Grant Agreement No. 718679
Safety – Sentinel for geohazard
prevention and forecasting

Deliverable DD.1: Test site characterization

A deliverable of

Task D: Test sites characterization and geodatabases

Due date of deliverable: 31/05/2016
Actual submission date: 31/05/2016

Lead contractor for this deliverable: UNIFI

Dissemination Level		
PU	Public	x
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the Consortium (including the Commission Services)	
CO	Confidential, only for members of the Consortium (including the Commission Services)	
TN	Technical Note, not a deliverable, only internal for members of the Consortium	

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EXECUTIVE SUMMARY

SAFETY is a two years research project funded under the ECHO (European Commission's Humanitarian aid and Civil Protection department call "Prevention and preparedness projects in Civil Protection and marine pollution", and it started 1 January 2016. The mission of the project is to improve the efforts in detecting and mapping geohazards (i.e. landslides and subsidence), by assessing their activity and evaluating their impact on built-up areas and infrastructures' networks. SAFETY will enhance ground deformation risk prevention and mitigation efforts in highly vulnerable geographic and geologic regions. The outcomes of the project will provide Civil Protection Authorities (CPA) with the capability of periodically evaluating and assessing the potential impact of geohazards on the selected sites.

D.D1 "Test site characterization" is the first of the two deliverables of Task D "Test sites characterization and geodatabases". This deliverable provides the characterization of the test sites selected for the project, especially from a geo-hazard point of view.

REFERENCE DOCUMENTS

N°	**Title**
RD1	DoW – FormT3a
RD2	

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1 INTRODUCTION

SAFETY project will be tested in two areas in Europe (in Italy and Spain). The selected study areas were chosen on the presence and relevance of known phenomena that threaten the urban fabric and population, and on the availability of significant thematic and environmental data, as well as on a specific interest of Civil Protection authorities.

2 DESCRIPTION OF THE TEST SITES

The two selected test sites are:

- Volterra site in Tuscany region (Italy)
- Canary Islands (Spain): Tenerife Island for deformation test and Gran Canaria Island for landslides test site.

For each test site, the geographical location, the physiographical and geological description, various thematic maps, as well as relevant geo-hazard phenomena are presented hereafter.

3 INTRODUCTION

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4.1 Volterra (Tuscany region, Italy)

Volterra municipality is located in Tuscany region, in central Italy. The municipal area extends up about 250 km^2, between Era river and Cecina river valleys (Figure 1).

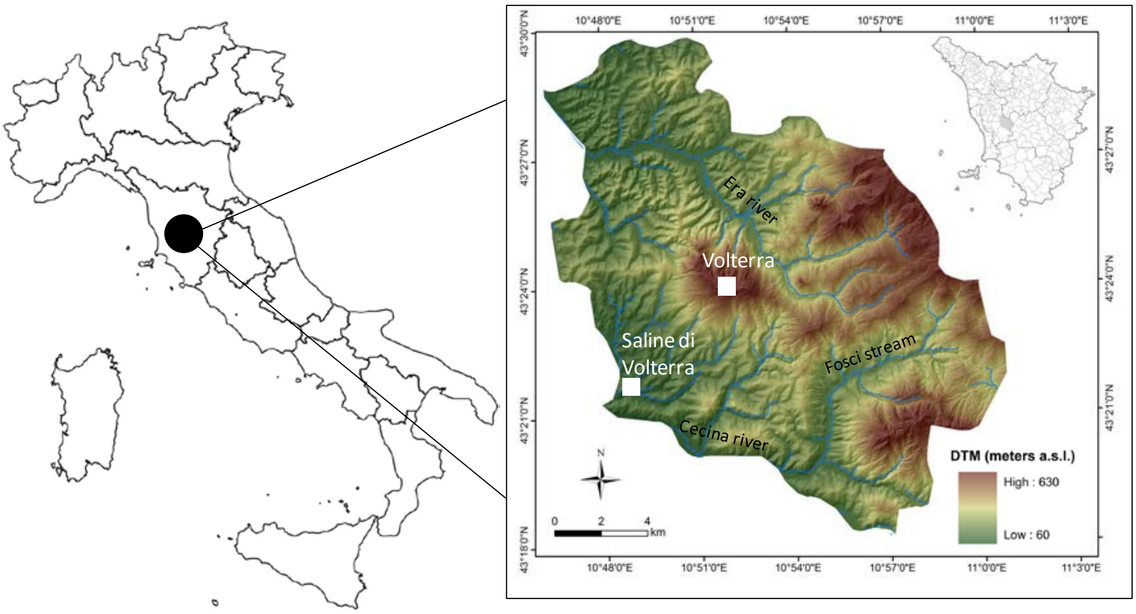


Figure 1 Location of Volterra municipality.

The most relevant urbanized zones are Volterra city and Saline di Volterra town (Figure 1). Volterra is an historical town that includes Etruscan, Roman and medieval settlements, still visible on the present urban centre enclosed by great defensive town-wall.

The territory has been chosen as test site as it is extensively affected by slope instability, consisting in shallow slow-moving and complex landslides, mainly rainfall-triggered, and falls (Volterra Crags), as well as gully erosion in a badland landscape.

This site has drawn the attention of many geoscientists and of the Italian Civil Protection due to some recent landslide occurrences within the city center and surrounding area. In particular, the historical city centre and its surroundings has been object of recent monitoring after two wall collapses occurred on 31st January 2014 and on 3rd March 2014 (Figure 2). After this emergency, the site has been investigated more in depth, with particular attention to the preservation of the cultural heritage of the urban setting.

Within this emergency phase, many data have been already collected including SAR images and many thematic data provided by the Municipality Authority in charge of Environmental Service and Civil protection activities.

Figure 2 Failures occurred on the Volterra city center: (a) Wall collapse on 31st January 2014; (b) Wall collapse on 3nd March 2014.

4.1.1 Physiographic and geological setting

The Volterra test area is characterized by a typically hilly morphology, with moderate relief and gentle slopes.

Altitudes range from 60 m a.s.l. up to about 630 m a.s.l. The historical city center of Volterra is located on a tableland at 550 m a.s.l. elevation.

The Volterra surroundings are deeply influenced by the geological settings and the geotechnical properties of the outcropping formations. In poorly-vegetated clayey slopes, heavy rainfall and freezing-thaw cycles trigger very rapid geomorphological processes such as soil erosion (rill and gullies) and shallow landslides, inducing strong erosion rates.

Shrinkage-swelling phenomena dominate the hydrogeological behavior of soils. Within clayey sediments, the landscape is characterized by eroded areas with well-defined deep incisions, desiccation cracks and decortication of the surfaces in the dry season followed by imbibition in winter (Bazzoffi et al. 1997).

Figure 3 Typical landscape nearby Volterra city, characterized by outcrops of clayey and sandy lithotypes and badlands environment.

The climate is mesothermic, humid, Mediterranean type with a dry summer and rainfall concentrated in spring and autumn (Bazzoffi et al. 1997). The average annual precipitation ranges approximately 760-800 mm/year, according to the most recent available data (AMI 2011).

The drainage network consists of different catchment water-basins; the Era river, Cecina river and Fosci river represent the most important waterways. The drainage pattern is sub-dendritic and characterized by a rather dense network of many tributary streams.

