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MAIN ACTIVE FAULTS FROM EASTERN PART OF ROMANIA (DOBROGEA AND BLACK SEA). Part II: TRANSVERSAL AND OBLIQUE FAULTS SYSTEM

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Abstract. The main target of this paper is to established a correlation between the seismicity of the Eastern part of Romania and the active tectonic (faults systems) of the area, the second target is to create a specific database of the faults (ROmanian DAtabase of SEismogenic Faults-RODASEF) in SHARE manner, for seismic hazard assessment process. This paper is a continuation of an article written by the same authors, in which were highlighted the longitudinal faults system from onshore and offshore of the Black Sea coast.

To define the active faults, the following elements have been taken into account:

– Geometrical parameters: length, active length, width and depth of the earthquakes foci.

– Seismological parameters: strike, dip, rake (slip).

In the studied area, there have been identified three fault systems: a longitudinal, transversal and an oblique one. In this paper, we present our results regarding the second and third type, *i.e.* main faults of the transversal and oblique systems.

We present the transversal fault systems, parallel to the Black Sea coast comprising Razelm, Lacul Rosu, and West Midia Faults and the oblique fault systems with a NW-SE direction of the faults, such as Nistru, Odessa and West Crimea.

Key words: focal mechanism, faults, seismogenetic sources.

1. INTRODUCTION

The goal of this paper is to define and describe the active transversal and oblique faults, from the Eastern part of Romania (Dobrogea) and from the Western basin of the Black Sea. The approach is using the Database of Individual Seismogenic Sources – DISS methodology, of the National Institute of Geophysics and Volcanology, Rome, Italy. The description of the faults is made in terms of geometrical parameters under a permanent updating [1, 2, 3]. The rationales behind DISS are highlighted in [2, 3, 4] and [5]. The methodology was used to create the European Database of Seismogenic Faults (EDSF) of the Seismic Hazard Harmonization in Europe-SHARE project. Other projects which use the DISS methodology are

European Research Infrastructure on Solid Earth – EPOS and Assessment, Strategy and Risk Reduction for Tsunamis in Europe – ASTARTE.

The DISS methodology was used in [6], an overview of the seismogenic sources of Northern Italy and Western Slovenia, in [7] the description of the seismotectonics of the Po Plain, [8] the study of the seismogenic sources of the Adria and the evaluation of the slip rates of the fold belt from the Dinarides [9] and of the Po Plain [10].

In Romania, the faults from Dobrogea and from the Western basin of the Black Sea were studied for seismic hazard assessment by [11], for active faults by [12] and especially Peceneaga-Camena and Sf. Gheorghe faults by [13, 14, 15] study the configuration of the Western basin of the Black Sea from the structural point of view and tectonic processes of Carpathians and Dobrogea [16]. A map of the Eastern part of Romania was created by [17] based on gravimetric data, based on gravimetric and magnetic map by [18] and based on reflection seismic data by [19, 20]. But only one paper, [1], the first part of the present work is written in a DISS manner.

2. GEOTECTONIC SETTING

The basins of the Black Sea seem to act as a structural boundary for the Late Cretaceous and Paleogene structures. These structures were formed after the first collision of continental fragments of Gondwanaland with the Eurasian active margin in the Middle-Late Cretaceous [21].

Since Permian, the Black Sea Basin has suffered few episodes of extension and shortening [22], and now days continues to experience the deformation procces in response to the northward movement of the Arabian plate and westward escape of the Anatolian block along the Anatolian Fault System (North and East branches).

The Black Sea can be subdivided into Eastern and Western basins based on its basement structures; these sub-basins are separated by the Archangelsky and Andrusov Ridges, which constitute a system of buried basement ridges and are collectively called the Mid Black Sea High [1].

Based on plate reconstructions and the ages of volcanic rocks with arc signatures, located in the Western Pontides, in Northern Turkey [4], a Middle to Upper Cretaceous opening is estimated for the Western Black Sea (WBS), after the separation of the Istanbul zone from the Moesian Platform [1].

The age of the EBS opening is estimated to be Cenozoic (Eocene); this observation together with documented structural relationships at the edges of the basin, ages of the arc magmatic products, and plate reconstructions indicate that major basin-forming events, probably occurred in the late Mesozoic or early Cenozoic [24].

