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# Building Civil Protection Capacity to Mitigate Geohazards in the Caucasus: A Regional Approach

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# *Abstract volume*

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**INFO AND CONTACTS**

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# Complexity of seismicity and fault zone strain under large dam: The case of Enguri high arc dam, Caucasus

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**Abstract**

The Enguri arch dam, still one of the highest arch dam in operation in the world, was built in the canyon of the Enguri river (West Georgia) in the 1970s. It is located in a zone of high seismicity (MSK intensity IX) and close to the Ingirishi active fault. The high seismic and geodynamical activities together with the large number of people living downstream of the dam made the Enguri dam a potential source of a major catastrophe in Georgia. Thus, the Enguri Dam with its 1 billion cubic meters water reservoir should be under permanent monitoring. At the same time this it is an amazing natural laboratory, where one can investigate both tectonic and geotechnical strains/processes and their response to the lake load-unload impact, i.e. the reaction to a controllable loading of Earth crust. This is an important scientific issue, connected with a problem of Reservoir Induces Earthquakes and other environmental geotechnical problems, related to safety of large dam.

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# Cost-effective Multi-sensor Automatic Telemetric Monitoring/Early Warning Systems for Mass-Movements

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**Abstract**

A multitude of dangerous sources, need of covering the source area by many sensors, expensiveness of supporting personnel for a long period at potential mass-movement areas, growing number of exposed vulnerable objects and limited resources of developing countries, which are most prone to mentioned hazards call for developing cost-effective and the same time accurate automatic monitoring/early warning telemetric systems. We developed the prototype of original cost-effective multi-sensor telemetric monitoring/early warning system with autonomous power source for forecasting initiation of landslide/mudflow and transfer of different level alarms to 15-20 km by radio signals or to large distance – by Internet or Mobile nets. Humidity, tilt and acceleration sensors using modern high-tech elements (modified MEMS sensors and processing-diagnostic-remote transmitting ARDUINO blocks) are manufactured. This warrants cost-effectiveness of the system (the price of hardware including rod-post is around 1300 $). The performance of our sensors is compared with standard devices. The system is tested in laboratory conditions for defining optimal sensitivity, frequency and amplitude ranges. For revealing anomalous changes in humidity, tilt and acceleration the special methodology, based on measurements of differential signals on humidity, tilt and acceleration relative to the same signals at reference station. The criteria for releasing different alarm signals (quiet, attention, warning, alarm) on the basis of information on differential humidity, tilt and acceleration are elaborated. October 2018, on the Gldani landslide (Tbilisi, Georgia) is installed and tested the EWS system based on measurements of differential signals on humidity, tilt and acceleration. The EWS shows significant anomalies during landslide and after mass-movement event of 25 January 2019. The map of high risk areas/objects is compiled for Georgia, where locations of dams, pipelines, roads, high density population are superimposed on the landslide hazard susceptibility map. This allows identification of areas, where the EWS systems is recommended to install first of all. The claim for the patent is registered by the Intellectual Property Agency of Georgia.

# Using seismic tomography to image the architecture of magma reservoirs: case studies from key end-member volcanic systems

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**Abstract**

The depth and size of a magma chamber is essential information used by Earth scientists to model volcanic systems and in turn support volcano monitoring and eruption forecasting. One way to learn about the plumbing system that extends below volcanoes is by producing three-dimensional images of the subsurface structure using the seismic waves generated by earthquakes. By analyzing the seismograms of these earthquakes, scientists can map the seismic wave velocities of the Earth's interior and gain information on the rock's properties. Tomography can help track spatial and temporal changes in the seismic structure and provide evidence of molten rock reservoirs and conduit pathways to the surface. Representing the basaltic volcano end-member, we targeted Makushin Volcano located in the eastern portion of the Aleutian arc in Alaska. Makushin is among the most active volcanoes in the United States and has been classified as high threat based on its eruptive history and proximity to the City of Unalaska and international air routes. In 2015, five individual seismic stations and three mini seismic arrays of 15 stations each were deployed on Unalaska island to supplement the Alaska Volcano Observatory permanent seismic network. Taking advantage of the increased network azimuthal coverage and the subsequent increased earthquake detection capability, we develop high-resolution seismic images of the velocity structure beneath the volcano. Body-wave tomography results show a complex structure: regions of low seismic velocity are found east of the caldera at approximately 3-6 km depth, indicating this region as a possible source of magma. For caldera-like system, we investigated the Laguna del Maule (LdM) volcanic field in the Chilean Andes. Recent observations at LdM by interferometric synthetic aperture radar and global positioning system satellite geodesy have revealed inflation at rates exceeding 20 cm/yr since 2007, capturing an ongoing period of growth of a potentially large upper crustal magma reservoir. We utilize multiple types of surface wave observations, involving ambient noise and regional earthquake coda, to tomographically constrain the location and geometry of low velocity domains beneath LdM. Here we present a three-dimensional shear-wave velocity model that delineates a shallow magma reservoir (~2 to 8 km below surface) of significant volume (~450 $km^3$) and average melt fraction (~5%) that is compatible with the gravity and geodetic observations, within uncertainties, as well as with petrologic observations consistent with rhyolitic eruptions originating via extraction of melt from relatively cool crystalline mush.

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# Influence of seismotectonic processes on slope stability near Enguri dam (Caucasus, Republic of Georgia)

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**Abstract**

The western mountain slope that directly faces the Enguri water reservoir (southwestern Caucasus, Republic of Georgia), is characterized by Quaternary landslide deposits and active deformations that affect a subaerial area up to about 1.2 $km^2$. The head scarp of this deformed slope involves also the Jvari–Khaishi–Mestia main road, with offsets of man-made features that indicate slip rates of 2–9 cm/yr. In order to improve the understanding of the deformation processes along this slope, we collected field data and carried out numerical analyses considering also the contribution of regional active tectonics and local geological, geomorphological and structural conditions. In this perspective, seismological data and the local Peak Ground Acceleration value have also been evaluated. Based on these data, static, pseudostatic and Newmark analyses suggest different unstable rock volumes based on the environmental conditions. An important effect of variation of the water table is shown, as well as the possible destabilization of the slope following seismic shaking, compatible with the expected local Peak Ground Acceleration. The possible causes of inception in the past of this slope deformations are also discussed, comprising seismic triggering, mountain rapid uplift, and river erosion.

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# Emergencies and risk management system in Georgia

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**Abstract**

Georgian diverse climate, the geological structure of the relief and high energetical potential, high seismic activity and abundant rainfall creates conditions for emergencies, such as earthquakes, landslides, mudflows, snowballs, floods, storms, droughts and more. Besides, the geopolitical location of the country and the current state of industrial processes causing a high risk of malignant catastrophes. In Georgia, the obligation to undertake possible disaster risk and risk reduction measures at the national and local level are defined in the “law on national defense”. According to the law, the national security system is created and functioning to ensure emergency management. The system incorporates the executive bodies of Georgia, legal entities of public law, local self-government bodies and organizations working on topics of civil security. The system aims at preventing emergencies and reacting to it with reparational activities. The system is also providing protection and safety of the population, ensuring a safe and stable operation of critical infrastructure facilities. The main guideline document for the Emergency Management System of Georgia is the National Security Plan that regulates the activities of system subjects in the field of civil security. The plan defines the measures and resources of the main and subsidiary subjects responsible for the protection of the population and the territories, their volume, the implementation procedure and its fulfillment. The National Plan is based on the emergency management and risk management plans of national system actors. Under the National Plan, provision of emergencies, mitigation, reaction and rehabilitation is carried out by enacting 17 functions of emergency assistance. The coordination of each of the special aid functions is carried out by the relevant Ministry, with the participation of supporting agencies, organizations and municipalities. The essence of risk, the determination of its methodology and all the basic matrix requirements for this purpose are defined: threat (its probability and trength), impact (economic, anthropogenic, ecological and political), vulnerability (physical and social) and endurance.

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# 3D reconstruction for onshore and offshore environment: challenges and criticisms

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**Abstract**

Over the past decades the importance of geohazard assessment has rapidly increased, driven by huge development of structures for the exploitation of natural resources (hydropower plants, nuclear power plants, mining areas and oil and gas infrastructures), by the needing of expansion for the communication net (railways, ports, airports and highways) and by the grow up of cities. At the same time, the fast proliferation of new satellite, aerial, terrestrial and marine remote sensing techniques has undoubtedly greatly improved our knowledge of geomorphic features that can be regarded as geohazard indicators. Such techniques as Radar, LiDAR, Terrestrial Laser Scanner (TLS), photogrammetry and Multibeam Echosounder System (MBES) performed on both manned and unmanned vehicles, in terrestrial and marine environments, provided new technological and scientific opportunities to create high-resolution 3D point clouds and 3D model. Conventional photogrammetry is being replaced by Structure-from-Motion (SfM) photogrammetry, introduced from computer-vision disciplines, which allow much versatility, high resolution, low-cost equipment and create very high-resolution models in problematic environments (related to extreme conditions, hard to reach, dangerous for standard equipment, etc.). The major limiting factors in this methodology are related to a correct GCPs (ground control points) network and considerable machine-processing time. In particular, GCPs network could be hard to setup due to site logistics, environment condition and available time. This is the case of the marine environment, where the areas are too shallow for a MBES or where the environment is too deep, where collecting data with underwater vehicles take a long time and there is no possibility to set up GCPs. In this work we face on some problematic situation onshore and offshore, using unmanned platform or human-based vehicles, coupling SfM 3D points cloud with Digital Terrain Models provided by traditional equipment, in order to create high-resolution models (with the best accuracy allowed by the available equipment) for detailed mapping and interpretation of geomorphic features thus represent the primary, necessary step for the identification and characterization of geohazards.

