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ODETTE MAGRI (*), MATTEO MANTOVANI (**), ALESSANDRO PASUTO (**)
& MAURO SOLDATI (***)

GEOMORPHOLOGICAL INVESTIGATION AND MONITORING OF LATERAL SPREADING ALONG THE NORTH-WEST COAST OF MALTA

ABSTRACT: MAGRI O., MANTOVANI M., PASUTO A. & SOLDATI M., *Geomorphological investigation and monitoring of lateral spreading along the north-west coast of Malta*. (IT ISSN 0391-9838, 2008).

The north-west coast of Malta is characterized by lateral spreading phenomena which occur within the brittle Upper Coralline Limestone formation (Upper Miocene) overlying the Blue Clay formation (Middle Miocene), the latter being a softer and unconsolidated material. Upper Coralline Limestone features a prominent plateau scarp face, whereas Blue Clay produces slopes which in most cases extend from the base of the Upper Coralline Limestone scarp face to sea level. The Upper Coralline Limestone plateau is heavily jointed and faulted, resulting from past tectonic activity. Chemical weathering, especially solution processes, have produced a karst terrain which aids in further widening the joints and faults and allows deeper infiltration of rainwater. These two geological formations have diverse hydrogeological characteristics which favour mass movement processes and landslide activity. Upper Coralline Limestone is a permeable material, allowing water to pass through, whereas Blue Clay is an impermeable material which retains water. This property renders the Blue Clay plastic when it is wet and causes lateral spreading in the above layer of limestone.

In September 2005, a GPS network was set up consisting of 24 GPS benchmarks installed in unstable areas at three field sites along the north-west coast to determine with high accuracy any displacement in the landslides and the state of activity of lateral spreading. These field sites include ll-Prajjet, Rdum id-Delli and Ghajn Tuffieha Bay incorporating also Il-Qarraba. They provide the best examples of lateral spreading phenomena from a scientific point of view and also present the issues of hazard and risk regarding the damage of the coastal tower at Ghajn Tuffieha Bay built in 1637 by Grand Master Lascaris for defence purposes and Popeye's Village, which constitutes one of the main tourist attractions in the Maltese Islands.

During the first survey that was carried out at the end of September 2005, the baselines between each benchmark and its reference point have been measured. Four other surveys have been conducted in April 2006, October 2006, February/March 2007 and October 2007. By comparing the differences in the baselines measured during the surveys it was possible to detect and quantify the displacements caused by the landslides in the elapsed time with millimetre accuracy. Preliminary results indicate that the coastal landslides are active. The displacements recorded so far from the GPS benchmarks range from 0.54 cm to 1.73 cm. It is intended that further results will be correlated with rainfall data and the behaviour of the Blue Clay material, especially geotechnical and mineralogical properties, to understand the causes of such displacements and activity of the landslides.

KEY WORDS: Coastal landslides, Lateral spreading, GPS monitoring, Malta.

INTRODUCTION

Lateral spreading usually refers to the lateral extension of cohesive rock or soil mass over a deforming mass of softer underlying material where the controlling basal shear surface is often not well defined (Pasuto & Soldati, 1996). This type of instability is characterised by the low-angled slopes involved and the unusual form and rates of movement (Dikau & *alii*, 1996). Lateral spreading may take place in relatively homogeneous rock or else due to the presence of a fractured capping stratum over weaker material, as in the case of Malta. However, in both cases movement occurs as a response to gravitational stresses (Pasuto & Soldati, 1996). Varnes (1978) and Cruden and Varnes (1996) widely accepted classifications for ground deformations and slope failures suggest that movements in lateral spreading may involve fracturing and extension of coherent material owing to liquefaction or plastic flow of subjacent material, such as clay.