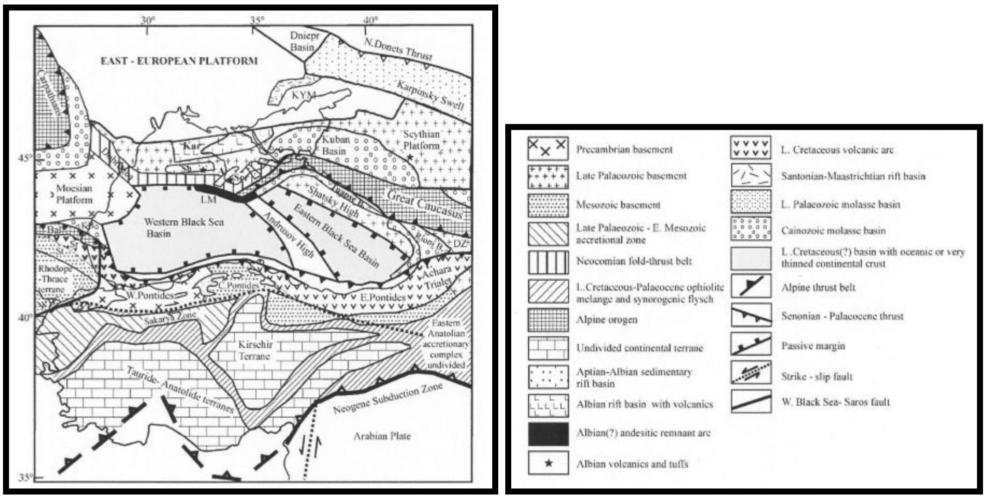

Fig. 1 – Geotectonic map of the Black Sea basin. A: Alma Basin, Bal: Balkanides, Dz:Dzirula, G: Guriy basin, K: Kamchia foreland Basin, Kar: Karkinit trough, KYM: Konka-Yaly-Molochanaya graben, Scr: South Crimea Orogen, Sh: Shtormovaya graben, Sr:Srednogorie, St:Strandzha, WBS: West Black Sea-Saros fault [23].

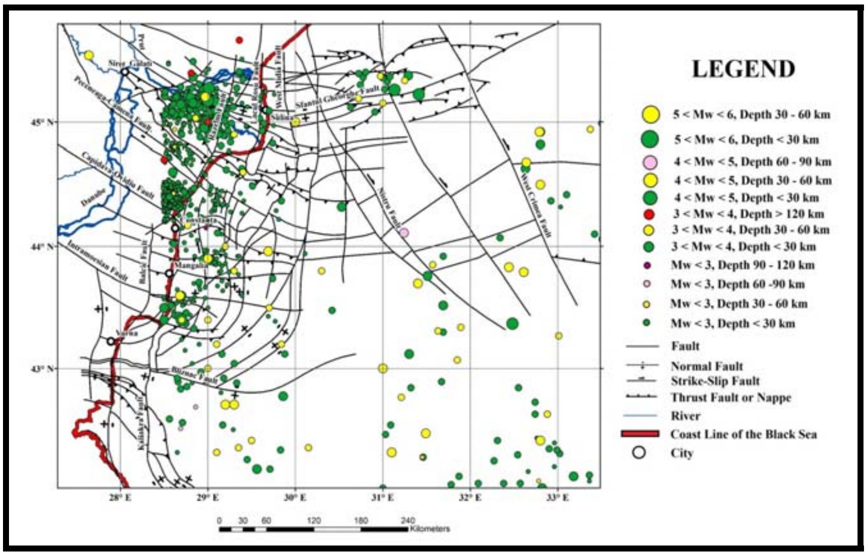

Fig. 2 – Tectonic map of the Romanian shelf. Dots with different color and dimension are earthquakes. Tectonics after [15].

From North to South the Western Black Sea basin is bounded by:

A) East European Platform, extended form onshore Romania and Ukraine, a pre-Riphean basement of gneiss, granite, granitoid with basic and ultrabasic rocks and sedimentary cover of Riphean-Paleozoic, Mesozoic and Cenozoic age [23];

B) Scythian Platform, west and east, which consists of basement (Late Palaeozoic age) deformed at the time of the Triassic/Jurassic boundary [25];

C) North Dobrogea, west, a permo-triassic rift basin, a narrow area situated between Scythian Platform and Moesian Platform that underwent thrusting and folding from Jurassic up til the Neocomian age [23, 1];

D) Moesian Platform, west, with a Baikalian basement and Phanerozoic sedimentary cover [1] affected by late Variscan deformation [23];

E) The Balkanide Alpine thrust belt;

F) Stradzha Mesozoic polyhase orogenic belt of main Neodomian age [23];

G) The Rodope Massif consisteing of Paleozoic and Precambrian basement, that experienced deformation and metamorphism in Barsican period and deformation during the Mesozoic (in pre-Cenomanian or pre–Mastrcihtian) [23];

H) The Western Pontides (or Istambul zone) with basement similar to the Moesian Platform [23];

I) The southern Crimea orogen with three orogenic phases (pre-Bajocian, pre-Callovian and intra-Berriasian) [23];

J) The central Pontides which consist of ophiolite complex (Early Triassic) covered by flysch (Triassic – Mid Jurassic) [26].

