4.3.13. PROVADIA REGION IN BULGARIA – NATURAL OR INDUCED SEISMICITY?

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4.3.13.1. Introduction

During the last decades, about 50 years after starting the salt exploitation in the Provadia region, NE Bulgaria, the occurrence of moderate earthquakes (magnitude 4.0-4.5) became more often. This circumstance created the public opinion that the shocks are caused by the method of exploitation which includes filling of the caverns by waste fluids. To proof or reject the induced character of the earthquakes, it turned out that some more detailed seismological investigations were necessary. On this reason a Local Seismic Network (LSN) in Provadia Region was constructed; it was put in operation in the second half of 1995. So, the seismological data base in this paper contains generalized information about more than 300 instrumentally recorded seismic events originated in the Provadia Region (42.6^o – 43.6^o N/ 27^o – 28^o E) during the last decades. Special emphasis is put on the period 1995 – 2003, the time of high sensitive registration by LSN. The most seismically active area takes place in the central part of the Provadia valley, where the geodynamic influence of four main tectonic faults is observed.

To answer the question is there any influence of salt deposit exploitation on seismic activity, non-instrumental and instrumental seismological approaches as well as some appropriate geodynamic results are used.

4.3.13.2. Data and discussion

The investigated area takes place in the NE Bulgaria. It is situated in the large contact zone between the Moesian Platform and the Balkan Alpine orogen complex.

The Moesian Platform and the Balkan Orogen complex represent structural units with specific characteristics The Moesian Platform is relatively stable structural unit. The Balkan Orogen complex includes numerous structural units with different degrees of mobility. The most northern of them in the NE Bulgaria is the Fore-Balkan. The Fore-Balkan unit has relatively moderate mobility.

The contact zone between the Moesian Platform and the Fore-Balkan is named a Transition zone. The zone posseses several characteristics that are close to the ones of the platform, or to the orogen.

Small anticlines and synclines with approximately E-W directions take place in Provadia sector of the Transition zone. They are flat and asymmetric fold structures. Mainly Upper Cretaceous and Neogene sediments are observed on their surfaces.

Faults with NNW-SSE, ESE-WNW, NE-SW and NW-SE directions cut the folds. One of them is the Provadia fault. It has a NNW-SSE main direction. The fault has a regional signification. The Provadia fault represents a recent active structure. It controls the contemporary deformation of the Provadia River's slopes. A number of new fractures

with a N-S general direction were observed from one of the authors in the upper part of the Eastern slope of the Provadia River. Landslides are manifested along limited sectors of the same Eastern slope of the river. They indicate the development of the Provadia faults that is not stopped in our days.

The Souk fault is another one with significance for the Provadia area. It has WNW-ESE direction. The fault is expressed in the relief of the area. The Souk fault causes the delimitation of the Provadia blocks from the Mirovo ones. Especially in the Mirovo blocks a salt body formation with the analogous name was generated. Now the Mirovo blocks are subjects of a salt extraction.

The blocks of the Provadia area and the surrounding territory from the Moesian Platform and the Fore-Balkan demonstrate specific recent activity. This activity is manifested in limited block structures or in groups of block structures. In the surrounding territory of NE Bulgaria there are groups of blocks with recent activity.

The seismic events represent one of the forms for the indication of the contemporary mobility in the studied territories. At the beginning of the tectonic and the seismological investigations in the Provadia area, we propose a scheme for the main seismotectonic conditions in the investigated area and the adjacent lands. The Provadia area is included in a group of blocks with considerable seismotectonic activity (Fig. 4.3.13.1.).