From a geological point of view, the study area is located in the wide Pliocene graben-basin, known as Volterra basin, which is NW-SE oriented and bordered by normal faults (Giannini et al. 1971).

This tectonic depression was generated during the Neogene post-orogenic extensional stage. The outcropping terrains are mainly Miocene-Pliocene clayey and Middle-Late Pliocene sandy marine formations (respectively “Blue Clays” and “Villamagna sands”) that represent the sedimentary filling of the basin. Calcarenites and limestones close the marine sedimentary succession and constitutes the tableland on which Volterra city was built (Bianchini et al., 2015). These 3 lithological units (Blue clays, sands and uppermost calcarenites) are stacked in horizontal or sub-horizontal layers, slightly dipping about 2-10° towards NE.

Fine and coarse detritic sediments, developed in lacustrine or lagoonal cycles (e.g. “Fosci Clays”) or in a continental fluvial-deltaic environment (e.g. conglomerates and breccias) are also present. Chemical sedimentary deposits, e.g. gypsum levels and travertine, crop out in the southern sectors of the area (e.g. on Saline di Volterra area), deriving from some Miocenic evaporitic episodes (Bazzoffi et al. 1997). Along the margins towards SE of the basin, some underlying Jurassic-Cretaceous ophiolitic rocks (serpentinites, basalts and gabbros) sporadically outcrop. Marls and sandstones belonging to various sedimentary cycles also crop out in the eastern-southern portion of the municipality. Recent colluvial debris which derives from the weathering of upper sandy and calcarenitic formations and alluvial deposits finally fill the valleys, incised by rivers and streams over the whole area (Pascucci et al. 1999).

In order to obtain an exhaustive geological map of the test area, the lithotypes cropping out in the Volterra municipality have been grouped into 10 lithological complexes, taking into account their geo-mechanical properties and consequently their predisposition to erosion: alluvial deposits, colluvial deposits, conglomerates and breccias, sands and silts, clays, limestones, sandstones, ophiolites (basalts, serpentinites and gabbros), evaporites (gypsum, travertine, anhydrite), marls (Figure 4).

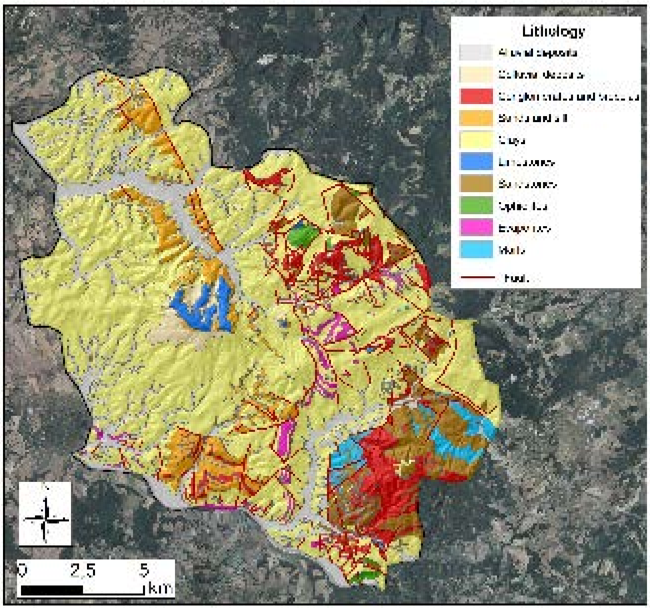


Figure 4 Geological map of the Volterra test area.

4.1.2 Thematic maps

The thematic layers that are available for the test site of Volterra municipality encompass raster and shapefile information for the geo-morphological description of the area and for its preliminary characterization regarding ground movements and geo-hazards.

The thematic maps that deals with the morphological description of the area are:

- *Digital Elevation Model:* raster layer. Digital Terrain Model (DTM) with 10x10 m cellsize resolution obtained from TINITALY/01 DEM Project (Tarquini et al. 2012) (Figure 5a).

- *Land use map*: shapefile and raster. This product derives from CORINE Land Cover project in Italy referred to 2006 (CLC, 2006). The chosen level of categorization is a merge of level 2 and

3 of CORINE Land Cover and distinguishes among: woods, sparse vegetation and scrubs, pastures, olive and vineyards, crops, bare soils, agricultural and natural areas, urban areas (Figure 5b).

- *Aspect map*: raster layer derived from DEM with 10 m cellsize, defined as the compass exposure direction that a slope faces with respect to N (Figure 5c).

- *Slope map:* raster layer derived from DEM with 10 m cellsize that defines the steepness of the territory. The map is measured from 0 to 90°. Within the Volterra Municipality, the steepest slopes, reaching up about 55-61°, occur on the mountain-sides of Mt. Montenero in the NE portion of the area and NE of Volterra city towards Era river valley (Figure 5d).

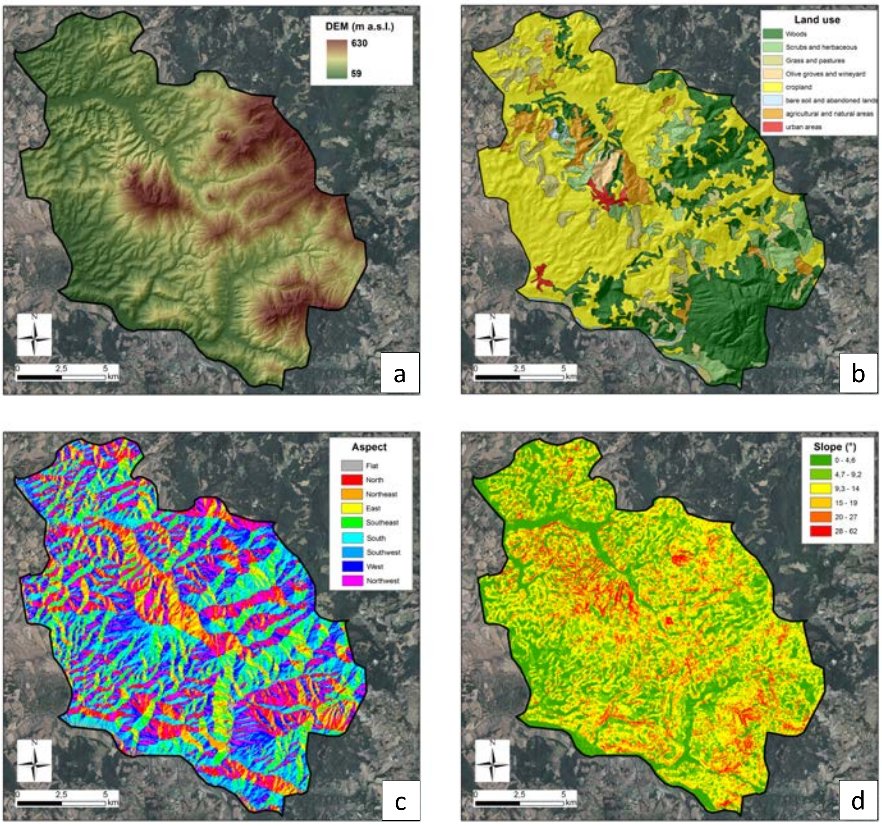


Figure 5 Thematic maps for the morphological description of the area: (a) DTM; (b) Land use map; (c) Aspect map; (d) Slope map.