To the south, the Black Sea Basin, is bounded by a Cretaceous magmatic belt named Srednogorie-Pontide-Karabalch [23]. To the northern margin of Western Black Sea Basin is also a remanent volcanic arc of the same age as those from south, Cretaceous age [26]. This remanent volcanic arc from the northern part is situated along the continental slope to the south and southwest of Sevastopol in Crimea ([24] and there in).

[1] highlights the presence of three fault systems in the Western Black sea basin: a longitudinal one, a transversal one (parallel to the Black Sea coast) and an oblique one with a NW to SE orientation.

The first system consists of 16 faults from which only 8 faults are described in [1]. The second system consists of Razelm, Lacul Rosu and West Midia Faults and the third one is represented by Nistru, Odessa and West Crimea Faults.

3. METHODOLOGY

Active faults can be described using different parameters, as those proposed in Table 1 and Table 2 [2, 3] distinguished three main categories of Seismogenic Sources: Individual Seismogenic Sources (Fig. 3), Seismogenic areas and Macroseismic sources. Our study is providing geometrical and seismological parameters for the active faults, using only the first and second category of seismogenic sources.

Individual Seismogenic Sources (ISS) (Fig. 3) are defined by geological and geophysical data (see Table 1) and are characterized by a full set of geometric (strike, dip, length, width and depth), kinematic (rake), and seismological parameters (single event displacement, magnitude, slip rate). As such, Individual Seismogenic Sources can be used for different scenarios: simulating earthquake, and tsunami scenarios, tectonic and geodynamic investigations [2, 3].

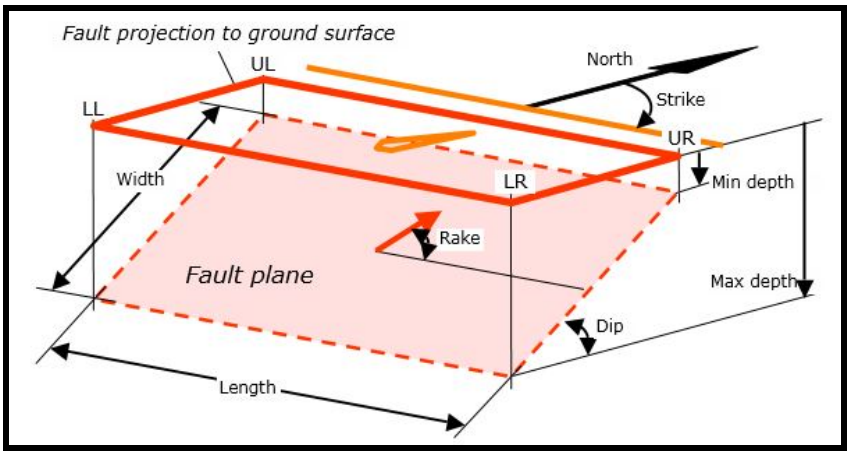

Fig. 3 – Schematic representation of an Individual Seismogenic Source and its characteristics [1].

Table 1

Main types of data and methods used to obtain the parameters of individual seismogenic sources (modified after [2, 3])

Parameter	Appropriate data and methods
Length	Source length measured along its strike. Geological maps of faults expressed at the surface. Geological sections across the active fault system. Scaling relationship between length and moment magnitude ([27]).
Active length	Length of epicentral area.
Width	Geological sections across the active fault system. Width of the epicentral area, measured along its dip. Scaling relationship between width and moment magnitude ([27]).
Minimum Depth	Value of the minimum depth of the earthquakes. Depth distribution of earthquakes. Geological sections across the active fault system.
Maximum Depth	Value of the maximum depth of the earthquakes. Depth distribution of earthquakes. Geological sections across the active fault system.
Strike, Dip, and Rake/Slip	• Displacement components of geological markers in maps and cross sections • Focal mechanisms of the larger associated earthquakes.
Magnitude	• Largest magnitude of associated earthquake(s) measured instrumentally. • Magnitude inferred from the area of the largest associated fault or fault set. • Scaling relationship between magnitude and fault size ([27]).

