EUROPEAN COMMISSION

Research Executive Agency

Seventh Framework Programme

Cooperation: Space Call 3

FP7-SPACE-2010-1

Grant Agreement: 262371

Enabling Access to Geological Information in Support of GMES

D7.1.25 Geohazard Description for Dublin

1.0

04/01/2013

Dissemination Level:	Public	
Author:	Michael Sheehy, GSI	Date: 04/01/2013
Checked by (WP Leader):	[WP Leader Name, Organisation]	Date:
Approved by (Coordinator):	[Coordinator, Organisation]	Date:
Date of Issue:	[Date]	

CHANGE RECORD

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EXECUTIVE SUMMARY

County Dublin is located on Ireland's eastern coastal margin and occupies an area of 920 km² (*c*. 1.3% of the total area of the Republic of Ireland). Dublin City is Ireland's capital city and the Dublin metropolitan area is Ireland's financial and administrative centre. Dublin is the hub of Ireland's transportation networks and a key gateway for international trade via air and sea. The Republic of Ireland has a total population of *c*. 4,588,000 and of that population *c*. 1,273,000 live in Co. Dublin making it the most densely populated part of the country.

Ground instabilities affect parts of Co. Dublin and the Geological Survey of Ireland has developed a map, and this report which shows and describes areas of potential or observed ground instabilities as part of the FP7 PanGeo project. Geological Survey of Ireland datasets along with Ordnance Survey of Ireland mapping, PSI datasets and limited field validation were used to develop this interpretation.

The PanGeo interpretation has led to the delineation of 9 polygons (areas) within which potential or observed ground instabilities have been identified. These polygons cover an area of c. 33.51 km² which is less than 4% of the entire Dublin PanGeo interpretation area. The main observed instabilities (by area) are those associated with compressible ground. The largest area of potential instability is associated with the peats of the Dublin Mountains which have the potential to give rise to instabilities associated with compressible ground.

The Geological Survey of Ireland, founded in 1845, is the National Earth Science Agency. It is responsible for providing geological advice and information, and for the acquisition of data for this purpose. The Geological Survey of Ireland produces a range of products including maps, reports and databases and acts as a knowledge centre and project partner in all aspects of Irish geology. It is a division of the Department of Communications, Energy & Natural Resources.

This map and report are broadly indicative of areas of terrain instability which have been produced using a wide variety of data sources at different scales and different levels of reliability. These data should never be used for site specific purposes. The Geological Survey of Ireland does not accept liability for any inaccuracies in this information. The entire dataset is designed for general information and strategic planning usage. The Geological Survey of Ireland makes no warranties on its fitness for any other purpose. The burden for determining fitness for other uses lies with the user. Information supplied is based on the material available to the Geological Survey of Ireland at the time of production and should not be regarded as complete data on the elements or areas being considered.

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2 INTRODUCTION

County Dublin (Fig 2.1) is located on Ireland's eastern coastal margin and occupies an area of 920 km² (*c*. 1.3% of the total area of the Republic of Ireland). Dublin City is Ireland's capital city and the Dublin metropolitan area is Ireland's financial and administrative centre. Dublin is the hub of Ireland's transportation networks and a key gateway for international trade via air and sea. The Republic of Ireland has a total population of *c*. 4,588,000 and of that population *c*. 1,273,000 live in Co. Dublin making it the most densely populated part of the country.

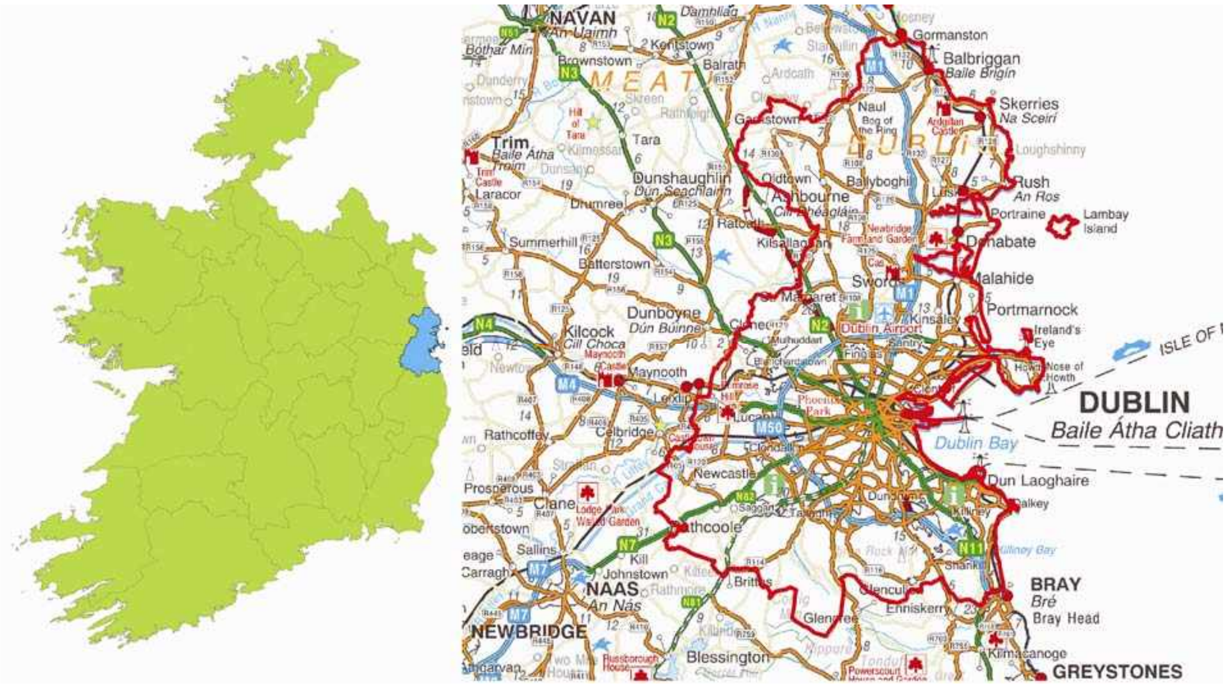

Fig 2.1 Location of County Dublin relative to the Republic of Ireland (Licence No. EN 0047212)

The Dublin Region comprises the administrative areas of Dublin City Council (pop. 528,000), Fingal County Council (pop. 274,000) South Dublin County Council (pop. 265,000), and Dun Laoghaire-Rathdown County Council (pop. 206,000). With the exception of Dublin City, each of the county administrative areas has a mix of rural and urban zones. The councils remit includes environment, recreation and sport, strategic planning and economic development, roads and transportation, housing and community, planning and development and culture and amenity. The councils administrative boundary corresponds to the County Dublin boundary and the area of interpretation of this project. These boundaries along with the extent of the PSI data are shown below in Fig 2.2.

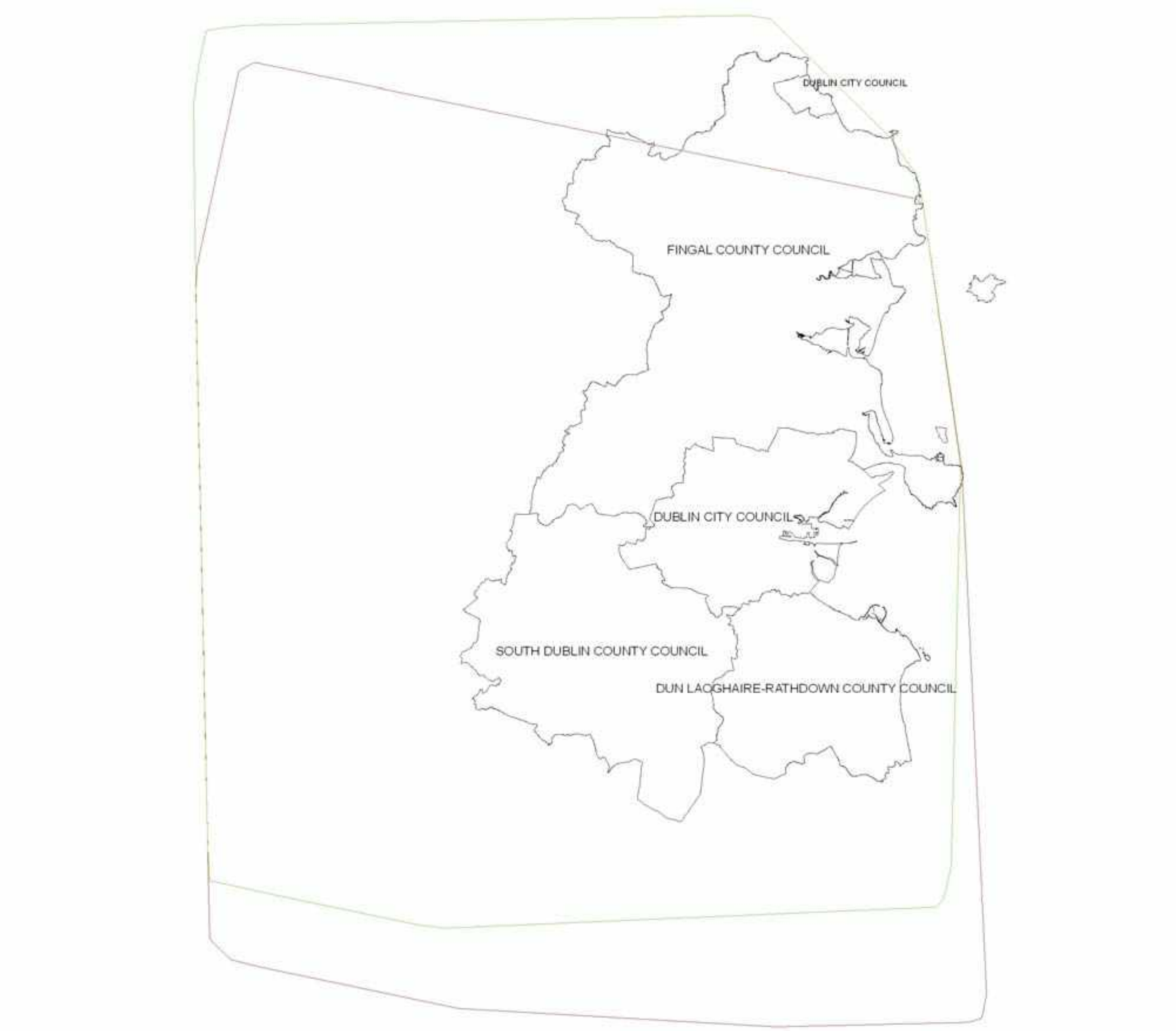

Fig 2.2 Co. Dublin administration areas and the boundary of PanGeo interpretation area (ERS data boundary in green, Envisat data boundary in red.

The bedrock geology of Co. Dublin (Fig 2.3) reflected in the rocks we see today represents a long and somewhat fragmented record of the palaeoenvironmental conditions and processes that obtained at the time of their deposition and the variety of tectonic setting that contributed to their current distribution and characteristics. Lower Palaeozoic age (540 - 415 million years ago) metasediments and volcanics are mainly found in the north and south of Co. Dublin with the central zone is underlain by Upper Palaeozoic (415 - 250 million years ago) rocks of Carboniferous age (360 - 300 million years ago). An emplacement of granite into the southern Lower Palaeozoic rocks also occurred in this timeframe.

The oldest rocks in County Dublin are the Cambrian (540 - 490 million years ago) greywackes, slates and quartzites of Howth Head.

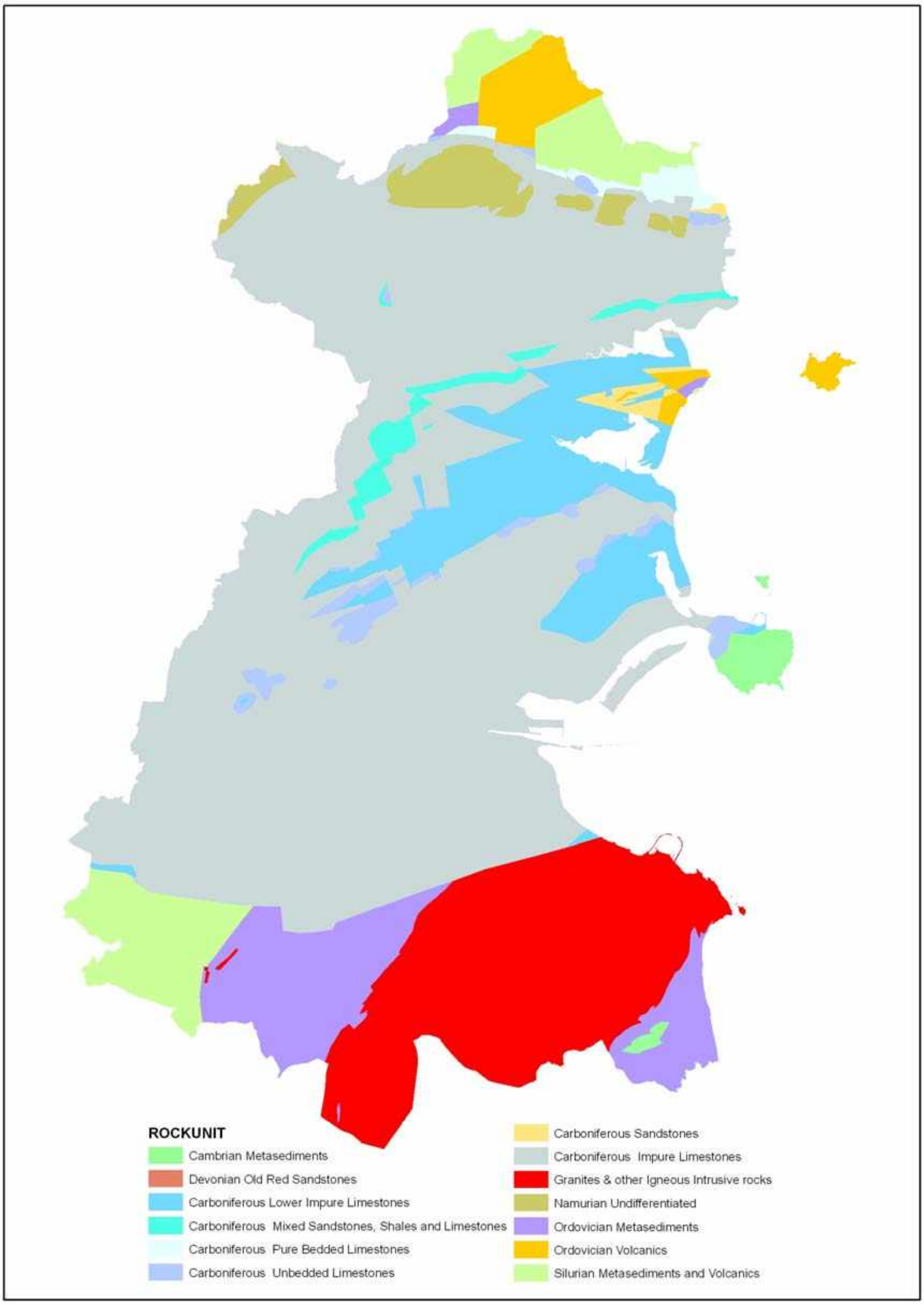

Fig 2.3 Simplified bedrock geology of the PanGeo interpretation area.