Data that deals with the preliminary characterization of ground movements and geo-hazards are (Figure 6):

- *Landslide Inventory Map:* shapefile of the Landslide Inventory Map (LIM) of the test area. Landslides are classified on the basis of their typology and state of activity (Figure 6a).

- *SAR data:* PSI data derived from SAR images from different satellite sensors: ERS (1992-2000) processed by means of PSInSARTM acquired in descending pass (Figure 6b), ENVISAT (2003-2010) processed by means of PSInSARTM acquired in descending and ascending passes (Figure 6c), and COSMO-SkyMed (2013-2015) processed by means of SqueeSARTM acquired in ascending and descending passes (Figure 6d).

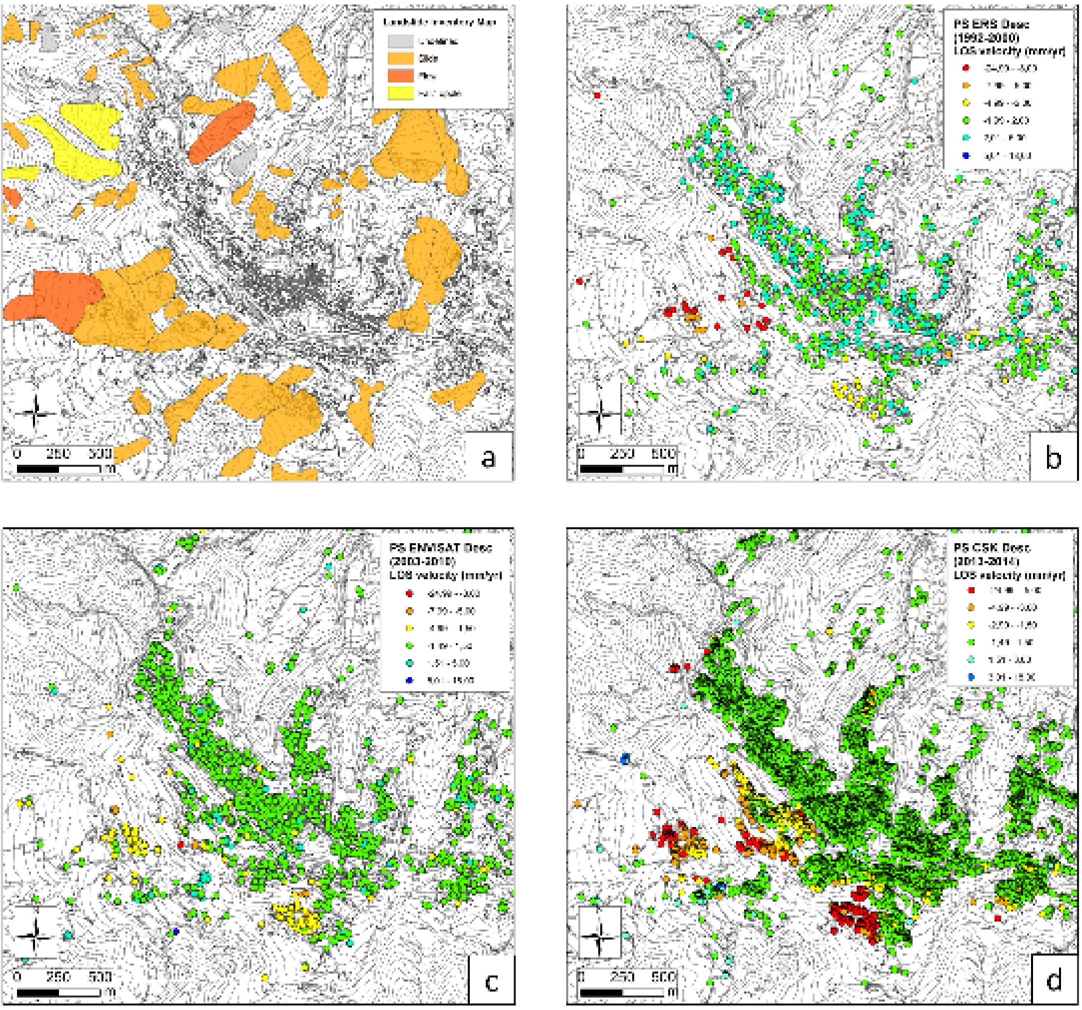


Figure 6 **Data for the characterization of ground movements: (a) LIM; (b) ERS data; (c) ENVISAT data; (d) CSK data.**

4.1.3 Relevant geo-hazard phenomena

The geological structure and topography of the Volterra tableland and surroundings influence the typology and the spatial distribution of mass movements in the area.

Nearby Volterra city, the layer inclination and the contrast between the impermeable clays, the upper erodible sands and the well-cemented calcarenites determine different kinds of landslides and soil erosion processes (Sabelli et al. 2012).

The most representative types of landslides are slides (64% of the total amount) and flows (29%). Falls and topples are mapped only in a very small sector characterized by the presence of *Balze* crags (Figure 7).

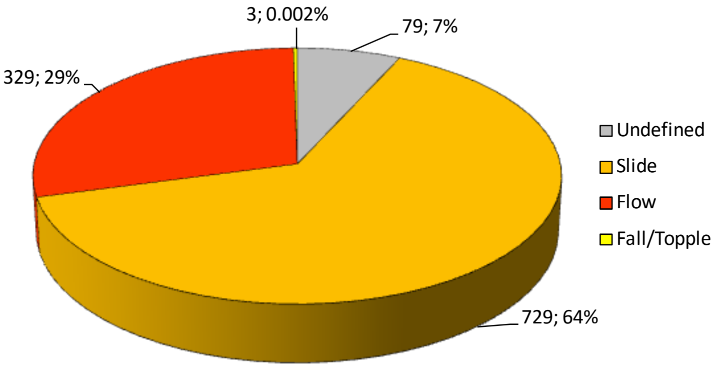


Figure 7 Amount and percentages of landslide typologies within Volterra municipality.

In particular, on the southwestern slope of the Volterra hill, the blue clays mainly crop out and the morphology is gentle (Pratesi et al. 2015). Thus, the area turns out to be widely affected by badlands, typical landforms of clayey soils, shallow slides, and flows.

Slow-moving landslides that occur on the SW sector of Volterra city threaten the urban fabric, causing several damages on the facades and compromising the stability of buildings (Figure 8a).

Figure 8 (a) Landslide impacts on building facade; (b) Translational slide affecting the provincial road SP15; (c) Fall within Balze crags area.

The shallow colluvial deposits, made up of chaotic detritus, contribute to determine ground instability, particularly affecting the road network (Figure 8b).

In the SW sector of the urban area of Volterra city, the colluvial debris reaches up a thickness of 20 meters. As a result, diffuse landsliding of this zone actually refers somewhere to shallow ground deformation related to the instability of the colluvial layer or to surface creep downslope, rather than to landslides.

Shallow slow-moving landslides also occur on badland areas where shallow slides and flows coexist with concentrated water erosion, leading to smooth slopes characterized by accelerated erosion in a incipient or residual morpho-dynamic *calanchi* stage.

From an altitude of 450 m a.s.l., sands crop out overlapped by calcarenites that outcrop on the opposite hillslope: here a more abrupt morphology prevails, characterized by complex movements and falls due to the undermining of the clayey bases of the hills and consequent retrogressive slope failures that generate very steep, sub-vertical cliffs (i.e. balze crags) around the Volterra tableland (Figure 8c).