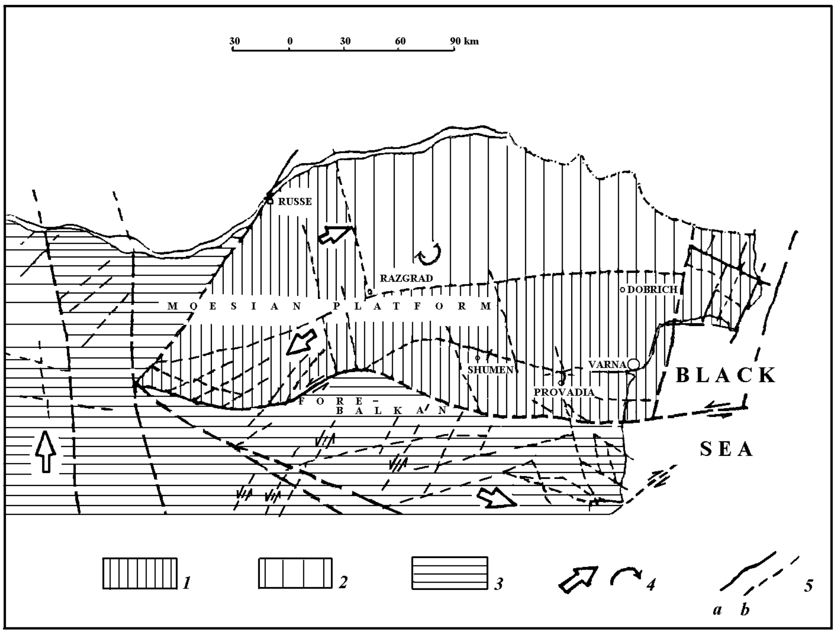

Fig. 4.3.13.1. Main seismotectonic manifestations in the Provadia area and its surrounding from NE Bulgaria.
1 to 3 – blocks of different seismotectonic activities: 1 – of considerable one, 2 – of limited one, 3 – of sporadic one; 4 – general directions of the block movements, 5 – faults: a – seismic active one, b – probably seismic active one.

In connection with the tectonic circumstances in the region, it is important to say that on the background of general uplifting of the salt body utself, separate blocks lagged behind by stages. A number of faults with various orientations form a complicated tectonic knot there. The faults through which the latest salt intrusion occurred are

characterized by the considerable amplitude of neotectonic displacements (Boncev, 1971; Matova, 1969; Shanov, 1983).

The earthquakes in Bulgaria have been regularly documented since 1892. It is known that the Provadia Region had experienced earthquakes from local origin long time before the salt body exploitation began. Some local earthquakes in 1901, 1911, 1912, 1921, and 1944 are signs of tectonically pre-determined seismicity in the investigated region.

In the latest three or four decades the local felt earthquakes started occurring more frequently (Fig. 4.3.13.2). They had caused effects of intensity up to 6-7 MSK, some stronger than in the past. Logically, the increased strength of impacts is connected with a small source depth, between 5 and 10 km under the Earth's surface. The illustration in Fig. 4.3.13.2 shows only 5 events within 70 years period and much more in the latest 3-4 decades. Possibly, some of the seismic events of M≥3.0 during the last decades are due to the accumulated modification of the geodynamic equilibrium caused by the salt body exploitation. Unfortunately, the uncertainty of previous seismic solutions gives no oportunity for better understanding whether the shallow activity is also typical of the previos earthquakes or the seismogenic depths has gone to smaller values as result from the salt exploitation.

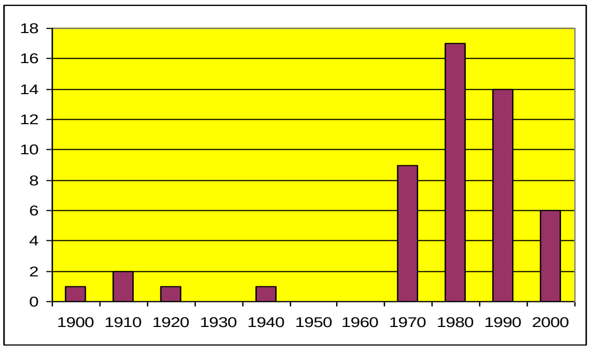

Fig. 4.3.13.2. Number of earthquakes with M≥3 in the course of time (decades), Provadia region