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# Recent tectonic stress field and deformations in the Rioni basin region, Georgia

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**Abstract**

A multidisciplinary analysis and detailed understanding of ongoing deformation processes in tectonically active areas is crucial for the evaluation of seismic hazard. Our case study is the Rioni basin region, at the southwestern front of the Greater Caucasus, where locally folded and uplifted marine and continental deposits of Cretaceous-Neogene age are located. The collection of 248 microtectonic data at brittle and ductile structures and the calculation of related paleostress tensors revealed a very complex Eocene-to-Quaternary tectonic evolution, consisting of four main phases. The first two phases were characterized by prevalent transcurrent faulting and subordinate reverse motions, with a greatest principal stress $\sigma_1$ that was firstly perpendicular to and successively parallel to the mountain belt. Afterwards, asymmetrical folds with vergence to the south and trending NW-SE to E-W developed, with a sinuous shape in plan view to the western part of the basin and a left-stepping en-échelon geometry to the east.

In this study, we focus on the south-vergent Tsaishi anticline, located at the southwestern tip of the Rioni basin, through the development of a 3D model by combination of geomorphological observations, field geological-structural data and seismic reflection sections. The fold growth, according to field observations such as the presence of upwarped late Quaternary river deposits, is still ongoing. Our 3D model shows that the fold backlimb is affected by three main backthrusts, whereas seismic sections reveal that at the foot of the forelimb a main north-dipping thrust comes very close to the surface, in correspondence of a 13-km-long fault scarp (or fold scarp) revealed by our field surveys. The scarp trace is associated with the epicenter of the strongest earthquake of the area to date: the MS 6.0 Tsaishi earthquake that struck in 1614 CE. Our results show that the overall structure can be classified as an active fault-propagation fold. The recognition of its very recent growing associated with a major, underlying active fault, represents also a major contribution to the seismic hazard assessment of this populated area.

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# Models of seismic source zones (SSZs) and their parameterization for Georgia and the surrounding region

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**Abstract**

The development of seismic source zones models is one of the first steps in the implementation of PSHA. Determination of these models include the delineation of seismic source zones (SSZs) and their parametrization. Seismic source zones models are the basic and most important inputs required for the PSHA, because on them depends reliability of the final results of seismic hazard assessment. Should be noted that in practical applications, when not exist clear procedures for constructing SSZs, this leads to large variations in the computed hazard and no believable results. Therefore, in the absence of formal and consistent procedures for developing and parameterizing SSZs the issue of their delineation is often a controversial one in the practise of PSHA Caucasus is a region where active faults are well defined and parameterized, and seismicity is relatively well documented, the source zones are fairly obvious. Therefore, in this study is used, developed by us a method of SSZ delineation, which includes formal and consistent procedures. The procedure for constructing SSZs is based on the delineation along the active fault the area of a certain width. In this case, the width of the SSZ is crucial in the creating a model SSZs of study region. In his turn the width SSZs dependent on the data of fault width, of slope of the fault plane, of thickness of the seismically active layer, of geometrical sizes the source of the maximum possible earthquake. SSZs asymmetry relatively the axial line of the sloping fault is a characteristic feature of these constructing. For each SSZ must be selected source model expressed by a set of parameters that will determine the basic input for the seismic hazard assessment. For each SSZ in the source model determined the following parameters: the maximum magnitude (Mmax); the magnitude-frequency parameters (b and a) of the seismicity, the parameters of depth (h) distribution. Mmax assessments implemented on the base of compilation of the multiple methods. In Georgia, for hazard assessments were used five methods to estimate Mmax within individual SSZ. Of these, three of the methods are seismological and two is geological. Calculations b-values were made for the 14 generalized tectonic units (GTUs), in which seismic statistics were complete enough and a-values was determined for each SSZ. A study of the distribution of earthquake depth showed seismicity in this region is shallow, and this conclusion is particularly important with respect to the choice of ground-motion models to be used in the hazard calculations.

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# National Seismic Hazard Model for Georgia

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**Abstract**

Earthquake Model of the Middle East (EMME) project has paved the road to a state of the art seismic hazard assessment in the region, with Georgia being one of the key participants.

After EMME project, it was decided to initiate the revision of the national seismic hazard model of Georgia, in light of the new findings of the EMME project, new harmonized datasets, fully aligned with the probabilistic framework promoted by Global Earthquake Model (GEM).

In this contribution we are presenting the main elements of the newly developed seismic hazard model of Georgia. The starting point is the updating of the regionally harmonized datasets (i.e. earthquake catalogues, active faults) with focus on data that become available within the recent years. Hence, the earthquake catalog compiled within the EMME project (Giardini et al 2018) were updated up to 2018 for the Caucasus area. Unification of the instrumental earthquake catalog for a uniform moment magnitude (Mw) was done using conversionequations between different magnitude scales. We began with the conversion equations obtained by Zare at al. (2014). However, these equations provide a significant bias towards small magnitudes. Various equations valid in other regions were considered, and for stability in this particular small range of magnitudes (3.5 to 5.0) the conversion equations by Lolliet et al (2016) gave reliable results. For declustering the earthquake catalogues a window-based procedure was used. Completeness of the earthquake catalogue within the sub-regions was also investigated.

We investigated the influence of declustering algorithm as well as the completeness intervals to the regional b (slope of Gutenberg-Richter curve) variability. The estimates of the b-value are in relative agreement with the observed seismicity. However, there are regions where the catalogue is limited in time and space, hence affecting the overall forecast of the seismic activity.

The seismogenic source model was built upon various ingredients including the earthquake catalogue, the location of active faults, the main geological structures and the active tectonic information. The seismogenic source model consists of two models: an area source model and an active fault combined with background seismicity. Earthquake catalogue were used to characterize the earthquake rate forecast on the area sources, while the slip-rates were converted to seismic productivity of active faults. Obtained results of b and a value are in very good agreements with observed seismicity. Overall, the b-values of West Greater Caucasus are lower than those for East Greater Caucasus, in number of large earthquake in West Greater Caucasus are higher the in East Greater Caucasus, however, the overall seismic activity in the East Greater Caucasus are higher than in West Greater Caucasus. For regions of low seismicity, or sources with scarce number of earthquakes, the earthquake productivity was estimated at a higher level on tectonically driven macro-zones.

The area source model and the active faults are spatially correlated, as the active faults were used as basis to delineate the former. The asymmetry of area sources with respect to the axial line of the inclined fault is a characteristic feature of this construction. All this information based on data of active faults, fault plane solution, seismicity distribution and macroseismic intensity data. Area sources were characterized by the different values of the maximum magnitude estimated by different techniques. The seismogenic sources of Caucasus region were categorized in three seismo-tectonic classes (i.e. shallow crust, volcanic sources and deep seismicity). Given this classification, four ground motion models were selected and used to quantify the inherent uncertainties of ground motion. Unfortunately, the lack of strong motion

data does not allow deriving new ground motion models. We follow the recommendations of the EMME project, where the center, body and range of ground motion distribution is described by a global (i.e.Cauzzi et al 2014), two pan-European (Akkar et al 2014, Kotha et al 2016) and one NGA-West (Chiou and Youngs 2014) models for shallow crust For volcanic sources the models of Faccioli et al.(2010) and Bradley (2013)were used while for deep seismicity sources Youngs et al.(1997), Abrahamson et al.(2015 –Slab) and Atkinson and Boore(2003) models were used.

Finally, the probabilistic seismic hazard was estimated for the entire region using OpenQuake engine (Pagani et al 2014) and the results consist of a full range of results, including mean and quantiles of hazard maps, hazard curves and hazard spectra.