Lateral spreading in Malta affects two specific and diverse geological formations. Upper Coralline Limestone (Upper Miocene) is a brittle and fractured permeable rock which develops a plateau above the Blue Clay (Middle Miocene), the latter being an unconsolidated and impermeable material which exposes itself as slopes. The lime-

(*) *Mediterranean Institute, Geography Division, University of Malta, Msida MSD2080, Malta.*
(**) *Istituto di Ricerca per la Protezione Idrogeologica, Consiglio Nazionale delle Ricerche, Corso Stati Uniti 4, 35127 Padova, Italy.*
(***) *Dipartimento di Scienze della Terra, Università degli Studi di Modena e Reggio Emilia, Largo S. Eufemia 19, 41100 Modena, Italy.*

stone plateau, which acts as a cap rock, is characterised by blocks which have been detached and displaced at the foot of the plateau or else extending over the clay slopes.

The occurrence of Upper Coralline Limestone and Blue Clay characterises the entire north-west coast of Malta over a distance of about 24 km. This coastal zone is influenced by the Great Fault system which traverses in a NE-SW direction and develops a horst and graben landscape in northern Malta (Alexander, 1988). The horsts correspond to the Upper Coralline Limestone plateaux which rest on the clay material. Outcrops of these two geological formations are most pronounced along the north-west coast of Malta which is also characterised by different types of landslides, including rock fall, earth slides, earth flows and rock spreading. The latter, in particular, occurs mainly due to the different hydrogeological properties of limestone and clay, and is favoured by the presence of discontinuities in the limestone which have a tectonic origin.

In the present article emphasis has been given on the development of landslides along the north-west coast of Malta, with special reference to lateral spreading phenomena. The latter have been monitored since September 2005 through the installation of a GPS network at three field sites along the north-west coast where GPS surveys take place approximately every six months, at the end of the wet and dry seasons. This is the first time that an attempt is being made to measure landslide displacements in the Maltese Islands, which besides the scientific value, the results have wider relevance regarding issues of hazard and risk and the protection of the cultural heritage. In this regard the results of preliminary research have already been published by Magri & *alii* (2007). Moreover, previous works by Magri (2001) and Dykes (2002) have investigated mass movement processes and Blue Clay slope instability along the north-west coast.

THE STUDY AREA

The study area is located in the Maltese Islands situated in the central Mediterranean region between Italy and North Africa (fig. 1), at a latitude of 35º48'28" to 36º05'00" North and a longitude of 14º11'04" to 14º34'37" East. The Islands lie approximately 96 km from Sicily to the north, 290 km from North Africa to the south, 1836 km from Gibraltar to the west and 1519 km from Alexandria, Egypt to the east (Schembri, 1993). They are situated on a shallow shelf, the Malta-Ragusa Rise, part of the submarine ridge which extends from the Ragusa peninsula of Sicily southwards to the North African coasts of Tunisia and Libya. Geophysically the Maltese Islands and the Ragusa peninsula of Sicily are regarded as forming part of the African continental plate.

The Maltese archipelago consists of three main islands: Malta, Gozo and Comino (fig. 1) and a number of small