It is to be noticed that the epicenters of these latest earthquakes are macroseismically well studied. They are located in the area 43.12 – 43.23°N, 27.45 – 27.55°E. The salt exploitation goes in the SW periphery of this area. Through macroseismic analysis of some strongest events in the area it could be verified that the minimal losses of released seismic energy are mainly in three directions: NW-SE, N-S and E-W. This way, the highest conductivity of energy in the region often coincides with the strike of significant faults. The macroseismic fields and isoseists of some of the events are shown in Fig. 4.3.13.3.

An excellent example of a field survey conducted by a combined team of experts of the Geophysical Institute and the Central Laboratory for Seismic Mechanics and Earthquake Engineering of Bulgarian Academy of Sciences is the case of 17 December 2003 magnitude 4.4 (M_d) earthquake (Dimova et al., 2004). The goal of primary importance was to examine the new European Macroseismic Scale 1998 (EMS-98, Gruenthal, 1998) in practice.

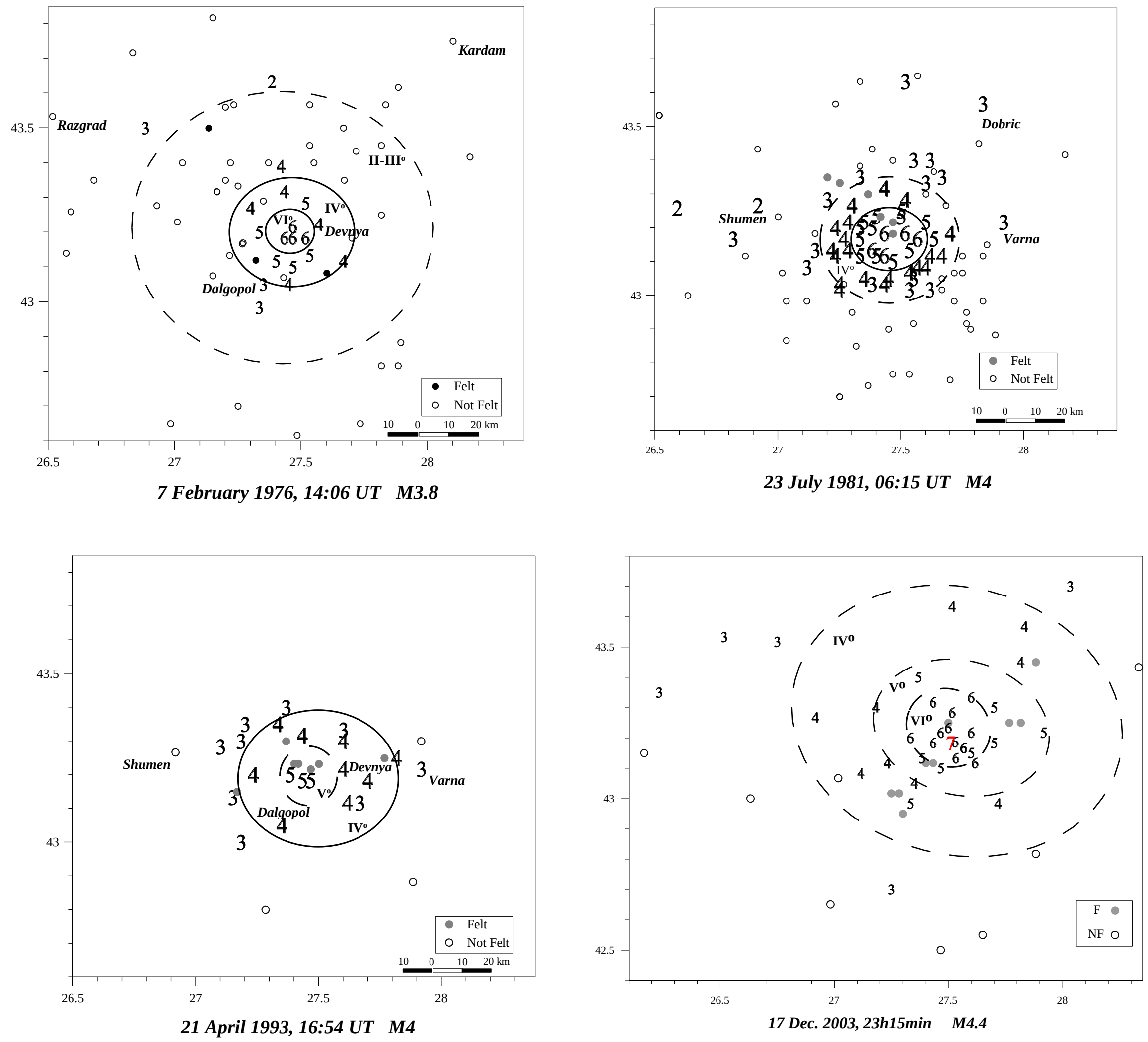

Fig. 4.3.13.3. Macroseismic fields and isoseists of some of the strongest events in Provadia region (four schemes)

The last plot in Fig. 4.3.13.3. (bottom, right) presents the entire macroseismic field and supposed isoseismals of the earthquake on 17.12.2003. Table 4.3.13.1 contains results from the macroseismic survey in the inspected part of the epicentral area.

The maximal seismic effect of 7 EMS-98 was established in the village of Manastir, to the east of the town of Provadia. This was in buildings of high vulnerability and at very unfavorable ground conditions, on river deposits. The other part of the same village, the same building stock but under better ground conditions, the effect was of 6 EMS-98. The seismic influence on both the unreinforced masonry and reinforced concrete buildings in the town of Provadia was of 6 EMS-98, too.

