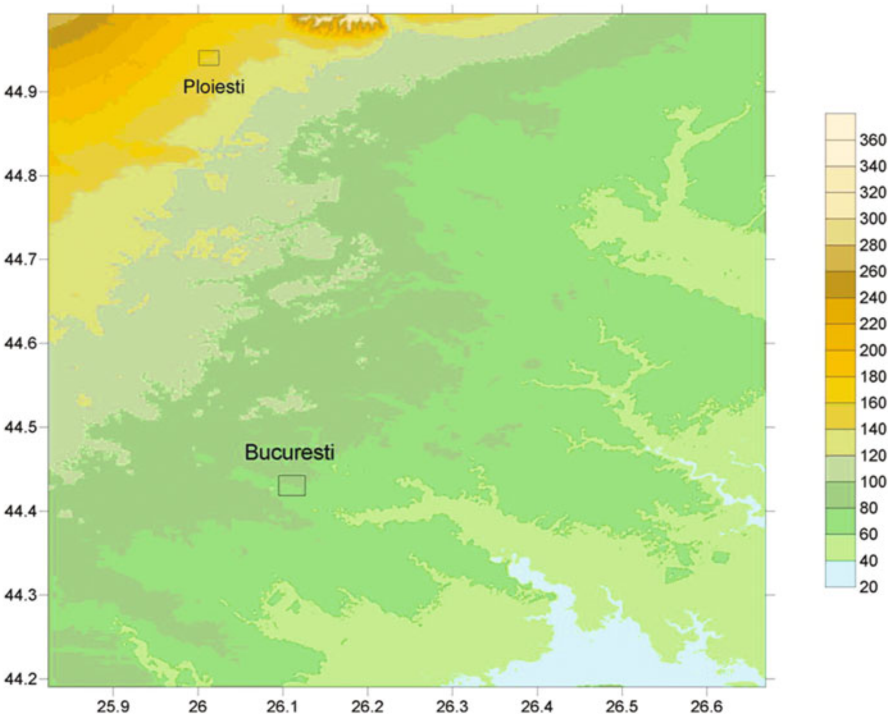

Fig. 2.2 Regional geomorphology between Bucharest and Ploiesti cities (topographic heights in meters)

rivers receive only left side tributaries, a feature obviously related to the riverbanks asymmetry already mentioned (higher right bank as compared to the left bank.

Colentina river, which crosses the northern part of the city, displays a meandering course especially at the northern Bucharest outskirts. Since numerous peat bogs developed between the river meanders, during the first half of the twentieth century these areas were transformed into lakes: Străuleşti, Băneasa, Herăstrău, Floreasca, Tei, Fundeni and Pantelimon.

Dâmboviţa river used to have a meandering course especially when crossing the Bucharest central part (Oltean 2005). Its course was modified into a straight one during the nineteenth century within the city limits and its tributaries may no longer be observed. Some of its former meanders were transformed into lakes: Carol and Tineretului lakes on the right bank and Cişmigiu Lake on the present day left bank (Mândrescu et al. 2008).

The main directions of the rivers network, analyzed at a regional scale, are as follows (Fig. 2.3):

- NW–SE: Mostiştea, Colentina, Dâmboviţa, Sabar, Argeş;
- W–E: Câlniştea, Argeş, Ialomiţa;
- NE–SW: tributaries of Ialomiţa, Mostiştea and Colentina