Rocks of Ordovician age (490 - 445 million years ago) are found in two locations in Co. Dublin: schists and other metasediments around the eastern and western flanks of the Leinster batholith in the south Dublin Mountains and a series of metamorphosed volcanic rocks and mudstones around Ballbriggan in north Co. Dublin.

Silurian (445 - 415 million years ago) metasediments and volcanics occur within the south Dublin Mountains adjacently and to the west of the Ordovician metasediments and also in the north of the county. At this time the Iapetus Ocean closure was in its final stages and continental collision and the mountain building of the Caledonian Orogeny began.

In Devonian times (415 - 360 million years ago) granite was intruded in a shear zone along the north-east trending foliation of the Lower Palaeozoic host rocks. This intrusion during the Caledonian Orogeny was precipitated by the deformation of the continental masses as they collided.

Carboniferous age rocks are the most common rock types in Co. Dublin. They are delimited to the south by a faulted contact with the Lower Palaeozoic rocks and the Leinster batholith and by Lower Palaeozoic Rocks to the north. The oldest Carboniferous rocks in Co. Dublin are argillaceous bioclastic limestones and shales. Younger Carboniferous rocks overlying these include pure poorly bedded limestone. In the north and central zones: dark calcareous mudstones which occasionally contain framboidal pyrite (potentially making these rocks unsuitable for use as construction materials) overly the pure poorly bedded limestones. The most extensive Carboniferous bedrock rock type, colloquially known as the Calp, covers most of the central zone and some of the northern parts. It consists of laminated argillaceous calcisiltites, calcareous shale and thinly bedded locally cherty limestone interbedded with black shale. These rocks were mainly deposited in warm shallow marine environments.

The youngest Carboniferous rocks were originally deltaic sands and muds often deposited in swampy conditions during the Namurian Stage (326 – 313 million years ago) of the Carboniferous. These are to be found in north Dublin forming the higher ground in that region. They consist of mudstones, shale, siltstones and sandstones, with occasional thin coal seams.

The effects of Quaternary age (2.6 million years ago until the present day) glaciations on the landscape stem from ice flowing and retreating over the area from different ice-bodies that extended from a number of well defined centres, each deflecting the flow pattern of the other where they met and coalesced. It is thought that a local ice centre in the Dublin and Wicklow Mountains advanced over the area followed by several advance, retreat and readvances of the Irish Sea Ice Sheet (ISIS). Subsequently the Northern Dome Ice Sheet advanced on a south-eastwards direction overriding most of the sediments deposited by the ISIS, this ice sheet extended offshore to the east and is delimited to the south by discontinuous mounds of sand and gravel occurring along the north margin of Dublin Mountains. Finally, a small readvance of the Wicklow ice dome is recognised from glaciofluvial material.

Following the deglaciation of the area, compressible Holocence Epoch (10,000 years ago until the present day) sediments were naturally deposited by rivers and in lakes and also created with human intervention. These sediments include alluvial deposits in the river channels, estuarine silts and clays and reclaimed land. A map showing the distribution of the Quaternary sediment cover is shown in Fig 2.4.

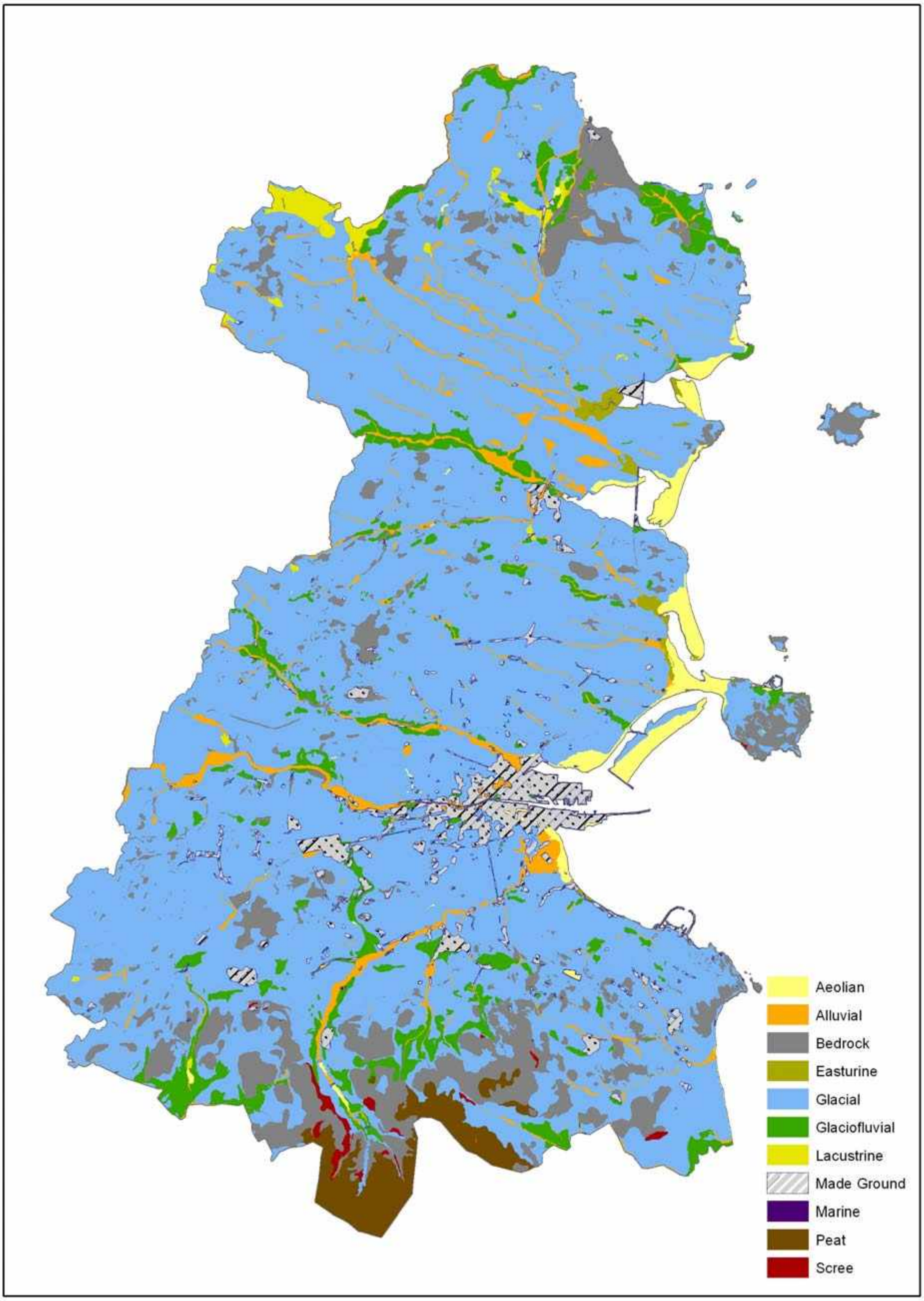

Fig 2.4 Simplified representation of the Quaternary geology of the PanGeo interpretation area.

The PanGeo interpretation has led to the delineation of 9 polygons (areas) within which potential or observed ground instabilities are identified. These polygons cover an area of c. 33.51 km^2 which is less than 4% of the entire Dublin PanGeo interpretation area. The main observed instabilities (by area) are associated with compressible ground. The largest area of potential instability is associated with the peat of the Dublin Mountains which have the potential to give rise to instabilities associated with compressible ground. A map showing the distribution of the potential and observed instabilities derived from the PanGeo interpretation is shown in Fig 2.5. Some polygons in Fig 2.5 may be obscured by others overlying them.

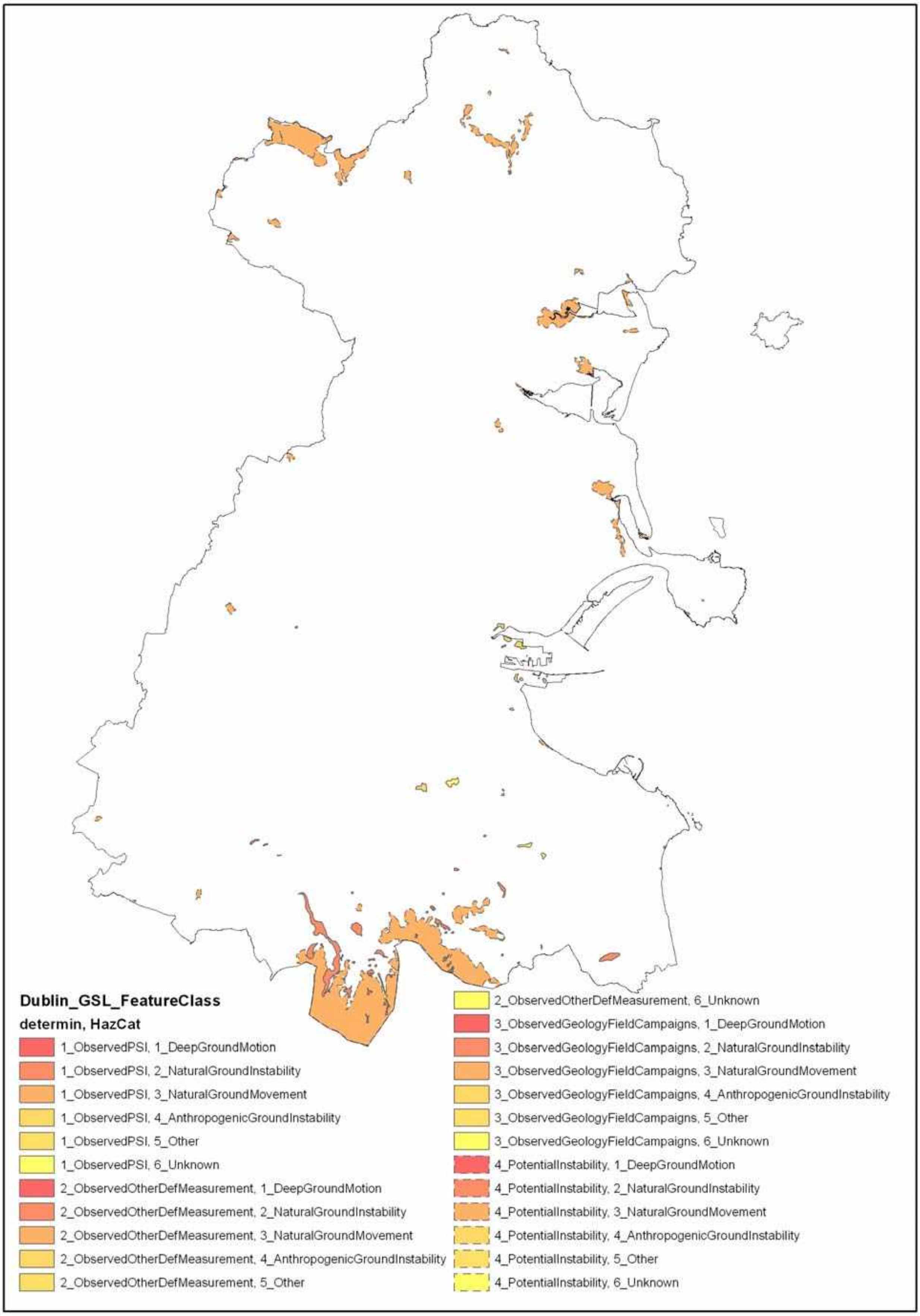

Fig 2.5 Potential and observed instabilities derived from the Dublin PanGeo interpretation

The datasets used to derive this interpretation are listed here and described below:

- ☐ Geological Survey of Ireland 1:100,000 Bedrock Geological mapping
- ☐ Geological Survey of Ireland 1:50,000 Quaternary Geological mapping
- ☐ Geological Survey of Ireland Karst Features Database (point data)
- ☐ Geological Survey of Ireland Geotechnical Database (point data)
- ☐ Geological Survey of Ireland Landslides Database
- ☐ Ordnance Survey Ireland Historic 6 inch mapping
- ☐ Ordnance Survey Ireland 2004 & 2000 Aerial imagery
- ☐ Cork Terrafirma PSI data

Geological Survey of Ireland 1:100,000 Bedrock geology mapping (point, line and plolygon data)

These maps show the distribution of rock units interpreted to lie beneath the superficial cover of soil and glacial deposits. This dataset is freely available for download, viewing or WMS connection on http://www.gsi.ie/Mapping.htm.