Table 4.3.13.1. Effects on buildings caused by Provadia earthquake on 17 December 2003 (M_d=4.4).

Abbreviations accepted according to the EMS-98:

MA: ***masonry;*** **RC:** ***reinforced concrete;*** **A, B, C:** ***vulnerability classes***

Locality	Structures					Intensity EMS-98
	Type	Number of buildings	Vuln. Class	Damage Grade	Quantity	
Devnya	MA: unreinforced, with wooden floors	1146	B B	1 2	60 %, many 5 %, a few	6
	MA: unreinforced with RC floors	453	C	1	a few	6
	RC: frame	2	C	-	no data	-
	RC: with shear walls (large panel prefabricated)	29	C	-	no data	-
Dobrina	MA: unreinforced, with wooden floors (two layers stone walls without connections)	c. 250	A A A	1 2 3 & 4	all 34%, many N=4	6+
	MA: Adobe with wooden frames and wooden floors	-	B	2	few	6
Manastir – on river deposits	MA: unreinforced, with wooden floors (two layers stone walls without connections)	120	A A	4 3	17 %, a few ca. 80%, most	7
Manastir – hill slope	MA: unreinforced, with wooden floors (two layers stone walls without connections)	120	A A	1 2	more than 80% a few probably	6
	RC: frame	1	C	no damage		(6)
Padina	MA: unreinforced, with wooden floors (one layer stone wall)	259	B B	2 1	16 %, a few many	6
	MA: unreinforced with RC floors	12	C		no data	-
Petrov Dol	MA: unreinforced, with wooden floors (two layers stone walls with transversal connections)	about 270	B	1 2	many a few	6
	MA: unreinforced with RC floors	1	C	1	-	(6)
	RC: frame	Post office	C	1	-	(6)
Provadya	MA: Adobe with wooden frames and wooden floors	561	B	-	no data	-
	MA: unreinforced, with wooden floors	3748	B	2 1	8 %, a few ¾, most	6
	MA: unreinforced	750	C	-	-	-

	with RC floors					
	RC: frame	408	C	1	a few	6
	RC: with shear walls	27	C	1	a few	6