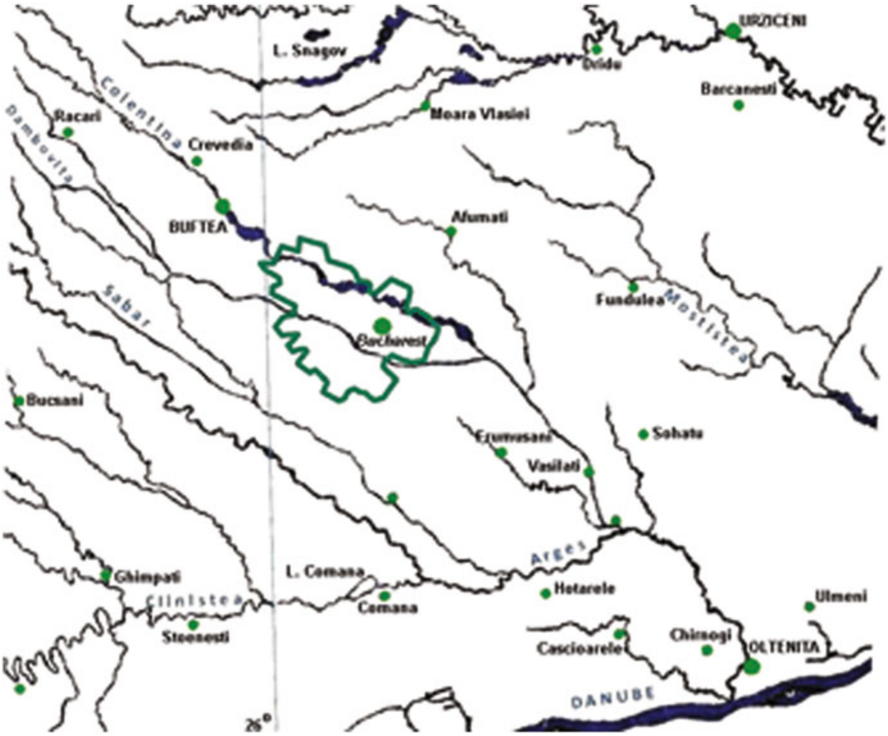

Fig. 2.3 Rivers network in the region where Bucharest is located

The two rivers which once favored the defense of medieval Bucharest, Dâmboviţa and Colentina, cross from NW to SE in the present time city area. Both river valleys displayed once large meanders within the old city centre.

Older city maps show small streams on the left side of the Dâmboviţa; the one that trends NNE–SSW started south of Victoria Square and the one that trends NNW–SSE started in Ioanid Park and crossed Rosetti Square. The Colentina river still keeps some of its tributaries (Pipera and Saulea streams) which trend NNE–SSW and NW–SE, respectively (Lăcătuşu et al. 2008).

2.3 Geological, Tectonic and Neotectonic Data

2.3.1 Geological Setting

Bucharest is situated on the Wallachian sector of the Moesian Platform, west of the Intramoesian Fault (Sandulescu 1984).

The crystalline basement is here situated at depths ranging between 6 and 8 km (Polonic 1998) and was not reached by boreholes.

The sedimentary cover was built during four main sedimentary sequences: Palaeozoic, Permian-Triassic, Lias-Upper Cretaceous and Middle Miocene-Holocene (Paraschiv 1979).

The Upper Cretaceous-Badenian unconformity is gently deepening between the Danube river and Bucharest, but starting from Bucharest it goes rapidly deeper toward the Carpathians.

Within Bucharest city limits the Upper Cretaceous sedimentary deposits were found in boreholes in its southern part at about 1,000 m, while in the northern part of the town they were intercepted at more than 2,000 m.

The thickness of the Middle Miocene-Holocene sequence increases rapidly in Bucharest from south to north, from 452 m at Berceni area to 2053 m at Otopeni area (Lăcătuşu et al. 2008), a distance of about 20 km.

The Quaternary unconsolidated geological formations have thickness variations ranging between 150 m at the city southern limit (Măgurele area) and more than 250 m (Otopeni area).

The Lower Pleistocene deposits (Beds of Frăteşti) consist of gravels (pebbles of quartzite, gneiss, micaschist, granite, conglomerate) and sands, separated by clay intercalations. This formation is continuously deepening northward: 80 m depth in the city southern part and 180 depth at its northern limit). The map at their upper surface in the Bucharest area shows NE–SW lineaments of sudden deepening (Mândrescu et al. 2008).

The Middle Pleistocene consists of sand and clay beds alternances (Beds of Uzunu).

The Upper Pleistocene consists of the Mostiştea sands (8–20 m), the intermediate clays (5–20 m), the Colentina gravels (thickness of 4–18 m, with pebbles of micashist, gneiss, sandstone) and loess. In the southern part of Bucharest the intermediate clay beds are lacking, the Mostiştea sands being in continuity with the Colentina gravels, both reaching 20–30 m in thickness.

The loess deposits have thickness of 3–5 m between Colentina and Dâmboviţa rivers, and 15–20 m south of Dâmboviţa river. They include within Bucharest city limits 2–3 Pleistocene and Holocene paleosol levels (Mândrescu et al. 2008).