4.2 Canary Islands (Spain)

The Canary Islands is a populated outermost Spanish region and one of the most popular touristic destinations in Europe (Figure 9). More than 2 million people live and work in the 7,447 km2 of the archipelago, resulting in an average population density three times greater than the rest of Spain. The archipelago is one of the major volcanic oceanic island groups of the world and have a long magmatic history, which began at the bottom of the ocean more than 40 million years ago (Araña and Ortiz, 1991). This volcanic archipelago is constructed on the passive continental margin of the African Plate on Jurassic oceanic lithosphere and comprises seven main volcanic islands that form a chain extending for some 500 km across the East Atlantic Ocean (e.g. Carracedo et al., 2002).

Figure 9. Image showing the Canary Islands archipelago in the Atlantic off the African coast

Most of the historical eruptions in the Canary Islands have been short lived (from few weeks to few months) basaltic, strombolian to violent strombolian eruptions, which have generated scoria cones of different sizes and lava flows of different extend (Romero, 1991). **Table 1** summarizes the historical eruptive activity in the Canarian Archipelago, and **Figure 10** shows the extent of the eruptive products.

Year	Name	Island	Start/End	days	Damages
2011/12	E. de El Hierro	El Hierro	10 Oct 2011 / 5 May 2012	147	Damages in the submarine environment
1971	V. Teneguía	La Palma	26 Oct / 18 Nov	24	1 casualty (due to gas inhalation)
1949	E. San Juan	La Palma	24 Jun / 30 Jul	47	Destruction of houses due to earthquakes, destruction of farmlands
1909	V. Chinyero	Tenerife	18 Nov / 27 Nov	10	No damage
1824	V. Tinguatón	Lanzarote	10 Oct / 24 Oct	86	Destruction of farmlands and water deposits
	V. Chinero		29 Sep / 5 Oct		
	V. Tao		31 Jul / 31 Jul		
1798	V. Chahorra	Tenerife	9 Jun / 14-15 Sep	99	No damage
1730/36	E. Timanfaya	Lanzarote	1 Sep 1730 / 16 Apr 1736	2055	Destruction of houses and water supply systems, destruction of farmlands and pastures, losses of livestock due to gas inhalation, population emigration
1712	E. Charco	La Palma	9 Oct / 3 Dec	56	Destruction of houses, destruction of farmlands
1706	E. Garachico or V. Arenas Negras	Tenerife	5 May / 13 Jun	40	Destruction of Garachico harbour, destruction of houses, destruction of farmlands, forest fires
1704/05	V. Arafo	Tenerife	2 Feb / 27 Mar	54	16 casualties due to earthquakes, collapse of more than 70 houses due to earthquakes
	V. Fasnia	Tenerife	5 Jan / 16 Jan	12	
	V. Sietefuentes	Tenerife	31 Dec / 4 or 5 Jan	5	
1677/78	V. de San Antonio	La Palma	17 Nov / 21 Jan	66	4 casualties, destruction of houses and water deposits, losses of goat livestock, destruction of pastures
1646	V. Martín or V.de Tigalate	La Palma	2 Oct / 21 Dec	82	Destruction of houses and water deposits, forest fires and losses of livestock
1585	Tehuya	La Palma	19 May / 10 Ago	84	Destruction of farmlands and forest fires
1492	E. de Colón	?	?	?	?
1430/ 1440	E. Tacande or Montaña Quemada	La Palma	?	?	?

Table 1. Historical eruptions in the Canary Islands, E. means ‘eruption’ and V. ‘volcano’. Extracted from table by Dr. Carmen Romero from La Laguna University at http://www.ign.es/ign/resources/actividades/volcanologia/TablaAmpliada.pdf

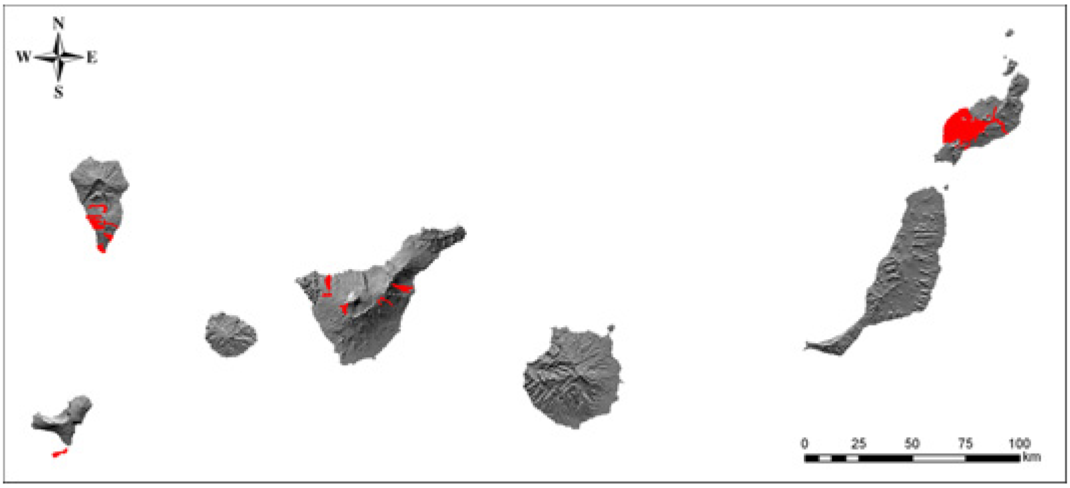


Figure 10. Area affected by the well documented eruptions since 1585 in the Canary Islands (source: IGN, www.ign.es)

In addition to the volcanic hazard SAFETY project will also address landslide susceptibility in the Canary islands. Rockfalls are the most frequent and damaging landslide type in the archipielago, in the past decade the Emergency Services from Gran Canaria and Tenerife island accumulate more than 7000 rockfall events producing damages to communication networks.

A pilot study will be made in the northwestern part of Gran Canaria island, along the GC-200 road (Fig. 11). The choice of this pilot area is due to Gran Canaria island emergency services priorities. Subsequently, depending on the performance of the susceptibility model and the confidence on the results on this first pilot, another test site will be probably be included from Tenerife island (Anaga road in Tenerife island). This test site will be described in future updates of this deliverables.