Geological Survey of Ireland 1:50,000 Quaternary Geological mapping (point, line and plolygon data)

These maps show the distribution of the superficial cover of Holocene and glacial deposits and also where bedrock outcrops or lies within 1 meter of the surface. The map distinguishes between the following broad categories of deposits: till (boulder clay), sand/gravel, peat, alluvium, lake silt and clay, marl and made ground. Sand/gravel and boulder clay are further divided to show the dominant stone type contained. The data collected during fieldwork based on the analysis of exposures available and the identification and description of morphological features is supported by the acquisition of geophysical or borehole data where sediment type was unknown or uncertain. The Quaternary geology map shows the dominant sediment type within 1 metre of the surface. This dataset is freely available for download and viewing on http://www.gsi.ie/Mapping.htm.

Geological Survey of Ireland Karst Features Database (point data)

A database of karst features, showing the location and relevant characteristics of individual karst features across Ireland. This dataset is freely available for download on http://www.gsi.ie/Mapping.htm.

Geological Survey of Ireland Geotechnical Database (point data)

This database contains the reports of site investigation work undertaken to determine the ground conditions at the location of proposed development projects. The reports typically contain a text report and borehole, trial pit and probe logs, as well as field tests and laboratory sample analyses. The data is also critical for the modelling of the subsurface geology and in geological mapping of the overburden (Quaternary sediments) and the bedrock. This dataset is freely available for download and viewing on http://www.gsi.ie/Mapping.htm.

Geological Survey of Ireland Landslides Database (point & plolygon data)

A database of past slope failure events with data, where available, on location, landslide type, materials, causes, and impacts. This dataset is freely available for download and viewing on http://www.gsi.ie/Mapping.htm.

Ordanance Survey Ireland Historic 6 inch (1: 10,560) mapping (raster data)

These data were captured between 1829 and 1842 when Ordnance Survey Ireland completed the first ever large-scale survey of an entire country. Several editions of these maps were produced. In the context of the PanGeo project these data provide valuable insights into Irish historic land-use patterns. These data are commercial products and are used by Geological Survey of Ireland under the terms of Ordnance Survey Ireland Licence No. EN 0047212.

Ordnance Survey Ireland 2004 & 2000 Aerial imagery (raster data)

Ortho rectified photographs corrected to allow for slopes and other distortions so that it corresponds exactly to large scale mapping. In the context of the PanGeo project these data provide valuable insights into present day land-use patterns. These data are commercial products and are used by Geological Survey of Ireland under the terms of Ordnance Survey Ireland Licence No. EN 0047212.

Dublin PSI data was produced by NPA Fugro Ltd. for use by the Geological Survey of Ireland in PanGeo project. ERS-1, ERS-2 and Envisat satellite data were used to derive two PSI results for an area somewhat larger than the site under investigation for the PanGeo interpretation as can be seen in Fig 2.2.

Dublin ERS Descending

- 20/05/1992 to 23/12/2001
- 62 scenes
- ~2,500 km², ~160k PS points
- Average motion -0.398 mm per year
- Maximum heave 15.581 mm per year
- Maximum subsidence -16.889 mm per year

According to NPA Fugro Ltd. the “large data stack available with good temporal sampling” does not present a challenge and that the results should be of high quality.

Dublin Envisat Descending

- 30/08/2003 to 21/11/2009
- 27 scenes
- ~2,500 km², ~150k PS points
- Average motion -0.269mm per year
- Maximum heave 22.755mm per year
- Maximum subsidence -20.125mm per year

According to NPA Fugro Ltd. this is a “relatively small data stack with low temporal sampling.” In addition NPA Fugro Ltd. state “PS processing was adjusted to account for sampling size and stricter thresholds were applied during modelling. PSI results may potentially be of lower quality.”

3 *PGGH_DUBLIN_001*

3.1 GENERAL PROPERTIES OF THE MOTION AREA

This polygon is distributed across a small area of south Co. Dublin with its parts resting on granite bedrock and glacial tills (Fig PGGH_Dublin_001.1).

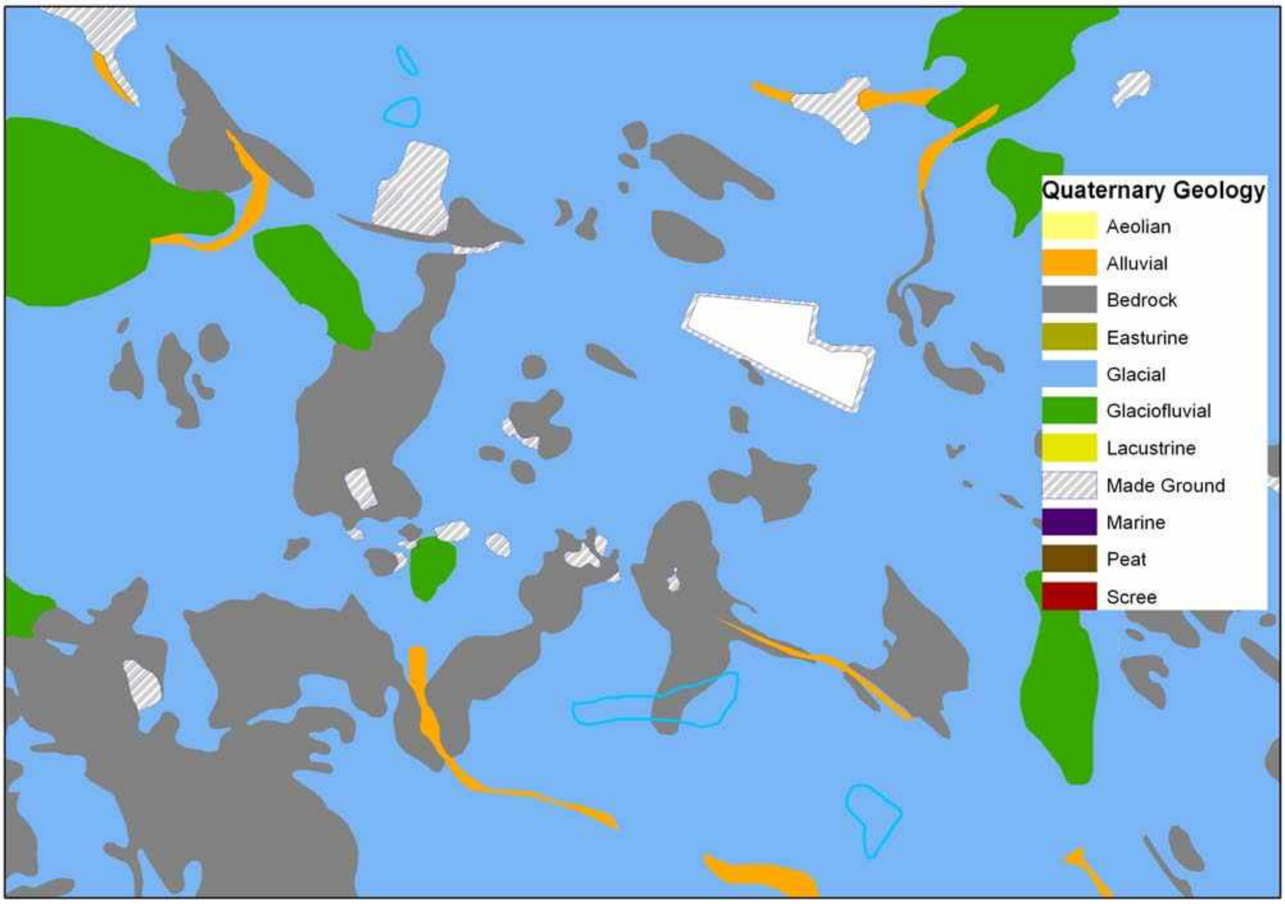

Fig PGGH_Dublin_001.1 Distribution of uplift polygon (blue outline) and Quaternary geology units

Landuse type of this polygon is urban fabric, mainly housing estates (Fig PGGH_Dublin_001.2). This polygon extends over c. 0.14 km².

Fig PGGH_Dublin_001.2 Distribution of uplift polygon (blue outline) and Envisat PSI point `data (blue indicates movement towards the satellite) on aerial imagery (Licence No. EN 0047212).

3.2 SPECIFIC GEOHAZARD TYPE

Unknown

3.3 TYPE OF MOTION

Uplift

3.4 THE DETERMINATION METHOD

Observed in PSI data.

3.5 CONFIDENCE IN THE INTERPRETATION

This polygon was delineated exclusively on the basis of the low quality Envisat PSI data and has a "Low" interpretation confidence.

3.6 GEOLOGICAL INTERPRETATION OF THE MOTION

Unknown

3.7 EVIDENCE FOR THE INSTABILITY

Images below (and their captions) give an indication of the nature of the instability in this polygon.

Fig PGGH_Dublin_001.3 Cracking in walls

Fig PGGH_Dublin_001.4 Cracking in walls

Fig PGGH_Dublin_001.5 Cracking in buildings

Fig PGGH_Dublin_001.6 Cracking in walls

Fig PGGH_Dublin_001.7 Cracking in walls

Fig PGGH_Dublin_001.8 Cracking in walls (circled)

Fig PGGH_Dublin_001.9 Cracking in houses (circled)

4 PGGH_DUBLIN_002

4.1 GENERAL PROPERTIES OF THE MOTION AREA

This polygon is distributed across a limited area around the port area of central Co. Dublin with its parts resting on Carboniferous impure limestone bedrock and made ground (Fig PGGH_Dublin_002.1). This polygon extends over c. 0.02 km².

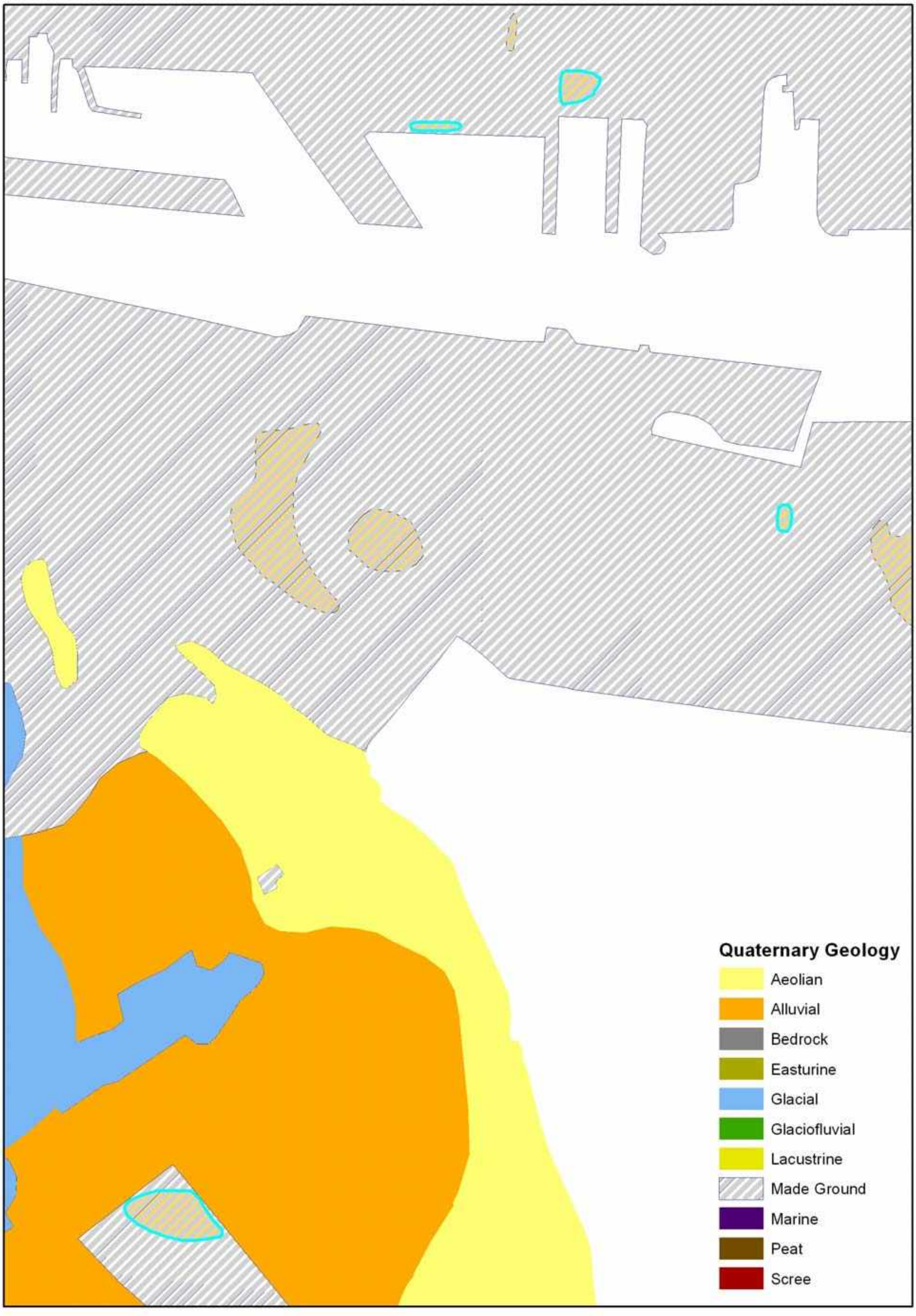

Fig PGGH_Dublin_002.1 Distribution of subsiding polygon (blue outline) and Quaternary geology units

Fig PGGH_Dublin_002.2 shows an image of a 3 km section of the estuary of the River Liffey. ERS PSI point data indicates subsidence in certain parts of the area.

Fig PGGH_Dublin_002.2 Distribution of anthropogenic subsidence polygon (blue outline) and ERS PSI point data (red & orange indicate movement away from the satellite) on aerial imagery (Licence No. EN 0047212).