2.3.2 *Tectonics*

2.3.2.1 Regional Tectonics

Bucharest is situated in the central part of the Moesian Platform, in the vicinity of the transcrustal Intramoesian Fault, considered as a senestral strike-slip regional fault (Cornea and Lazarescu 1982). The classical tectonic and geodynamic picture of the eastern Moesian Platform considers a tectonic block having as south-western limit the Intramoesian Fault (senestral) and as north-eastern limit the Peceneaga-Camena Fault (dextral). This crustal block is displaced toward north-west and is involved in the Vrancea zone seismicity (Cornea and Lazarescu 1982).

The dominant crustal fault systems in the Moesian eastern compartment trend NW–SE, while the western compartment displays a more complex picture, with faults trending NW–SE, N–S, W–E and NE–SW.

Recent interpretations of reflection seismic data attested that the NW–SE fault system affects also the Tertiary sediments, while the ENE–WSW system is active until present as transtensional strike-slip. During the evolution of this strike-slip system the NW–SE transpressional system was reactivated (Rabagia et al. 2000).

Bucharest is closely located in the contact zone between an older eastern compartment (Dobrogean) and a younger western compartment (Wallachian) along the NW–SE trending Intramoesian Fault system. Considering the regional relationship between the Moesian Platform and the Carpathian Mountains, the city northern limit overlaps the tectonic limit between the platform and the outer zone of the Carpathian foredeep (Sandulescu 1984; Visarion et al. 1998).

The reflection seismic surveys carried out for oil exploration in the Bucharest area depicted in the sedimentary cover a regional northward deepening monocline, affected by regional longitudinal normal faults trending E–W: Petreşti-Corbii Mari, Cartojani-Ileana, Fundeni-Harleşti, Videle-Vidra (Paraschiv 1979).

It was recently considered that in the Bucharest area the intersection of two major strike-slip systems are responsible for the active tectonics and high seismicity. Important wrench zones occur south of Bucharest, involving the Dobreni and Danube faults (Rabagia et al. 2000). Regional wrench tectonics was also suggested when interpreting recent GPS data (Munteanu 2009).

2.3.2.2 Local Tectonics

Geological cross-sections based on borehole data illustrate faults affecting the Upper Miocene-Holocene sedimentary formations beneath Bucharest, or only suggest such tectonic features at the upper part of the Quaternary sedimentary deposits:

1. A normal fault, interpreted on geological borehole information, is situated south of the Dâmboviţa river, affecting at least the Pliocene geological formations on more than 400 m depth (Fig. 2.4). Considering the coal intercalations in clay beds, better developed within Upper Romanian-Lower Pleistocene sedimentary deposits, the vertical displacement of its compartments may be approximated at 200 m. Since there are no possibilities of geologically correlating the two fault compartments based on data from seven boreholes on a N–S distance of 30 km, horizontal displacements along this fault must be also taken into consideration;
2. The necessity of interpreting vertical displacements within the geological structures in the first 50 m beneath the topography is well illustrated in a geological cross-section trending NE–SW, between Giuleşti and Bragadiru areas, a distance of ca 12 km that was investigated by more than 20 boreholes (Fig. 2.5).

There are a number of reasons to interpret local faults in this very detailed geological cross-section:

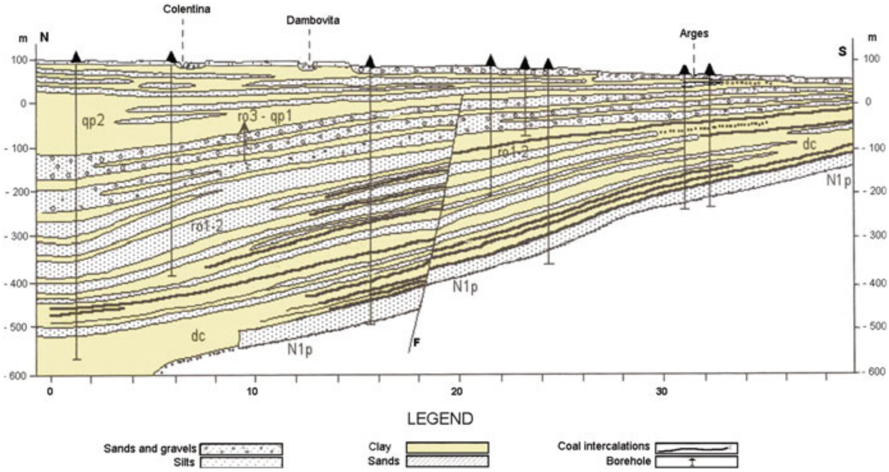

Fig. 2.4 Geological section across Bucharest city area (Lacatusu et al. 2008)