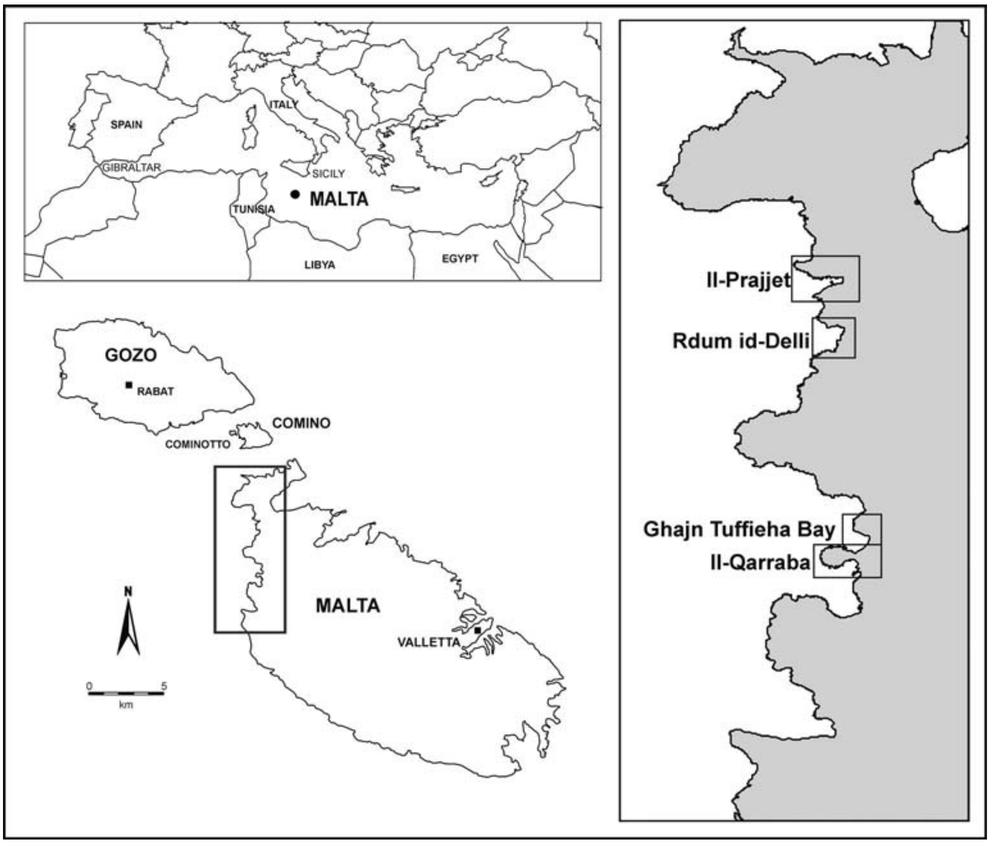

FIG. 1 - Location of the Maltese Islands and the three field sites along the north-west coast of Malta. Location of field sites is enlarged in the inset.

uninhabited islets. The Islands have a total land area of 316 km^2 (Malta: 245.7 km^2, Gozo: 67.1 km^2, Comino: 2.8 km^2) and a coastline about 190 km long, with a submerged area (up to 100 m) of 1940 km^2 (Schembri, 1990). The length of the whole archipelago is 45 km; Malta being 27 km long, Gozo 14.5 km long and Comino 2.5 km.

The area of the present study is situated along the north-west coast of Malta, covering a stretch of about 24 km. Three field sites, Il-Prajjet, Rdum id-Delli and Ghajn Tuffieha Bay including also Il-Qarraba (fig. 1), have been selected for detailed investigation to monitor the state of activity and to detect any displacements in the coastal landslides using the GPS technique.

GEOLOGY OF THE MALTESE ISLANDS

Lithology

The stratigraphic sequence of the Maltese Islands represents a varied cross-section of Oligo-Miocene lithologies and facies, consisting entirely of Tertiary limestones with subsidiary marls and clays deposited within a variety of shallow water marine environments (Pedley & *alii*, 1978) some 30 to 35 million years ago. The succession ends with Upper Coralline Limestone (Upper Miocene) which is the youngest formation reaching a maximum thickness of 175 m. This is preceded by Greensand (Upper Miocene, maximum thickness is 16 m), Blue Clay (Middle Miocene, maximum thickness is 75 m), Globigerina Limestone (Middle to Lower Miocene, maximum thickness is 110 m) and Lower Coralline Limestone (Upper Oligocene) which is the oldest formation reaching a maximum thickness of 140 m (fig. 2). Quaternary deposits, mostly Pleistocene in age, are limited to few localities and take the form of cliff breccias, cave and valley loams, sands and gravels.

The geological formations of the Islands are very distinctive lithologically and this is reflected in characteristic topography and vegetation (House & *alii*, 1961). The Lower Coralline Limestone is responsible for forming spectacular cliffs, some reaching 140 m in height, which bound the Islands especially in the west (fig. 2). Inland the Lower Coralline Limestone forms barren grey limestone-pavement topography. The succeeding Globigerina Limestone, which is the most extensive formation on the Islands, forms a broad, rolling landscape. The soil is thin but intensively cultivated and hillslopes on it are densely terraced.

