

## GEOHAZARD DESCRIPTION FOR SOFIA IN THE FRAME OF THE PANGEO PROJECT

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**ABSTRACT.** PanGeo project is a 3-year Collaborative Project of the European Commission that started 1st February 2011. During the project PanGeo provide free online geohazard information for 52 of the largest towns in Europe, mapping geohazards that could potentially affect up to 13% of the EU population. The GeoHazard Description for Sofia was prepared as support for the PanGeo Ground Stability Layer (GSL) of Sofia (intermediate product), Bulgaria. The area covered by the GSL corresponds to the administrative area of Sofia Municipality (~1,342 km<sup>2</sup>) and includes the City of Sofia and other surrounding boroughs. The identification of geohazards was performed through combined interpretation of geological, land use and other geospatial layers together with satellite Persistent Scatterers (PS) ground motion data for 1992-2003 for the city of Sofia, by processing ERS-1/2 SAR with the Interferometric Point Target Analysis (IPTA) algorithm. The results of PanGeo project are included also in OneGeology-Europe portal which aims to create dynamic digital geological map data for Europe.

### ОПИСАНИЕ НА ГЕОЛОЖКИТЕ РИСКОВЕ ЗА РАЙОНА НА ГРАД СОФИЯ КАТО ЧАСТ ОТ ПРОЕКТА ПАНГЕО

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**РЕЗЮМЕ.** PanGeo е 3-годишен съвместен проект на Европейската комисия, който започна на 1 февруари 2011 година. По време на проекта PanGeo осигури безплатна онлайн информация за геоложките рискове за 52 от най-големите градове в Европа и картографиране на георисковете, които потенциално биха могли да засегнат до 13% от населението на ЕС. Геоложките рискове описани за София се получават както част от PanGeo Ground Stability Layer (GSL) за София (междинен продукт), България. Районът, обхванат от GSL картата съответства на административна област на Столична община (~ 1342 km<sup>2</sup>) и включва град София и други населени места. Идентифицирането на георисковете е извършено чрез комбинираното тълкуване на геоложки, данни за земеползване и други геопропространствени слоеве заедно със сателитни (PS) данни за земното движение за периода 1992-2003 г. за град София, чрез преработка на ERS-1/2 SAR с InterferometricPointTargetAnalysis (IPTA) алгоритъм. Резултатите от проекта са включени в портала OneGeology-Europe имащ за цел създаването на дигитална геоложка карта на Европа.

### Introduction

PanGeo project provides information describing the stability of the ground. Ground instability can be dangerous and costly, yet information on these phenomena has, to date, been difficult to obtain (Frey et al., 2012). PanGeo provides free access to ground instability geohazard information for many of Europe's largest cities (Cigna et al., 2012). Users of the PanGeo service include local authorities, civil protection agencies, geological surveys, insurers and businesses providing environmental and land reporting services and of course the general public (Bateson et al., 2011; Jordan et al., 2011).

PanGeo provides open access to validated and INSPIRE compliant geohazard products for 52 cities and towns. Products are generated by the European geological surveys; using satellite derived terrain motion data and integrated with geological information.

The University of Mining and Geology is responsible for the generation of the PanGeo products for Sofia and Varna, Bulgaria. This paper presented the results obtained for Sofia.

The product consists of the polygon-wise Ground Stability Layer (GSL) showing location, extent and typology of the observed and potential geohazards, and the GeoHazard

Description (GHD) document, a supporting report which describes in detail the geological setting and places of interest affected by each geohazard, the confidence and any additional evidence associated with the interpretation.

PanGeo project provides a 'ground stability layer' product which describes the spatial location and extent of geohazards for all the towns mapped. Each polygon within the ground stability layer is linked to a full interpretation made by that country's National Geological Survey. PanGeo data is created by combining the following information:

- Satellite measurements of ground and building movement
- Geological information already held by National Geological Surveys.

