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# Monitoring of natural and induced seismicity of Provadia Region (NE Bulgaria)

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## Introduction

The region of Provadia is remarkable with the exploitation of the biggest salt deposit body in Bulgaria by the method of the underground leaching. Some moderate earthquakes with magnitude M= 4 – 4.5 during the last decades created the public opinion that the shocks are caused by the method of exploitation which includes filling of the caverns by waste fluids. The main goal of this paper is to throw light on the problem to what extent the seismicity may be influenced by this salt body exploitation. To proof or reject the induced character of the earthquakes, some more detailed seismological investigations turned out to be necessary. On this reason a Local Seismic Network (LSN) in Provadia Region was constructed and started routine 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 in the Provadia Region ($42.6^o$ – $43.6^o$ N/ $27^o$– $28^o$ E) for the last decades, putting special emphasis 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, some non-instrumental and instrumental seismological approaches as well as some appropriate geodynamic results are used.

## Data and discussion

In connection with the tectonic circumstances in the region which includes the salt

body especially, it is important to say that on the background of general uplifting separate blocks lagged behind by stages. A number of long living faults with various orientations form a complex tectonic knot there. The faults through which the latest salt intrusion occurred are characterized by the greatest 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 decades the local felt earthquakes occur more frequently and have caused some stronger effects than in the past, namely of intensity up to 6-7 MSK. Logically, the increased strength of impacts is connected with a small source depth, between 5 and 10 km under the Earth's surface. Unfortunately, the previous events are scarcely documented and it is impossible to assess whether similar shallow activity is also typical for earlier earthquakes or it has been changed due to the salt exploitation. It is to be added that the epicenters of these latest earthquakes, macroseismically well studied (an excellent example is the macroseismic study of the magnitude 4.4 earthquake in 2003 [Dimova et al., 2004]), are located in the area 43.12 – 43.23$^o$N, 27.45 – 27.55$^o$E. The salt exploitation goes in the very SW sector of this area. The macroseismic analysis of the strongest events in the area shows that minimal losses of released seismic energy are mainly in three directions: NW-SE, submeridional and subparallel. This way, the highest conductivity of energy in the region often coincides with the strike of significant faults.

Time-space and energy earthquake distributions in a region, which includes the salt deposit body in exploitation, are thoroughly studied for the time after 1980, when the National Operative Telemetric System for Seismological Information (NOTSSI) of Bulgaria was created [ Mihajlov et al., 1994, Botev et al., 2004]. Special emphasize on the seismicity of the region during the operation of the Provadia LSN is made (after 1995). The recording and space localization of the seismic events in NOTSSI is realized by means of 14 permanent stations all over the country and the Provadia LSN which consists of 5 stations. The sensitivity of the local seismographs allows recording and processing of weak earthquakes with $M > 0.5$. The precision of determining the epicentral location is different and it depends first of all on the specific position of the epicentre towards the geometry of the recording national and local network. For the last 9-years period of high sensitive LSN observations, presented in this communication, the data about more than 360 seismic events with $M>0.5$ on the territory of the Provadia region are used. A relatively low seismic activity is observed - only 128 events are successfully localized and identified as earthquakes for this 9 years period.

The magnitude-frequency distribution of earthquakes shows that the number of the events (N) increases with the decrease of magnitude (M). The abrupt diminishing of the number of the 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** (the slope) of the averaged straight line is bigger in comparison with the standard dependence for North-East Bulgaria (for long period and strong events) which means that some prevalence of weak events is available. The space distribution of the epicenters shows well an NE-SW oriented active strip in the Provadia region. The most seismically active place (with concentration of more than 60 events) in the Provadia valley seems to have been associated with the geodynamic influence of Hrabrovski, Provadijski, Padinski and Sultanski 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. The underground injection-extraction exploitation here is carried out on three depth levels, from 1000 m down to 1750 m [Paskaleva & Kouteva, 1997]. The accuracy of the depth determination 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. The slight decrease in the number of the 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. This fact does not allow us to suppose some induced character of the stronger seismicity in the region of interest. Finally, the time distribution of the earthquakes does not allow noting any quasi-periodic correlation 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]. Some increase in the number of seismic events during 1993, 1997 and 2000 is due to the aftershock sequences of earthquakes with magnitude up to $M = 4$. The last 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 it this to be considered as one directly induced event.

## Conclusions

The availability of a complex tectonic knot in the salt body region, occurrence of earthquakes prior to the start of salt body exploitation and the seismic source depth which reaches to more than 10 km are 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 almost 30 years means that the tectonic balance might have been disturbed by the long-lasted salt body exploitation. If so, some induced earthquakes could be provoked. It is not to be excluded that the resulting disbalance would be favorable to trigger some tectonic seismic events, too.

For the present, the presented observational results lead to the conclusion about existence of combined tectonic-induced effects in the Provadia region. Still, each relatively stronger shock in the salt body immediate vicinity would cause unfavorable consequences in the exploitation process due to possibility of producing cracks in the inhomogeneous salt-rock media.

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