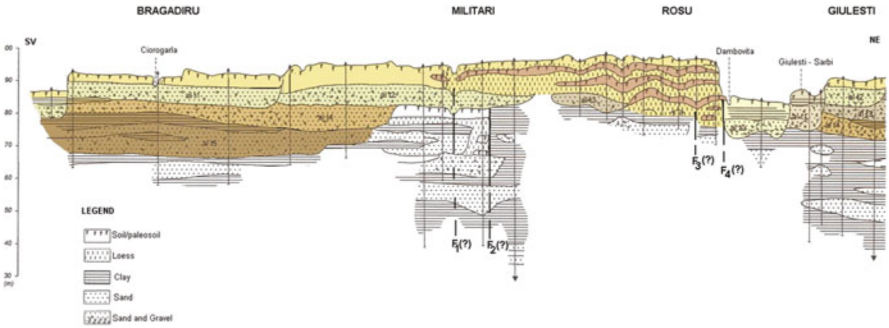

Fig. 2.5 Geological section crossing the western part of Bucharest city area (Modified after Lacatusu et al. 2008)

- The Dâmboviţa river banks display a sudden variation in surface topography (the south-western bank is higher than the north-eastern one) and in geology (the south-western bank is formed of loess and paleosols accumulated during the last 400,000 years, while the north-eastern bank is formed by alluvium deposits accumulated during the last 240,000 years). Furthermore, the boundary between the mentioned geological formations and the underlying clay bed is situated at lower levels beneath the north-eastern bank and at successively higher levels beneath the south-western bank;
- In the Militari district the alternances of loess and paleosols ends at lower levels beneath this area, thick deposits of buried loess, sands and gravels being rapidly replaced by thick clay deposits between two closely situated boreholes (Fig. 2.5).