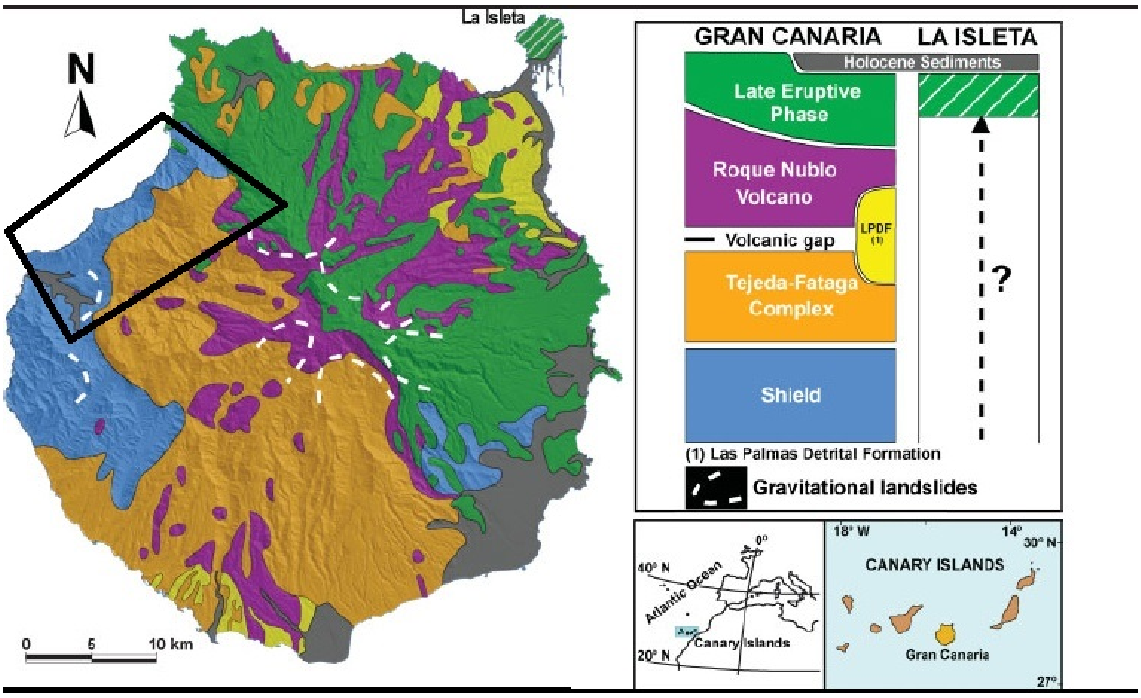


Figure 11. Simplified geological map of Gran Canaria, with the main volcanic phases and deposits (Rodríguez-González et al., 2009). Massive flank failures are indicated.

Aldea study area is located in the western extreme of Gran Canaria, and specifically between the localities of Agaete (5767 inhabitants) and Aldea (8633 inhabitants). The GC-200 road constitutes the main transportation corridor between both localities. With a length of 34 km, the road path is very tortuous following the contour of the coast, a very step coastline (Figs. 11 and 12) with the highest cliffs in Europe (Risco Faneque, 1027 m a.s.l.). From the point of view of mobility, the GC-200 is a strategic road as it is the transportation via of the tomato production cultivated in numerous plastic greenhouses in Aldea. Additionally, the road is very attractive for tourism due to the spectacular landscape views. The road has heavy traffic estimated on average at 1500 vehicles per day, with a greater influx of vehicles during the months from October to May.

Figure 12. The road cut the alkaline basaltic formation (hard rocks) from the shield stage deposited during Middle Miocene

4.2.1 Physiographic and geological setting

Tenerife

Tenerife is located in the central area of the Archipelago, between 27º 59’ 59’’ N and 28º 35’ 15’’ N and 16º 50’ 27’’ W and 16º 55’ 40’’ W. It is the larger island with a surface of 2.057 km^2 and also the most populated. Its highest point, Mount Teide, with an elevation of 3.718 m (12,198 ft) above sea level, is the highest point in all of Spain, and is also the third largest volcano in the world from its base at the bottom of the sea. The origin of its magmatism is still controversial and several hypotheses, including a mantle plume hotspot (Hollik et al., 1991; Hoernle and Schminke, 1993; Carracedo et al., 1998), a local extensional ridge model (Fúster, 1975), and an uplifted tectonic block model (Araña and Ortiz, 1986), have been mooted to explain its geological features. Petrological, geophysical, and geochemical evidence from its sub-lithospheric mantle have even provided evidence for other possible explanations including those reported by Anguita and Hernán (2000), who unify in a single model thermal mantle anomaly features and the critical role of regional fractures and tectonic forces at the onset of magmatic activity. The uneven and steep orography of the island and its variety of climates have resulted in a diversity of landscapes and geographical and geological formations, from the Teide National Park with its extensive pine forests juxtaposed against the volcanic landscape at the summit of Teide and Malpaís de Güímar, to the Acantilados de Los Gigantes (Cliffs of the Giants) with its vertical precipices (**Figure 13**).

The principal structures in Tenerife make the central highlands, with the Teide–Pico Viejo complex and the Las Cañadas areas, as the most prominent area with a surface of 130 km^2. Las Cañadas caldera was formed by vertical collapses produced after intense explosive volcanic activity (Martí et al., 1997; Martí and Gudmundson, 2000). The area is partially occupied by the Teide-Pico Viejo strato-volcano and completed by the materials emitted in the different eruptions that took place. The Teide is one of the 16 Decade Volcanoes identified by the International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI) as being worthy of particular study in light of their history of large, destructive eruptions and proximity to populated areas.

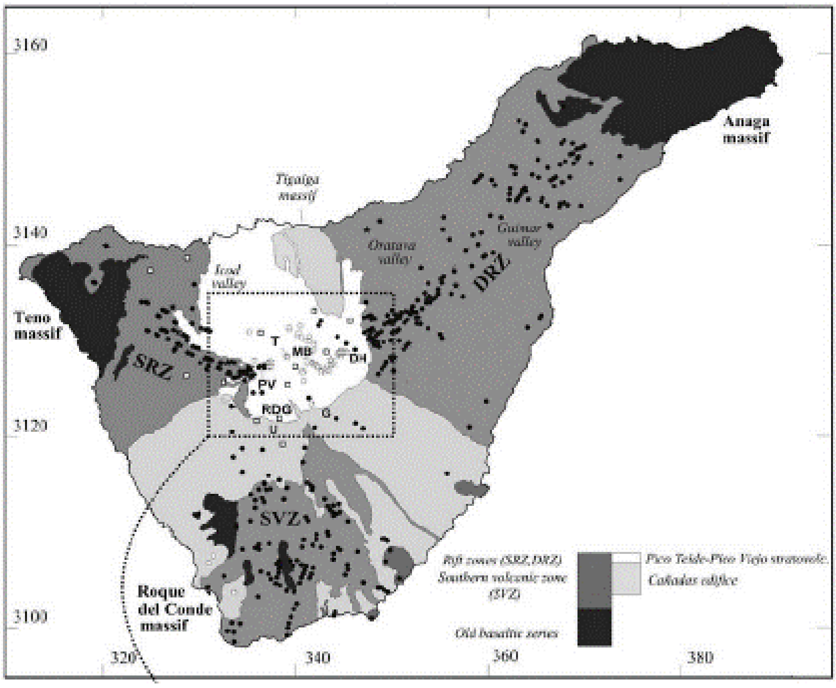


Figure 13. Simplified geological and topographic map of Tenerife illustrating the general distribution of visible vents. RDG, Roques de García; G, Guajara; T, Teide volcano; PV, Pico Viejo volcano; MB, Montaña Blanca; SRZ, Santiago rift zone; DRZ, dorsal rift zone; SVZ, southern volcanic zone. Black symbols, mafic and intermediate vents; white symbols, felsic vents; stars, historic and subhistoric vents; circles, other vents. Names and locations of landslide valleys are also shown (Sobradelo et al., 2010).

