GEOLOGICA BALCANICA, 37. 1–2, Sofia, Iun. 2008, p. 73–78.

Zoning of Sofia valley according to the level of geological hazard

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(Submitted: 24.09.2007; accepted for publication: 16.11.2007)

Б. Беров – Зональное расчленение Софийской котловины по степени геологической опасности. В работе приведены основные критерии общей оценки геологической опасности в Софийской котловине. Их описание дополнено основными характеристиками геологических, тектонических, морфологических, геотехнических и гидрогеологических условий и факторов которые связаны с резким и непредусмотренным изменением физико-геологических процессов. Геологическо-геоморфологические, литологическо-геотехнические и гидрогеологические условия являются основыми факторами, определяющими физико-геологические процессы и степень геологичской опасности. При оценке опасности акцент поставлен на: роль тектонических движений (медленных и внезапных, т.е. землетрясений), на пространственные конфигурации разломов и на зоны с возможной активизацией. Отмечены и взяты под учет все проявления эндогенной и экзогенной геологической активности в разных частях Софийской котловины. В предложенной шкале геологической опасности выделены четыре степени: очень высокая, высокая, средняя и ниская.

Abstract. The main criteria for evaluation of the integral geological hazard in Sofia valley are presented in this paper. The criteria of the geological hazard are supplemented with the main characteristics of the geological, tectonic, morphological, geotechnical and hydrogeological conditions and factors, which are related to the emergence of phisicogeological processes. The geological-geomorphological, the lithological-geotecnical, the hydrogeological conditions are considered as a main factors that determinate the phisicogeological processes and then the level of geological hazard. The role of the tectonic movements – slow and sudden (earthquakes), the spatial configuration of faults, the possible activation zones are prioritized when determinate the level of hazard. The manifestation of all endogenic and exogenic geological activities are taken in consideration for different part of Sofia valley. A four-degree scale of geological hazard is determined, which include the following levels – very high, high, average and low.

Berov, B. 2008. Zoning of Sofia valley according to the level of geological hazard. – *Geologica Balc.*, 37, 1–2; 73–78.

Key words: geological hazard, physicogeological processes, zoning.

Criteria for evaluation of the integral geological hazard in Sofia valley

The combination and interweaving of different in type and level of impact destructive geological processes over one and the same areas in Sofia valley require estimation and area partitioning according to the level of damage based on several criteria, that reflect both the conditions, and the evolvement of the processes. Thus, the criteria for evaluation of the geological hazard are supplemented with the main characteristics of the geological, tectonic, morphological, geotechnical and hydrogeological conditions and factors, which are related to the emergence of physicogeological processes and therefore related to the evaluation of the level of geological hazard.

The geological-geomorphological, the lithological-geotechnical, the hydrogeological factors and the development of physicogeological processes can be

determined as the main criteria for the integral geological hazard. The role of the tectonic movements — slow and sudden (earthquakes), the spatial configuration of faults, the possible activation zones, etc. are prioritized when examining the very processes.

According to the geological-geomorphological criterion the main factors related to the geological hazard are the existing terrain slopes, the vertical and horizontal relief tortuous and its lithology. It is considered that from 0–4° the slope is favourable, it is a source of safety and low levels of geological hazard. Terrain slopes with 4–8° are semi-favourable and those over 8° are unfavourable. The relief tortuous, allowing for the lengths of the linear forms in a certain area (m/km^2), is one of the main parameters in landslide hazard zoning (Mora and Vahrson, 1993).

The lithological-geotechnical criterion classifies rock formations according to their genesis and geotechnical characteristics into 4 types. It also includes the evaluation of the stability of foundation bed, which is most favourable in case of rock type of geotechnical formations and respectively least favourable in case of incoherent sediments. The four types of geotechnical rocks – rock, semi-rock, coherent and incoherent formations determine the development of different in nature and intensity exogenetic geological activities, which at their turn cause different levels of geological hazard.

According to the hydrogeological conditions, the main criterion for high level of geological hazard is the level of distance between ground water and terrain surface. According to this criterion distances of 0–2 m are estimated as highly unfavourable, of 2–4 m – unfavourable, of 4–6 m moderate and over 6 m – favourable.