4.2 SPECIFIC GEOHAZARD TYPE

Man Made (Anthropogenic) Ground Instability: Made ground

4.3 TYPE OF MOTION

Subsidence

4.4 THE DETERMINATION METHOD

Observed in PSI data.

4.5 CONFIDENCE IN THE INTERPRETATION

This polygon has a "Low" interpretation confidence. The polygon was delineated on the basis of ERS PSI data and Geological Survey of Ireland 1: 50,000 Co. Dublin Quaternary geology mapping, with reference to the Geological Survey of Ireland Geotechnical Database.

Geological Survey of Ireland Quaternary geology mapping show the distribution of the superficial cover of Holocene and glacial deposits and also where bedrock outcrops or lies within 1 meter of the surface. The uppermost deposit that achieves a thickness of >1m is the deposit that appears on the map. A more detailed 3D model of the deposits, which is in development for central Dublin, will allow a more comprehensive analysis of the lateral and vertical distribution of the made ground deposits.

Geological Survey of Ireland Quaternary geology mapping distinguishes between the following broad categories of deposits: till (boulder clay), sand/gravel, peat, alluvium, lake silt and clay, marl and made ground. Sand/gravel and boulder clay are further divided to show the dominant stone type contained. The data collected during fieldwork based on the analysis of exposures available and the identification and description of morphological features is supported by the acquisition of geophysical or borehole data where sediment type was unknown or uncertain. The Quaternary geology map shows the dominant sediment type within 1 metre of the surface. This dataset is freely available for download and viewing on http://www.gsi.ie/Mapping.htm.

The Geological Survey of Ireland Geotechnical Database contains the reports of site investigation work undertaken to determine the ground conditions at the location of proposed development projects. The reports typically contain a text report and borehole, trial pit and probe logs, as well as field tests and laboratory sample analyses. The data is also critical for the modelling of the subsurface geology and in geological mapping of the overburden (Quaternary sediments) and the bedrock. This dataset is freely available for download and viewing on http://www.gsi.ie/Mapping.htm.

4.6 GEOLOGICAL INTERPRETATION OF THE MOTION

Man made ground is a deposit of variable characteristics. Made ground can range from precisely engineered materials to mixtures of material that can potentially contain voids, compressible material, material that can decompose, dissolve or expand. Made ground is not subdivided in the Geological Survey of Ireland Quaternary geology mapping.

These adverse characteristics of made ground can lead to instability in infrastructure built on these deposits. Pre-development geotechnical and geophysical site investigation can mitigate or avoid the unfavourable effect of this geohazard. Detailed geotechnical investigations are usually carried prior to major developments in the Dublin Port area and as a result the buildings and structures normally perform well within the design tolerances for movement. Access routes are not generally as well designed and, coupled with the vibration effects from heavy traffic, often reflect the adverse characteristics of the made ground.

4.7 EVIDENCE FOR THE INSTABILITY

Site access is limited in the Dublin Port areas within this polygon.

Images below (and their captions) give an indication of the nature of the instability in this polygon.

Fig PGGH_Dublin_002.3 undulations in a road surface and tilting lamp post

5 *PGGH_DUBLIN_003*

5.1 GENERAL PROPERTIES OF THE MOTION AREA

This polygon is located in south Co. Dublin resting on impure Carboniferous limestone bedrock and glacial tills.

Landuse type of this polygon is urban fabric, mainly housing estates and retail units (Fig PGGH_Dublin_003.1). This polygon extends over c. 0.16 km².

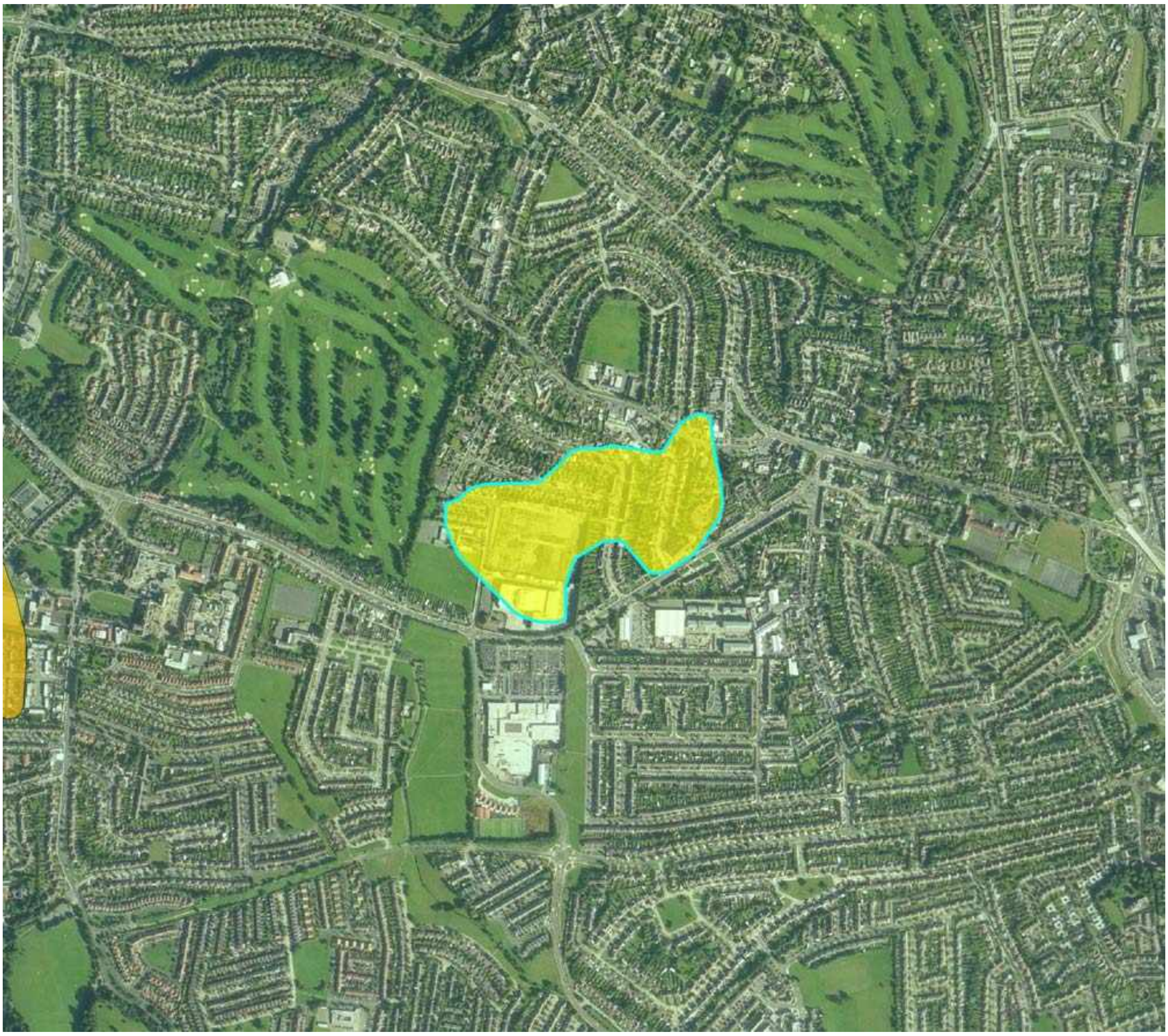

Fig PGGH_Dublin_003.1 Distribution of polygon delineating uplift in part of the Whitehall area of Dublin (Licence No. EN 0047212)

5.2 SPECIFIC GEOHAZARD TYPE

Unknown

5.3 TYPE OF MOTION

Uplift

5.4 THE DETERMINATION METHOD

Observed in PSI data.

5.5 CONFIDENCE IN THE INTERPRETATION

This polygon was delineated exclusively on the basis of the low quality Envisat PSI data and has a “Low” interpretation confidence.

5.6 GEOLOGICAL INTERPRETATION OF THE MOTION

Unknown

5.7 EVIDENCE FOR THE INSTABILITY

Images below (and their captions) give an indication of the nature of instability in this polygon.

Fig PGGH_Dublin_003.2 Cracking in walls

Fig PGGH_Dublin_003.3 Cracking in houses (within the lines)

Fig PGGH_Dublin_003.4 Cracking in walls

6 PGGH_DUBLIN_004

6.1 GENERAL PROPERTIES OF THE MOTION AREA

This polygon is distributed on the slopes of the Dublin Mountains, in places along the Co. Dublin coastline and also in west central Co. Dublin. Its parts rest mainly on granite and Lower Palaeozoic bedrock units (Fig PGGH_DUBLIN_004.1). This polygon was delineated using scree polygons from the Quaternary geology map of Co. Dublin (Fig 5.1.2), buffered point data and polygon data from the Irish Landslides Database.

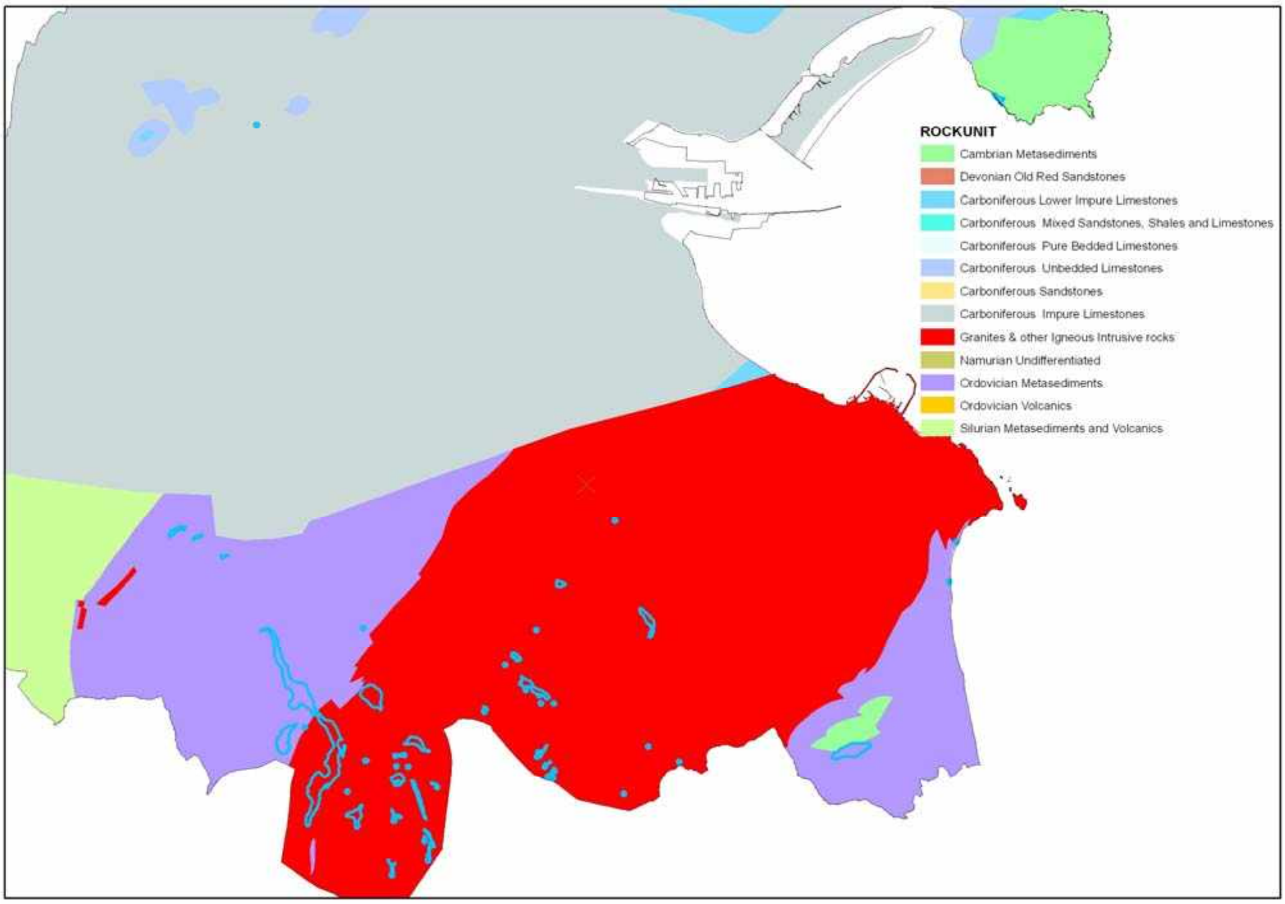

Fig PGGH_Dublin_004.1 Distribution of landslide polygon (blue outline) and bedrock units