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# GPS observations of slope deformations with the use of reference system along the road Zugdidi - Mestia

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**Abstract**

The purpose of this research was to evaluate of geohazard risk in the Enguri Hydroelectric Power Station, located on the Enguri River on the way to Upper Svaneti. Several small landslides occurred on the slopes near the reservoir and on one side of the lake, there is a huge landslide "Khoko", the fall of which in the reservoir will cause an emergency situation. However, despite the fact that seismicity can increase tilt instability and cause landslides, no dynamic analyzes of the stability of the slopes surrounding the reservoir have been carried out. The main methods for measuring soil settlements and deformations of engineering structures are geodesic. They allow us to determine not only the relative displacements of points, but also their absolute magnitudes due to practically fixed marks of the geodetic station. Observations of the deformations of landslides and potentially unstable arrays are carried out with the help of benchmarks, plan and high-altitude geodesic signs, the arrangement of which has been previously established by visual observations and investigations. Control benchmarks are made of metal, installed at a depth of 1 meter in the ground. At the beginning of the work, an observation geodetic station (network of benchmarks) was established along the Mestia-Zugditi road. The length of this station is 1.8 km. On the road Zugdidi-Mestia, 20 control points were established to measure the dynamics of its movement due to the danger it poses to the Jvari reservoir and Enguri dam. The landslide body length is 38 km. With the help of high-precision geodetic instruments (total station Leica TS11 and GPS geodetic equipment) two series of instrumental measurements of benchmarks were carried out in in years 2016 -2018. The average velocity of displacements over the entire period 0,12 mm/day. The average displacement 81 mm. The minimum velocity 0 mm/day, the maximum 0,25 mm/day. Our research shows that this area is in equilibrium stage of motion and the characterized a constant rate of displacement. On the site of the landslide of Khoko movements not dangerous, the average speed of movements is 0,12 mm/day. Critical rates of displacement and deformation were not detected during the entire period of work on the site of the Khoko landslide.
*Recommendations*: Continue observation at the current observation station. Periodicity of observations once a year. In case of detection of critical deformation rates >1mm/day), it is necessary to increase the periodicity of observations and modernize (add benchmarks on the slope) the observing station in areas of increased deformation of the massif.

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# The role of regional model EMME - from data sets to hazard estimates

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**Abstract**

The Middle East and Caucasus regions have a long history of destructive earthquakes, and seismic risk can severely affect the society, as shown by the tragic events of Spitak (Armenia, 1988), Izmit (Turkey, 1999), Bam (Iran, 2003), Kashmir (Pakistan, 2005), Van (Turkey, 2011) and Hindu Kush (Afghanistan, 2015). Minimization of the loss of life, property damage, and social and economic disruption due to earthquakes depends on reliable estimates of earthquake related hazards. The collaborative project Earthquake Model of the Middle East (EMME, 2010–2015) brought together scientists and engineers from the leading research institutions in the region and delivered state-of-the-art seismic hazard assessment covering Afghanistan, Armenia, Azerbaijan, Cyprus, Georgia, Iran, Iraq, Jordan, Lebanon, Palestine, Pakistan, Syria and Turkey. The EMME project generated homogeneous datasets that included seismotectonic regionalization, historical and instrumental earthquake catalogues (Zare et al. 2014); seismically active faults (Gülen et al. 2014); models of deep seismicity in Hindu Kush (Pakistan) and subduction zones (e.g. Hellenic Subduction Arc, Cyprian Arc, Makran, Iran). Inherent uncertainties of quality and accuracy of earthquake sources were incorporated by modelling alternative seismogenic source models (Danciu et al. 2017). Regional ground motion data were extensively studied (Akkar et al. 2014) and data driven techniques combined with sensitivity analyses were used when building the ground motion model (Danciu et al. 2016). A probabilistic framework was used to assess the seismic aiming to capture the range of epistemic uncertainties for model components and hazard results. The EMME seismic hazard results described in detail by Şeşetyan et al. (2018) provided an overview of the potential shaking associated with future earthquakes in the Middle East. Since their release, the datasets, models and results of the seismic hazard related components of the project have been extensively used in various studies, especially in national models of the participating countries. One of the main objectives of the project was the homogenization of the datasets and resulting hazard models across national boundaries, which was achieved through extensive collaboration of the contributing researchers from the different countries. This key characteristic has paved the road for the use of the models in several hazard studies especially where data from different countries were needed. In this paper we focus on the data and model harmonization efforts throughout the region, challenges encountered, specific hazard results as well as examples of use of the models in various other studies.

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# Assessing thrust fault geohazards in contractional mountain belts

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**Abstract**

Thrust faulting is likely to be the dominant mode of tectonic strain release in contractional mountain belts such as the Caucasus, yet the geological signature of these shallowly dipping structures is notoriously hard to recognise, hampering mitigation efforts. This problem is exemplified by the 1991 $M_w$ 7.0 Racha earthquake, the strongest recorded in Georgia but without the clear ground rupturing expected from an earthquake of this size. Other examples include the 1952 $M_w$ 7.3 Kern County earthquake and the 1994 $M_w$ 6.7 Northridge earthquake, respectively north and south of the Transverse Ranges in California. However, such blind thrusts frequently betray themselves by generating actively growing folds, particularly where they propagate out from mountain belts into adjacent foreland regions. Analysis and Optically Stimulated Luminesence dating of terrace gravels deformed and uplifted some 120 metres within the Tsaishi anticline south of the Caucasus indicates an uplift rate of 2.1 – 4.6 mm $a^{-1}$, and a slip rate of 4.3 – 9.2 mm $a^{-1}$ on the underlying thrust, assuming a 30 deg dip. This rate is comparable with structurally similar folds elsewhere; the extensively-studied Wheeler Ridge anticline in California, for example, has an estimated uplift rate of ~3 mm $a^{-1}$. Also comparable is the slip rate of 8.1 – 17.7 mm $a^{-1}$ on the foreland-propagating Chelungpu thrust activated during the 1999 Mw 7.6 Chi Chi earthquake in Taiwan.

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# Non-Ergodic Ground-Motion Models for Crustal Earthquakes in Georgia

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**Abstract**

Traditionally, ground-motions are developed for broad tectonic categories: active crustal, stable continental, and subduction zones. Within each tectonic category, the ground motion is assumed to follow the same scaling with magnitude, distance, and site condition (the ergodic assumption). Evaluations of the larger ground-motion data sets now available have shown that the aleatory variability of the ground motion from earthquakes in a small region recorded at a single site is much smaller than the aleatory variability of global models based on the ergodic assumption. This led to the development of non-ergodic ground-motion prediction equations (GMPEs) which have spatially varying coefficients (Landwehr et al, 2016). The non-ergodic GMPEs are based on the variance and correlation lengths of the GMPE coefficients (hyperparameters for a Gaussian process).

Although Georgia is an active tectonic region, the currently available ground-motion data set for Georgia sparse with less than 100 recordings. There is a common belief that non-ergodic GMPEs are only useful in regions with large data sets; however, non-ergodic approach should be used in both regions with large amounts of data and in regions with sparse data. The lack of data does not imply that the ground motion in a region is consistent with an ergodic model; instead, lack of data implies large epistemic uncertainty in the non-ergodic terms. The available ground-motion data from Georgia is not sufficient to constrain the hyperparameters for the non-ergodic terms, but using the hyperparameters from California, we use the available ground-motion data from Georgia to develop a non-ergodic GMPE for Georgia. In the regions of Georgia with some ground-motion data (e.g. E Rache aftershock region), the uncertainty will be reduced compared to regions in Georgia without any data. In regions with no data, the mean non-ergodic hazard is the same as the mean ergodic hazard, but the epistemic fractiles are much wider than implied by ergodic GMPEs.

The advantage of using a non-ergodic GMPE for regions with sparse data, such as Georgia, is that it can be used to quantify the actual epistemic uncertainties in seismic hazard and allows this uncertainty to be considered when making engineering judgments about adequate seismic safety. It also sets up a framework to reduce the epistemic uncertainty in the non-ergodic coefficients and the resulting hazard, as new ground-motion data is collected for the region. Finally, it quantifies the benefits of installing additional seismic stations in terms of reduction of uncertainty of seismic hazard.

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# Geological hazard (Landslide, Debris/mudflow, rockfall et. al) assessment methodology in Georgia

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**Abstract**

Geological Hazards (Landslides, debrisflows, rockfall, rock avalanche et. al) have always caused and still creates a threat to the important part of the population, also causes damage/destroy of existing infrastructure facilities.

In the last decades, protection of the population from Geological hazards and safe operation of infrastructure objects became significant social-economic and geoecological problem for the most countries in the word. These problems are more in countries with the complicated geology and relief. With the above mentioned causes hazards are also triggered by global climate change, earthquakes, wide-scale human activities. Negative impacts caused by disasters including human losses gains increasingly irreversible character. Georgia belongs to the most complicated region among the world's mountainous countries with development scale of geological hazards (landslide, debrisflow/mudflow, rockfall, rock-avalanche etc.), recurrence of these processes, and with negative impacts to the agricultural lands and infrastructural objects.

Thousands of settlements, buildings, agricultural lands, roads, oil and gas pipelines, high voltage power transmission towers and etc. are periodically affected by geological disaster.

Hazard assessment is an important step towards geological hazard and risk management. Several methods are used for Geological Hazard Assessment: Qualitative, Quantitave, Spatial Multi Criteria decision making et al.

In Georgia different researches were conducted for the purpose of Geological Hazard Assessment. Bellow will be disscused different approaches for geological hazard assessment in Georgia.

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# Analysis of Recorded Hydrometeorological Hazardous Events and Their Negative Consequences over the Territory of Georgia

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**Abstract**

Global Climate Change has significantly increased hydrometeorological hazards during last period. To overcome and reduce the expected results of disasters, many countries started prevention measurements to decrease damages and a loss.