Blue Clay produces slopes that tend to slide over the underlying Globigerina Limestone Formation. It forms the most fertile bedrock on the Islands, especially where springs seep from the overlying Upper Coralline Limestone. The latter, which also includes Greensand, forms massive cliffs and limestone pavements with karstic topography similar to Lower Coralline Limestone. It caps tabular hills and mesas

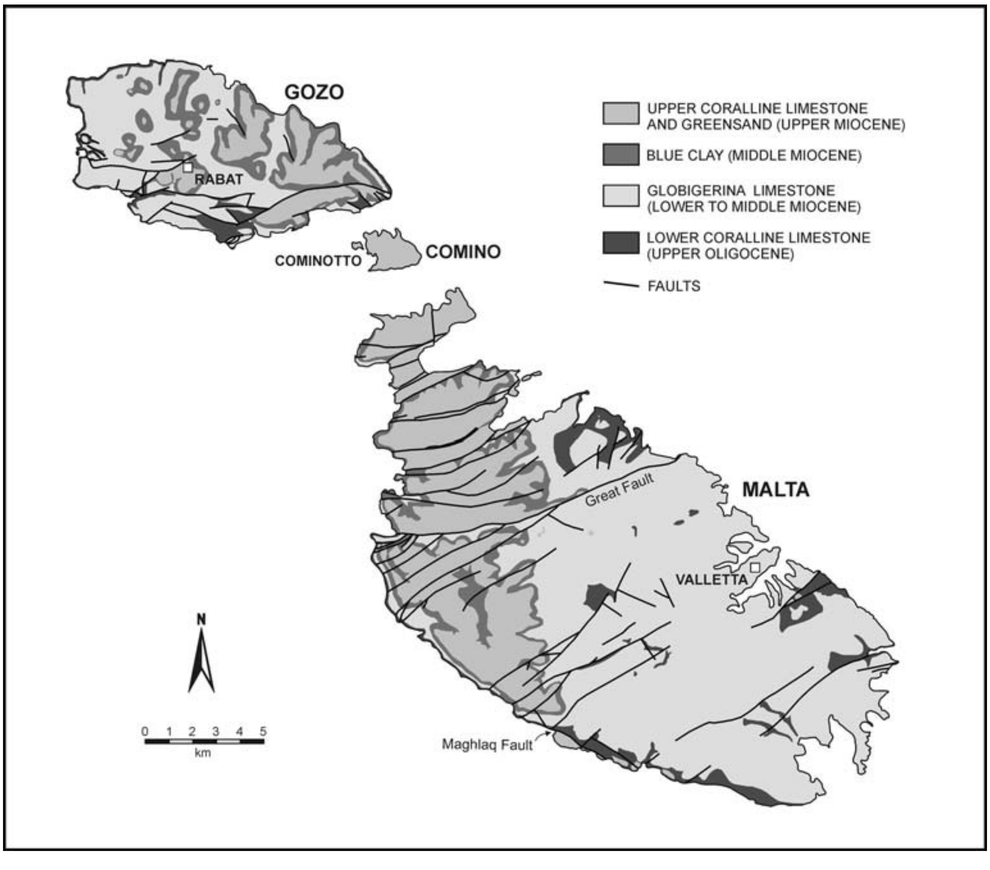

FIG. 2 - Geological setting of the Maltese Islands (adapted from Various Authors, 1993).

reaching a maximum height of 253 m at Ta' Zuta, near Dingli in south-west Malta (Pedley & *alii*, 1978).

The geology of the north-west coast is characterised by the Upper Coralline Limestone and Blue Clay formations (fig. 2). The different physical and hydrogeological properties of these two geological formations favour the occurrence of mass movement processes. Rock fall is the most widespread mass movement process but excellent examples of lateral spreading can also be observed.

Tectonics

The Maltese Islands rise up to 253 m above sea level, from an emerged part on the southern upwarped north-east shoulder of the Pantelleria Rift. The latter is a graben system active in Late Miocene to recent time, which interrupts the shallow shelf platform connecting Europe and Africa (Illies, 1981). The fracture pattern of the Islands has been created by tectonic processes governed by the relative motions between the European and African plates. The plate boundary runs about 200 km to 400 km to the north of Malta from Tunisia to Sicily.