Table 2

Earthquakes with fault plane solutions for onshore and offshore Black Sea Coast (Dobrogea)

No.	Year	Mo.	Day	Hour	Lat	Lon	Depth km	Mw	Plane A			Plane B			NS/ References
									az	dip	slip	az	dip	slip	
7	1972	8	6	00: 53:08	44,63	32,63	0	4,8	235	79	–22	330	69	–168	**/**
19	1986	3	3	07:26:03	43,76	31,51	18	4,6	75	47	63	292	50	116	**/**
23	1987	7	19	02: 18:57	45,53	27,64	37	4,8	254	61	–26	358	66	–147	**/**
28	1990	08	16	04:32:18	44,71	34,95	25	4.6	216	52	75	59	41	108	9/[30]
31	1991	7	25	08:26:24	43,12	31,3	10	4,6	235	88	168	325	78	2	9/[30]
35	1992	9	24	11: 42:46	44,66	34,48	33	3,3	77	57	176	169	87	33	7/[30]
42	1997	4	19	21: 00:41	43,12	29,16	10	3,3	335	52	–4	65	87	–142	14/[30]
48	1997	10	19	01:56:38	44,83	33,78	57	3,5	105	84	38	11	52	173	7/[30]
52	1998	10	16	15:24:12	44,04	33,6	33	4,1	132	63	107	278	32	60	8/[30]
54	1998	10	18	05:22:09	44,03	33,62	33	4,1	251	90	20	161	70	180	10/[30]
57	1999	6	2	16:40:55	44,65	34,65	10	*	114	87	75	11	15	167	*/*
68	2001	7	29	1:30:45	44.015	34.496	33	4,2	281	32	139	47	70	65	10/[30]
90	2006	2	7	22: 58:38	44,53	34,44	10	*	56	72	131	165	44	26	7/[30]
106	2007	4	27	07: 54:40	44,32	33,03	10	3	274	69	0	184	90	159	7/[30]
118	2008	5	7	08:00:21	45,37	31.29	20	4,9	264	55	115	45	42	59	*/*
129	2008	7	24	14:14:30	45,18	36,49	11	3,5	274	69	0	184	90	159	7/[30]
136	2008	9	15	09:58:19	44,01	29,2	5	2,3	34	55	157	137	17	37	7/[30]
145	2009	1	6	02:20:30	45,12	29,25	5	2,3	34	89	54	303	36	178	7/[31]
161	2009	5	25	10:56:19	44,10	29,16	12,7	2,2	260	86	151	352	61	4	8/[31]
171	2009	8	4	15:01:07	43,54	28,57	3,4	2,9	169	62	74	21	32	118	8/[31]
178	2009	8	31	01:21:37	43,52	28,59	10	2,2	258	82	22	165	68	172	9/[31]
187	2009	10	7	05:41:55	43,50	28,56	10	2,5	278	58	87	103	32	95	10/[31]
251	2011	3	15	12:08:28	43,601	29,385	0,6	2,6	106	66	–133	352	48	–34	12/[31]
252	2011	3	28	08:58:14	43,791	29,24	0,3	2,5	171	75	23	75	67	164	14/[31]
253	2011	05	04	10:05:04	45,088	29,075	10	3,2	289	48	80	123	43	100	23/[31]

NS – number of stations

Every parameter of each Individual Seismogenic Source is qualified according to the type of analysis that was done to determine it. The qualifiers are defined as follows:

– Literature Data (LD): data taken from a published source.

– Original Data (OD): original data obtained in field surveys, unpublished original measurements and interpretations for the purposes of this Database;

– Expert Judgement (EJ): assignments made by the compiler on the basis of tectonic information or established knowledge at a larger scale than that of the seismogenic source under consideration and data collected from studies published in scientific journals and technical reports of research projects [2, 3].

We use 25 earthquakes (Fig. 6) with fault plane solutions in terms of nodal planes (Table 3) to describe the faults from a seismological point of view.

The fault plane solutions have been obtained as in [1]. For our estimations, the selected threshold is 7 polarity data for 7 earthquakes; between 7 to 10 polarity data for 9 earthquakes, for another 4 earthquakes, the number of available observations is greater than 10; and 5 earthquakes are from different papers.