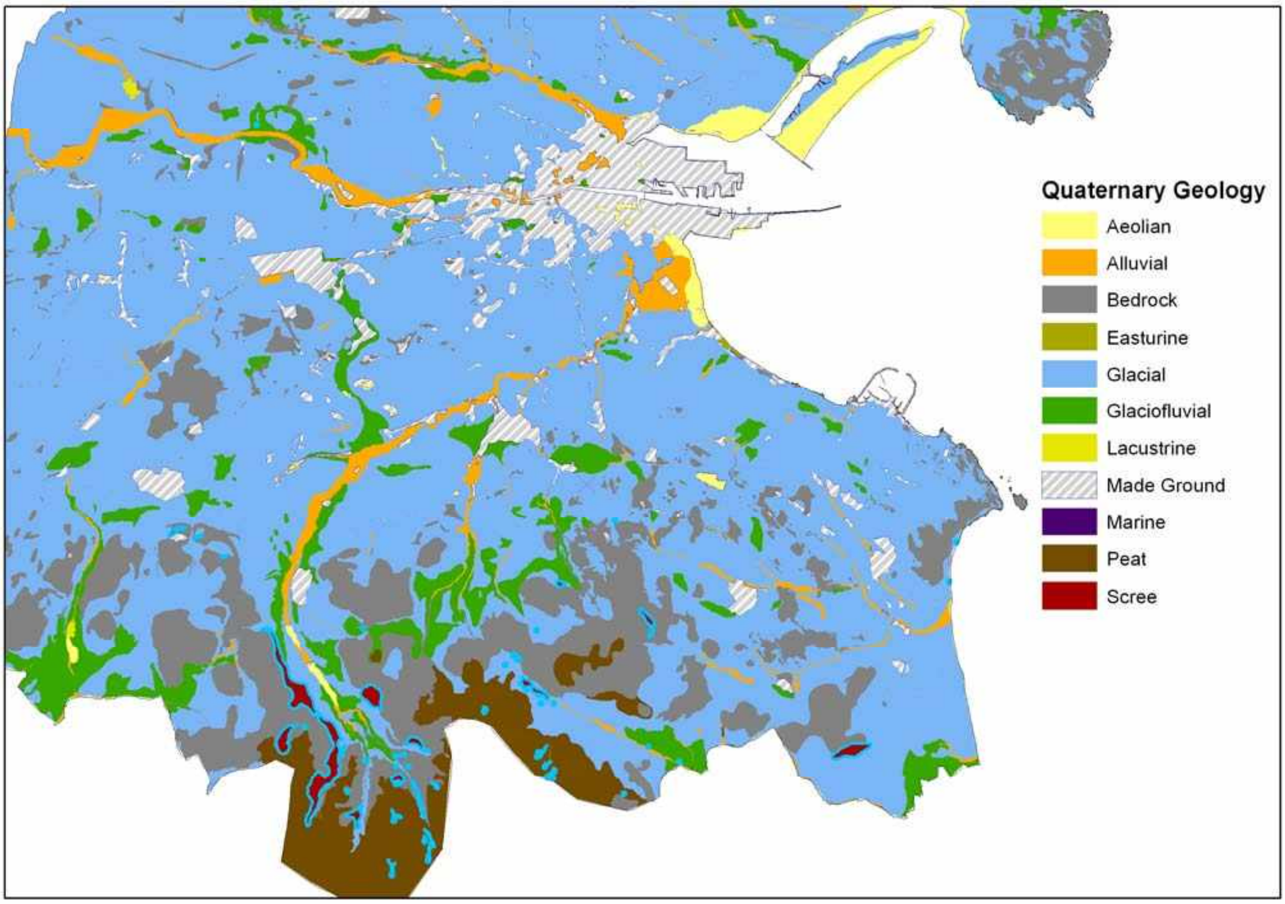

Fig PGGH_Dublin_004.2 Distribution of landslide polygon (blue outline) and Quaternary geology units

The typical landuse type for this polygon is natural and agricultural land in rural areas. Occasionally infrastructure intersects this polygon, as is the case with Dublin's light rail and the coastal slope instabilities, but usually landslides are not built on. Pre-development geotechnical site investigation and landslide hazard analysis can help to mitigate or avoid the unfavourable effect of this geohazard. This polygon extends over c. 3.0 km².

6.2 SPECIFIC GEOHAZARD TYPE

Natural Ground Instability: Landslide

6.3 TYPE OF MOTION

Down slope

6.4 THE DETERMINATION METHOD

Observed in Geology field campaigns.

6.5 CONFIDENCE IN THE INTERPRETATION

A value of "External" is assigned to the confidence of this polygon which is derived from the Geological Survey of Ireland 1:50,000 Co. Dublin Quaternary geology mapping and Geological Survey of Ireland

Landslides Database. Landslide data was, in part, compiled from a variety of external sources and reports.

The Geological Survey of Ireland Landslides Database contains details of past slope failure events with data, where available, on location, landslide type, materials, causes, and impacts. This dataset is freely available for download and viewing on http://www.gsi.ie/Mapping.htm.

Geological Survey of Ireland Quaternary geology mapping distinguishes between the following broad categories of deposits: till (boulder clay), sand/gravel, peat, alluvium, lake silt and clay, marl and made ground. Sand/gravel and boulder clay are further divided to show the dominant stone type contained. The data collected during fieldwork based on the analysis of exposures available and the identification and description of morphological features is supported by the acquisition of geophysical or borehole data where sediment type was unknown or uncertain. The Quaternary geology map shows the dominant sediment type within 1 metre of the surface. This dataset is freely available for download and viewing on http://www.gsi.ie/Mapping.htm.

6.6 GEOLOGICAL INTERPRETATION OF THE MOTION

The presence of particular sets of conditioning factors such as the slope characteristics and geological conditions predisposed certain area to landslides. Triggering mechanisms such as heavy rainfall or construction activity can give rise to slope failures in these susceptible areas.

6.7 EVIDENCE FOR THE INSTABILITY

Fig PGGH_Dublin_004.3 Typical shallow slope failure in the Dublin Mountains

7 PGGH_DUBLIN_005

7.1 GENERAL PROPERTIES OF THE MOTION AREA

This polygon is located in south Co. Dublin and rests on granite bedrock overlain by made ground.

Landuse type of this polygon is urban fabric, housing estates (Fig PGGH_Dublin_005.1). This polygon extends over c. 2200 m².

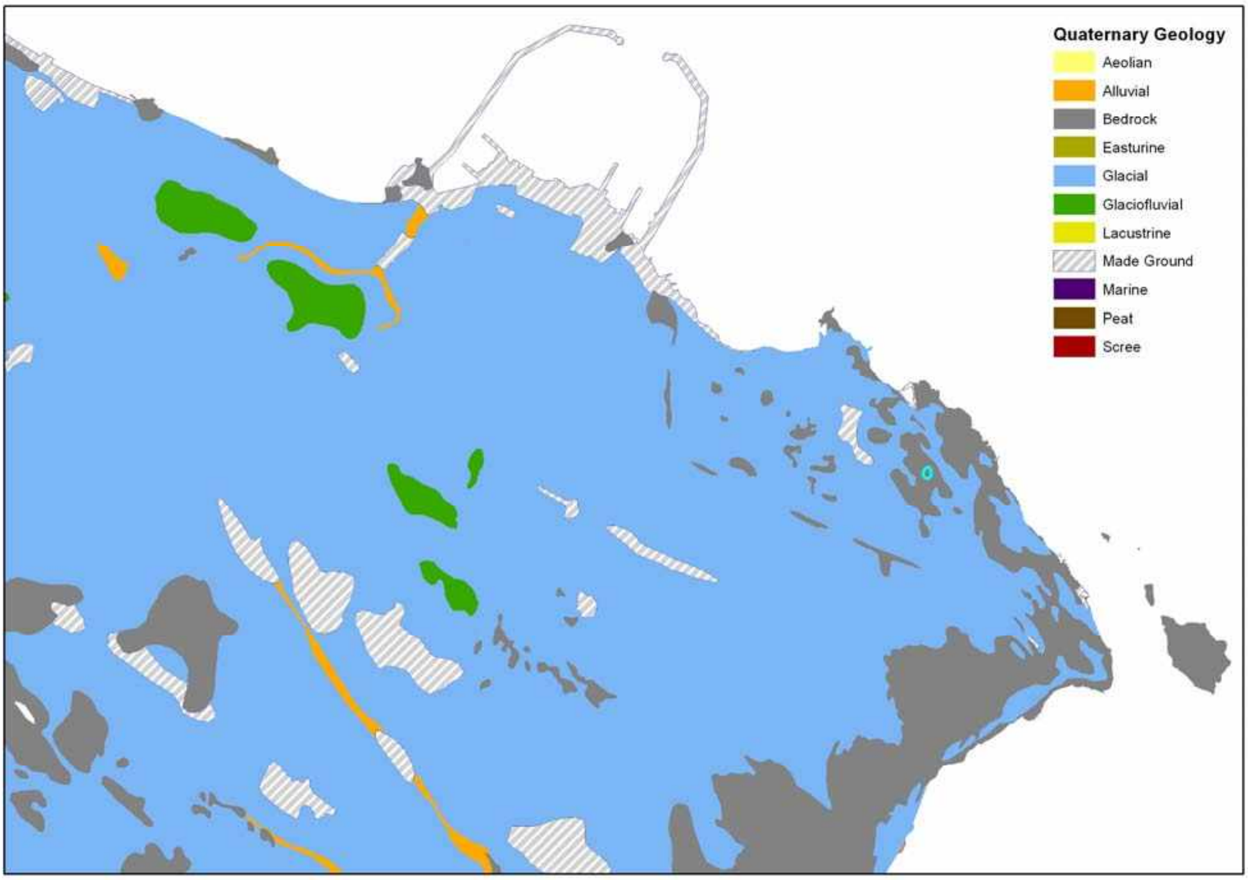

Fig PGGH_Dublin_005.1 Location subsiding polygon (blue outline) and Quaternary geology units

7.2 SPECIFIC GEOHAZARD TYPE

Man Made (Anthropogenic) Ground Instability: Made ground

7.3 TYPE OF MOTION

Subsidence

7.4 THE DETERMINATION METHOD

Observed in PSI data.

7.5 CONFIDENCE IN THE INTERPRETATION

This polygon has a “high” interpretation confidence. The polygon was delineated on the basis of both ERS and Envisat PSI data (Fig PGGH_Dublin_005.2).

Fig PGGH_Dublin_005.2 Red and orange ERS points (with black outline) and Envisat PSI points (no outline) showing a confined area of subsidence (Licence No. EN 0047212).

7.6 GEOLOGICAL INTERPRETATION OF THE MOTION

Man made ground is a deposit of variable characteristics. Made ground can range from precisely engineered materials to mixtures of material that can potentially contain voids, compressible material, material that can decompose, dissolve or expand. Made ground is not subdivided in the Geological Survey of Ireland Quaternary geology mapping.

These adverse characteristics can lead to instability in infrastructure built on these deposits. Pre-development geotechnical and geophysical site investigation can mitigate or avoid the unfavourable effect of this geohazard.

7.7 EVIDENCE FOR THE INSTABILITY

The PSI data from ERS and Envisat products indicate that prolonged subsidence has taken place in this area. Anecdotal evidence from residents of the estate revealed the houses are all built on rafts that overly a quarry that was infilled. Most of the houses in the estate have required underpinning and the road, pavements and services have required repair on several occasions.

8 *PGGH_DUBLIN_006*

8.1 GENERAL PROPERTIES OF THE MOTION AREA

This polygon is distributed around the port area of central Co. Dublin and within the urban fabric of south Co. Dublin with its parts resting on Carboniferous impure limestone bedrock and made ground (Fig PGGH_Dublin_006.1). This polygon extends over c. 0.46 km².

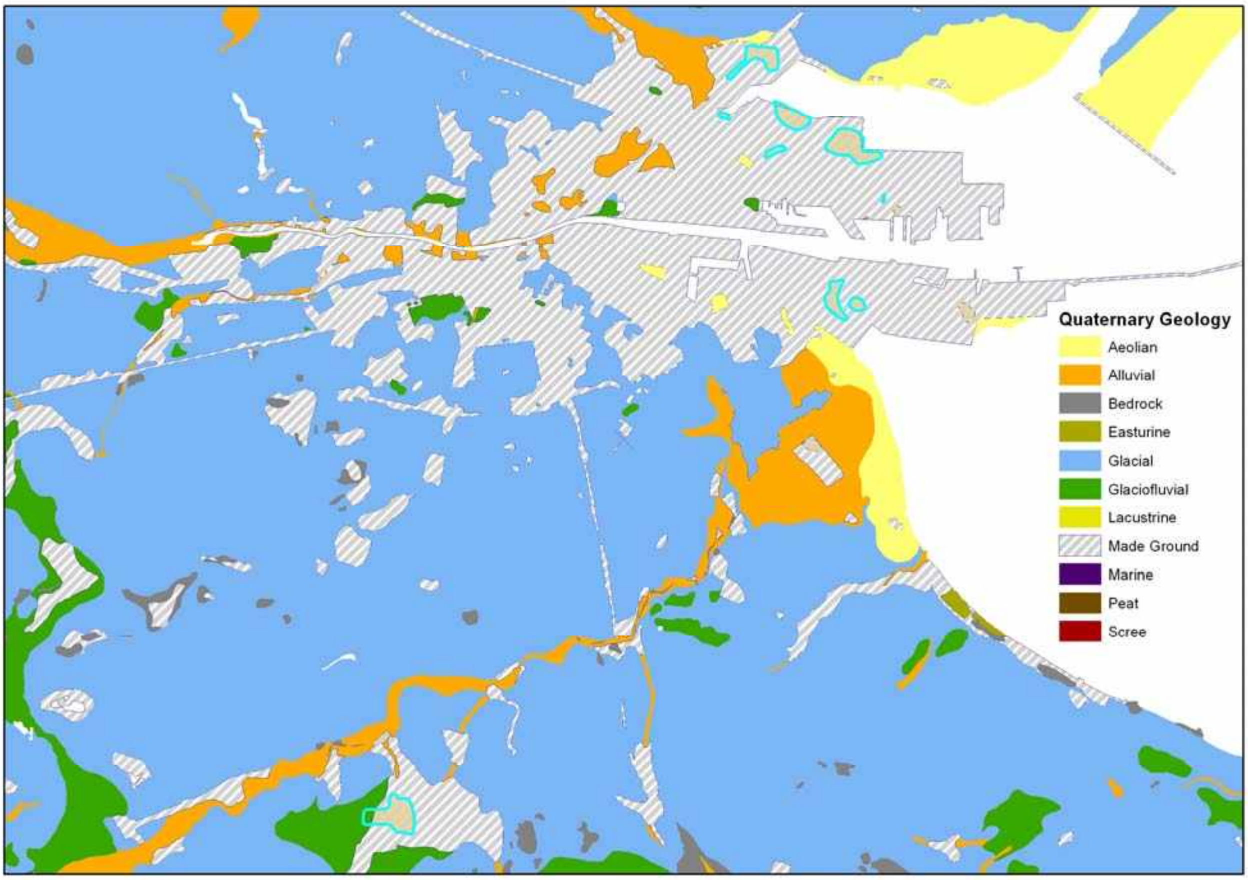

Fig PGGH_Dublin_006.1 Distribution of subsiding polygon (blue outline) and Quaternary geology units

8.2 SPECIFIC GEOHAZARD TYPE

Man Made (Anthropogenic) Ground Instability: Made ground

8.3 TYPE OF MOTION

Subsidence

8.4 THE DETERMINATION METHOD

Observed in PSI data.