Two rift systems of different ages and trends dominate the structural setting of the Maltese Islands. A horst and graben structure has been developed on western Malta, Comino and eastern Gozo resulting from the older rift generation which traverses the Islands striking at about 50° to 70°. This structure constitutes the oldest tectonic movements observable on the Maltese Islands. The second-generation rift, associated with the Pantelleria Rift, strikes Malta at about 120° and Gozo between 80° and 90°. Rifting mainly originated during the Late Miocene - Early Pliocene, to continue in parts up to the present (Illies, 1981).

The fracture pattern is dominated by two intersecting fault systems which alternate in tectonic activity (fig. 2). A NE-SW to ENE-WSW trending fault, the Great Fault, traverses the Islands and is crossed by a NW-SE trending fault, the Maghlaq Fault with a vertical displacement of at least 240 m to the SW (House & *alii*, 1961). The latter is parallel to the Malta trough, which is the easternmost graben of the Pantelleria Rift System. In general the faults, all vertical or subvertical, are part of a horst and graben system of relatively small vertical displacement. The major faults all influence the entire Oligo-Miocene succession (fig. 2) and there is considerable evidence that movement has been continuous since Miocene times.

LANDSLIDES ALONG THE NORTHWEST COAST

The north-west coast of Malta is sparsely inhabited with few settlements which are found inland. This region is characterised by agricultural activities, where landslides have provided the setting for such activities to take place. The latter are in decline or have been abandoned altogether due to the steep topography of the clay and scree slopes rendering agriculture as a labour-intensive activity. Bird hunting and trapping is however very widespread especially during the spring and autumn hunting seasons.

Despite the sparse population, this region is highly frequented by both locals and tourists for recreational purposes and outdoor activities due to the aesthetic qualities of the rural and coastal landscapes. Being characterised by landslides, therefore an unstable terrain, this region presents elements of hazard and risk for its multiple users. Accidents have in fact been reported in the media in recent years (October 2004 and August 2005) where people have been injured due to rock fall or difficult accessibility of the terrain. Moreover, the landslides are also putting at risk the cultural heritage and tourism activities in this coastal region.

Landslides along the north-west coast include rock fall, earth slides, earth flows and rock spreading. The role of tectonics remains significant (Alexander, 1988), however the influence of the geological setting is equally crucial. In this coastal region of Malta, slope instability conditions are especially caused due to the exposure of Blue Clay below the Upper Coralline Limestone (fig. 2). Rock fall results from the breaking, dislodgement and falling of blocks from the limestone plateau on the underlying slopes. This type of mass movement is especially widespread. Large blocks extend to sea level and protect the coast from further erosion, or else they rest close to the scarp face from which they have been detached.

Earth slides and earth flows occur in the Blue Clay formation and are triggered as a result of rainfall during the autumn and winter months, when the clay material becomes plastic and wet. After a prolonged summer drought, deep desiccation cracks develop in the Blue Clay material which is able to absorb a significant amount of water, thus becoming saturated and increasing in volume. Earth slides occur especially where the clay slopes are bare of any vegetation cover or where boulders, rock fragments or debris are absent.

This research deals with one specific type of landslide, that is lateral spreading. In Malta these phenomena occur within the Upper Coralline Limestone formation which overlies the Blue Clay formation (fig. 3). The former is a brittle type of rock whereas the latter consists of unconsolidated material. Along the north-west coast the exposure of these two geological formations has produced an Upper Coralline Limestone plateau and Blue Clay slopes which extend from the base of the Upper Coralline Limestone scarp face to sea level. Upper Coralline Limestone and Blue Clay have different hydrogeological properties. The limestone is permeable whereas clay is impermeable, rendering the Blue Clay plastic when it is wet and causing further instability in the limestone, thus favouring mass movement processes and landslide activity. Rainwater infiltrates deep into the limestone along joints and faults which are further widened through solution weathering and the development of a karst terrain.

Three coastal field sites have been selected to perform detailed investigation. These sites provide the best examples of lateral spreading from a scientific point of view and also present the issues of hazard and risk regarding the damage of the coastal tower at Ghajn Tuffieha Bay (fig. 4) built in 1637 by Grand Master Lascaris for defence pur-

FIG. 3 - Lateral spreading along the north-west coast of Malta develops due to the superimposition of Upper Coralline Limestone which overlies the Blue Clay. Limestone blocks extend over the clay material and even act as buttressing to the shoreline (courtesy of Patrick Bonnici).