Also included in the PanGeo product is the European Commission's Urban Atlas land use data; this provides insights into what types of urban land use are affected by geohazards described in the ground stability layer. Access to the GSL and the GHD for a town is via the PanGeo website ([www.pangeoproject.eu](http://www.pangeoproject.eu)).

The area covered by the GSL of Sofia (fig. 1), a ~1,342 km<sup>2</sup>, area that includes the City of Sofia and other surrounding boroughs, with a total population of about 1,3 million inhabitants in 2011 (~5,200 inhabit/km<sup>2</sup>). Urban areas cover ~

258km<sup>2</sup> while the Sofia town covers ~ 153.6km<sup>2</sup>. Mountains and forest units cover ~618km<sup>2</sup>. Agriculture and semi-natural areas are mainly concentrated in the external sectors of Sofia, for a total of 309km<sup>2</sup>.

## Geological settings

The Sofia valley is situated between West Balkan Mountain unit (part of the Balkan zone) and Western Srednogorie Mountain unit (part of the Srednogorie zone).

The West Balkan Mountain unit is composed of greenschist facies Vendian-Cambrian ophiolite, island-arc and olistostrome assemblages at the base, overlain by Ordovician, Silurian and Lower-Middle Devonian slates and clastic rocks, Upper Devonian to Lower Carboniferous flysch, Upper Carboniferous coal-bearing continental sediments and Permian clastics. The Mesozoic succession begins with Triassic clastics and platform carbonates, followed upward by Lower-Middle Jurassic continental to shallow marine sediments and a dominantly carbonate succession of Late Jurassic to Late Cretaceous-Paleocene age. Lower-Middle Eocene continental to shallow marine clastic and carbonate sediments are locally exposed. The main compressional deformations are of Late Cretaceous age. Mid-Eocene thrusting over the Moesian platform affected the northern periphery of the unit.

The West Srednogorie Mountain unit is composed of locally exposed high-grade metamorphic rocks of Precambrian (?) age at the base, overlain by Devonian flysch, Permian clastics, Triassic platform carbonates, Jurassic shallow marine clastics and carbonates, Upper Jurassic - Lower Cretaceous flysch and Lower Cretaceous carbonate successions (Dabovski et al., 2002). The Upper Cretaceous section begins with Cenomanian-Turonian continental to shallow-marine clastics and shales, followed upward by an over 4 km thick Coniacian-Campanian volcano-sedimentary succession that is transgressively overlain by Campanian-Maastrichtian shales and carbonates. Typical magmatic rocks are basic to intermediate varieties of the calc-alkaline and high-potassium calc-alkaline series with shoshonitic trends in some polyphase plutons. The cover comprises Oligocene and Neogene continental sediments.

The Vitosha paleovolcano is situated south of Sofia. Part of the city is situated on its products. The Vitosha volcano is largest well shaped volcanic structure in the Western Srednogorie zone (Zhelev, 1982, 1988). The volcano products are presented by lava flows and lava breccias. Their thickness is from 10 to 80-100m. They are Ca-alkaline and of basaltic to andesitic chemistry.

The subvolcanic rocks related to the Vitosha volcano are represented by numerous dykes, situated near the volcanic centre. They are of basaltic-andesite to andesitic and dacitic chemistry. Pyroclastic rocks outcrop on the northern slopes of the Vitosha Mountain. The Vitosha pluton is of area about 120 km<sup>2</sup>. It is intruded in the central part of the volcano (Zhelev, 1982, 1988). The plutonic rocks are gabbros, monzonites, syenites and aplitic granosyenites.

Rock complexes outcropped in the Sofia area are presented by Upper Cretaceous magmatic products and sediments,

Paleogene sediments and Quaternary depositions. Upper Cretaceous rocks are presented by sediments: sands and marls, volcanic products: lavas of andesitic composition, tuffs and subvolcanic bodies. The Paleogene sediments are thick complexes represented mainly by clays, sands, gravels and conglomerates. The Quaternary depositions are built up predominately by alluvial and proluvial sediments. They consist of gravels, sands and clays.