8.5 CONFIDENCE IN THE INTERPRETATION

This polygon has a "Medium" interpretation confidence. The polygon was delineated on the basis of ERS and Envisat PSI data and Geological Survey of Ireland 1: 50,000 Co. Dublin Quaternary geology mapping, with reference to the Geological Survey of Ireland Geotechnical Database.

Geological Survey of Ireland Quaternary geology mapping show the distribution of the superficial cover of Holocene and glacial deposits and also where bedrock outcrops or lies within 1 meter of the surface. The uppermost deposit that achieves a thickness of >1m is the deposit that appears on the map. A more detailed 3D model of the deposits, which is in development for central Dublin, will allow a more comprehensive analysis of the lateral and vertical distribution of the made ground deposits.

Geological Survey of Ireland Quaternary geology mapping distinguishes between the following broad categories of deposits: till (boulder clay), sand/gravel, peat, alluvium, lake silt and clay, marl and made ground. Sand/gravel and boulder clay are further divided to show the dominant stone type contained. The data collected during fieldwork based on the analysis of exposures available and the identification and description of morphological features is supported by the acquisition of geophysical or borehole data where sediment type was unknown or uncertain. The Quaternary geology map shows the dominant sediment type within 1 metre of the surface. This dataset is freely available for download and viewing on http://www.gsi.ie/Mapping.htm.

The Geological Survey of Ireland Geotechnical Database contains the reports of site investigation work undertaken to determine the ground conditions at the location of proposed development projects. The reports typically contain a text report and borehole, trial pit and probe logs, as well as field tests and laboratory sample analyses. The data is also critical for the modelling of the subsurface geology and in geological mapping of the overburden (Quaternary sediments) and the bedrock. This dataset is freely available for download and viewing on http://www.gsi.ie/Mapping.htm.

8.6 GEOLOGICAL INTERPRETATION OF THE MOTION

Man made ground is a deposit of variable characteristics. Made ground can range from precisely engineered materials to mixtures of material that can potentially contain voids, compressible material, material that can decompose, dissolve or expand. Made ground is not subdivided in the Geological Survey of Ireland Quaternary geology mapping.

These adverse characteristics can lead to instability in infrastructure built on these deposits. Pre-development geotechnical and geophysical site investigation can mitigate or avoid the unfavourable effect of this geohazard. Detailed geotechnical investigations are usually carried prior to major developments in the Dublin Port area and as a result the buildings and structures normally perform well within the design tolerances for movement. Access routes are not generally as well designed and, coupled with the vibration effects from heavy traffic, often reflect the adverse characteristics of the made ground.

8.7 EVIDENCE FOR THE INSTABILITY

Site access is limited in some of the Dublin Port areas within this polygon.

Images below (and their captions) give an indication of the nature of the instability in this polygon.

Fig PGGH_Dublin_006.2(a) Cracks in buildings

Fig PGGH_Dublin_006.2(b) Cracks in buildings highlighted

Fig PGGH_Dublin_006.3 Cracks in walls

Fig PGGH_Dublin_006.4 Cracks in walls (clear daylight between)

Fig PGGH_Dublin_006.5 Undulations in pavements

Fig PGGH_Dublin_006.6 Cracks in houses

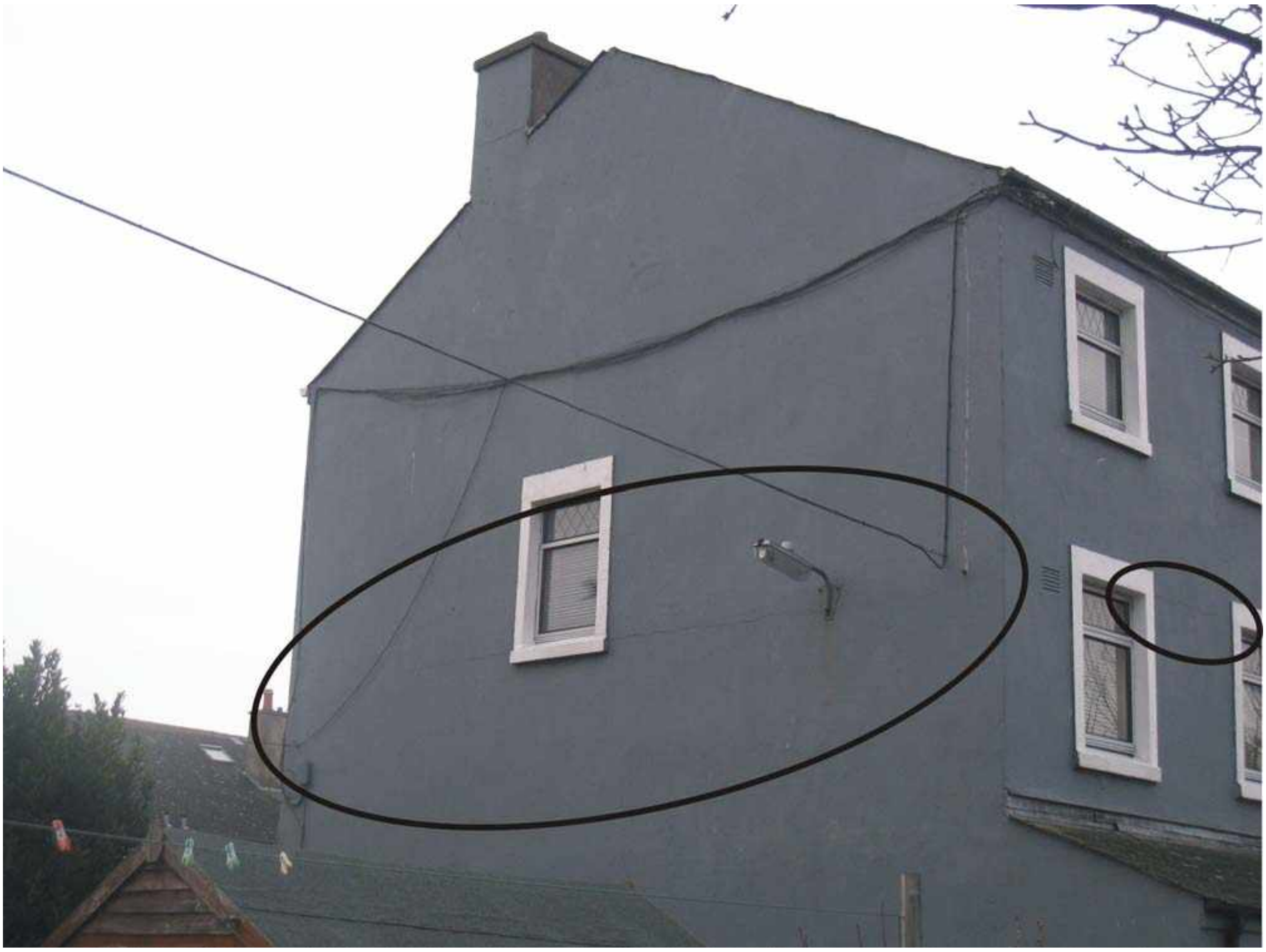

Fig PGGH_Dublin_006.7 Cracks in houses (circled)

Fig PGGH_Dublin_006.8 Cracks in walls

Fig PGGH_Dublin_006.9 Wall collapse

Fig PGGH_Dublin_006.10 differential movement of *c*. 5 cm

9 *PGGH_DUBLIN_007*

9.1 GENERAL PROPERTIES OF THE MOTION AREA

This polygon is distributed across north Co. Dublin (Fig PGGH_Dublin_007.1) and its surface parts are on exposed Carboniferous limestone bedrock units. The polygon was delineated using point data from the Geological Survey of Ireland Karst Features Database. Two cave feature locations were buffered (50m) as the parts of this polygon.

Fig PGGH_Dublin_007.1 Location of Cave features (blue outline) in Naul Village and by the coast just south of Portraine (Licence No. EN 0047212).

The landuse types for this polygon are urban fabric and agricultural land. Pre-development geotechnical and geophysical site investigation coupled with karst hazard potential mapping can mitigate or avoid the unfavourable effect of this geohazard. This polygon extends over c. 0.01 km².

9.2 SPECIFIC GEOHAZARD TYPE

Natural Ground Instability: Ground Dissolution

9.3 TYPE OF MOTION

Subsidence

9.4 THE DETERMINATION METHOD

Potential Motion.

9.5 CONFIDENCE IN THE INTERPRETATION

A value of “External” is assigned to the confidence of this polygon which is derived from the Geological Survey of Ireland Karst Features Database. These data were, in the most part, compiled from a variety of external sources and reports.

The Geological Survey of Ireland Karst Features Database is a database of karst features, showing the location and relevant characteristics of individual karst features across Ireland. This dataset is freely available for download on http://www.gsi.ie/Mapping.htm.

9.6 GEOLOGICAL INTERPRETATION OF THE MOTION

The areas where these caves have developed in the past are also considered to have the potential for caves to develop in the future.

9.7 EVIDENCE FOR THE INSTABILITY

The sites where these caves occur were inaccessible but the reports of their presence have adverse implications for ground stability in these areas.

10 *PGGH_DUBLIN_008*

10.1 GENERAL PROPERTIES OF THE MOTION AREA

This polygon is distributed across Co. Dublin (Fig PGGH_Dublin_008.1.1) and its parts rest on a wide variety of bedrock units (Fig PGGH_Dublin_008.2.2). The polygon was delineated using polygons of potentially compressible deposits from the Quaternary geology map of Co. Dublin. The estuarine deposits are found in tidal areas or at the mouths of rives, lacustrine deposits are mainly found in the north of the county and the peat deposits in mountainous areas of the south. The lacustrine and estuarine deposits are generally found in flood prone areas.

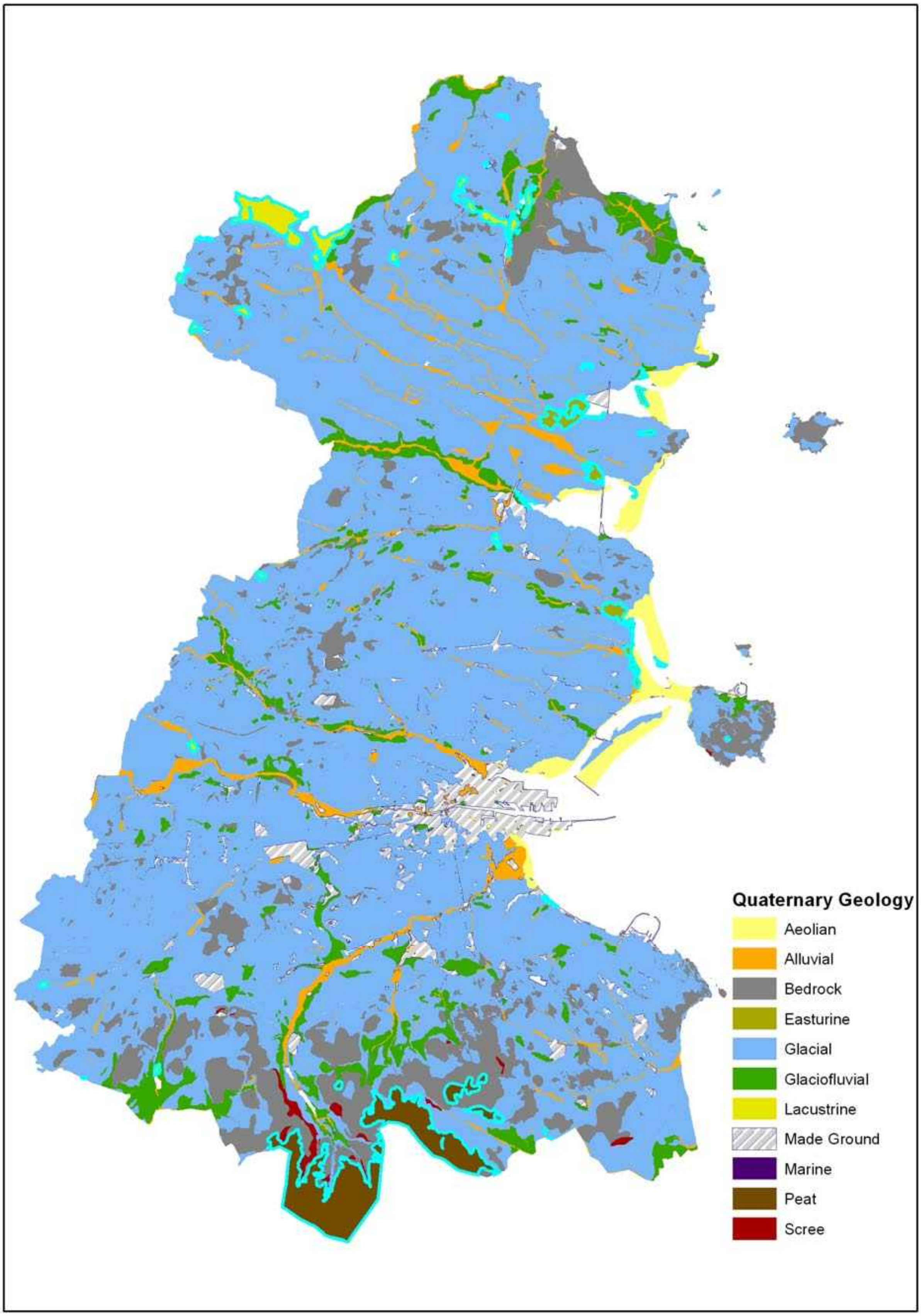

Fig PGGH_Dublin_008.1 Distribution of potential compressible ground polygon (blue outline) and Quaternary geology units