FIG. 4 - The coastal tower overlooking Ghajn Tuffieha Bay was built for defence purposes in 1637 by Grand Master Lascaris. The deep fracture within the Upper Coralline Limestone plateau is putting the historical tower at risk due to the retreating cliff.

poses and Popeye's Village (fig. 5), a main tourist attraction in the Maltese Islands.

Geological and geomorphological settings of Il-Prajjet

Il-Prajjet is located at the northernmost part of the three field sites (fig. 1). It consists of a narrow inlet, geologically composed of Upper Coralline Limestone. Blue Clay is present on the northern side of the inlet below the Upper Coralline Limestone plateau which varies in height between 10 m to 12 m. The southern side presents a sheer cliff face, also composed of Upper Coralline Limestone, whereas the northern side features excellent examples of lateral spreading phenomena. The landslides on this part

FIG. 5 - Popeye's Village found at Il-Prajjet on the north-west coast of Malta was constructed as the film set of a movie in the early 1980s and is now a popular tourist attraction in the Maltese Islands. An element of risk exists for the visitors due to cliff instability.

of the inlet are posing a hazard to Popeye's Village, which is one of the most popular tourist attractions in the Maltese Islands. At this site monitoring of the lateral spreading is taking place through the installation of eight benchmarks on detached blocks and a reference point located at a more stable site further inland.

Geological and geomorphological settings of Rdum id-Delli

Rdum id-Delli is located 0.68 km to the south of Il-Prajjet and extends over a distance of 0.67 km (fig. 1). The geology of this site consists of Upper Coralline Limestone, Blue Clay and Globigerina Limestone. The Greensand formation is assimilated within the basal layers of Upper Coralline Limestone which features a plateau, 10 m to 15 m high, below which Blue Clay slopes descend reaching a Globigerina Limestone cliff. The southern part is delimited by a Quaternary solution subsidence structure, whereas the northern part is characterised by a plunging coastal cliff, 40 m above sea level. Three benchmarks were installed on the faulted plateau at the northern side of Rdum id-Delli above the plunging cliff to monitor lateral spreading phenomena, whereas the reference point has been fixed further inland.

Geological and geomorphological settings of Ghajn Tuffieha Bay and Il-Qarraba

Ghajn Tuffieha Bay is the third field site being investigated along the north-west coast of Malta (fig. 1). The geology is composed of Upper Coralline Limestone and Blue Clay. The northern part of the Bay is composed of an Upper Coralline Limestone plateau, which features a cliff face (27.5 m high) and plunges directly into the sea where Blue Clay is absent. Where the latter formation is present, Blue Clay slopes descend from the base of the plateau to sea level. A coastal tower, built for defence purposes in 1637 by Grand Master Lascaris, dominates the northern part of the Bay (fig. 4). The tower is situated at the edge of the cliff which is retreating due to the presence of coastal landslides, and is thus at risk of being damaged.

To the southern part, the Bay is delimited by a promontory, known as Il-Qarraba (fig. 1), composed of an Upper Coralline Limestone cap rock (7.5 m to 23 m high) and Blue Clay slopes which descend to sea level. The clay slopes are characterised by the presence of large blocks detached from the above plateau. The Bay itself consists of a sandy beach, backed by Blue Clay slopes above which an Upper Coralline Limestone cap rock is found. Monitoring of the landslides is taking place both on the southern promontory where 11 benchmarks have been installed and on the northern cliff where 2 benchmarks have been set up. A reference point has been fixed further inland on the northern plateau and is being used for both monitoring sites in this Bay.