For Georgia, which is developing in hydrometeorology the forecast and early warning systems is the main priority because of complicated topography, high density of population and other factors.

Georgia lacks meteorological and hydrological stations. Nowadays there are only 55 hydrological and 95 meteorological facilities. Statistical data show that the number of disasters is growing annually and Government has to mitigate damages and consequences.

We think that the Governmental structures as a first priority have to carry out creation of united spatial database, risk zoning maps, improvement of hydrometeorological observation net and installation of weather radars with the full country coverage. Money spent for all this measures will bring profit for Georgia finally.

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# Geohazard assessment of the southern slope of Greater Caucasus (Azerbaijan) based on the earthquake scenarios and mud volcanism

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**Abstract**

The study area is situated in the complex zone from the viewpoint of geodynamics and tectonics, included in the Alpine folded system. The seismic activity in the area is characterized by uneven seismicity with periodic format. This region hosts a large number of mud volcanoes on land which are linked to the ongoing tectonics for what concerns fault activity. Here we present a new approach that analyzes the possible effects of four potential earthquakes on the studied region. Topics of interest include moment magnitude, seismic energy, b-value, simulated earthquake scenario-based Peak Ground Acceleration (PGA), site effects, rock site characterization and intensity. Earthquake scenarios of various distances were plotted, peak ground acceleration were assessed at the maximum magnitude, series of peak ground acceleration models were simulated at respective MSK-64 intensity, and amplification factor distribution map was also plotted. This geohazard assessment study is a large scale seismicity analysis for seismic source zone clarification and estimation of maximum earthquake magnitude. The earthquake catalogue from the Republican Center of Seismological Survey (RCSS) at Azerbaijan National Academy of Sciences (ANAS) was used. The intensity distribution classifies regions in the highest hazard level with intensity value of 7 and above in the western and also in the eastern part of the area. The b-value result shows that a decrease is observed in the western part of the region and in some areas of the northern part which is an indication of higher stress in those areas. The very high PGA is scattered also in the western and eastern parts. It may have significant impact on engineering design, especially for critical facilities in those areas. Independently from the epicenter of scenario earthquakes, the low and very low PGA is scattered in the central part of the study area.

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# Flood/Flash-Flood Hazard Assessment Using Hydrological and Hydraulic Modelling in Kakheti Region

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**Abstract**

Georgia is looking for enhanced cooperation with the European Union. In the European Union, one of the most important pieces of environmental legislation is the Floods Directive. For the EU Flood Directive implementation, it is important to create flood hazard/risk maps and develop flood risk management plans. Hydrological and hydraulic models are a major tool for mitigating the effects of flooding. They provide predictions of flood flows, extent and depth that are used in the development of spatially accurate hazard maps. These allow the assessment of risk to life and property in the floodplain, and the prioritisation of either the maintenance of existing flood defences or the construction of new ones.

A combined hydrological and hydraulic models are presented for flood hazard assessment in the Alazani River basin. The hydrologic and hydraulic modelling software HEC-HMS and MIKE 11 in combination with GIS were utilized in flood modelling and inundation mapping. Flood inundation maps with 10, 100, 500-yr return periods were generated for the five northern Alazani tributaries, namely, Avaniskhevi, Chelti, Intsoba, Lopota, Shromiskhevi.

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# Monitoring deformation at the Khoko landslide using state-of-the-art extensometers

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**Abstract**

In the framework of NATO Project N. G4934, focused on the Enguri Dam area, efforts have been made to investigate the Khoko landslide, which is presently affecting the left hand side of the Enguri Valley, about 2.3 km north of the Dam. This deep-seated landslide stretches 600 m in a N-S and about 1.6-1.7 km along an E-W direction. The lower boundary of the unstable mass extends as far downward as the bottom of the Enguri Valley, about 300 m a.s.l. The fluctuations in the lake's level, ranging from 520 to 430 m a.s.l., affect the upper portion of the landslide, whereas its toe lies underwater. The upper portion of the landslide coincides with the watershed between the Enguri Valley and the Magana Valley, 800 m a.s.l. Another major landslide overlooks the Magana Valley and produces deformation in the road. The Khoko Landslide is cut, across along a 2-km-long stretch, by the Zugdidi-Jvari-Mestia-Lasdili road, at about 700 m a.s.l. There are clues to active displacements, observed along two road stretches, about 150-200 m long, and represented by deformation and differential failure of the road surface, opening of holes, deformation of walls and road drainage systems, etc. Locally, the asphalt paving on the road surface is periodically replaced every 2-5 years.

Two locations (trench 1 and trench 2) were chosen for the installation of extensiometers, designed to monitor the deformation of the road and indirectly, the local movements of landslide. Measurements at extensimeter located in trench 1 have been going on since October 2016, whereas measurements within trench n. 2 began in May 2017.

The data, recorded continuously until January 2019, can be graphically compared with lake level variations and rainfall amounts. Results show that deformation variations across the landslide are poorly consistent with rainfall, whereas they seem to be related to reservoir filling and drawdown operations. In particular, when the lake's level increases at a high rate, the higher permeability of the deposits of the lower slope, mostly constituted by ancient landslide deposits and slope debris, may induce a major acceleration in slope motion. Even during drawdown operations (lake's level decreases), the low permeability of the upper slope may contribute to slightly increasing movements in the onshore part of the slope.

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# NATO and Earth Scientists: An ongoing collaboration aimed at tackling geohazards and related risks

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**Abstract**

The North Atlantic Treaty Organization (NATO) has been funding several international Earth Science research projects in Central and Eastern Asia as well as the Caucasus over the last 16 years. The projects are aimed at improving the security of people and the safety of infrastructures, and fostering peaceful scientific collaboration between scientists from NATO and non-NATO countries. Earth Science can contribute to improving scientific collaboration also among countries that are politically in tension, and it can also play a key role in preventing situations that may escalate into conflicts. Four different NATO-funded research projects, carried out over the last 16 years, have been aimed at tackling, through an interdisciplinary approach, different geohazards affecting important infrastructure and lifelines in Asia and the Caucasus. These research efforts have focused on: i) volcanic and seismic hazards in the Kamchatka Peninsula, Eastern Asia; ii) geo-related threats to the following, major infrastructures: the Caspian oil and gas pipelines in the Republic of Georgia, the Toktogul water reservoir in Kyrgyzstan and the Enguri hydropower plant, located partly in the Republic of Georgia and partly in the disputed territory of Abkhazia. In Kamchatka, during the 2003-2005 project, a joint Russian-US-Italian research team looked into the relationship between eruptive activity and major tectonic earthquakes; particular emphasis was placed on the 120-km-long Kumroch fault, arguably the largest active fault in the peninsula, with at least three major rupture events in the last 9 ka, each with an offset of 1-1.5 m. In 2007-2009, another project was aimed at providing an essential understanding of the volcanic and seismic geohazards threatening the Georgian section of the strategic Caspian oil and gas pipelines within the recent Javakheti plateau, and developing mitigation and remediation measures. In 2008-2012, the project in Kyrgyzstan was intended to assessing the potential geo-environmental threats and impacts to the major Toktogul hydroelectric scheme. One major goal of the project was the definition of mitigation measures, crucial to ensuring economic development and political stability in Central Asia. The latest, NATO-funded project, conducted between 2015 and 2018, was focused on assessing the vulnerability to geohazards of the Enguri Dam and associated hydroelectrical facility, the largest of its kind in the Republic of Georgia.

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# Quaternary volcanic activity in the Great Caucasus

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**Abstract**

Three neovolcanic centers of the Great Caucasus – Elbrus, Kazbegi and Keli are discussed in the presented work. Three phases of volcanic activity have been distinguished on the basis of undertaken isotope geochronology, geological, petrological and mineralogical studies of these centers. 5 phases have been defined at the Elbrus volcanic center: I phase - 950-900 ka, II phase - 800-700 ka, III phase - 225-170 ka, IV phase - 110-70 ka and V phase – not less than 35 ka. 4 phases have been defined at the Kazbegi center: I phase - 460-380 ka, II phase - 310-200 ka, III phase - 130-90 ka, IV phase – less than 50 ka. At the Keli center 3 phases have been defined: I phase - 245-170ka, II phase - 135-70 ka, III phase – less than 30 ka. Due to Holocene age of the latest phases of volcanic activity these volcanic centers could be considered as potentially active (dormant).

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# Seismic microzonation for the reconstruction after destructive earthquakes: the case of the Amatrice earthquake

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**Abstract**

The $M_w$ 6.0 Amatrice earthquake struck Italy in August 24th 2016, causing hundreds of deaths and injuries, and the destruction of many villages. Unfortunately, the subsequent seismic sequence left behind a widespread damage across a territory distributed in four Regions.

After the emergency, the Government Commissioner for reconstruction funded a project devoted to the seismic microzonation of 533 urban areas in 138 municipalities, and involving more than 500,000 citizens. The main request of the Commissioner was to provide information for reconstruction in the municipalities struck by the earthquakes.

The project involved authorities, researchers and freelance consultants, and its coordination was entrusted to the Italian Centre for Seismic Microzonation (CentroMS), an association of 25 research institutions and university departments providing expertise in geology, applied geophysics, engineering-seismology, geotechnical earthquake-engineering, and engineering-geology.