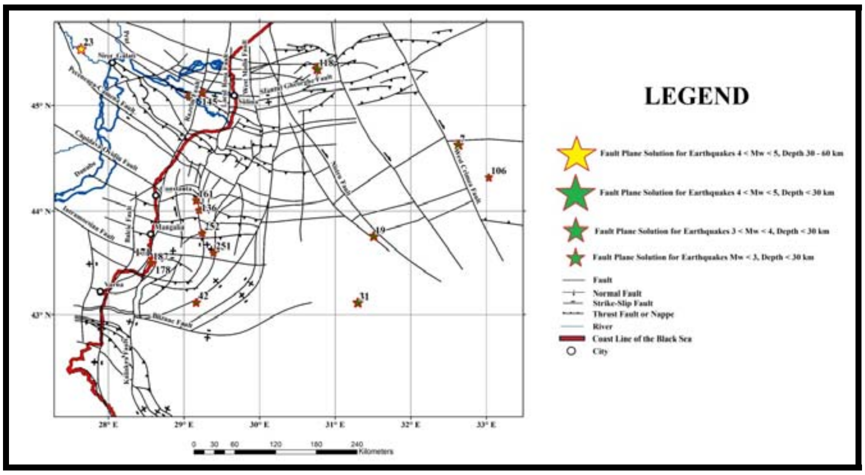

Fig. 4 – Earthquakes with fault plane solutions on the tectonic background. Numbers indicate the current event number in Table 3. Tectonics after [15], [29].

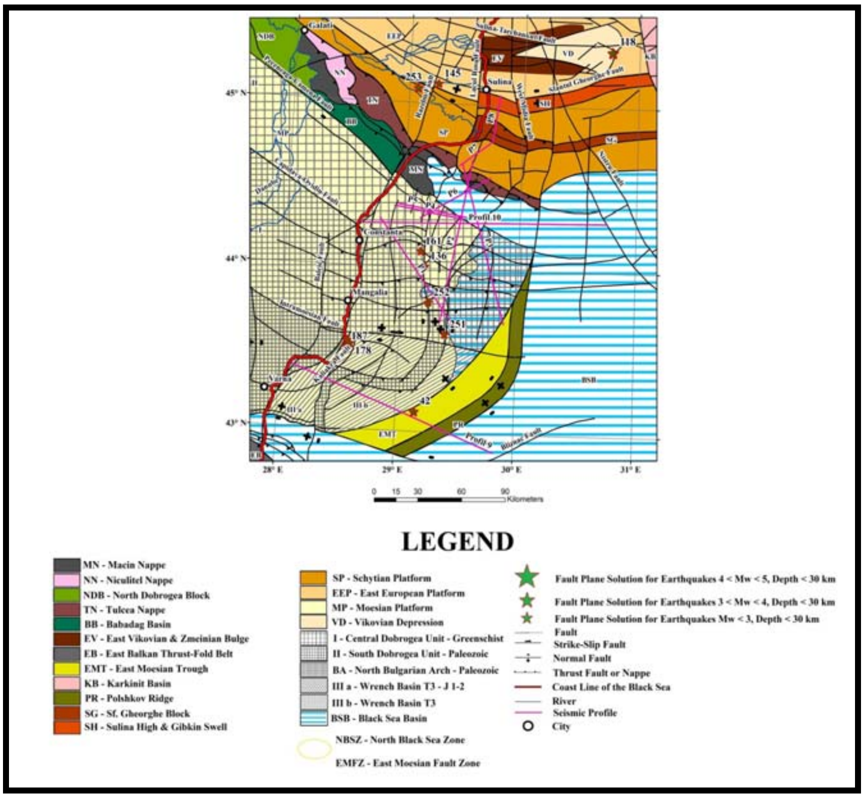

Fig. 5 – Seismic profile distribution and distribution of earthquakes with focal mechanism. Tectonics after [29].

Geometrically, we described the faults with the aim of width taking in consideration the epicentral distribution, the length taking in consideration the maps generated by [15] and [28] and the depths of the faults as proportional to the hypocenter of the earthquakes. The earthquakes catalogue used is the Romplus catalogue by [27].

4. RESULTS

According to the epicenters distribution map we present the following active faults: Razelm Fault (Table 3), Lacul Rosu Fault (Table 4) and West Midia Fault (Table 5), which are transversal faults and the oblique faults: Nistru (Table 6), Odessa (Table 7), and West Crimea Faults (Table 8). We characterize these faults with the aim of geometrical parameters (width, depth, length) and seismological parameters (strike, dip, rake and maximum magnitude).