## Input data

PanGeo thematic services are based on advanced satellite interferometry products; however they exploit additional data sources. During the interpretation of Sofia and surrounding area a series of geologic datasets composed primarily of recent vector geological maps Scale 1: 100000 are used. The biggest part of the data are restricted, some of them are available in the National Geofond (vector Geological maps in 100 000 or 50 000 scale) or in the Sofia municipality.

## PSI processing and methodology

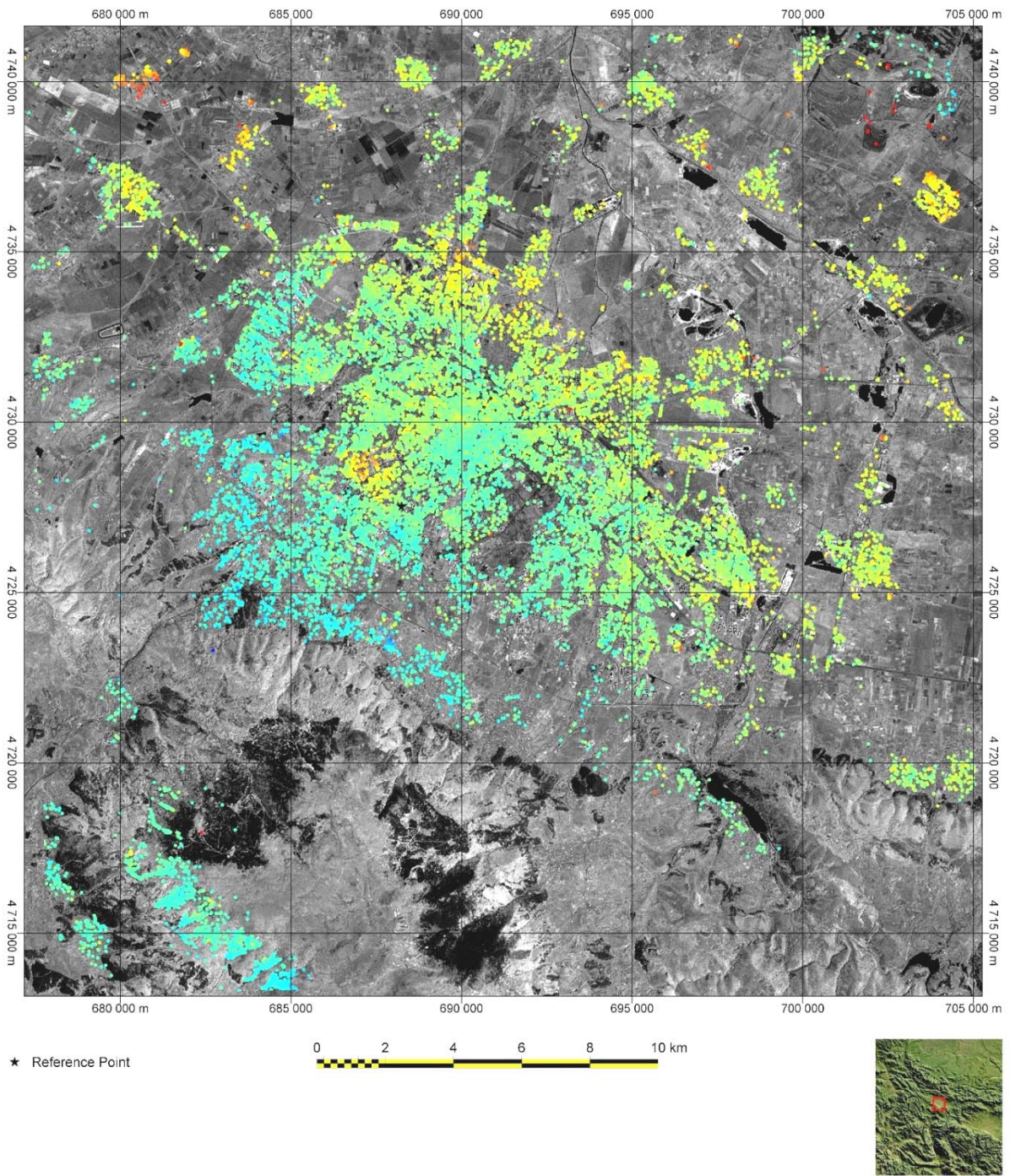
Persistent Scatterer Interferometry (PSI) is the most advanced class of differential interferometric Synthetic Aperture Radar techniques (DInSAR) based on data acquired by spaceborne SAR sensors. One of the advantages of PSI is its sensitivity to small deformations, which in terms of deformation velocity are in the region of 1 mm/yr. PSI also offers wide-area coverage (ERS standard imagery, for instance, cover 100 by 100 km) typically associated with a relatively high spatial resolution (Ferretti et al., 2001).