The main project activities concerned:

- geological surveys and in situ geotechnical testing for the identification of the engineering-geological units;
- geophysical surveys for characterizing the sub-surface units in terms of dynamic properties;
- geotechnical laboratory testing for the estimation of the non-linear behavior of the units under cyclic and/or dynamic conditions;
- numerical simulations for the estimation of local seismic response (LSR);
- seismological analysis for i) retrieval of waveforms compatible with the building code to be used as seismic input for the numerical simulations, ii) calibration of numerical simulations, and iii) empirical determination of LSR.

The work presents the results of the project, to be used as a good practice at national and international level.

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# Holocene-Historical volcanism and other geohazard risk factors in Armenia

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**Abstract**

In current contribution we focus on overview of the regional Holocene volcanism, and recent case studies of volcanic hazards in Armenia. Current tectonically and volcanically active geological structure of the entire region of Caucasus and Armenian Highlands was formed mainly by continental collision of Arabian plate with the active margin of Eurasia, occurred in Early Miocene and resulted in formation of Anatolian-Armenian-Iranian elevated orogenic plateau. Geodynamic monitoring and GPS data indicates that the Arabian plate moves northward at a rate of about 17 mm/year (Reilinger et al., 2006; Vernant et al., 2004), while deformations internal to the orogenic plateau, take place along regional strike-slip fault systems. Continental collision was followed by slab-breakoff processes, which resulted in orogenic uplift associated with long-lasting, widespread volcanism (Keskin et al., 2003, Skolbeltsyn, 2014; Neill et al., 2015, Meliksetian et al., 2015).

Quaternary volcano locations are closely associated with major active fault systems and pull-apart extension basins related to strike-slip tectonics. Several volcanoes and volcanic systems in Caucasus, Armenian Highlands and Anatolia were active during Upper Pleistocene, Holocene and/or Historical time, namely: Gegham monogenetic volcanic upland, Smbatasar volcano, Porak volcano, Karkar monogenetic volcanic plateau in Armenia, Samsari volcanic ridge, Kazbegi stratovolcano in Georgia, Nemrut, Ararat, Mount Hasandag, Tendürek (Tondrak) in Turkey and others. Historical volcanic activity, for instance is evidenced for Nemrut volcano, in NW part of Van Lake, and is dated to 1441 AD according to historical observations in “Memory Notes of Armenian Chronicles” of the 15th century. Ararat stratovolcano in easternmost part of Turkey adjacent to Armenian border was active in Holocene and Historical times (Karakhanyan et al., 2002).

Geological records in Armenia indicate widespread occurrence of violent explosive eruptions, including plinian tephra fall deposits and ignimbrites sheets from local volcanoes, such as Aragats, Irind, but also those, related to distal eruptions form Nemrut and Ararat volcanoes in eastern Turkey.

Geological evidences, as well as recurrence rate estimations of volcanic systems in the region, indicate that future volcanic eruptions from these upper Pleistocene-Holocene-Historical volcanic systems cannot be ruled out. In this case, the populated places and regional and country infrastructure will be at significant risk from a diverse range of volcanic phenomena and the accompanying seismic activity.

Especially important is evaluation and probabilistic volcanic hazard assessment for critical infrastructure objects such as Nuclear Power station in Armenia. Volcanic hazard assessment of Armenian NPP was performed according to IAEA safety Guide (IAEA SSG-21, 2012) during 2009-2012 was used as a case study in official IAEA-TECDOC 1795 publication.

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# Impact of short-term geomagnetic activity on weather and climate formation in Georgian region

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## Abstract

Solar Flares, Coronal Mass Ejections (CMEs), Solar Energetic Particles (SEPs) are the drivers of the Space Weather effect in Geo-Space. They can produce the following affects: electrostatic spacecraft charging, shifting of the Van Allen radiation belt, space track errors, launch trajectory errors, radar errors, radio propagation anomalies, electrical power blackouts, oil and gas pipeline corrosion, communication landline and equipment damage, electrical shock hazard, electrical fires, heart attacks, and traffic accidents A magnetospheric storm is short period phenomenon spanning all the magnetosphere regions, and it features sharp depressions in the magnetic field. Huge energy increases the ionosphere temperature and causes large-scale ion drifts and neutral winds.

The investigation of possible effect of powerful magnetospheric storms on the evolution character of meteorological processes in the atmosphere aiming to identify correlation between magnetospheric disturbances and meteorological variations is presented in paper. The Sun, together with the Earth's motion along its orbit, govern changes in the solar–terrestrial environment on time scales ranging from minutes to glacial cycles. Changes in Earth's climate have been the focal point of recent research in the solar–terrestrial physics and a special emphasis has been placed on the coupling between the troposphere, middle atmosphere, near Earth Geospace (mesosphere, thermosphere, ionosphere, and magnetosphere), and solar activity. Meteorological effects resulting from fluctuations in the solar wind are presently poorly represented in weather and climate models.

Earth Observation System (EOS) program is designed to examine the role of Earth-Sun connection in wide-scale global processes in order to determine the function of the Earth as a single system. One of global climate change reason is caused due to emissions of greenhouse gases like carbon dioxide into the atmosphere. The real drivers of climate are the Sun's insulation (light and heat), its magnetic flux, and the relative position and orientation of the Earth to the Sun.

The variations in the Sun's magnetic flux control the amount of cosmic rays enter the atmosphere. Cosmic rays produce ionizations and the ions form nuclei for cloud formation. Cloud cover has a great effect on global temperature, but this area is still poorly understood and not addressed in climate models. Meteorological effects resulting from fluctuations in the solar wind are presently poorly represented in weather and climate models. Geomagnetic storm is a major disturbance of Earth's magnetosphere that occurs when there is a very efficient exchange of energy from the solar wind into the space environment surrounding Earth. These storms result from variations in the solar wind that produces major changes in the currents, plasmas, and fields in Earth's magnetosphere. The largest storms that result from these conditions are associated with solar coronal mass ejections (CME) where a billion tons of plasma from the sun, with its embedded magnetic field, arrives at Earth. CME typically take several days to arrive at Earth.

Geomagnetic indices are measure of geomagnetic activity occurring over short periods of time. They have been constructed to study the response of the Earth's ionosphere and magnetosphere to changes in solar activity. The correlation between geomagnetic storms and meteorological elements (temperature, precipitation, wind) have been carried out for Georgian region using meteorological observation and

NASA's Solar Dynamics Observatory and NOAA Space Weather Prediction Center data. The results show that there exist dependence between weather parameters and income radiation

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# Shallow-subduction versus intra-lithosphere thrusting – overtime and seismogenic case studies

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**Abstract**

Intra-lithosphere seismicity at the base of orogenic systems is almost always directly interpreted in association with the subduction process. Geodynamic scenarios that could exclude subduction are rarely explored, even when there is no trace of the seismic activity at sub-lithospheric depths.

Similarly, the Quaternary Compressional Belt (QCB) of peninsular Italy, developed at the outer front of the eastward migrating Tyrrhenian-Apennines system, is classically interpreted in the frame of a subduction scenario controlled by the progressive retreat of the westward-dipping Adriatic slab. Given to the lack of seismic activity a depth > 70-80 km, arguments among authors has arisen in assuming QCB either as an example of "shallow subduction" or of "deep aseismic subduction".

In our opinion, it should be considered the possibility that the crustal earthquake activity would not match a subduction interface, but rather low-angle mantle shear zones bounding discrete lithospheric bodies that overthrust eastward.

In this paper, we test this hypothesis by building a high-detailed and realistic 3D geometric and kinematic fault model of QCB in eastern Central Italy, at lithospheric scale. Our reconstruction is based on the integration of structural data from active and long-term geology with data from 1D and 3D relocated seismicity and from a new and very complete database of focal mechanisms, implemented with stress field inversion and tomographic image of the lithospheric structure.

Results unveil two well distinct regional compressional shear zones that dislocate the Adriatic crust and penetrate across the underlying continental lithosphere. A lack of intermediate depth earthquake (depth >70 km) is highlighted, and no compatibility of P- and T-axes trend with subduction models is observed. Shmax trajectories, built at a dense grid of measure nodes, show a kinematic compatibility between the two identified shear zones, with a common outward-diverging P-axes radial pattern, possibly reproducing the basal drag of the stretched and outward migrating Tuscan-Tyrrhenian mantle.

Our findings not only do allow to renegotiate the geodynamic context of the Apennine fold-and-thrust system, but also have a direct application on the definition of new 3D seismotectonic provinces and individual structures in eastern Central Italy.

In general, we auspicate that data and ideas here presented may, on one side, stimulate the discussion on mantle earthquakes in the absence of subduction and on the other contribute to hazard mitigation practices and forecasts of mid- and deep- crust thrust earthquakes in continental contexts.