Table 3

Parameters of Razelm Fault (represented on Fig. 2, Fig. 4, Fig. 5, and Fig. 6)

Total length (km)	286	LD	Inferred from regional tectonic considerations [5, 29]
Active length (km)	190		Inferred from earthquakes distribution
Wide (km)	11		Inferred from earthquakes distribution
Minimum depth (km)	0.4		Inferred from earthquakes distribution
Maximum depth (km)	25	OD	Inferred from earthquakes distribution
Strike (degree)	170	OD	Based on fault plane solutions, earthquake no. 171, Table 2
Dip (degree)	62	OD	Based on fault plane solutions, earthquake no. 171, Table 2
Rake (degree)	74	OD	Based on fault plane solutions, earthquake no. 171, Table 2
Max magnitude	5 (M_w) (25 April 1901)	OD	Based on the strongest earthquake occurred along fault

Razelm Fault is a normal fault, with the Eastern compartment down and moved to the north. This fault shifts all the longitudinal faults so we can say that is a younger fault in respect to the longitudinal system.

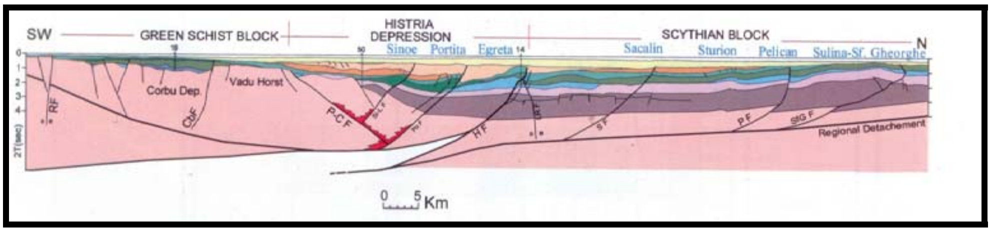

Fig. 6 – Seismological cross-section along the seismic lines P7 and P8 (Fig. 6) after [15].

The NW-SE trending extension specific to normal and compressional faults is in concordance with the way that Razelm Fault affects the Early and Late Cretaceous rock formations [32].

Corbu-Constanta Depression System is bounded by Lacul Rosu and Razelm faults, continuing further south, with the Varna Trough [29].

The green schist zone (central Dobrogea Unit), which is an uplifted basement block, extended offshore and bounded by the Razelm Fault, Lacul Rosu Fault and West Midia Faults [29]

Table 4

Parameters of Lacul Rosu Fault (represented on Fig. 2, Fig. 4, Fig. 5, Fig. 6)

Total length (km)	248	LD	Inferred from regional tectonic considerations [5, 29]
Active length (km)	248	OD	Inferred from earthquakes distribution
Wide (km)	5	OD	Inferred from earthquakes distribution
Minimum depth (km)	0.3	OD	Inferred from earthquakes distribution
Maximum depth (km)	11	OD	Inferred from earthquakes distribution
Strike (degree)	171	OD	Based on fault plane solutions, see earthquake no. 252, Table 2
Dip (degree)	75	OD	Based on fault plane solutions no. 252, Table 2
Rake (degree)	23	OD	Based on fault plane solutions no. 252, Table 2
Max magnitude	3.4 (M_w) (2 march 2013)	OD	Based on the strongest earthquake occurred along fault

Lacul Rosu Fault is a normal fault, with the Western compartment down and moved to the north. This fault shifts all the longitudinal faults so we can say that is a younger fault in respect to longitudinal system.

Table 5

Fault Parameters of West Midia Fault (represented on Fig. 4, Fig. 5)

Total length (km)	268	LD	Inferred from regional tectonic considerations [5, 29]
Active length (km)	134	EJ	Inferred from earthquakes distribution
Wide (km)	5	EJ	Inferred from earthquakes distribution
Minimum depth (km)	0.5	EJ	Inferred from earthquakes distribution
Maximum depth (km)	33	EJ	Inferred from earthquakes distribution
Strike (degree)	352	OD	Based on fault plane solutions, earthquake no. 251, Table 2
Dip (degree)	48	OD	Based on fault plane solutions, earthquake no. 251, Table 2
Rake (degree)	–43	OD	Based on fault plane solutions, earthquake no. 251, Table 2
Max magnitude	4.1(M_w) 12 December 1967	OD	Based on the strongest earthquake occurred along fault

The Lacul Rosu affects the Early and Late Cretaceous rocks, [32] in agreement with the SE trending extension of the compressional faults.