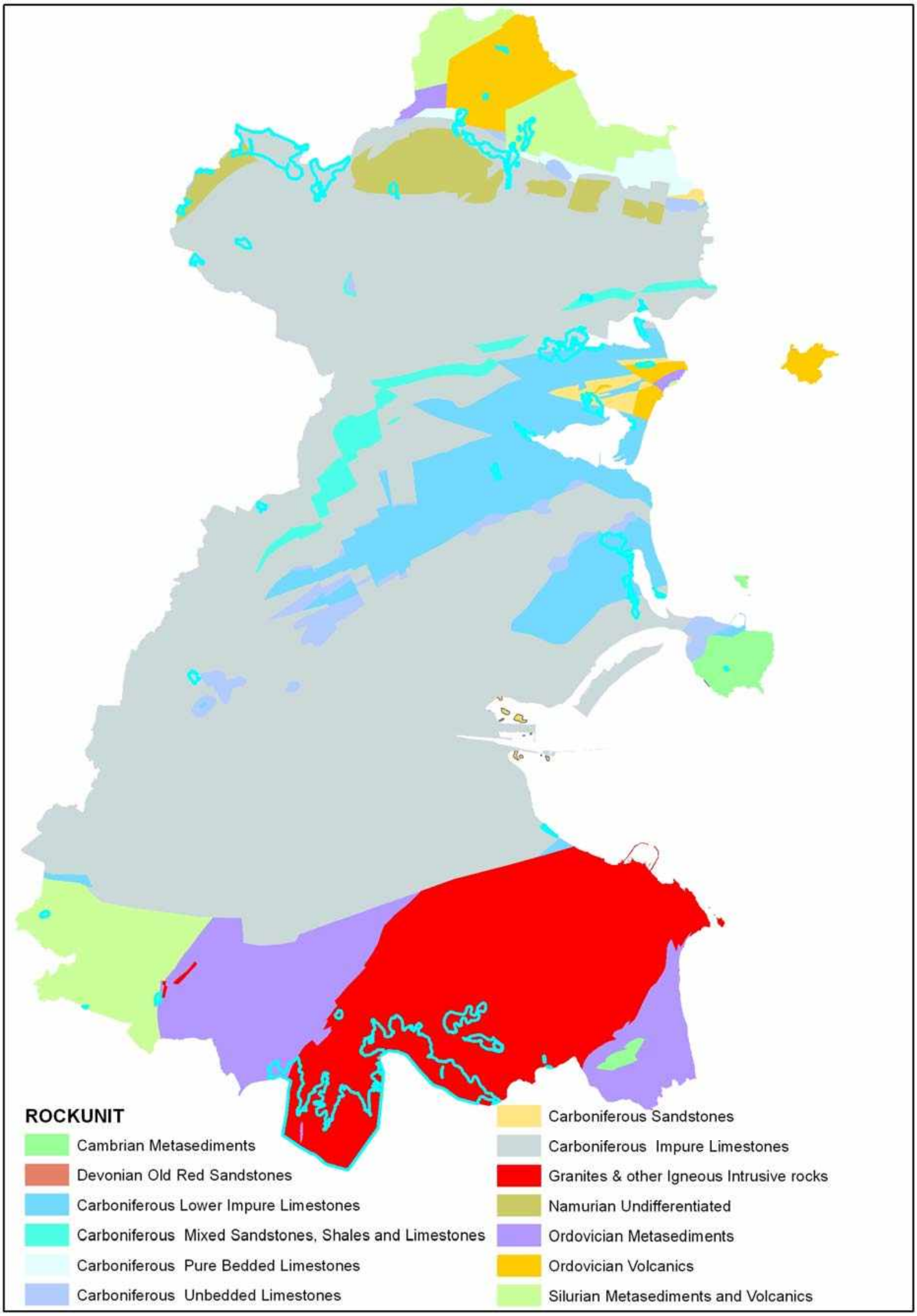

Fig PGGH_Dublin_008.2 Distribution of potential compressible ground polygon (blue outline) and bedrock geology units

The typical landuse type for this polygon is nature reserves in urban areas and agricultural land in rural areas. Occasionally housing estates, industrial and retail units are developed on this polygon. Pre-development geotechnical site investigation can mitigate or avoid the unfavourable effect of this geohazard. This polygon extends over c. 29.91 km².

10.2 SPECIFIC GEOHAZARD TYPE

Natural Ground Movement: Compressible Ground

10.3 TYPE OF MOTION

Subsidence

10.4 THE DETERMINATION METHOD

Potential Motion

10.5 CONFIDENCE IN THE INTERPRETATION

Medium confidence is assigned to this polygon which is derived from deposits shown on the Geological Survey of Ireland 1:50,000 Co. Dublin Quaternary geology mapping.

Instability in these deposits has the potential to occur where they are intersected by development. Geological Survey of Ireland Quaternary geology mapping is primarily conducted using aerial imagery and DEM interpretation combined with geological drilling and geophysical survey techniques. These techniques are difficult to use in urban areas where the natural deposits are obscured by buildings, infrastructure and the landscaping of, and sometimes limited access to, open areas.

Geological Survey of Ireland Quaternary geology mapping show the distribution of the superficial cover of Holocene and glacial deposits and also where bedrock outcrops or lies within 1 meter of the surface. The uppermost deposit that achieves a thickness of >1m is the deposit that appears on the map. A more detailed 3D model of the deposits, which is in development for central Dublin, will allow a more comprehensive analysis of the lateral and vertical distribution (and potential for compression) in the Holocene deposits.

The map distinguishes between the following broad categories of deposits: till (boulder clay), sand/gravel, peat, alluvium, lake silt and clay, marl and made ground. Sand/gravel and boulder clay are further divided to show the dominant stone type contained. The data collected during fieldwork based on the analysis of exposures available and the identification and description of morphological features is supported by the acquisition of geophysical or borehole data where sediment type was unknown or uncertain. The Quaternary geology map shows the dominant sediment type within 1 metre of the surface. This dataset is freely available for download and viewing on http://www.gsi.ie/Mapping.htm.

10.6 GEOLOGICAL INTERPRETATION OF THE MOTION

The areas of peat (Fig PGGH_Dublin_008.3), Lacustrine (Fig PGGH_Dublin_008.4) and estuarine deposits (Fig PGGH_Dublin_008.5) mapped on the Geological Survey of Ireland's Quaternary geology mapping for Co. Dublin are considered to present a potential risk to development as they are compressible deposits. Applying a loading to these deposits has the potential to compress the deposits and result in the lowering of the land surface. These deposits are usually regarded as marginal land and are not developed on should other land be available. Land scarcity in urban areas can result in these deposits used as development sites.

Fig PGGH_Dublin_008.3 Peat deposits south Dublin Mountains


Fig PGGH_Dublin_008.4 Lacustrine deposits north Co. Dublin

Fig PGGH_Dublin_008.5 Estuarine deposits north Co. Dublin

10.7 EVIDENCE FOR THE INSTABILITY

Instability in these deposits has the potential to occur where they are intersected by development. Images below (and their captions) give an indication of the nature of the deposits and the types of instability.

Fig PGGH_Dublin_008.6 Cracking in buildings (circled)

Fig PGGH_Dublin_008.7 Cracking in walls

Fig PGGH_Dublin_008.8 Subsiding of paved areas

Fig PGGH_Dublin_008.9 Tilting of structures

Fig PGGH_Dublin_008.10 Cracking in walls and differential settlement of building extensions

11 *PGGH_DUBLIN_009*

11.1 GENERAL PROPERTIES OF THE MOTION AREA

This polygon is located in the port area of central Co. Dublin it rests on Carboniferous impure limestone bedrock and made ground (Fig PGGH_Dublin_009.1). This polygon extends over c. 0.03 km².

Fig PGGH_Dublin_009.1 Red and orange Envisat PSI points showing an area of subsidence on aerial imagery (Licence No. EN 0047212)

The landuse type for this polygon is a wastewater treatment facility, specifically wastewater tanks atop a c. 20m structure containing processing machinery (Fig PGGH_Dublin_009.2).

Fig PGGH_Dublin_009.2 Wastewater treatment plant

11.2 SPECIFIC GEOHAZARD TYPE

Man Made (Anthropogenic) Ground Instability: Made ground

11.3 TYPE OF MOTION

Subsidence

11.4 THE DETERMINATION METHOD

Observed in PSI data.

11.5 CONFIDENCE IN THE INTERPRETATION

This polygon was delineated on the basis of the low quality Envisat PSI data and Geological Survey of Ireland 1: 50,000 Co. Dublin Quaternary geology mapping, with reference to the Geological Survey of Ireland Geotechnical Database has a "Low" interpretation confidence.

Geological Survey of Ireland Quaternary geology mapping show the distribution of the superficial cover of Holocene and glacial deposits and also where bedrock outcrops or lies within 1 meter of the surface. The uppermost deposit that achieves a thickness of >1m is the deposit that appears on the map. A more detailed 3D model of the deposits, which is in development for central Dublin, will allow a more comprehensive analysis of the lateral and vertical distribution of the made ground deposits.

Geological Survey of Ireland Quaternary geology mapping distinguishes between the following broad categories of deposits: till (boulder clay), sand/gravel, peat, alluvium, lake silt and clay, marl and made ground. Sand/gravel and boulder clay are further divided to show the dominant stone type contained. The data collected during fieldwork based on the analysis of exposures available and the identification and description of morphological features is supported by the acquisition of geophysical or borehole data where sediment type was unknown or uncertain. The Quaternary geology map shows the dominant sediment type within 1 metre of the surface. This dataset is freely available for download and viewing on http://www.gsi.ie/Mapping.htm.

The Geological Survey of Ireland Geotechnical Database contains the reports of site investigation work undertaken to determine the ground conditions at the location of proposed development projects. The reports typically contain a text report and borehole, trial pit and probe logs, as well as field tests and laboratory sample analyses. The data is also critical for the modelling of the subsurface geology and in geological mapping of the overburden (Quaternary sediments) and the bedrock. This dataset is freely available for download and viewing on http://www.gsi.ie/Mapping.htm.

11.6 GEOLOGICAL INTERPRETATION OF THE MOTION

Man made ground is a deposit of variable characteristics. Made ground can range from precisely engineered materials to mixtures of material that can potentially contain voids, compressible material, material that can decompose, dissolve or expand. Made ground is not subdivided in the Geological Survey of Ireland Quaternary geology mapping.

These adverse characteristics can lead to instability in infrastructure built on these deposits. Pre-development geotechnical and geophysical site investigation can mitigate or avoid the unfavourable effect of this geohazard. Detailed geotechnical investigations are usually carried prior to major developments in the Dublin Port area and as a result the buildings and structures normally perform well within the design tolerances for movement. Access routes are not generally as well designed and, coupled with the vibration effects from heavy traffic, often reflect the adverse characteristics of the made ground.

11.7 EVIDENCE FOR THE INSTABILITY

Site access is restricted in this polygon.

The image below (and its caption) gives an indication of the nature of the instability in this polygon.

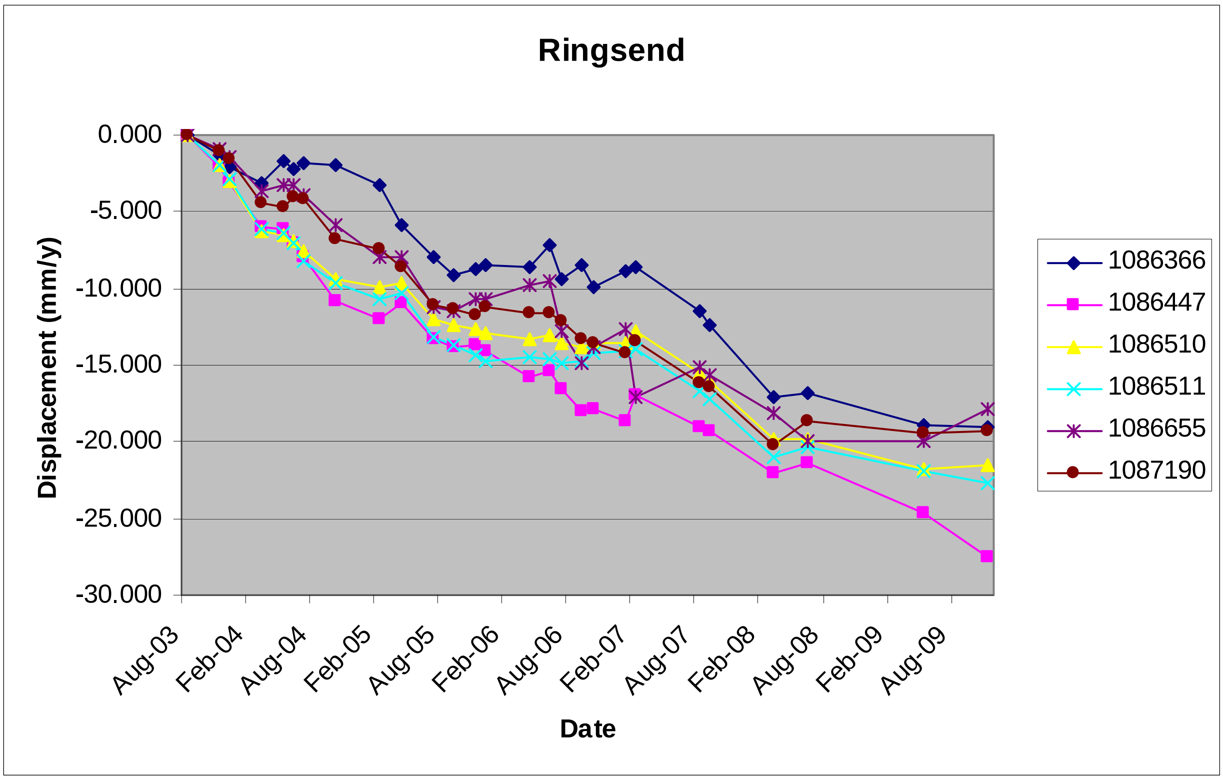

Fig PGGH_Dublin_009.3 A selection of points from the polygon showing the time series of motion

Fig PGGH_Dublin_009.3 shows the rate of motion declining from around February 2008 onwards. This would agree with a hypothesis that initial loading (filling of tanks) causes settling of the structure followed by repose or less downward motion.