The earthquake distribution in time-space also to the energy released is studied for the period after 1980 (Mihajlov et al., 1994, Botev et al., 2004). The investigated region includes the salt body in exploitation. In 1980 the National Operative Telemetric System for Seismological Information (NOTSSI) of Bulgaria was created; 15 years later the Local Seismic Network (LSN) was installed in Provadia Region. During the time of Provadia LSN operation more than 360 local seismic events with M>0.5 have been recorded. Only 128 of them are successfully localized and identified as earthquakes. The seismicity is moderate taking into account the 9 year duration of the observation interval (Fig. 4.3.13.4). The recording possibility and space localization of the seismic events in NOTSSI is realized on the basis of 14 stations spread all over the country and of the 5 stations Provadia LSN. The local seismographs' sensitivity allows the recording and processing of weak earthquakes with M > 0.5. The precision of the epicentral location determining is different. It depends first of all on the specific position of the epicentre towards the geometry of the recording national and local network. The precision was quite low prior to 1980. After 1980 most of the epicenters (about 100 events) have uncertainty in the depth determination up to 10 km as result of a lack of seismic stations in vicinity.

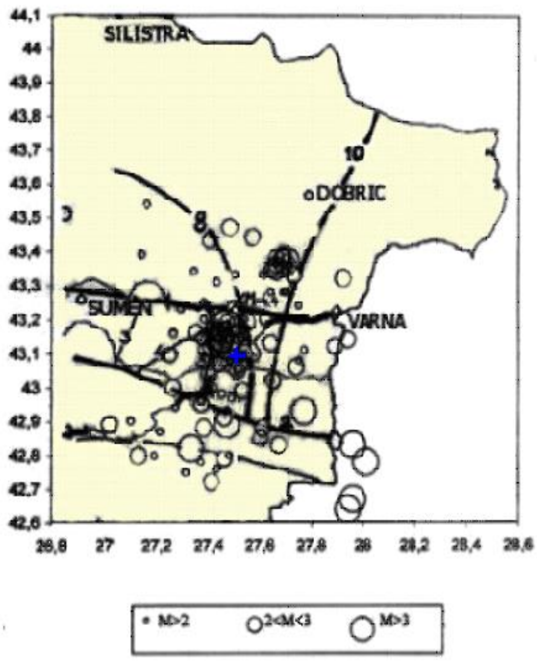

Fig. 4.3.13.4. Earthquake epicenters after constructing the Provadia LSN (1995 till now)

After constructing Provadia LSN, the uncertainty of epicenter determination decreases to 1-2 km. The earthquake distribution in Fig. 4.3.13.4 shows that the strongest events (M>3.0) are grouped along the main faults of the Balkan orogen complex. The considerable concentration of earthquakes takes place in and around the Provadia depression, i.e. between the Provadia fault (to the W), South Moesian faults (to the N), Sindel-Vetren fault lineament (to the E) and Sultantsi fault (to the S).

The territorial distribution of the epicenters shows well an NNE-SSW oriented active strip in the Provadia region. The most seismically active territory (with concentration of more than 60 events) in the Provadia valley seems to have been associated with the geodynamic influence of Hrabrovo, Provadia, Padina and Sultantsi faults (Mihajlov et al., 1994, Georgiev, 1990). This namely is the central part of the Provadia valley where, nearby, the Mirovo salt deposit body is situated. Here the underground injection-extraction exploitation is carried out on three depth levels, from 1000 m down to 1750 m (Paskaleva & Kouteva, 1997).