In Tenerife two rift zones run NW-SE and ENE-WSW and are marked by parallel rows of aligned cones and eruptive fissures (*e.g.*, *Ancochea et al.*, 1990; *Carracedo*, 1994; *Carracedo*, 1996; *Martí et al.*, 1996) and fault/dyke swarms (*e.g., Walter & Schmincke*, 2002; *Walter et al.*, 2005). These are the Santiago del Teide and the Dorsal rifts (SRZ and DRZ), respectively (Figure 13). In the southern part of the island, the Southern Volcanic Zone (SVZ), basaltic volcanism is characterized by scattered vents and non-coherently orientated eruptive fissures. Some authors have associated the SVZ with a third rift zone orientated N-S, which may comprise, with the Dorsal and the Santiago del Teide rifts, a three-armed or "Mercedes Star" rift structure *(Carracedo, 1994; Carracedo, 1996; Walter & Troll*, 2003).

Gran Canaria

The Canary archipelago is located in a transitional zone between temperate and tropical conditions. The conical morphology of Gran Canaria retains the humidity of the predominant north/northeast trade winds of the subtropical Azores anticyclone on the north side of the island. As a result, the northern flanks are humid and vegetation is vigorous, while the south is very dry and the conditions are very arid and desert-like. Rainfall increases with altitude, ranging between less than 200 mm/yr at the coast and over a wide area in southern Gran Canaria, and more than 1400 mm/yr in the higher peaks of the central part of the island. The climate in the test-site area is very dry, with annual average precipitation of 190 mm and annual average temperature of 20.6ºC. The maximum precipitation takes place during the autumn and winter months, being December the rainiest month. Heavy storms are frequent, accompanied by intense rainfall and strong winds, with episodes of up to 250 mm in 24 h.

From the geological point of view, the Canary Islands are developed over Jurassic oceanic lithosphere, as a result of the eastward movement of the African plate over a mantle hospot (Holik et al., 1991). The origins of the scenery of Gran Canaria began about 15 million years ago with the first submarine building stages of the Gran Canaria Volcano. The first sub-aerial activity took place about 14 Million years ago. This shield-building phase (growth phase) continued until about 9 Million years ago when there was a massive collapse that formed the 20 km in diameter Tejeda Caldera.

After the collapse, the Caldera gradually filled up with lava and other volcanic material over the next few million years. This period was followed by 3 million years of volcanic inactivity and erosion. The next major stage, between 4.5 and 3.5 Million years ago, was characterized by explosive eruptions. Gran Canaria is now in an erosional stage. The last eruption took place about 2000 years ago.

Figure 11 shows a simplified geological map of the island with the main volcanic features. The main stages of evolution of Gran Canaria are the shield stage, including a basaltic shield volcano; the vertical caldera collapse, giving place to the Tejeda-Fataga complex, with a salic post-caldera resurgence; and a rejuvenated stage, including the Roque Nublo stratovolcano and the post- Roque Nublo volcanism (late eruptive phase) which created a composite monogenetic volcanic field. Additionally, massive flank failures are mapped (see gravitational failures) giving place to chaotic deposits which cover large areas.

The geology of the test-site area is within the domain of the basaltic shield stage, Middle Miocene in age (Fig. 11). Along the road, an alternance of alkaline basaltic deposits (hard rocks) and piroclastic flows can be observed. Both materials can be the source areas for rockfalls blocks. In some parts, gravitational deposits also outcrop and some boulders frequently invade the road.

4.2.2 Thematic maps and data

The thematic layers that are available for both Gran Canaria and Tenerife island encompass raster and shapefile information useful for the geo-morphological description of the area and for its preliminary characterization regarding ground movements and geo-hazards.

Digital Elevation Model: raster layer. Digital Elevation Model (DEM) with 5x5 m cellsize resolution elaborated by IGN under the Spanish National Plan of Aerial Ortophography and LiDAR (http://www.ign.es/ign/main/index.do). Derived datasets: aspect and slope maps are also available.

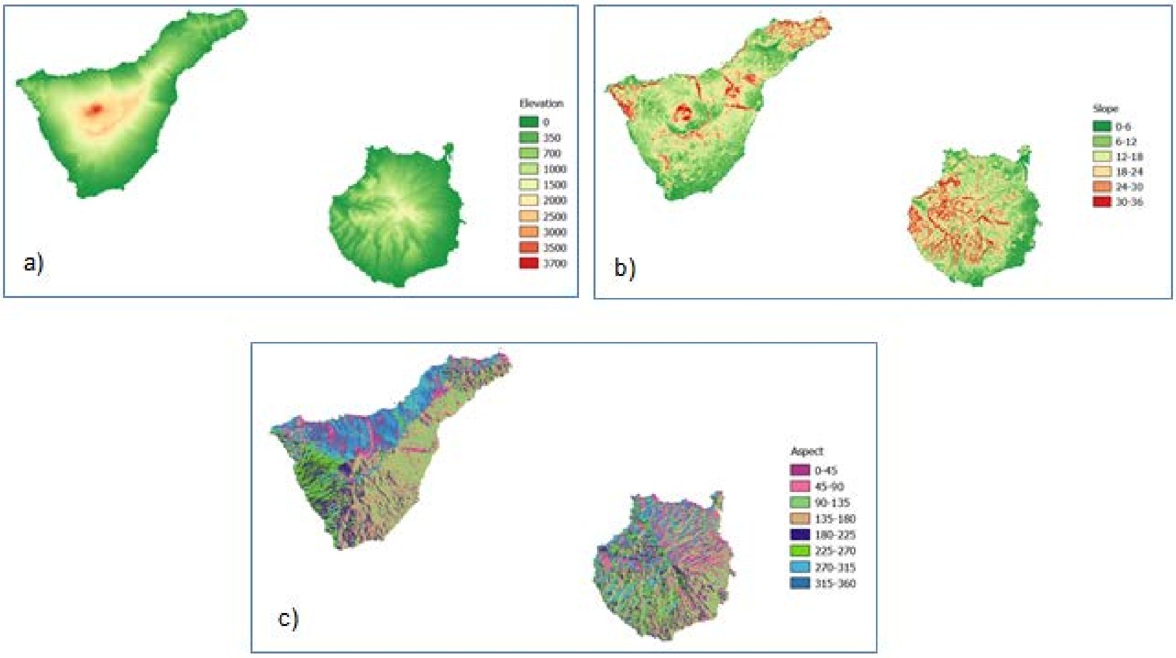


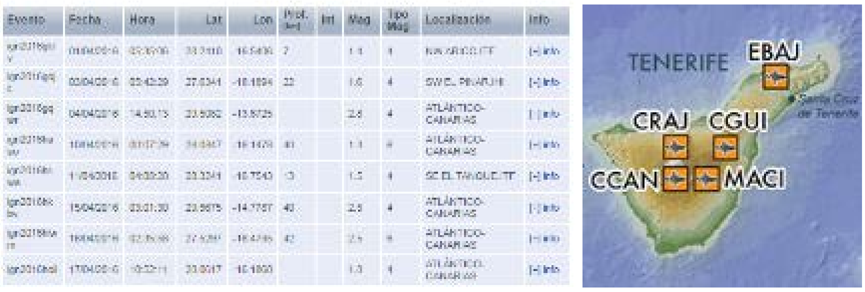
Figure 14. Thematic maps for the morphological description of the area: (a) DEM (elevation in meters), (b) Slope map (in degrees), (c) Aspect map (in degrees)

- *Land use map*: shapefile and raster. This product derives from the Spanish Information System on Land Cover (SIOSE) referred to 2014 (http://www.ign.es/ign/main/index.do).
- *Topographic map*: shapefile. This product derives from the national topographic map at a 1:25.000 sale from IGN (http://www.ign.es/ign/main/index.do).
- *Geological map*: shapefile. This product derives from national geological continuous map (GEODE) in Spain at a 1:50.000 scale (www.igme.es).