LANDSLIDE MONITORING AT THE THREE FIELD SITES

A GPS network consisting of 24 benchmarks was installed in September 2005 at the three field sites to determine any displacements in the landslides and the state of activity of lateral spreading. The GPS technique was chosen because it has already been tested as a powerful tool in ground deformation analysis with high accuracy and reliability (see for example Mantovani & *alii*, 1996; Gili & *alii*, 2000; Malet & *alii*, 2002; Coe & *alii*, 2003; Corsini & *alii*, 2005). Since the deformations occurring in lateral spreading phenomena are usually very slow (few millimetres per year) attention was especially given to the planning and preparation of the survey procedures. Two dual frequency SR530 Leica Geosystems GPS receivers capable to track the L1 C/A code and L2 P code on 24 channels were used. The static relative positioning technique was employed in order to achieve more accurate results (Hofmann-Wellenhof & *alii*, 2001) within an acquisition time of 20 minutes and a 2 second sampling rate. The baselines range from a minimum of 37 m to a maximum of about 693 m. Every survey was planned using broadcast almanacs to exploit the temporal windows with the best possible satellite configuration and within a value of the GDOP (Geometric Dilution Of Precision) parameter minor or equal to 5. Data were stored and post-processed using precise ephemeris with the Leica SKI-Pro software. In order to guarantee the uniformity of the surveys, avoiding positioning errors, a forced centring device for the GPS antenna was performed for each benchmark.

Surveys are carried out approximately every six months in April and October corresponding to the end of the wet season and dry season respectively. These months have been chosen on purpose so as to determine whether rainfall plays an important role in the instability and displacements of the landslides. Five GPS surveys have been carried out in September 2005, April 2006, October 2006, February/March 2007 and October 2007. During each GPS survey, the baselines between each benchmark and its reference point are measured. Displacements caused by the landslides can be determined with a theoretical precision of up to about 3 mm to 10 mm + 1 ppm when differences in the baselines are compared between one survey and the other.

RESULTS DERIVED FROM GPS MONITORING

To date eight benchmarks have been lost due to activities of vandalism at the three field sites, including the complete removal of all three benchmarks at Rdum id-Delli. At the latter site only the reference point has remained and since the three benchmarks installed in the unstable plateau edge were removed, further monitoring could not be performed. Also the reference point at Il-Prajjet has been lost twice but has now been replaced at a more secure location.

The planar displacements recorded by the benchmarks with a reliability of 95% are summarized in tab. 1. The vertical component of the deformation process is not taken into account since the determination of the height coordinates was not accurate enough to highlight significant displacements.

Fourteen benchmarks, corresponding to 58% of the total number of benchmarks, recorded significant displacements. Preliminary results collected over a 24-month period (September 2005 to October 2007) indicate that the coastal landslides are active, with displacements ranging from 0.54 cm to 1.73 cm. The velocity of the deformation process ranges from 1 mm to 3 mm per month. When the deformations are larger than the statistical uncertainty of the measurements, it is possible to observe that during the wet period six benchmarks have moved while during the dry period only three benchmarks recorded significant displacements. Landslides have been observed to be active at all the three field sites: Rdum id-Delli (0.67 cm to 1.02 cm) (fig. 6), the plateau of Il-Qarraba separating Ghajn Tuffieha Bay from Gnejna Bay (1 cm to 1.73 cm) (fig. 7), the historical tower overlooking Ghajn Tuffieha Bay (1.13 cm) (figure 7) and ll-Prajjet (0.54 cm to 1.17 cm) (fig. 8). It is worth noting that the deformations do not occur continuously with time and that the direction of the displacement vectors changes throughout the surveys. This is probably due to the differential settlement of the limestone blocks over the Blue Clay. It is intended that further results will be correlated with rainfall data and the behaviour of the Blue Clay material, especially geotechnical and mineralogical properties, to understand the causes of such displacements and activity of the landslides.

CONCLUSIONS

Lateral spreading of coastal cliffs is being monitored along the north-west coast of Malta to identify any dis-