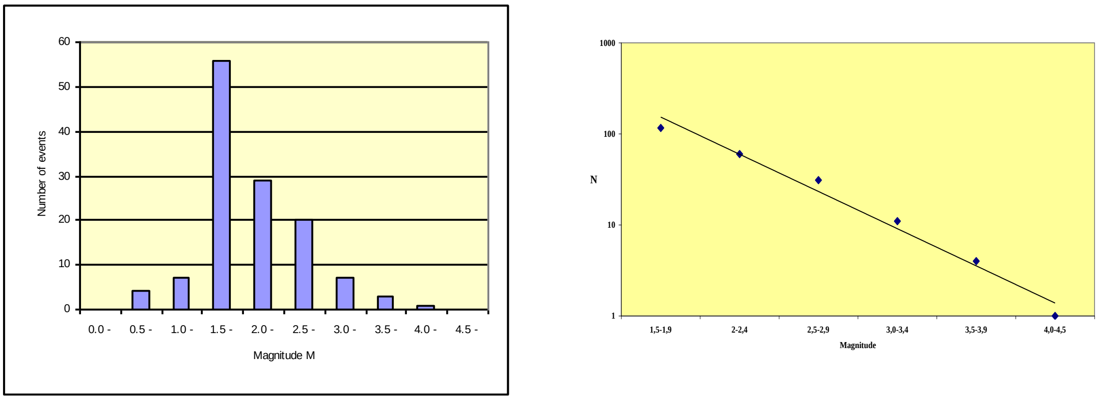

Fig. 4.3.13.5. Magnitude-frequency (a) and magnitude-LogN (b) distribution of earthquakes

The magnitude-frequency distribution of earthquakes (Fig. 4.3.13.5a) shows that the number of events (N) increases with the magnitude (M) decrease. The abrupt diminishing of the number of weakest earthquakes determines also the registration possibilities of the seismic stations network. Then, it can be concluded that the magnitude sample of the M > 1.5 events is comparatively closer to the reality for the region of interest. The Log(N)–magnitude dependence for the events with M > 1.5 shows that the coefficient b of the averaged straight line (the slope in Fig. 4.3.13.5b) is bigger (about 1) in comparison with the standard b, the long-term and for strong events, for the whole Bulgaria which points to the prevalence of weak events.

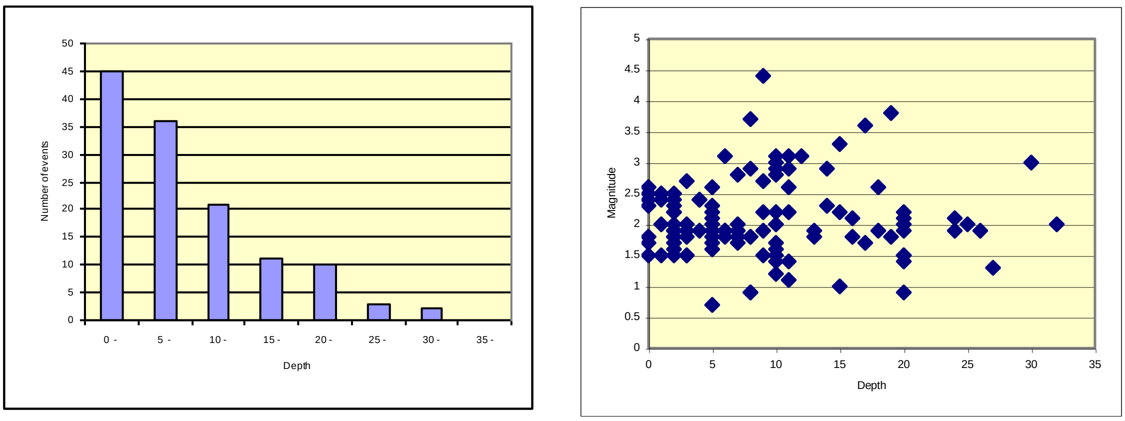

Fig. 4.3.13.5. Depth-frequency (a) and depth-magnitude (b) distribution of earthquakes

The accuracy of depth determinations of the local earthquakes is very different – from several hundred meters up to several kilometers. The hypocenters of the earthquakes are concentrated in the surficial 20 km depth interval (Fig. 4.3.13.5a). The slight decrease in the number of events when the depth grows is a natural phenomenon for the intraplate tectonic seismicity. The extraordinary great number of earthquakes in the depth interval 0-5 km could be associated with some influence of the salt body exploitation.