The effects and the combinations of physicogeological activities take main part in evaluating the integral geological hazard. Considering the variety of processes that affect the territory of Sofia valley, the endogenetic activities have the highest priority when examining these processes. The whole valley is differentiated by levels of geological hazard as a part of Bulgaria where earthquakes with magnitude IX from MSK-64 scale (Bonchev et al. 1982) can occur. Thus, the dependence between exogenetic and endogenetic geological activities, as well as forecasting the behaviour of the earth environment during strong seismic impacts, must be considered when classifying areas according to the level of geological hazard. On the other hand, the spreading of exogenetic processes and their certain dependences become an additional criterion, which refers one or another area of the valley to a zone with lower or higher level of geological hazard. The absence of exogenetic processes determines an area with higher level of safety and lower level of geological hazard. The effects of gravity processes – rockfalls, screes, landslides, creeps, mudstone floods, increase with 1 degree the level of geological hazard. Erosive and subsurface erosive processes, variations of the level of shallow ground water, the possibility of sands liquefaction, the variability of soils capacity, and karst areas – increase with 0.5 to 1 degree the level of geological hazard. When there is accumulation of 2–3 or more exogenetic processes over one and the same areas, the geological hazard increases with 1–2 degrees.

The technogenetic intervention, which has created new relief forms, geotechnical and hydrogeological conditions in several locations in the valley, and also has changed the geodynamical conditions and destroyed the ecological balance, is considered as an influencing factor, which increases with 1–2 degrees the level of geological hazard in certain areas of the valley.

A four-degree scale of geological hazard is determined according to the aforementioned criteria, which includes the following levels – very high, high, average and low (Fig. 1).

Zoning of Sofia valley according to the level of geological hazard

The analysis of the geodynamic development (Berov, 2007) and the seismic activity allow us to specify some areas in the valley with very high or high level of geological hazard. A key factor in specifying these areas is the seismogenic factor and other factors along with it are the tectonic one – junctions of fault structures, and the geotechnical factor – structure and characteristics of the near-surface geological environment. From the geotechnical factor the most important are the presence of low-permeable layers, which cover layers of water-saturated sands that are able to leak during seismic impacts, or the presence of water level in immediate vicinity to the terrain surface. Other important factors related to the exodynamics in the valley are the level of alteration and the development of erosive processes. They are supplemented by the geometry of terrain surface and the static stability of slope areas. According to the so enumerated factors in the valley there are two areas with very high level of geological hazard, which are provisionally called Sredets and Novi Iskar area.

Sredets area includes the central parts (the historical city of Sredets) and the southern parts of modern Sofia. To the West the area includes the housing estates "Suhodol", "Filipovtsi" and "Obelya"; to the East – "Vrazhdebna", "Druzhba", "Darvenitsa" and "Mladost"; to the North – "Orlandovtsi", "Benkovski" and "Suhata reka"; to the South – "Knyazhevo", "Boyana", "Dragalevtsi", "Simeonovo", "Bistritsa" and "Gorublyane". The area is connected to an intensively fractioned, horst elevated socle with plenty of junctions of the subequatorial with the North-eastern faults. Highest seismic activities have the faults with North-North-eastern direction (Matova, 1970). There have been registered open fissures with symptoms of hydrothermal processes. This explains the elongated configuration of the isoseists towards North-Northeast direction when earthquakes were registered with epicentre in the valley. It can be anticipated that the seismogenic processes shall be most destructive in the junctions of the equatorial with the West-