We offer also dynamic real time and updated thematic maps and data as a result of the IGN monitoring seismic and volcanic networks, offering:

- IGN Real time seismic Catalogue
  http://www.ign.es/ign/layoutIn/volcaFormularioCatalogo.do

It includes the information related to all seismic events localized in the entire Canary Archipelago as date, time, latitude, longitude, depth, intensity, magnitude of earthquakes, etc.



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[illegible]	01/04/2016	[illegible]	[illegible]	[illegible]	2		1.1	4	[illegible]	[+] Info
[illegible]	02/04/2016	03:42:29	27.9341	-18.1894	22		1.6	4	SW EL PINAR.IHI	[+] Info
[illegible]	04/04/2016	[illegible]	[illegible]	-13.8725			2.6	4	ATLÁNTICO-CANARIAS	[+] Info
[illegible]	10/04/2016	[illegible]	[illegible]	[illegible]	[illegible]		1.1	4	ATLÁNTICO-CANARIAS	[+] Info
[illegible]	11/04/2016	[illegible]	[illegible]	-16.7543	[illegible]		1.5	4	SE EL TANQUE.TF	[+] Info
[illegible]	15/04/2016	03:01:30	[illegible]	-14.7787	40		2.5	4	ATLÁNTICO-CANARIAS	[+] Info
[illegible]	16/04/2016	[illegible]	[illegible]	[illegible]	42		2.5	4	ATLÁNTICO-CANARIAS	[+] Info
[illegible]	17/04/2016	[illegible]	[illegible]	[illegible]			1.3	4	ATLÁNTICO-CANARIAS	[+] Info

Figure 15. Real time seismic catalogue and seismic stations located in Tenerife Island.

- IGN Real time seismic waveform and spectrograms of different stations located in the Canaries (one in Tenerife): http://www.ign.es/ign/layoutIn/volcaSenalesAnteriores.do

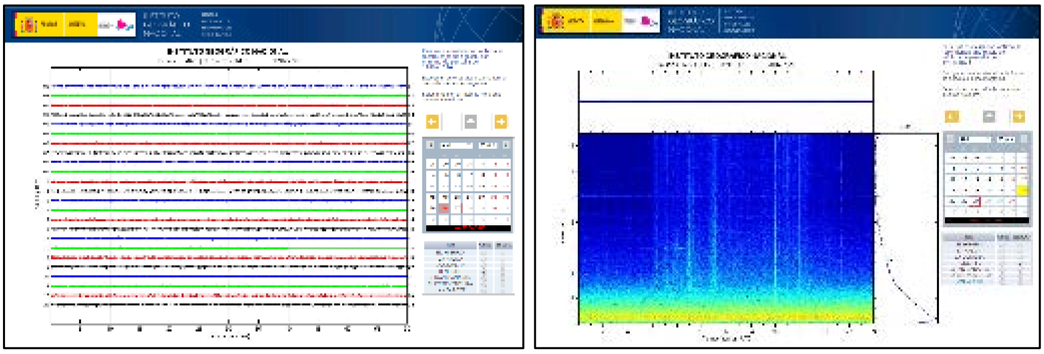

Figure 16. Example of seismic wave form and spectrogram from MACI seismic station in Tenerife.

- IGN Accelerogram Catalogue:
  http://www.ign.es/ign/layoutIn/sismoFormularioAcelerogramas.do
  There are two stations located in Tenerife and Gran Canaria Islands that continuously record the maximum acceleration of the ground.

Figure 17: Location of accelerographs in Tenerife and Gran Canaria Islands.

- IGN GNSS data server download:
  http://www.ign.es/ign/layoutIn/geodesiaDatosGNSS.do
  RINEX files of GNSS Stations Network (ERGNSS) are available for several stations in the Canary Islands, 4 stations in Tenerife.
- IGN mareograph data series:
  http://www.ign.es/ign/hwide/redMareografica.do
  There are several stations in the Canary Islands, (three stations in Tenerife) continuously measuring sea surface levels.

Figure 18: a) GNSS stations and b) marigraph stations in the Canary Islands.

In addition to these datasets, the close collaboration with the Emergency Services from Canary Island have permitted to collect additional data, in different formats, necessary for the preliminary characterization of rockfalls. All this information needs to be adapted into a geodatabase so it can be useful for rockfall susceptibility analysis, being the following:

- Damages produced due to rockfall events in the Aldea test site, the GC-200 road in the past 6 years. Pdf scanned documents of the companies in charge of the road manteinance.

- Damages produced due to rockfall events in Gran Canaria and Tenerife islands since 2004 (approximately 5000 events). Excel file without coordinates. The location is provided by km points,

- Damages produced due to rockfall events in Anaga test site in the past 6 years. Shapefile with location and date of the rockfall event (approximately 2000 events). This shapefile was elaborated by the road manteinance Company.

4.2.3 Relevant geo-hazard phenomena

2.2.3.1 Volcanism

In Tenerife we find two types of volcanism, monogenetic and polygenetic volcanism. Monogenetic volcanism is mainly concentrated in the rift zones and it is usually of basaltic (or more generically, mafic) composition. Polygenetic volcanism is associated to the Central Volcanic Complex: Teide – Pico Viejo system (TPV), twin volcanoes that have been constructed by several eruptions and involve highly evolved magmas. The Monogenetic volcanism is the same type of volcanism that has been described for the historical eruptions on the other islands, being mainly concentrated in the NW-SE and NE-SW rift zones of the island. Teide-Pico Viejo complex is the only volcanic system nowadays in the Canaries with a permanent and active magmatic chamber, in which evolved magmas (phonolite type) are produced, and is the volcanic edifice in the Canary Islands with the higher probability of hosting an explosive eruption. This fact, joined with the great increase in the population surrounding the volcano makes it a potentially high risk volcano. The main concern about potential future volcanic activity on Tenerife has traditionally been addressed towards basaltic eruptions taking place along the two active rift zones, as they have occurred in historical times. However, despite the occurrence of numerous eruptions during the Holocene and of unequivocal signs of activity in historical times (fumaroles, seismicity) (IGN seismic catalogue) and even an unrest episode in 2004 (Domínguez Cerdeña et al. 2011), TPV has not been considered as a major threat. Although the highest probability of having a new eruption on Tenerife corresponds to a basaltic eruption along the rift zones, which today would also represent a significant trouble for the island, the probability of having a new eruption from the TPV central complex is not negligible (Marti et al., 2012).