In the same time almost all stronger events (with magnitude M > 3.0) are localized on deeper levels – from 8 down to 20 km (Fig. 4.3.13.5b). This fact does not allow us to suppose any direct connection of the relatively stronger seismicity in the region with the salt exploitation.

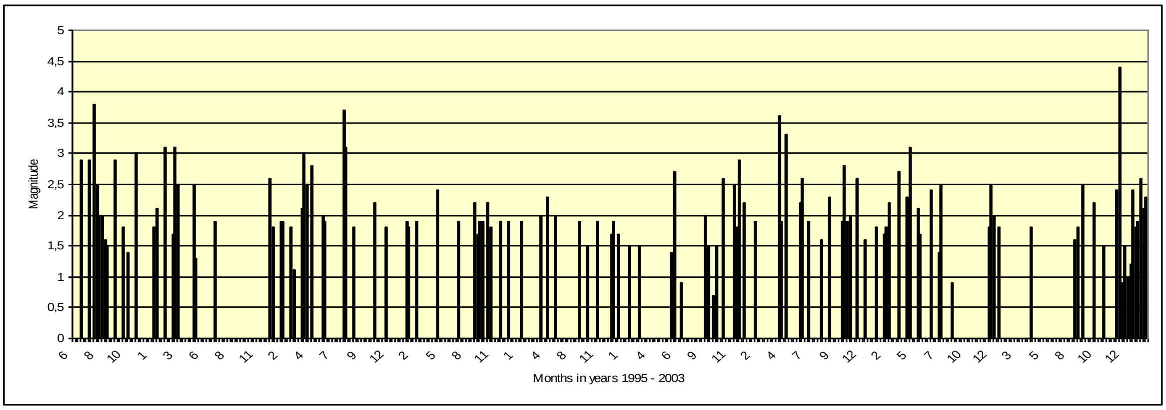

Fig. 4.3.13.7. Magnitude-time distribution of local earthquakes recorded by Provadia LSN since 1995

Finally, the time distribution of the earthquakes does not give any sugestion about some correlation between the quasi-periodic behavior of the seismicity with the rate level of the salt body exploitation or the level of vertical subsidence observed on the surface (Mihajlov et al., 1994, Paskaleva & Kouteva, 1997, Milev et al., 2005).

The relative increase in the number of seismic events during 1993, 1997 and 2000 (Fig. 4.3.13.7) is due to the aftershock sequences of earthquakes with magnitude nearly 4. The latest strong increasing in the earthquake frequency is due to the normal aftershock series of the strongest event (M=4.4) on 17.12.2003 whose mechanism and depth do not allow this to be considered as one directly man-induced event.

4.3.13.3. Conclusions

For the present, the observational results lead to the conclusion about existence of combined tectonic and man-induced effects in the Provadia region. The significantly higher number of stronger events during the last decades could be associated with the accumulated modification of the geodynamic equilibrium caused by the salt body exploitation. Still, each relatively stronger shock in the salt body's immediate or its closed vicinity would cause unfavorable consequences in the exploitation process due to possibility of producing cracks in the inhomogeneous salt-rock media.

The availability of a complicated tectonic knot in the salt body region, realization of earthquakes prior to starting salt body exploitation and the thickness of the main

seismogenic layers of more than 10 km represent facts which produce evidence in support of the tectonic nature of seismicity. On the opposite, the fact that the strongest earthquakes in Provadia Region have grown in number for the latest decades means that the tectonic balance might have been disturbed by the long-lasted salt body exploitation. Also, the high concentration of hypocenters in the 0-5 km depth could be related to the salt exploitation. Then, some man-induced earthquakes could have been provoked. It is not to be excluded and maybe the most possible is the combination of both factors – natural and artificial ones for the manifested seismicity.

4.3.13.4. References

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