PANGEO GEOHAZARD GLOSSARY

Hazard
Something with the potential to cause harm.

Natural Hazard
A natural hazard is a natural process or phenomenon that may cause loss of life, injury or other impacts, property damage, lost livelihoods and services, social and economic disruption, or environmental damage. (Council of the European Union – Commission Staff Working Paper – Risk Assessment and Mapping Guidelines for Disaster Management).

Geohazard (Geological hazard)
A geological process with the potential to cause harm.

Risk
The likelihood that the harm from a particular hazard will be realised.

Types of Geohazard

1. Deep Ground Motions

Ground motion can occur at different scales and depths. This section contains the geohazards that are caused by processes in the deep subsurface.

1.1. Earthquake (seismic hazard)

Earthquakes are the observable effects of vibrations (known as seismic waves) within the Earth's crust arising from relatively rapid stress release, typically along a fault zone.

Damage to buildings and other infrastructure can be caused as the ground shakes during the passage of seismic waves. Other effects include liquefaction of water-saturated soft ground, potentially leading to a loss in ground strength and the extrusion of water-saturated sediments as 'mud volcanoes' and the like. Ground shaking can also trigger secondary events such as landslides and tsunami. Secondary effects such as these should be mapped into the other relevant PanGeo geohazard classes. Some earthquakes are associated with significant permanent vertical or lateral ground movement. Changes to drainage systems can cause flooding. There is potential for injury and loss of life during earthquakes.

Seismic hazard can be assessed by reference to the size and frequency of recorded earthquakes, although individual earthquakes are essentially unpredictable. Individual events occur on time-scales of seconds or minutes. Modern infrastructure should be designed to withstand probable local seismic events.

1.2. *Tectonic Movements*

Tectonic movements are large scale processes that affect the earth's crust. These processes can lead to areas of the crust rising or falling. Importantly it is the neotectonic movements that are still active and may therefore produce a ground motion that can be measured by PSI. Neotectonic movements are typically due to the stresses introduced through movements of the earth's plates. These types of motion are likely to be on a broad scale and so it may not be possible to measure them using the SAR scene relative measurements of PSI.

1.3. Salt Tectonics

Localised motions can be associated with the movement of evaporate deposits, these are termed salt tectonics and can produce both uplift and subsidence depending on the exact mechanisms at play.

1.4. Volcanic Inflation/Deflation

Volcanic activity can lead to the creation of lava flows, ash flows, debris and ash falls, and debris flows of various kinds. It might be accompanied by release of poisonous or suffocating gases, in some instances with explosive violence, or by significant seismic activity or ground movement. Secondary effects can include landslide and flooding. For PanGeo we are interested in hazards associated with ground instability. Ground instability associated with volcanoes tends to relate to inflation and deflation of the ground surface as magma volumes change. Secondary effects such as landslides should be mapped into the other relevant PanGeo geohazard classes.

2. Natural Ground Instability

The propensity for upward, lateral or downward movement of the ground can be caused by a number of natural geological processes. Some movements associated with particular hazards may be gradual or occur suddenly and also may vary from millimetre to metre or tens of metres scale. Note that anthropogenic deposits can be affected by natural ground instability.

Significant natural ground instability has the potential to cause damage to buildings and structures, and weaker structures are most likely to be affected. It should be noted, however, that many buildings, particularly more modern ones, are built to such a standard that they can remain unaffected in areas of even significant ground movement. The susceptibility of built structures to damage from geohazards might also depend on local factors such as the type of nearby vegetation, or the nature of the landforms in the area.

The effects of natural ground instability often occur over a local area as opposed to the effects of natural ground movements which occur over larger areas.

2.1. Land Slide

A landslide is a relatively rapid outward and downward movement of a mass of rock or soil on a slope, due to the force of gravity. The stability of a slope can be reduced by removing ground at the base of the slope, increasing the water content of the materials forming the slope or by placing material on the slope, especially at the top. Property damage by landslide can occur through the removal of supporting ground from under the property or by the movement of material onto the property. Large landslides in coastal areas can cause tsunami.

The assessment of landslide hazard refers to the stability of the present land surface, including existing anthropogenically-modified slopes as expressed in local topographic maps or digital terrain models. It does not encompass a consideration of the stability of new excavations.

Land prone to landslide will normally remain stable unless the topography is altered by erosion or excavation, the land is loaded or pore water pressure increases. Landslide might also be initiated by seismic shock, frost action, or change in atmospheric pressure.

This hazard is significant in surface deposits but may extend to more than 10 m depth. The common consequences are damage to properties, including transportation routes and other kinds of infrastructure, and underground services. Some landslides can be stabilised by engineering.

2.2. Soil Creep

Soil creep is a very slow movement of soil and rock particles down slope and is a result of expansion and contraction of the soil through cycles of freezing and thawing or wetting and drying.

2.3. Ground Dissolution

Some rocks and minerals are soluble in water and can be progressively removed by the flow of water through the ground. This process tends to create cavities, potentially leading to the collapse of overlying materials and possibly subsidence at the surface.

The common types of soluble rocks and minerals are limestones, gypsum and halite.

Cavities can become unstable following flooding, including flooding caused by broken service pipes. Changes in the nature of surface runoff, excavating or loading the ground, groundwater abstraction, and inappropriate installation of soakaways can also trigger subsidence in otherwise stable areas.

2.4. Collapsible Ground

Collapsible ground comprises materials with large spaces between solid particles. They can collapse when they become saturated by water and a building (or other structure) places too great a load on it. If the material below a building collapses it may cause the building to sink. If the collapsible ground is variable in thickness or distribution, different parts of the building may sink by different amounts, possibly causing tilting, cracking or distortion. Collapse will occur only following saturation by water and/or loading beyond criticality. This hazard can be significant in surface deposits and possibly also in buried superficial deposits.

2.5. Running Sand/ Liquefaction

Running sand occurs when loosely-packed sand, saturated with water, flows into an excavation, borehole or other type of void. The pressure of the water filling the spaces between the sand grains reduces the contact between the grains and they are carried along by the flow. This can lead to subsidence of the surrounding ground.

If sand below a building runs it may remove support and the building may sink. Different parts of the building may sink by different amounts, possibly causing tilting, cracking or distortion. The common consequences are damage to properties or underground services. This hazard tends to be self-limited by decrease in head of water.

Liquefaction of water-saturated soft ground often results as an effect of earthquake activity but can also be triggered by manmade vibrations due to construction works. It can potentially lead to a loss in ground strength and the extrusion of water-saturated sediments as 'mud volcanoes' and the like. Soils vulnerable to liquefaction represent areas of potential ground instability.

3. Natural Ground Movement

The effects of natural ground movement often occur over a larger area as opposed to the effects of natural ground instability, which occur over local areas.

3.1. *Shrink-Swell Clays*

A shrinking and swelling clay changes volume significantly according to how much water it contains. All clay deposits change volume as their water content varies, typically swelling in winter and shrinking in summer, but some do so to a greater extent than others. Most foundations are designed and built to withstand seasonal changes. However, in some circumstances, buildings constructed on clay that is particularly prone to swelling and shrinking behaviour may experience problems. Contributory circumstances could include drought, leaking service pipes, tree roots drying-out of the ground, or changes to local drainage such as the creation of soakaways. Shrinkage may remove support from the foundations of a building, whereas clay expansion may lead to uplift (heave) or lateral stress on part or all of a structure; any such movements may cause cracking and distortion.

The existence of this hazard depends on a change in soil moisture and on differential ground movement. Uniform ground movement may not of itself present a hazard. This hazard is generally significant only in the top five metres of ground.

3.2. Compressible Ground

Many ground materials contain water-filled pores (the spaces between solid particles). Ground is compressible if a load can cause the water in the pore space to be squeezed out, causing the ground to decrease in thickness. If ground is extremely compressible the building may sink. If the ground is not uniformly compressible, different parts of the building may sink by different amounts, possibly causing tilting, cracking or distortion.

This hazard commonly depends on differential compaction, as uniform compaction may not of itself present a hazard. Differential compaction requires that some structure that might be susceptible to subsidence damage has been built on non-uniform ground. The common consequences are damage to existing properties that were not built to a sufficient standard, and possible damage to underground services.

4. Man Made (Anthropogenic) Ground Instability

Anthropogenic instability covers a local area which has been 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 tunnelling (for transport, underground service conduits, or underground living or storage space).

Subsidence over a regional area can result from fluid extraction (for water, brine, or hydrocarbons). Uplift or heave of the ground can occur when fluid is allowed to move back into an area from where it was previously extracted and groundwater recharge occurs. This fluid recovery may include injection of water or gas.

4.1. Ground Water Management - Shallow Compaction

11.7.1.1 Ground water management may be applied for example to ensure the exploitability of existing agricultural land in lowland coastal areas. Groundwater management can lead to higher or lower water levels of phreatic groundwater and of deeper aquifers in the shallow subsurface. Groundwater occupies pore and interstitial spaces and fractures within sediments and rocks and therefore exerts a pressure. When the water is drained the pore pressure or effective stress is reduced. This leads to consolidation of especially soft sediments, such as clay and peat. This change in the sediment volume leads to subsidence. Similarly when groundwater levels are allowed to recover, uplift may be a result of increasing pore pressure.

4.2. Ground Water Management - Peat Oxidation

11.7.1.2 Ground water management may be applied for example to ensure the exploitability of existing agricultural land in lowland coastal areas. Groundwater management can lead to higher or lower water levels of phreatic groundwater and of deeper aquifers in the shallow subsurface. Peat oxidation is the chemical reaction where peat starts decomposing and will waste away with time. This loss of soil volume leads to subsidence. It occurs when layers of peat in the subsurface are exposed to oxygen. As long as peat is located in saturated ground layers this process does not take place. However peat oxidation does occur in unsaturated soils, for instance in areas where ground water management lowers ground water levels.

4.3. Groundwater Abstraction

Groundwater also occupies pore and interstitial spaces and fractures within sediments and rocks in the deeper subsurface. When this water is removed, for instance through pumping for drinking water or lowering of water levels in mines, the pore pressure or effective stress is reduced and consolidation of the sediments and rocks causes a change in the sediment and rock volume. This leads to subsidence. Similarly when aquifer levels are allowed to recover, uplift may be a result of increasing pore pressure. Deep geothermal energy systems should not lead to ground movement. They involve closed systems where water, which was extracted from a deep aquifer, will be pumped back into that same aquifer. However, geothermal heat pumps are used at shallower depths. Although these are also closed systems, ground movement might occur temporarily (e.g. seasonally) or even permanently.

4.4. Mining

Mining is the removal of material from the ground, in the context of PanGeo we consider mining to relate to the removal of solid minerals. The ground surface may experience motion due to readjustments in the overburden if underground mine workings fail.

4.5. Underground Construction

In PanGeo we are interested in underground construction that might bring about ground instability. An example of this would be underground tunnelling; the removal of subsurface material can alter the support for the overlying material therefore leading to ground motions.

4.6. Made Ground

Made ground comprises of anthropogenic deposits of all kinds such as land reclamation, site and pad preparation by sand infill, road and rail embankments, levees and landfills for waste disposal. Examples of land reclamation are artificial islands, beach restoration and artificial harbours. Reclaimed land as well as embankments and levees are generally made up of sand, which is not prone to compaction as are clay and peat. However, two ground instability processes will occur: consolidation of this artificial ground and compaction of the ground below due to the load of the artificial ground and the structure it supports, e.g. a building. Depending on its composition and mode of deposition, landfill can also be a compressible deposit.

4.7. Oil and Gas Production

Similar to abstraction of groundwater the production of oil and gas decreases the pore pressure of the reservoir rocks and therefore can cause consolidation and subsidence of the surface. Storage of material in the depleted reservoir (such as natural gas or CO^2) can lead to surface uplift.

5. Other

These are areas of instability for which the geological explanation does not fit into any of the categories above.

6. Unknown

These are areas of identified motion for which a geological interpretation cannot be found.

Geohazard Groupings to be used in PanGeo

1. Deep Seated Motions
    a. Earthquake (seismic hazard)
    b. Tectonic Movements
    c. Salt Tectonics
    d. Volcanic Inflation/Deflation

2. Natural Ground Instability
    a. Land Slide
    b. Soil Creep
    c. Ground Dissolution
    d. Collapsible Ground
    e. Running Sand/Liquefaction

3. Natural Ground Movement
    a. Shrink-Swell Clays
    b. Compressible Ground

4. Man Made (Anthropogenic) Ground Instability
    a. Ground Water Management - Shallow Compaction
    b. Ground Water Management - Peat Oxidation
    c. Groundwater Abstraction
    d. Mining
    e. Underground Construction
    f. Made Ground
    g. Oil and Gas Production

5. Other

6. Unknown