In the investigated area, two main fault systems are present: an older, Paleozoic to Cretaceous fault system, with its faults (Sf. Gheorghe, Peceneaga-Camena, Capidava-Ovidiu, Intramoesian, etc.) both normal or reversed and mainly trending NW-SE; the younger fault system with normal and strike-slip faults (Razelm, Lacu Roşu, West Midia Faults), also trending NW-SE [31].

West Midia Faults belonging to the NE-SW oriented fault system which consists of normal and strike slip faults.

Table 6

Fault Parameters of Nistru Fault (represented on Fig. 7 and Fig. 8)

Total length (km)	317	LD	Inferred from regional tectonic considerations [5, 29]
Active length (km)	127	EJ	Inferred from earthquakes distribution
Wide (km)	4	EJ	Inferred from earthquakes distribution
Minimum depth (km)	1	EJ	Inferred from earthquakes distribution
Maximum depth (km)	66	EJ	Inferred from earthquakes distribution
Strike (degree)	123	OD	Inferred from earthquakes distribution
Dip (degree)	Non available	–	–
Rake (degree)	Non available	–	–
Max magnitude	5.3(M_b) 20 December 2007	OD	Based on the strongest earthquake occurred along fault

The Nistru Fault, trending from N-S, represents the Eastern limit of the Fore-Dobrogea Domain [15].

The Western segment of the Nistru Fault is of Proterozoic age and ends at the Serpent Island being also named as the Soroca-Serpent Island Fault [15].

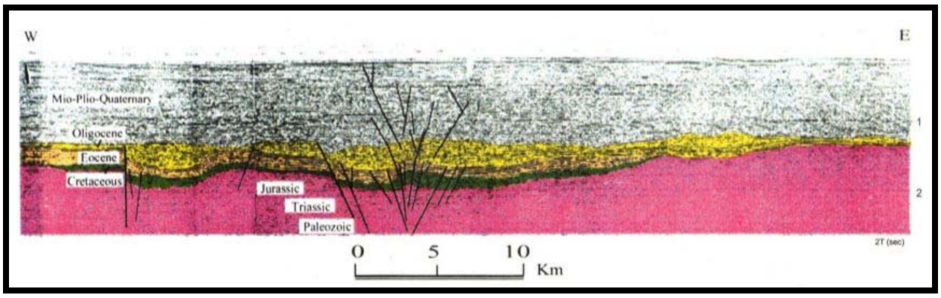

Fig. 7 – P 11-Seismic line over Nistru Fault after [15] (see Fig. 5).

The vertical movements were the first movements of the area (in the left side of the seismic line) and the horizontal movements, the second. This strike-slip character, of the fault, creates the positive flower structure (central part of section). These horizontal type movements are still active [15].

Nistru Fault may be a limit, between Fore Dobrogea Trough and extended crust of East European Craton to the south (Fig. 8).

In the middle part of the Dobre-5 profile (Fig. 8), the transition between the domains of the Scythian Platform (the offshore Karkinit Trough and the onshore Central Crimean Uplift) can be associated with the Western Crimean Fault. The N-S oriented, Western Crimean Fault, together with the, also N-S oriented Odessa Fault, forms one of the major fault systems in the area [33].

Table 7

Fault Parameters of Odessa Fault (represented on Fig. 2, Fig. 4, and Fig. 8)

Total length (km)	300	OD	Inferred from regional tectonic considerations [5, 29]
Active length (km)	141	OD	Inferred from earthquakes distribution
Wide (km)	9	OD	Inferred from earthquakes distribution
Minimum depth (km)	5	OD	Inferred from earthquakes distribution
Maximum depth (km)	46	OD	Inferred from earthquakes distribution
Strike (degree)	104	OD	Inferred from earthquakes distribution
Dip (degree)	Non available	–	–
Rake (degree)	Non available	–	–
Max magnitude	5.7(M_D) 7 may 2008	OD	Based on the strongest earthquake occurred along fault