PSI processing was carried out in the period between 11 December 1992 and 05 October 2003. It was used two satellite data type – ERS-1 and ERS-2 and 57 number of scenes. For this period were identified 37399 number of PS. The Average PS density (PS/km<sup>2</sup>) is about 48.

The area shows wide spread stability (table 1). There are a couple slow moving areas in the center of the scene, showing some movement away from the satellite. A clear moving area is identified on the north-east corner of the scene: in that case, both movement towards and away from the satellite is measured.

Table 1  
*PS motion statistics*

PS motion statistics (mm/year classes)	Number of points in each mm/year class
-27.51 to -5	24
-5 to -3.5	71
3.5 to -1.5	1724
-1.5 to +1.5	34357
+1.5 to +3.5	1214
+3.5 to +5	7
+5 to +6.65	2
Average annual motion rate of the entire processed area	0.01
Standard deviation of average annual motion rate	0.77



Period: 11th December 1992 to 5th October 2003  
No. Scenes: 45  
Master Scene: 5th December 1999

Coordinate System: Universal Transverse Mercator  
Zone: 34 (E 18 to E 24)  
Projection: Transverse Mercator  
Datum: World Geodetic System 1984  
Ellipsoid: WGS 1984  
Units: meters

Fig. 1. Persistent Scatterers (PS) ground motion data for 1992-2003 for the city of Sofia