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# Poroelastic contributions to induced seismicity – underground pressure management

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**Abstract**

Anthropogenic activities affect the fluid pressure in the underground in quite different ways: Injection of fluids into or production of fluids from porous reservoirs causes an increase or decrease of reservoir pore pressure, respectively. Cyclic pore pressure variations occur in underground gas storage sites (UGS). In geothermal applications with well doublets the fluid pressure in the underground is lowered close to the production well and increased in the surrounding of the injection well. Other type of pore pressure modifications result from impoundment of hydropower reservoirs and the annual water level variation, which in case of the Georgian Enguri hydropower reservoir can lead to annual variations in the order of 100 m. Induced seismicity in connection with impoundment of hydropower reservoirs has led to severe loss of life (e.g. Koyna, 1967) and failure of important infrastructure in the vicinity of the reservoirs.

Seismicity can occur if the state of stress at fault zones is critical. To explain seismicity, a geomechanical model based on Mohr-Coulomb type friction on faults and Terzaghi´s concept of effective stress, which is generally the total stress minus the pore pressure, is considered. Using this approach, reduction of effective stresses due to pressurization can explain the seismicity for cases of pore pressure increase. In the U.S. the massive injection of waste water with high-rates into porous (thus not low permeable) rocks causes earthquakes at rather large distance and only after several years of injection in areas that had not been seismically active before. Hydropower reservoirs frequently are located in mountainous and already previously seismic active regions, which points to rather critical initial state of stress.

However, seismicity can also occur if the pore pressure is reduced. Stress changes due to reservoir depletion are of growing interest because more challenging wells (extended reach, deep-water or partially depleted reservoirs) are drilled nowadays. The seismicity in relation with production has also severe societal impact since the seismicity in the Dutch Groningen gas field has led the Dutch government to the decision to close the gas field, which is one of the major fields in Europe supplying numerous neighbouring countries. Production induced perceived seismicity can be explained by the increase of differential stress due to so-called pore pressure stress coupling based on a poroelastic geomechanical model.

Especially for operations with significant pore pressure changes, the consideration of related stress changes is essential. With poroelastic numerical models the influence of injection/production rate and well locations can be simulated.

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# Preliminary studies for seismic microzonation of the urban areaof Mtskheta (Georgia)

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**Abstract**

Seismic hazard and risk assessment is crucial for Southern Caucasus and particularly forGeorgia.

The goal of a modern society is to create urban environments that are resilient and minimize losses in case of destructive earthquakes. However, complete elimination of risk is unreal. One of the reasons for it is the deficiency of knowledge about real seismic hazard and vulnerability of urban areas and infrastructure.

In Georgia, seismic hazard was estimated at national level applying tools developed in the GEM project. By the way, this assessment performed considering the approximation of an outcropping bedrock with S-wave velocity VS equal 760 m/sec; i.e., no local site conditionshave been taken into account.

The effect of site conditions is widely acknowledged to be the most important factor in the definition of surface ground motion. In this respect, seismic microzonation can be regarded as the identification of zoneshaving homogeneous behavior in case of earthquake, depending on local site effects. On this regard, sseismicmicrozonation represents a highly useful tool for seismic prevention and risk assessment to be applied in urban management, design of buildings and infrastructures, emergency planning.

In the urban area of Mtskheta (Georgia), for the purposes of performing preliminary studies aimed at seismic microzonation, all the previously available geological, geotechnical, geophysical information was collected, provided by City Hall of the city.

New field surveys were performed in order to refine the subsoil model, based on lithological-geotechnical units, their stratigraphic and geometric relationships, their physical-mechanical parameters. New site-investigations were carried out by means of MASW and HVSR techniques.

In order to evaluate S-wave velocity profiles with depth, joint inversion of Raylegh wave dispersion curve and H/V curvewere used. The inversion procedure was carried out by means of a Montecarlo algorithm, a multimodal Monte Carlo inversion based on a modified misfit function proposed by Maraschini and Foti (2010).Starting from the underground model, using the STRATA one-dimensional modelling software, local seismic response analyses were performed, and acceleration response spectra and amplification factors were calculated for the urban area of Mtskheta.

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# Factors and causes of coastal hazards on the Georgian Black Sea

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**Abstract**

It is already one and a half century that the Black Sea coastal zone of Georgia became an arena of significant elemental forces. Violation of balance of natural processes contributed to development of such phenomena on the sea coastal zone. It should be emphasized that 80% of the Black Sea coastal zone of Georgia is of accumulative type, while 20% - abrasive - accumulative one. Therefore, with the view of stability of shores keeping the balance of depositions has always been urgent. The first cause of violation of balance of depositions was building of sea ports in Poti and Batumi in the second half of the 19th century. Along the sea coast, at dozens of kilometers balance of depositions suffered drastic violation. In the next decades, because of withdrawal of abundant material feeding the beaches and river beds, uncontrolled processes in the form of intense erosion of the coast was spread along hundreds of kilometers. Within the 20th century for protection of shores from wash-off the hydro-technical constructions were built on various type coasts, without provision of regularities of litho-dynamic processes. In most cases hydro-technical constructions failed to give positive results. Such approach to the problem resulted in high economic losses. By the 60s of the 20th century territory of washed off lands reached hundreds hectares. It is enough to state that due to some factors, exploitation of Poti port at the mouth of river Rioni is faced by serious problems. Due to incorrect regulation of depositions at the juncture of big rivers of Georgia with the sea, excess accumulative material was lost in underwater canyons. Building of dams in the basin of the riv. Chorokhi from the 90s of the 20th century had extremely high negative impact on stability of the south section of the coast. Because of it, depositions of material on the coastal zone by the riv. Chorokhi was almost stopped. From the end of the 70s of the 20th century such process was developed at the mouth of the river Enguri too. In recent 15-20 years various anthropogenic meddling is in progress in the Black Sea coastal zone of Georgia without consideration of morpho- and litho-dynamic regularities. Many hydro-technical constructions are built without provision of ecological expertise and besides, mass withdrawal of inert material from river beds is still continued for building purposes.

It should be emphasized that by a big probability, uncontrolled meddling in coastal processes will still be continued. Therefore, spontaneous processes going on at the sea shore require further analysis and systemic approach. To mitigate results of negative intervention in sea shore processes, it is necessary to perfect relevant legislative base taking into consideration current situation. Otherwise, at the background of global climatic changes it will be impossible to preserve the present day sea shore landscape.

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# Evaluation of landslide hazards in the areas surrounding the Enguri reservoir, Georgia

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**Abstract**

The Enguri Reservoir is situated between steep, north-south trending slopes. The major surficial geologic units trend east-west, nearly perpendicular to the long (N-S) axis of the reservoir. The dam is constructed among carbonate rocks on the south end of the reservoir. Volcanic rocks encompass the majority of the northern half of the reservoir. The land surface between these two major rock units is a massive clay deposit (Khoko), with interbedded gypsum layers, creeping towards the reservoir. The rock outcrops are highly fractured and weathered. Rock falls pose frequent hazards to travelers along the main travel route along the eastern slopes. The creeping Khoko slide requires frequent repairs to the main road, which traverses across the main head scarp. The tectonic history has caused extensive folding and faulting. Active compressional tectonics pose significant seismic hazards. Detailed landslide inventories do not exist for this region. Deterministic, 2-dimensional profile modeling of the Khoko slide was performed to ascertain the factors contributing to its movement. Probablistic regional analyses were performed using 3-dimensional computation models and included peak ground acceleration estimates from previous work on seismic hazards. The Khoko creeping slide is affected primarily by pore-water pressure and topographic slope. On a regional scale, the limestone and volcanic slopes are more vulnerable to failures resulting from earthquakes, although we also know well that rock falls are frequent, almost daily.

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# GeoInt, the macroseismic intensity database for the Republic of Georgia

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**Abstract**

This work is an outcome of the NATO Project G4934 – Science for Peace and Security Programme – titled: Security against geohazards at the major Enguri hydroelectric scheme in Georgia (http://www.enguriproject.unimib.it). We present the new macroseismic intensity database for the Republic of Georgia, named GeoInt, that is available on the NATO Project G4934 website (http://www.enguriproject.unimib.it/?page_id=1874). Such database is composed of 3944 intensity data points (IDPs) for 1509 different localities, reported in the Medvedev-Sponheuer-Karnik scale (MSK). They are related to 111 selected earthquakes that occurred from the historical to the instrumental era (from 1250 B.C. onwards). Earthquakes magnitude is reported in $M_S$ and it ranges from 3.3 to 7, the depth is in the 2-36 km range.

The set of IDPs, characterized by intensities ranging from 2-3 to 9-10, is located in an area spanning 39.508° N - 45.043° N in N-S direction and 37.324° E - 48.500° E in E-W direction. Some IDPs are located outside the Georgian border, in the Republic of Armenia, Russian Federation, Republic of Turkey, and Republic of Azerbaijan. Each single IDP has been revised and intensities values have been reevaluated and homogenized to the MSK scale. In particular, among the 3944 IDPs, 348 belong to the Historical era (pre-1900) whereas 3596 belong to the instrumental era (post-1900). Regarding the latter 3596 IDPs (post-1900), 105 are brand new (3%), whereas the intensity values for 804 IDPs have been reevaluated (22%); intensities of the remaining IDPs have been confirmed from previous studies. This database represents a key input for further improvements in seismic hazard modeling and seismic risk calculation for this region, based on macroseismic intensity.