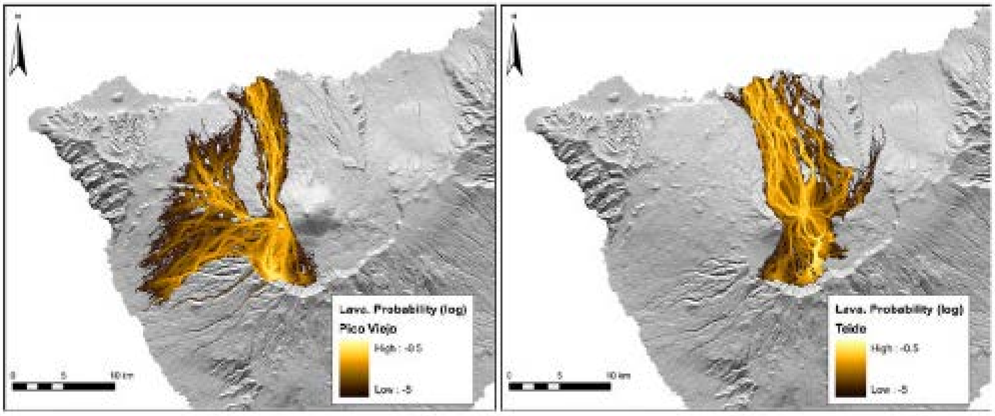

Figure 19. Examples of numerical scenarios for phonolitic lava flows for Pico Viejo (left) and Teide (right) central vents (from Martí et al., 2013).Scenarios were computed with a maximum slope model (Felpeto et al., 2007) and input parameters obtained from the recent geological record.

2.2.3.2 Seismicity

The regional seismic activity of the area could be considered as moderate with magnitude less than 5.0 (Mezcua et al., 1992), and mainly concentrated between the two major islands (Tenerife and Gran Canaria). During 2004 the island of Tenerife experienced a seismic crisis with more than 2000 recorded events (more than 350 located and 5 felt by the population) (www.ign.es) which were considered evidence of a volcanic reactivation after almost 100 years of calm (Martí et al., 2009 and references therein). This crisis produced a significant social impact due to the high population of the island and the previous long repose periods in volcanic activity on Tenerife**. Figure 20** shows the seismicity from 2004 to 2016 located by the IGN (www.ign.es).

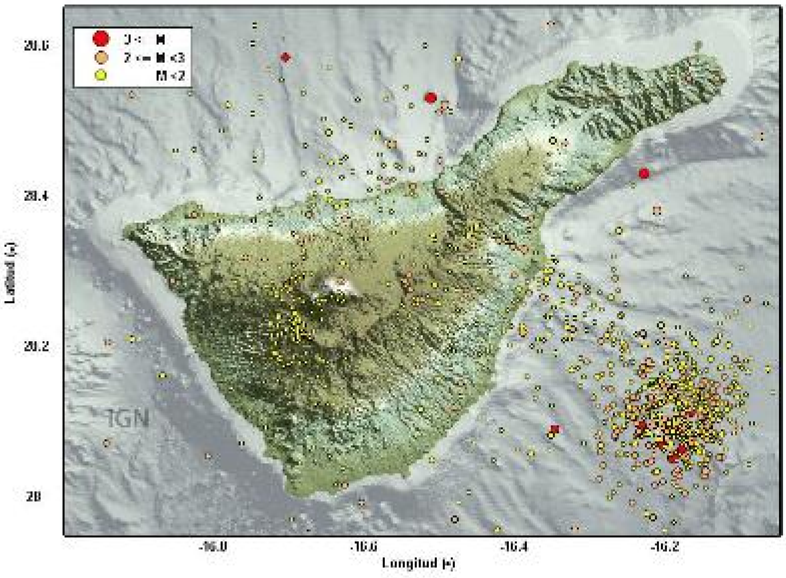

Figure 21. Image showing the seismicity located by the IGN from 2004 to 2015 (source: IGN).

2.2.3.3 Deformation

Several studies of deformation in Tenerife have been carried out by GPS and InSAR time series analysis (e.g. Fernández et al., 2015). Analyses reveal that the volcanic rifts and the caldera determine the current deformation pattern of Tenerife. These results, coupled with GPS ones, structural and geological information and deformation modeling, suggest an interpretation based on the gravitational sinking of the dense core of the island into a weak lithosphere and that the volcanic edifice is in a state of compression. They also detected localized deformation patterns correlated with water table changes and variations in the deformation time series associated with the seismic crisis in 2004. No deformation at Las Cañadas caldera was detected in the InSAR study of Fernández et al., (2015) during the period 1992-2000, but there were detected two deformation zones in the region where the most recent eruptions in the island occurred (Montaña Negra 1706, Chahorra 1798, Chinyero1909): the Garachico and Chío deformations areas. Both of them were subsidences, increasing from 1992 to 2000. **Figure 21** displays the location of these deformations and their magnitudes.

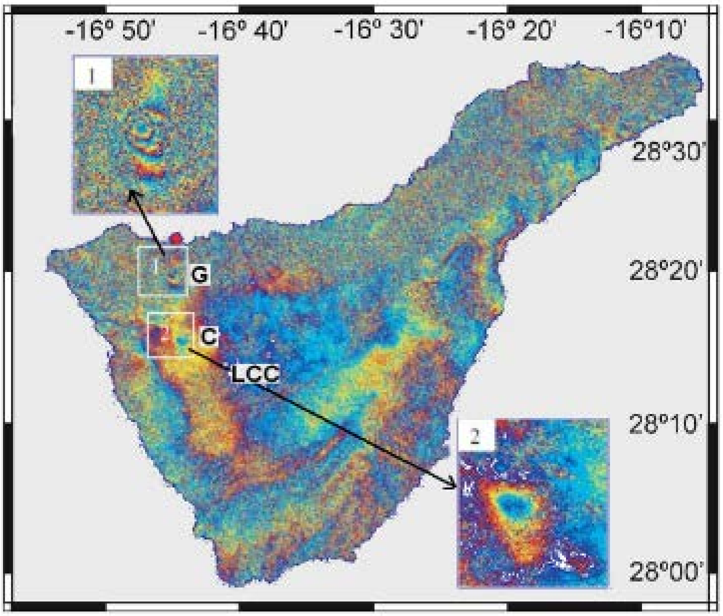

Figure 21. Differential interferogram from Tenerife Island corresponding to August 2, 1996–September 15, 2000 ERS-2 radar images. Garachico (G) and Chío(C) subsidence areas, respectively (modified from Fernández et al., (2003, 2004).

2.2.3.4 Rockfall hazard

SAFETY susceptibility maps will target rockfall events in the Canary island. The pilot study will be made in the GC-200 road. Rockfall events affect regularly the GC-200 road that can be divided into two main sections:

- From Agaete to El Risco, 13.380 km. Numerous rockfalls have been recorded in this section, and specifically between the PKs 10-11. Most of the rockfalls are small in volume (below 0.5 m^3) and very frequent (one event per week). During rainy and windy periods, rockfalls with a larger volume (over 50 m^3) usually occur, with an average of two significant events per year that cause the blockage of the road. Erosion control measures to maximize the slope stabilization have been carried out along the stretch, and wire netting over the the road-cuttings helps to prevent rockfalls from bouncing outward.
- From El Risco to Aldea, 20.2 km. It is the most hazardous section where the largest rockfalls occur. Dynamic retaining walls and numerous steal wire-nettings have been installed in this section. Currently, and alternative route (with numerous tunnels) is going to be opened in the following months.

Figure 22. The GC- 200 road between the localities of Agaete and Aldea. It is considered one of the most hazardous roads in Europe. Numerous rockfalls cut the road off every year.

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