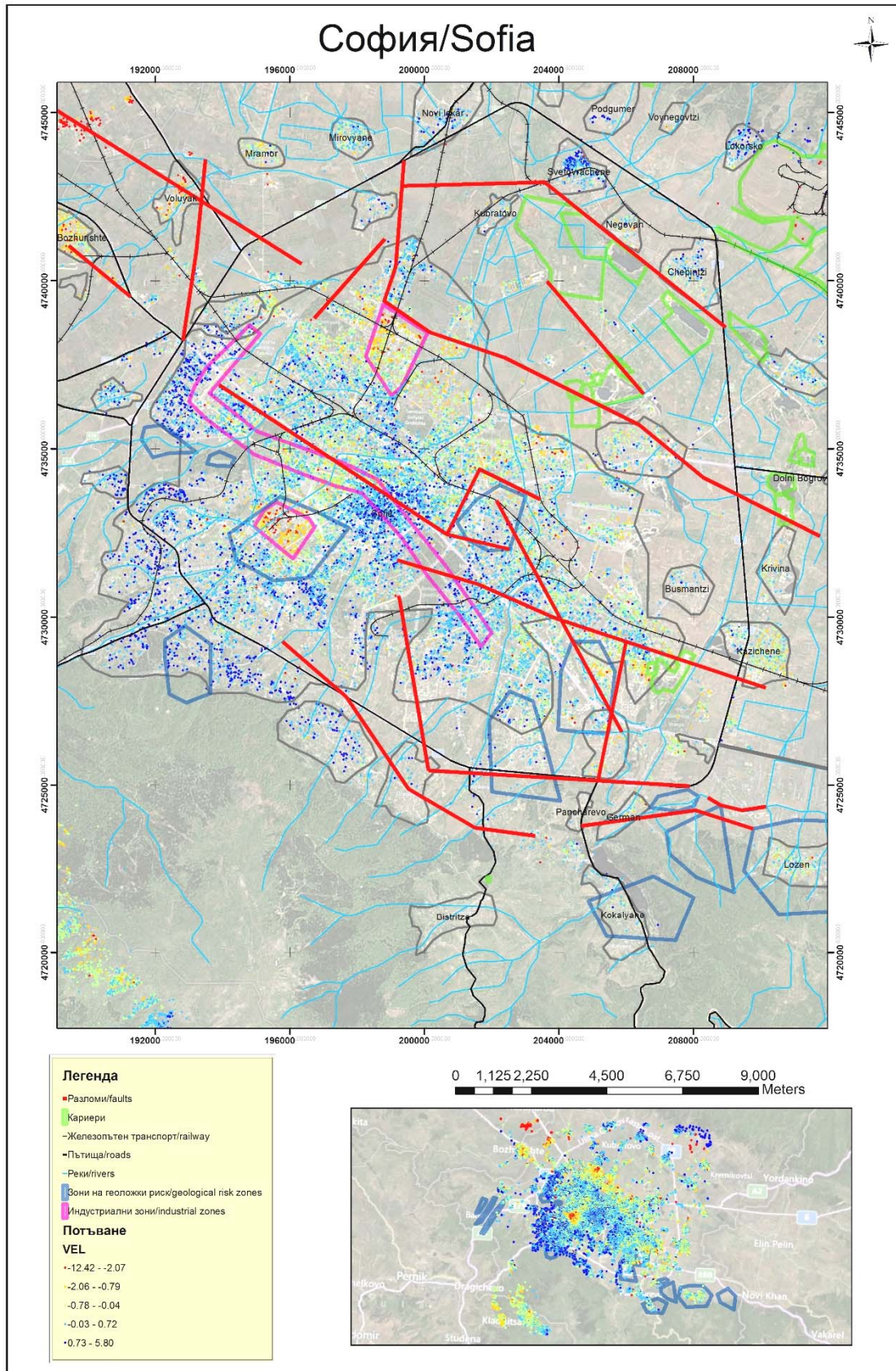


Fig. 2. Identified ground instabilities polygons for the city of Sofia

### A summary of the identified ground instabilities

Geological conditions capable of causing damage, or loss of property and life, are called geological hazards and commonly referred to as "geohazards".

PanGeo is specifically focused on geohazards relating to ground instability and mapping phenomena in the urban environment where their effect is most damaging. Ground movements (upwards, sideways or downwards) can be caused

by a wide range of natural and manmade geological processes with some processes being so slow as to be imperceptible to the naked eye whilst others may cause large scale obvious movement in the ground. Whatever the "geohazard" they have the potential to severely damage urban infrastructure and buildings (Bateson et al., 2011).

Geohazards can be described as either 'potential' or 'observed'. A potential geohazard exists in the case that the local geology makes it more probable for ground movement to occur even if movement has not been measured. At the other hand observed geohazards are where ground movement has been measured (by whatever method). The PanGeo ground stability layers captures both potential and observed geohazards.

In PanGeo project ground stability geohazards are grouped into common classification themes describing the broad scale processes at work (Cigna et al., 2012):

- 1) Deep ground motions
  - Earthquake (seismic) hazard
  - Tectonic movements
  - Salt Tectonics
  - Volcanic Inflation/deflation
- 2) Natural ground instability
  - Landslide
  - Soil Creep
  - Ground Dissolution
  - Collapsible Ground
  - Running Sand/ Liquefaction
- 3) Natural ground movement
  - Shrink-swell clays
  - Compressible Ground
- 4) Man-made ground instability
  - Ground water management - Shallow compaction
  - Ground water management - Peat oxidation
  - Groundwater abstraction
  - Mining
  - Underground construction
  - Made ground
  - Oil and Gas Production
- 5) Other

In this research for the city of Sofia were recognized geohazard polygons mainly in two groups - Natural ground instability and Man-made ground instability. The first one describes ground conditions where there is a propensity for upward, lateral or downward movement of the ground. Some movements associated with particular hazards may be gradual or occur suddenly and also may vary from millimeter to meter or even tens of meters scale. Man-Made Ground Instability are ground motions covering a local area brought about by the activity of man. Subsidence (downward movement) of the ground can result from a number of different types of anthropogenic activity, namely mining (for a variety of commodities), or tunneling (for transport, underground service conduits, or for underground living or storage space).