# Structural architecture of the Georgian part of Lesser Caucasus orogen using seismic reflection profiles

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**Abstract**

Our interpretation has integrated seismic reflection profiles, several oil-wells, and the surface geology data to reveal structural characteristics of the Georgian part of Lesser Caucasus orogen. The Lesser Caucasus, which is one of the good examples of the far-field deformations is associated with Arabia-Eurasia convergency. Seismic reflection data reveal the presence of basement wedge, south-vergent backthrust, north-vergent forethrust and triangle zone. Seismic reflection profile crossing the frontal part Lesser Caucasus reveals the presence of upper and lower structural complex. Upper structural complex is represented by shallow triangle zone which includes a north-vergent Mtskheta fault-propagation fold, north-vergent duplex and south-vergent passive-backthrust at the mountain front. Lower structural complex is represented by structural wedge and is made up of Mesozoic strata. The kinematic evolution of the south-vergent backthrust zone is related to the northward thrusting structural wedge. The south-vergent fault-related folds is interpreted as a fault-propagation folds whose front limb is broken by thrust faults. Seismic reflection profiles showing that basement uplift in response to deep seated thrusting. Formation of north-vergent basement wedge of thick-skinned sector of the Lesser Caucasus may be caused by reactivation of pre-existing normal faults. Building of thick-skinned structures of the Georgian part of Lesser Caucasus was formed by basement wedges propagated (from south to north) along detachment horizons within the cover generating thin-skinned structures. According to the doubly vergent orogenic wedge model, the Georgian part of Lesser Caucasus is constituent part of retro wedge.

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# On the seismic waves propagating in the layered Earth stratum

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**Abstract**

Materials science distinguishes seismic waves into a separate section, which is caused by three main features of these waves: 1) the environment in which seismic waves propagate is thicker than the Earth;
2) the seismic waves are waves with low frequency values; 3) the source of the seismic waves are earthquakes, volcanic eruptions, the movement of magma in the Earth, large natural landslides, or large anthropogenic (human-caused) explosions. The seismic wave propagation environment is generally considered to be deformable (material) and various deformation models of materials are used to model it, most often choosing the elastic deformation model. Therefore, it is important in the analysis of seismic waves to know the physical characteristics of the various components of the earth's soil - soils, rocks and others. In the model of elastic deformation, this means knowledge of density and elastic constants. Historically, seismic waves have been analyzed in the framework of the theory of elasticity, which operates with such types of waves as bulk waves, plane waves, surface waves. It is often accepted that the source of seismic waves is localized and generates the spherical waves. However, when the object of study of seismic waves is far enough from the source, the waves are considered flat. Therefore, plane waves occupy much of the science of seismic waves. This presentation is devoted to the theoretical analysis of the propagation of a plane horizontally po-larized harmonic wave (SH-wave) from rocky soil through soil layers to the Earth's surface. Such an ana-lysis results in formulas for calculating the oscillations of the Earth's surface and the required coefficients of reflection and propagation of waves across the boundaries between the elements of the system "rocky massif - soil layers - atmosphere". Knowledge of the oscillation of the Earth's surface due to the arrival of the seismmic SH-wave is a necessary component of seismic microzoning of building sites. Therefore, the importance of theoretical justification for data on the vibrations of the Earth's surface is obvious. The direct method of mechanics is utilized in studying the passing and reflecting of SH-wave while it propagates through the finite number of ground layers with differing thicknesses and rheological proper ties. The mechanical properties of the ground layers are described by the Hookean and standard rheologi-cal models. The explicit formulas for evaluation of the wave number and attenuation of the harmonic SH-wave are obtained. The wave attenuation is studied by two variants – by the spatial coordinate and in time. The obtained formulas can be treated as some continuation of classical works of Prof. Savarensky (Russia) in the area of elastic seismic waves and Prof. Stepanishen (USA) in the area of viscoelastic seismic waves. A general conclusion of the study is that the utilized solving procedure is not formalized and at all steps reveals the physical sense and mathematical transparency. The algebraic formulas obtained for oscillations on the Earth's surface and the aggregate wave in a rock massive are simple and suitable for computer simu-lation. An applicability is shown for the standard rheological model of deformation of layers to a simple mathematical description of attenuation of the wave motion amplitude, which actually exists when the wave propagates in the soil layers.

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# Influence of a soil strata with rheological properties on seismic hazard parameters

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## Abstract

The increasing pace and volume of construction of high-rise buildings and important engineering structures require the development of new territories, which, according to the expert estimates, are often characterized by the complex engineering and geological conditions and deteriorated seismic properties. The Cities expand, mastering territories for development, the soils of which belong to the III and IV categories according to seismic properties, according to SBC R.1.1-12: 2014 [1, 2]. Such soils have significant nonlinear properties, which will manifest themselves in different ways, depending on the intensity and frequency composition of the seismic actions. The destructions and damages of earthquake-resistant structures during earthquakes are associated not only with poor construction quality and unfavorable ground conditions of their sites, but also with the coincidence of the natural frequencies of structures with their own frequencies of frequency characteristics of the soil strata (resonant effects); liquefaction of soils or partial loss of their bearing capacity (nonlinear effects). The problem of assessing seismic hazard, seismic risk and seismic protection is complicated by the poorly predicted effects of resonant amplification of seismic vibrations by loose near-surface soils. Depending on their type and the thickness of beds, the oscillations of some frequency intervals can be selectively amplified, and others cannot to change, or almost are completely absorbed. The resonant amplification of vibrations is especially dangerous in buildings and structures, in which the center of gravity is significantly removed from the fulcrum, what is typical for high-rise buildings, bridge supports, pipes, etc. Usually, objects of this type are characterized by low values of their own damping. In connection with the possibility of occurrence of resonance phenomena, the design of seismic resistant buildings requires not only information on the strength and location of possible earthquakes, but also reliable data on the natural oscillation periods of the projected objects, and the resonant properties of grounds at their base. With the study of reaction of the soil models to seismic impacts, it has been established that the soil types, which are of equal strength but different in seismic properties (see Table 5.1 SBC R.1.1-12: 2014 [1]), are characterized by different frequencies at which they weaken or enhance seismic vibrations. The frequencies corresponding to the maximum amplifications of seismic signal (resonant frequencies) depend on the thickness and number of sediment layers, their lithology composition, the geometry of boundaries, and for large earthquakes, due to the appearance of nonlinear effects, also on intensity of the seismic influences. The theoretical modeling of reaction of the soil sequence under various real objects has shown that with the deterioration of seismic properties of soils, as well as with increasing the thickness of sedimentary layer, the maxima of frequency characteristics are shifted to the low-frequency region. With an increase in intensity of the seismic actions, a nonlinearity of the soil reaction manifests itself, the maxima of the frequency characteristics shift to the low-frequency range, and a relative weakening of the seismic oscillations amplitude is observed. The further improvement of the seismic microzoning methodology for seismic design and construction requires a more detailed consideration of the resonant and rheological properties of soils under each built-up or operational site in the seismic regions of the country.

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# Influence of inherited crustal faults zones on the geodynamic evolution of the Caucasus and Black Sea basins

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## Abstract

The main rifting of the Greater Caucasus basin occurred during the Jurassic, the Black Sea basin during the Cretaceous and the Transcaucasus-Lesser Caucasus post collisional basins during the Late Eocene. Shapes and location of these basins seem guided by former structural heterogeneities within the Eurasian crust (Greater Caucasus, Black Sea, Adjara-Trialeti basins) and within the Taurides-Anatolides-South Armenian Microplate (TASAM) (in the Lesser Caucasus following its collision with Eurasia). According to our results which are been taken into account in the new paleotectonic reconstruction of the Tethyan realm (Darius programme maps, Barrier et al., 2018) we present four keys areas allowing to demonstrate the major role of inherited faults zones during the tectonic basins evolution and the geodynamical p: 1) in the NW Black Sea and Crimea domains, 2) in the northern tectonic units of the Rioni Basin (Greater Caucasus, Georgia), 3) in the Adjara-Trialeti basin in the Transcaucasus domain (Georgia) and 4) in the Late Eocene basin in the Lesser Caucasus (in Armenia).

The results show that thick skin tectonics have been at the origin of most inversion of these basins. However, these inversions were also combined with thin-skin deformations due to the occurrence of particular decollement levels from place to place as: 1) thick Triassic and Cretaceous turbidites in the North Western Black Sea, 2) Triassic turbidites, Upper Jurassic evaporites, Cretaceous turbidites, Oligo-Miocene Maykop series in the Greater Caucasus, 3) Eocene turbidites and Oligo-Miocene Maykop series in the Transcaucasus and, 4) part of ophiolites (serpentinites) in the Lesser Caucasus. In all of these cases it is evidenced the important role of pre-structuration of the continental crust on the fragmentation of it, yielding creation of basins and then their inversions. These results must be taken into account in numerical modelling of the continental crust behavior.