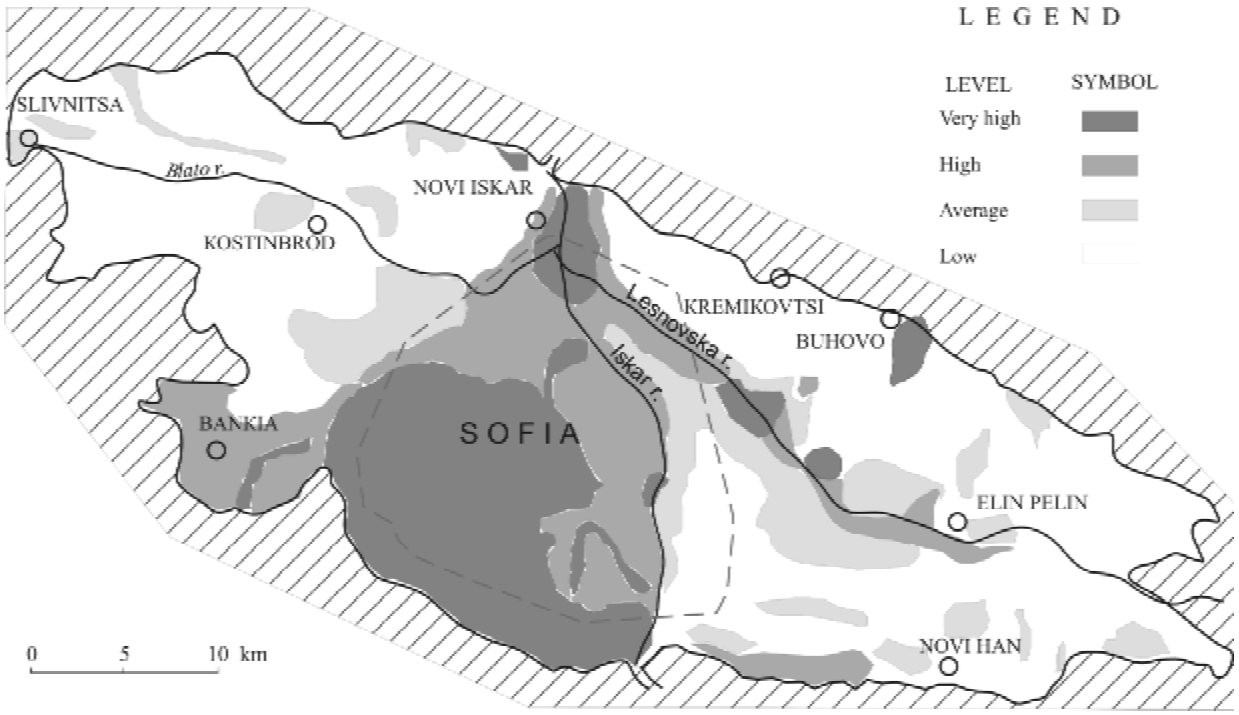

Fig. 1. Zoning of Sofia valley according to the level of geological hazard

ern – North-western and the Eastern – South-eastern systems, as well as in the connection points with the arc-shaped faults created during the structural elevation of Vitosha Plutonic rocks. The external circle of the arc-shaped systems of faults surrounds an area in which highest destructive consequences can be anticipated in case of shallow focused earthquakes, with the typical vertical movements of ground surface.

The hazard shall increase alongside these faults structures in the areas where there are water-saturated, susceptible to liquefaction, sand layers, as well as in the areas where the covering confining layers are thick up to 5 m. Such conditions are observed both in the Pliocene surface and in the deluvial-proluvial quaternery deposits. In close vicinity there is increased geological hazard in the areas on the Western slope of Iskar River between the housing estates of "Gara Iskar" and "Gorublyane" and on the terraces of rivers Suhodolska, Vladayska, Boyanska, Dragalevska, Perlovska and Darvenishka. The urbanized areas in Sofia that are located close to the main edge of Slatina terrace slope also represent zones with very high geological hazard. In this regard, very endangered are the residential and industrial buildings in "Poligona" h.e., where several buildings are located closely to the Slatina slope.

Novi Iskar area, with very high level of geological hazard, covers the areas where Blato and Lesnovska Rivers congregate into the bed of Iskar River. The valleys of these two main rivers from the Western and Eastern part of Sofia plain have been formed in the most sunk part of the valley, therefore the alluvium mantles consist of sands and clay and high concentration of decayed swamp vegetation. This seriously reduces their geotechnical parameters. At the same time here are located the groundwaters that are most close to the soil surface. The areas in those territories, which are covered by permanent swamps and temporary marshlands, are mostly very close to the buildings.

Similar geotechnical conditions are observed in the valleys of all rivers from Vitosha Mountain that run into Iskar River. Spots with sporadic distributions have been discovered, where the geotechnical conditions are extremely bad due to the swamp origin of the clay sediments that might leak in case of seismic impact. In Novi Iskar region the developed alluvium plain with many swamps and marshlands is located in the close proximity to or within Kremikovtsi-Negushevo fault zone. If there is a stronger seismic impact, the high water saturation of the plain will cause unpredictable distribution of secondary seismic deformations in the area of "Gnilyane" h.e. Especially since here the terraces of Iskar River react with hydraulic ruptures in case of earthquakes with epicentres outside Sofia seismic area. Such deformations in the intensively water-saturated plain shall cause serious damages and destructions on the buildings and local infrastructure from the secondary seismic effect.

One of the areas with high level of geological hazard terrains are affected by landslides and the river area with intense erosion and landslide activity. Almost all old and new landslides are controlled by

faults and the slow tectonic movements within them. As a result of the slow oscillatory movements in the faults, the action of the river erosion and the slow creep of the slopes become more intense. There have been discovered geological cycles when slope deposits caused by fault displacements and increased deep erosion are in a continuous state of gravitational instability and landslides start to develop. This cycle of the valley is definitely unknown and it can be only assumed that there is an interval of several hundred years. If the oscillatory movements and the cycle of active water exchange coincide, the areas in Sofia valley with high level of geological hazard shall move to the upper, very high level of hazard, and the areas with average level of hazard shall move to high level. In the areas with low level of hazard it can be expected that in certain regions geological phenomena shall occur, that are typical for the average and the high level of geological hazard. The section from Dragoman-Negushevo fault zone in Dragovishtitsa-Katina region, where the fault tectonics is very intensive, can be considered being endangered. In other places highest significance have the degree of water saturation of slope deposits and the inclinations of slopes. The strength parameters of the over-damped slope deposits are reducing and form an angle of a natural slope that is close to the inclination of the valleys at the foot of Vitosha mountain. In many places these slopes are close to the limit equilibrium, which can be easily transformed by technogenic factors into big landslides.