The Ground Stability Layer is represent a collection of polygons representing areas of ground instability within the Sofia. Potential for natural ground movements is observed for the majority of the area of interest. Geohazards observed

through the PS data include both natural processes (landslide) and anthropogenic instability due to underground construction, recent engineering works and mining. There were identified 40 geohazard polygons (fig. 2) over city of Sofia in 3 different categories (geological risk, industrial area, mining sites). The polygons which fall in first category (mainly landslides) cover ~ 46 km<sup>2</sup>; the mining sites polygon cover ~ 160.7 km<sup>2</sup>; the industrial area polygons cover ~ 12.5 km<sup>2</sup>.

In geological risk category there are identified 15 polygons. The hazard type is recognized as landslide and confidence level is high (fig. 2). There are 22 polygons which are recognized in hazard category Anthropogenic Ground Instability (fig. 2). That is quarries from hazard type mining with external confidence. The industrial area polygons are situated in the downtown (fig. 2). Hazard type is Underground Construction and other. Confidence level is medium. There are 3 polygons of this type. All of the identified geohazard polygons are described as "potential".

Detailed information for all of these 40 polygons is available in Geohazard Description Document for Sofia (Stoykov et al., 2013). For each polygon is made geological interpretation of the motion which include the mechanisms that are at play including the relationships between the interpreted ground stability areas and the geological and ancillary datasets.

It is used a digital terrain model created with the mission of the space shuttle in February 2000, known as SRTM (shuttle radar topographic mission) and having a resolution of 90 m (pixel size).

The product created by PanGeo is a web-based geoportal based on the One-Geology Europe infrastructure. Within this geoportal is a Ground Stability Layer for each of the 52 towns for which PanGeo information is to be made available. In the geoportal the Ground Stability Layer will be automatically integrated with the Urban Atlas data. Since the Urban Atlas gives information on land cover types (exposure) and the Ground Stability Layer provides information on hazards the user can make informed decisions on risk. The portal provides the ability to both view and download the Ground Stability Layer and Geohazard Summary (as GHD).

## Conclusions

Combined interpretation and integration of geological maps, land-use layers and other geospatial information with ground motion estimates derived from Persistent Scatterers data in the period between 1992 and 2003 allowed the identification and mapping of observed and potential geohazards in 40 polygons over Sofia valley. The identified geohazard polygons include both natural processes and anthropogenic instability. This information is synthesized and made available to the public through the PanGeo Ground Stability Layer and Geohazard Description document, and will act as a support for local authorities, planners, regulators and decision makers in their long and short term land-use planning and risk management activities.

PanGeo represent an online service that provides to all users open access to geohazard information across European cities

and towns down to a mapping scale of 1:10 000. Geohazards are natural and man-made phenomena that make the ground unstable and in a built environment can be both costly and dangerous. PanGeo's geohazard products have been created to improve decision making and reduce risk. PanGeo data can be viewed in Google Earth or via the integrated "portal".

The results of Pangeo project are included also in OneGeology-Europe portal (<http://onegeology-europe.brgm.fr/geoportal>) which aims to create dynamic digital geological map data for Europe. This geological portal will make a significant contribution to the progress of INSPIRE directive- i.e. develop systems and protocols to better enable the discovery, viewing, downloading and sharing of core European spatial geological data. OneGeology-Europe portal will make geological spatial data held by European geological surveys both discoverable and accessible.

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