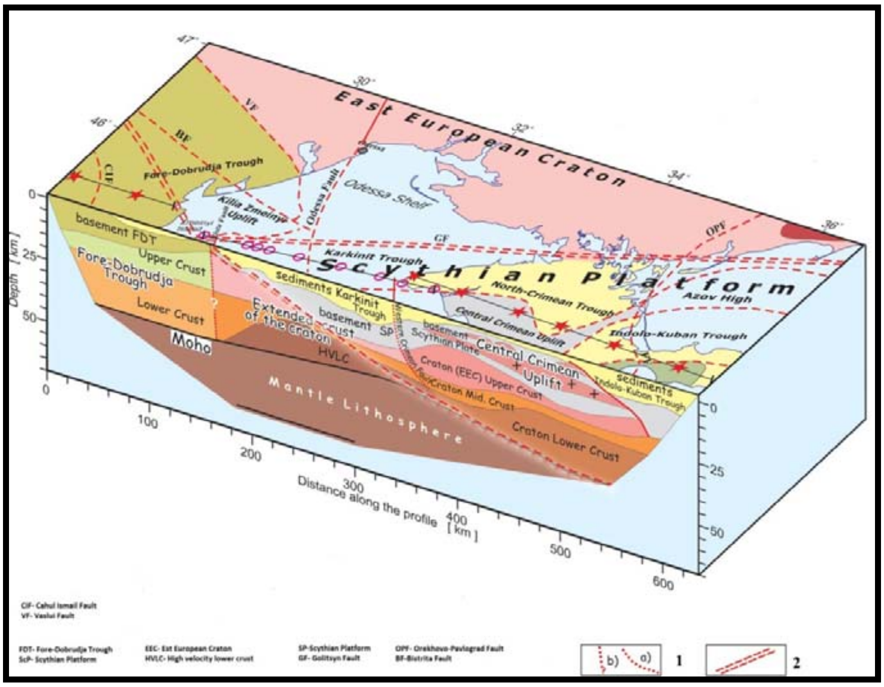

Fig. 8 – Dobre 5 profile. Interpreted velocity model *vs* surface geology. 1. Deep Faults:
a) clearly distinguished in the seismic section and related to surface fault-Western Crimea Fault;
b) not clearly distinguished on seismic section but related with surface fault – Nistru Fault.
2. Crustal fault between the Scythian Platform and Est European Craton associated with the Golitsyn Fault (GF) on the surface (after [33]).

Table 8

Fault Parameters of West Crimea Fault (represented on Fig. 2, Fig. 4, and Fig. 8)

Total length (km)	330	LD	Inferred from regional tectonic considerations [5, 29]
Active length (km)	115	EJ	Inferred from earthquakes distribution
Wide (km)	6	EJ	Inferred from earthquakes distribution
Minimum depth (km)	0	EJ	Inferred from earthquakes distribution
Maximum depth (km)	33	EJ	Inferred from earthquakes distribution
Strike (degree)	335	OD	Based on fault plane solutions, earthquake no. 7, Table 2
Dip (degree)	69	OD	Based on fault plane solutions, earthquake no. 7, Table 2
Rake (degree)	–168	OD	Based on fault plane solutions, earthquake no. 7, Table 2
Max magnitude	4.8 (M_b) 6 august 1972	OD	Based on the strongest earthquake occurred along fault

The Scythian's Platform Odessa Shelf continental margin, rifted and extended, is separated by the N-S trending, West Crimean Fault, from the buckled and subjected to compressional tectonics domain of the Central Crimean Uplift. The Karkinit Trough is parted from the Central Crimean Uplift by the West Crimean Fault. The Central Crimean Uplift is separated from the Indolo-Kuban Trough by the means of the southern continuation of the Proterozoic Orekhovo-Pavlograd Fault which originates in the Ukrainian Shield [33].

The Western Crimean Fault is the tectonic feature that marks the separation between regions affected by the extension/rifting of the Cretaceous and the present compressional tectonic regime of Crimea, also being the element of transition between the offshore Karkinit Trough and the onshore Central Crimean Uplift [33].

5. CONCLUSION

This is the second paper (from a series of four), concerning active faults in Romania, particularly from onshore and offshore of the Black Sea Coast which fill a gap, with [1], in European projects Share and Epos where, until now, Romania was missing. Besides this, the description of active faults setting up an important role in defining seismic sources for seismic hazard purpose [34, 35]. All the faults discussed in this paper (from transversal and oblique systems) are younger then the first faults system, a transversal one, because these two systems shift in different measurement the transversal one.

The faults presented in this paper can generate a tsunami [36] by themselves. The lengths of the active faults are of enough dimensions to generate earthquakes with high magnitudes and energy that and could be a tsunami generator [34, 35]. Reference [36] state's that only earthquakes with a magnitude higher than 7.5 with normal or reverse faulting of the focal mechanisms can produce tsunami at shallow depth. However, are known, also, tsunamis generated by earthquakes with smaller magnitudes *i.e.* (www.ngdc.nooa.gov).

Is necessary to continue to pay attention to these faults because the geological database of them is poorly and not well defined. In these conditions, the single objective criteria of characterization remains the seismological one.

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