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# Geohazard Risk Assessment along the Oil &Gas Pipeline Courses; Seismically triggered Volcanic Debris Flows and Landslides. NE Anatolia, Turkey

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## Abstract

Energy Lines connecting South Caspian to East Mediterranean crossing TransCaucasia- NE Anatolia, are prone to several geohazards. Prevailing hazard risk sources are high seismicity fault zones and secondly mass flow generating poor grounds. This research focused on geotechnical projects applied to overcome possible destructive hazards on Oil and Gas Pipelines. Erzurum- Ardahan- Kars Volcanic Plateau (basalt-andesite) extends in SW Georgia. Plateau dissected dominantly by NE-SW striking active faults which combine Caucasian Thrust to North Anatolian Fault zone, in Erzurum Area.

Major tectonic and structural deformations in NE Anatolia-Transcaucasia- Azerbaycan are basicly controlled by convergence between Arabian and South Margin of Eaurasian Plates.

BTC, Baku-Tbilisi-Ceyhan Crude Oil Pipeline, Shahdeniz-Erzurum NG Pipeline and TANAP Trans-Anatolia NG Pipelines follow approximately the same route. Akhalsitze - Posof- Ardahan- Harasan- Erzurum corridore. Posof Fault, Ardahan Fault, Sarikamish Fault and CobanDede Fault (Horasan Earthquake 1983, M=7.1) have high risk crosses, in this corridore. Five Pump Station constructed along Turkey segment of BTC Pipeline, between Posof and Ceyhan. PT1 Pump Station located on North slopes of Ilgar Volcano. First Pump and Control Station of Shahdeniz- Erzurum Pipeline located at Georgia-Turkey Border. Special engineering projects for hazard reduction applied.

Seismotectonic features consists of oblique strike slip active faults ; dominant strikes are N30E, N50-60 E left lateral and N30- 40W right lateral , conjugate fault system. Another conjugate set includes N70E and N65-70 W striking Faults. N-S striking tensional fractures are less abundant. One such fracture resulted in huge volcanic debris flow ( Xrami Geopark ) at a few km South of Posof.

Two major genetic catagories of active Mass Flows were identified; a) Landslides, formed in red clayey sedimentary deposites of lacutrine-fluvial facies. Red molass deposites , clayey sedimentary sequences,, of Late Oligocene- Pliocene age. Lacustrine- Fluvial environment. b) Thick volcanic debris accumulated in palaeo-topograhic low areas, by intense subaerial eruptions. Almost all mass flows triggered by earthquakes and controlled by lithology, either mud or loose pyroclastic-volcanic ash deposites. Pyroclastic Flows (volcanic debris flows) particularly dominant in the area neighbouring Georgia Border. Ardahan- Posof- Akhalsitkhe Region. Landslides common in clay-rich fluvial-lacustrine deposites. Major mass movements occurred in lithology units formed in syncollision (Oligocene-Middle Miocene) and postcollision (Late Miocene-Quaternary) periodes. Debris Flows are common in thick pyroclastic accumulations ( Plio-Quaternary).

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# Commercial-UAV-based Structure from Motion for geological and geohazard studies

***Authors:*** *Noemi Corti[1], Fabio L. Bonali[1], Alessandro Tibaldi[1,2], Fabio Marchese[1], Elena Russo[1], Luca Fallati[1], Alessandra Savini[1]*

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## Abstract

Data collection and direct observation are key issues for geological studies, particularly when they are aimed at studying an ongoing geohazard. Unfortunately, very often, key geological sites are inaccessible due to difficult logistic conditions (e.g. vertical cliffs, volcanic craters, giant faults), as well as the areas to be studied are too large for classical field studies only.

The Structure from Motion techniques (SfM), combined with Unmanned aerial vehicles (UAVs), or drones, represent a modern tool to overcome problems of inaccessibility and to collect plenty of data aimed at geohazard assessment. The analysis performed by experts conducted on the resulting high-resolution Orthomosaics, Digital surface models (DSMs) and 3D models allow the scientific community to dramatically improve data collection and mapping for geohazard assessment.

We applied this approach in two different countries (Iceland and Georgia), affected by volcanic, seismic and landslide hazards. Our effort has been focused on volcano-tectonics, active tectonics and geomorphological studies, in order to quantify: i) the present strain field in the Theistareykir Fissure Swarm (Northern Iceland) by measuring the vertical offset along normal faults and the opening direction/dilation along extension fractures; ii) recent movement of the Kokho Landslide, that is in proximity of the Enguri dam (Western Georgia), by providing an high-resolution geomorphological map.

Our results confirmed that the use of UAV-based SfM is efficient and convenient in geological studies and geohazard assessment; we recommend its use, particularly, to study areas prone to dangerous geological phenomena like volcanic eruptions, earthquakes, landslide and floods.

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# Large Landslides in post-orogenic landscape: LiDAR-based inventory of mass movements in the Czech Flysch Carpathians

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## Abstract

Moderate-relief landscapes, such as the Czech Flysch Outer Western Carpathians (COWC), in comparison with alpine regions are rarely subject to extensive landslide inventory mapping. This finding is a paradox because densely populated hilly landscapes in temperate zones are usually of major socio-economic importance. In this study, we performed the first LiDAR-based landslide mapping for the entire area of COWC (~7539 km2), one of the most landslide-prone regions in Europe. The region is internally heterogenous in terms of geology (individual flysch nappes with different lithology) and topography (e.g., high monoclinal ridges in the north-eastern part with local relief > 500 m and subdued hilly landscape in the southwest). We mapped a total of 13,611 landslides, of which 1357 failures are large landslides (≥0.1 km2) and deep-seated gravitational slope deformations (DSGSDs). Our inventory provides significant extension of existing landslide database and shed more light on the distribution pattern of various types of landslides in the COWC. Whereas the lower and more subdued areas in the southern part of COWC are hotspots in terms of the total number of landslides, the higher and more topographically pronounced areas in the northeast are affected predominantly by large landslides and DSGSDs. Our data suggest that 1) distinct geological units (nappes) produce landslide populations with different frequency-area distributions; 2) stratigraphic composition alongside the tectonic style of flysch formations control the type of landslides; 3) DSGSDs affect mainly slopes formed by rigid rocks sitting atop soft formations; and 4) geological conditions, rather than topography, control distribution of large landslides and DSGSDs in COWC. Spatial pattern of landslides mimics available data from the monitoring and dating of mass movements. Lower, claystone-dominated areas host numerous active landslides with highly recurrent activity throughout the Holocene, whereas sandstone-dominated mountain ranges reveal that major landslides have been activated nearly exclusively only in the most humid Holocene periods.

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## Scientific posters

1. ***Development of Seismic Strong motion Network for Georgia***

   Tamar Shubladze[1], Nino Tsereteli[1], Tengiz Qiria[1], Nicholas Mchedlishvili[1]

   Mikheil Nodia Institute of Geophysics of Ivane Javakhishvili Tbilisi State University, Tbilisi, Georgia

2. ***Seismicity Near Ennguri Dam***

   Nazi Tughushi[1], Ninio tsereteli[1], Manana Kupradze[1]

   [1]Mikheil Nodia Institute of Geophysics of IvaneJavakhishvili Tbilisi State University, Tbilisi, Georgia

3. ***Some closed-bed hydrodynamic problems in the Vere valley***

   Irine Khvedelidze[1], Zurab Kereselidze[1]

   [1]Mikheil Nodia Institute of Geophysics of Ivane Javakhishvili Tbilisi State University, Tbilisi, Georgia

4. ***Laboratory modeling of natural disasters and their triggering***

   Dimitri Amilakhvari[1], Levan Dvali[1]

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5. ***Electro prospecting and its use to assess landslide hazards***

   Dimitri Amilakhvari[1], Levan Dvali[1]

   [1]Mikheil Nodia Institute of Geophysics of Ivane Javakhishvili Tbilisi State University, Tbilisi, Georgia

6. ***Landslides monitoring and early warning acoustic system laboratory model***

   Dimitri Tefnadze[1]

   [1]Mikheil Nodia Institute of Geophysics of Ivane Javakhishvili Tbilisi State University, Tbilisi, Georgia

7. ***Special Features of the Convective Process in Atmosphere wichCaused Landslide into Akhaldaba and Catastrophic Flood in Tbilisi on June 13-14, 2015***

   Khvedelidze I.[1], Mitin M.[1], Tavidashvili Kh[1].

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8. ***Radar Monitoring of Hail Processes in Eastern Georgia and Its Neighboring Countries (Azerbaijan, Armenia)***

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9. ***On the Possibility of Predicting Floods Caused by Rainfall in the 200-km Radius of Action of the "METEOR 735CDP10" Meteorological Radar***

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10. ***Prospects of Using Radar «METEOR 735CDP10» for Detection in Atmosphere in the South Caucasus Dust Storms, Volcanic Formations and Smoke from the Large-Scale Fires***

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11. ***The investigation of hazardous meteorological events in Georgia***

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12. ***Investigation of dynamics of earthquake's temporal distribution***

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13. ***Nowcasting and very short range Weather Forecast for Georgia***

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