When separating regions with average and low level of geological hazard it must be noted that there are individual areas in which the effect from a certain exogenic process can become destructive after some time. This is a result of the impossibility to foresee where exactly this process shall occur, because of the accidental nature of the event that depends also on chance factors, the most important of which is the weather. Nevertheless, as a whole, these regions have lower geological hazard – average and low level, because of the nature of processes, more restricted expansion and the smaller probability for a future activation. There can be outlined zones endangered by potential development of landslides, rockfalls, processes of volumetric inconsistency, etc. The combination of more than two geological processes on one and the same areas increases the level of geological hazard in these areas.

The areas with average level of hazard are located mainly in the Eastern part of the valley, close to the settlements Elin Pelin and Ravno pole. Here the major role belongs to the sands with small and fine grains that are susceptible to liquefaction and correspond to the highest parts of the alluvium plain. There is a danger of leakage of water-saturated sands when making construction excavations for various purposes. Thixotropy can be made if there is deep dewatering and simultaneous disclosure of fine sand fractions. Terrain subsidence is also possible in case of drainage and dewatering. Subsidence with several centimetres of the near-surface clay level shall cause fissures on the houses, like the already registered in the region of Gorna Malina. Part of the areas with average level of geological hazard is also a big section of Western Sofia plain where are located mainly chernozem – smolnitza soils. The typical volumetric inconsistency of these soils remains a geotechnical factor which if not observed can lead to unpleasant consequences and expenditures for additional reinforcement of buildings. Sometimes the combination of deeper located Pliocene clays and thick layers of smolnitza soils above them is the reason for fissures on higher buildings at the territory of Sofia.

One of the areas with low level of geological hazard are some of the terrains occupied by gravel alluvial deposits and alluvial sediments close to Stara Planina Mts. edge of the valley, some of the terrains occupied by Pliocene sediments in the Western and the central part, part of the areas with Quaternary deposits in the Eastern part of the valley and the boundary areas where the geotechnical stratum is of rock and semi-rock type. The physical and mechanical parameters of the Pliocene and Quaternary stratum put them in the less favourable geotechnical groups of coherent and non-coherent sediments, but the level of ground water in these areas is established at greater depth and this contributes to their safety as construction foundation and smaller level of geological hazard. As a whole, in Sofia valley the areas with low level of geological hazard cannot completely avoid strong seismic effects. Nevertheless, no big secondary seismic processes and deformations shall develop in these areas, and the geotechnical conditions suggest more limited destructions and damages to the completed infrastructure.

Conclusions

The analysis of the destructive geological processes in Sofia valley brings to the outlining of series or problems, which solving shall help to limit the geological hazard. The problems that have to be solved refer to continuing and extending the scientific research, expanding and directing the analyses, organizing and carrying out preventive measures, informing and training the population in adequate actions in case of critical situation of geological nature (e.g. strong earthquake, activation of landslides, etc.).

In the scientific area the future researches shall be targeted more specifically to:

– Seismic hazard and the resulting potential risk for the highly populated and very urbanized territory of Sofia valley. Due to high concentration of people, industrial and power facilities, administrative, economic and cultural institutions at the territory of Sofia, the city represents an important production and communications centre of Bulgaria, and its protection from seismic impact is of national importance.

– Continuation and more detailed analyses of other destructive lithosphere processes and forecasting possible critical situations under extreme weather

conditions — abnormally strong and continuous precipitation, fast melting of very thick snow cover, continuous drought and use of the ground water from Sofia Neogene basin, etc. Because of the diversity of physical and geological processes it would be convenient to group them by level of impact and scope of distribution, as well as to plan properly their step-by-step analysis in time. The first place among the exogenic and technogenic processes and modifications of the geological environment shall be given to: gravitation phenomena – landslides, rockfalls, debris flows; erosive and subsurface erosive processes (piping); variation of the level of shallow ground waters and volumetric changes in the soils; tailings ponds, industrial waste depots, domestic waste dumps, and ballast dumps.