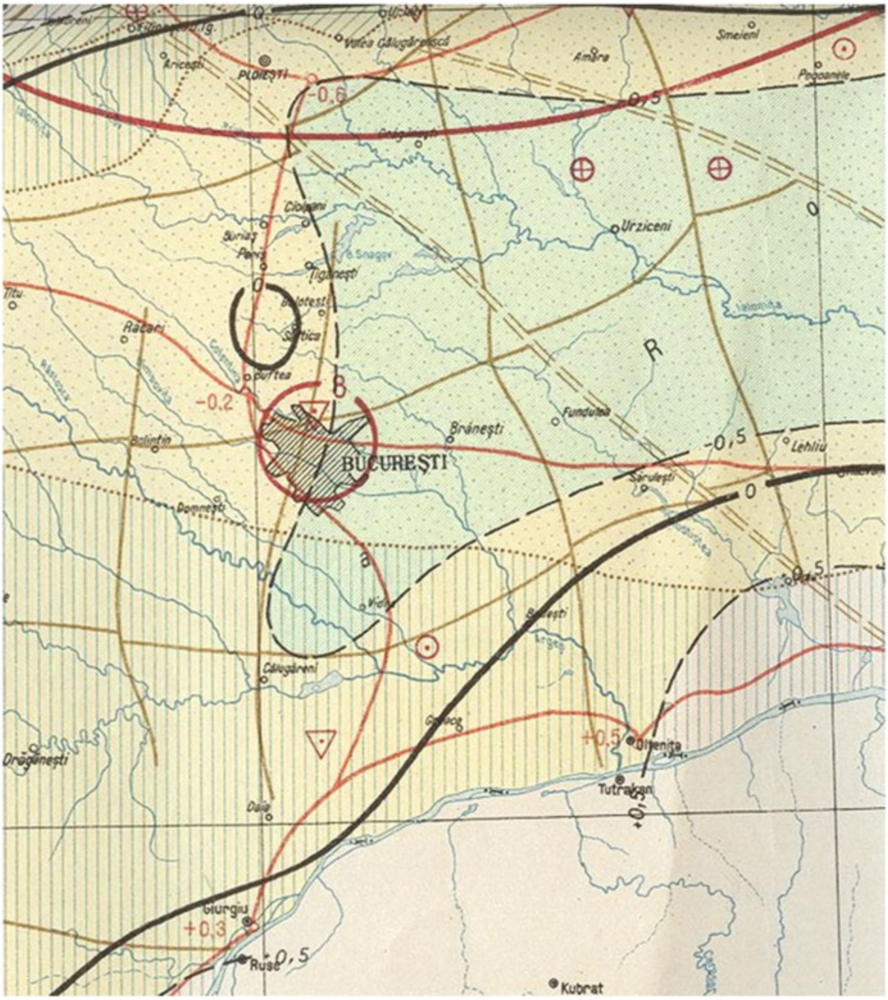

Fig. 2.6 Neotectonic data in the Bucharest city area (*Black lines*: isolines of similar rate of vertical movement; Brown lines: faults; Triangles and circles: earthquake epicenters) (Visarion et al. 1977)

2.3.3 Neotectonics

2.3.3.1 Recent Vertical Movements of Crustal Blocks

Modifications during the time of relief heights, resulted from repeated topographic leveling in a region affected by active geodynamic processes, have been utilized since the mid-twentieth century for assessing actual vertical positive (uplift) or negative (subsidence) movements of crustal blocks.

For the territory of Romania there are several maps published by different authors describing sectors with similar rates of vertical displacements (uplifting or subsiding areas on the Romanian territory). In Fig. 2.6 is presented a map of the region where

Bucharest is located, extracted from the 1: 1,000,000 scale *Map of recent crustal vertical movements in Romania* (Visarion et al. 1977).

One may observe a N–S trending boundary between two areas with different rates of vertical displacements, the eastern sector being affected by subsidence (0.5 mm/year). This boundary crosses the central part of Bucharest and may be associated with a N–S active crustal fault, also depicted on this map, situated between the Danube and Ialomiţa rivers.

2.3.3.2 GPS Monitoring

The area of Bucharest, due to its proximity to the Vrancea seismic zone, has been included since 1995 in numerous European or Romanian geodynamic projects based on GPS high precision positioning and monitoring of crustal blocks, for both horizontal and vertical displacements. Data on the velocity field have been published since late 1990, when especially the vectors of horizontal movements became consistent for large areas.

A study that presents data accumulated during 1994–2003 in Central Europe (Hefty 2004) offers horizontal displacements for Bucharest and Vrâncioaia stations NW to SE, while the Fundata station (the contact zone between the Eastern and Southern Carpathians) displays a higher horizontal velocity, trending N to S.

The interpolated GPS regional velocity field (Grenerczy 2004) illustrates for the southern part of Romania a general trend from NW to SE. The central part of the Moesian Platform in Romania displays a transit from WNW to ESE (western part) toward NW to SE (eastern part), suggesting the presence of a NW–SE boundary between two sectors with different trending and different intensity of the velocity field vectors.

A recent work, based on a detailed GPS network dedicated to the actual geodynamics of the Vrancea seismic zone, presented vectors for horizontal displacements in the south-eastern part of Romania (Mocanu et al. 2008). Between the Capidava-Ovidiu and the Intramoesian crustal faults the vectors describing horizontal displacements trend NW to SE, with higher intensities in the vicinity of the Capidava-Ovidiu Fault. West of the Intramoesian Fault the velocity field is less homogeneous and less intense, the vectors trending W to E north of Bucharest, N to S within Bucharest and NNW to SSE at Măgurele, a few kilometers south-west of Bucharest. GPS network stations situated at ca 50 km west and north-west of Bucharest illustrate a more homogeneous velocity field, the vectors trending NW to SE or NNW to SSE. In the latter case, this trend is similar to that obtained at Măgurele, at the outskirts of Bucharest.

Quantitative data on the tectonic blocks horizontal movements were recently published, based on 5 years of GPS observations. For the territory situated north-east of the Intramoesian Fault south-eastward horizontal displacements of 2 mm/year were determined, while in the Bucharest city area, located south-west of the Intramoesian Fault, southward horizontal displacements of 1 mm/year were observed (Munteanu 2009).

http://www.springer.com/978-94-007-7980-8

Earthquake Hazard Impact and Urban Planning
Bostenaru Dan, M.; Armas, I.; Goretti, A. (Eds.)
2014, XIII, 313 p. 155 illus., 100 illus. in color., Hardcover
ISBN: 978-94-007-7980-8