The possibilities to reduce the geological hazard at this stage are related to the outlining of areas that are potentially endangered by the impact of the above-mentioned destructive geological processes. This is the first stage with regard to the spatial aspect of forecasting. A logical continuation shall be marking the very hazardous areas in a larger scale and legal regulation of construction works within those areas.

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Резюме. Б. Беров – Зонално разделяне на Софийската котловина по степен на геоложка опасност. В настоящата статия се разглеждат основните критерии за оценка на сумарната геоложка опасност в Софийската котловина. Съчетанието и наслагването на различни по вид и сила на въздействие разрушителни геоложки процеси върху едни и същи площи от котловината налагат преценката и площната подялба по степени на засегнатост въз основа на няколко критерия, отчитащи както условията, така и развитието на самите процеси. Така към критериите за оценка на геоложката опасност се включват основните характеристики от геоложките, тектонските, морфоложките, инженерногеоложките и хидрогеоложките условия и фактори, имащи отношение за проявата на физикогеоложки процеси и от там за определяне степента на геоложката опасност. Като основни критерии за интегралната геоложка опасност се извеждат геолого-геоморфоложкият, литолого-инженерногеоложкият, хидрогеоложкият и развитието на физикогеоложките процеси. Ролята на тектонските движения – бавни и внезапни (земетресенията), пространствената конфигурация на разломите, възможните огнищни зони и др. се отчитат с приоритет при разглеждането на самите процеси. При геолого-геоморфоложкия критерий основно отношение към геоложката опасност имат съществуващите наклони на терена, вертикалната и хоризонтална разчлененост на релефа и неговата литология. От 0–4° се приема, че наклонът е благоприятен, носител е на сигурност и ниска геоложка опасност. Наклони на терена от 4–8° са средно благоприятни, а над 8° наклоните са неблагоприятни. Релефната разчлененост, отчитаща дължините на линейните форми в дадена площ (m/km^2), е един от основните параметри при районирането на свлачищната опасност. Литолого-инженерногеоложкият критерий поделя скалните разновидности според техния генезис и инженерногеоложки свойства на 4 типа. Той включва и преценката за устойчивост на земната основа, която е най-благаприятна при скалния тип инженерногеоложки разновидности и съответно най-неблагоприятна при несвързаните седименти. Четирите инженерногеоложки типа скали – скални, полускални, свързани и несвързани, обуславят развитието на различни по характер и интензивност екзогенни геоложки процеси, които сами по себе си създават различни степени на геоложка опасност. Основна тежест при оценката на интегралната геоложка опасност имат проявите и съчетанията на физикогеоложките процеси. Отчитайки разнообразието от процеси, засягащи територията на Софийската котловина, приоритет при тяхното разглеждане заемат ендогенните процеси. Цялата котловина по степен на сеизмична опасност е обособена като част от България с възможност за проява на земетресения от IX степен по скалата MSK-64. Това налага при отделянето на райони по степен на геоложка опасност в Софийската котловина отчитането на зависимостта на екзогенните от ендогенните геоложки процеси и прогнозирането на поведението на земната среда при силни сеизмични въздействия. От друга страна разпространението на екзогенни процеси и установените между тях зависимости се включват като допълнителен критерий, отнасящ една или друга територия от котловината към район с по-ниска или по-висока степен на геоложка опасност. Според избрани-

те критерии се определя четиристепенна скала на геоложка опасност, включваща степените много висока, висока, средна и ниска. Анализът на геодинамичното развите и на сеизмичната активност позволяват да се очертаят някои райони в котловината като застрашени с много висока и висока степен на геоложка опасност. Водещ фактор при отделянето на тези райони е сеизмогенният, а спрегнати с него са тектонският фактор – възлите на разломните структури и инженерногеоложкият – структурата и свойствата на приповърхностната геоложка среда. При инженерногеоложкия фактор от важно значение са наличието на слабопроницаеми слоеве, покриващи слоеве от водонаситени, способни да протичат при сеизмични въздействия пясъци или непосредствено близко разположено водно ниво до земната повърхност. Други спрегнати фактори от екзодинамиката в котловината са степента на изветряне и развитието на ерозионните процеси. Към тях се добавят геометрията на теренната повърхност и статичният стабилитет на склоновите участъци. Според така изброените фактори в котловината се очертават два района с много висока степен на геоложка опасност, условно наречени Средецки и Новиискърски. При отделянето на районите със средна и ниска степен на геоложка опасност трябва да се подчертае, че съществуват отделни участъци, в които проявата на даден екзогенен процес може след време да се окаже разрушителна. Последното произтича от невъзможността да се предвиди конкретното местопроявление на дадения процес, поради случайния характер на събитието, зависещо също от случайни фактори, най-важни от които са метеорологическите.