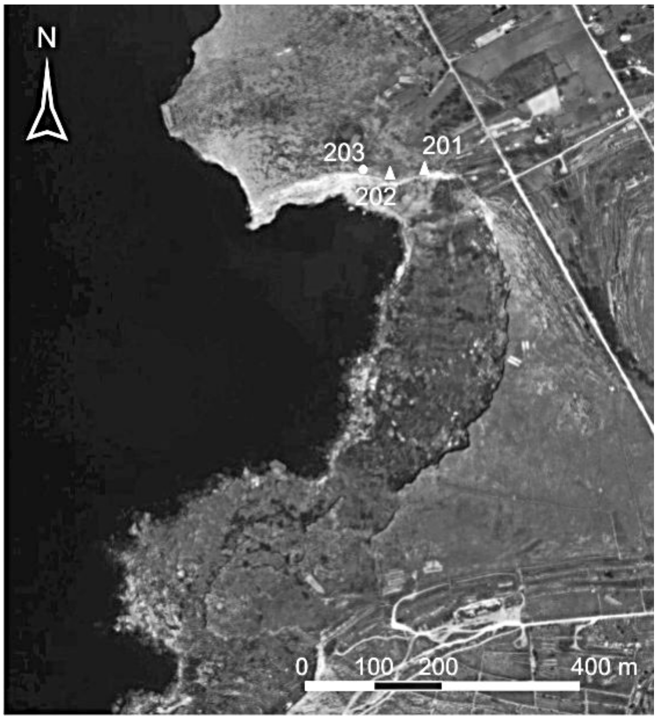

FIG. 6 - Satellite image of Rdum id-Delli: benchmarks that recorded significant planar displacements are indicated with a triangle symbol, those which have moved during the wet period are indicated with a circle symbol.

TABLE 1 - Planar displacements recorded for lateral spreading along the north-west coast of Malta (September 2005 to October 2007). Benchmarks with an (*) symbol were not measured during survey 0, those with a (") symbol were not measured during survey 0 and 4 while the symbol (^) refers to those benchmarks which were removed by vandals after survey number 2

<table>
<tr><th>BENCHMARKS</th><th colspan="10">GPS SURVEYS</th></tr>
<tr><th>N°</th><th colspan="2">September 2005
0</th><th colspan="2">April 2006
1</th><th colspan="2">October 2006
2</th><th colspan="2">March 2007
3</th><th colspan="2">October 2007
4</th></tr>
<tr><td>102*</td><td colspan="7"></td><td colspan="2">0.82 cm</td><td></td></tr>
<tr><td>103*</td><td colspan="7"></td><td colspan="2">0.54 cm</td><td></td></tr>
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<tr><td>105"</td><td colspan="5"></td><td colspan="2">1.17 cm</td><td colspan="3"></td></tr>
<tr><td>201^</td><td></td><td colspan="2">1.02 cm</td><td colspan="2">0.67 cm</td><td colspan="5"></td></tr>
<tr><td>202^</td><td></td><td colspan="2">0.91 cm</td><td colspan="2">0.67 cm</td><td colspan="5"></td></tr>
<tr><td>203^</td><td></td><td colspan="2">0.82 cm</td><td colspan="7"></td></tr>
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<tr><td>305</td><td colspan="5"></td><td colspan="2">1.00 cm</td><td colspan="3"></td></tr>
<tr><td>306</td><td></td><td colspan="2">1.34 cm</td><td colspan="7"></td></tr>
<tr><td>307</td><td colspan="5"></td><td colspan="4">1.64 cm</td><td></td></tr>
<tr><td>309</td><td colspan="3"></td><td colspan="2">1.73 cm</td><td colspan="4">0.92 cm</td><td></td></tr>
<tr><td>312</td><td></td><td colspan="4">1.13 cm</td><td colspan="2">0.73 cm</td><td colspan="3"></td></tr>
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placements and determine the state of activity of the landslides. The north-west coastal region displays excellent examples of lateral spreading resulting from the superimposition of jointed limestones overlying the clay material. The different physical and hydrogeological properties of these two formations favour mass movement processes and slope instability conditions, which characterise the entire north-west coastal stretch.

The GPS technique was chosen to monitor displacements in the coastal cliffs since such a technique has already been used successfully in several studies dealing with ground deformation and landslides due to the high accuracy and reliability. Moreover this is the first time that coastal landslide research is taking place in the Maltese Islands and that the GPS technique is being used for this purpose.

Since the installation of the GPS network at three selected field sites in September 2005, four more surveys have been carried out at the end of the wet and dry seasons. These surveys have yielded relevant results, with 14 benchmarks out of the initial 24 benchmarks recording significant displacements in the lateral spreading and indicating that the coastal landslides are active at the three field sites. Preliminary results collected between Septem-

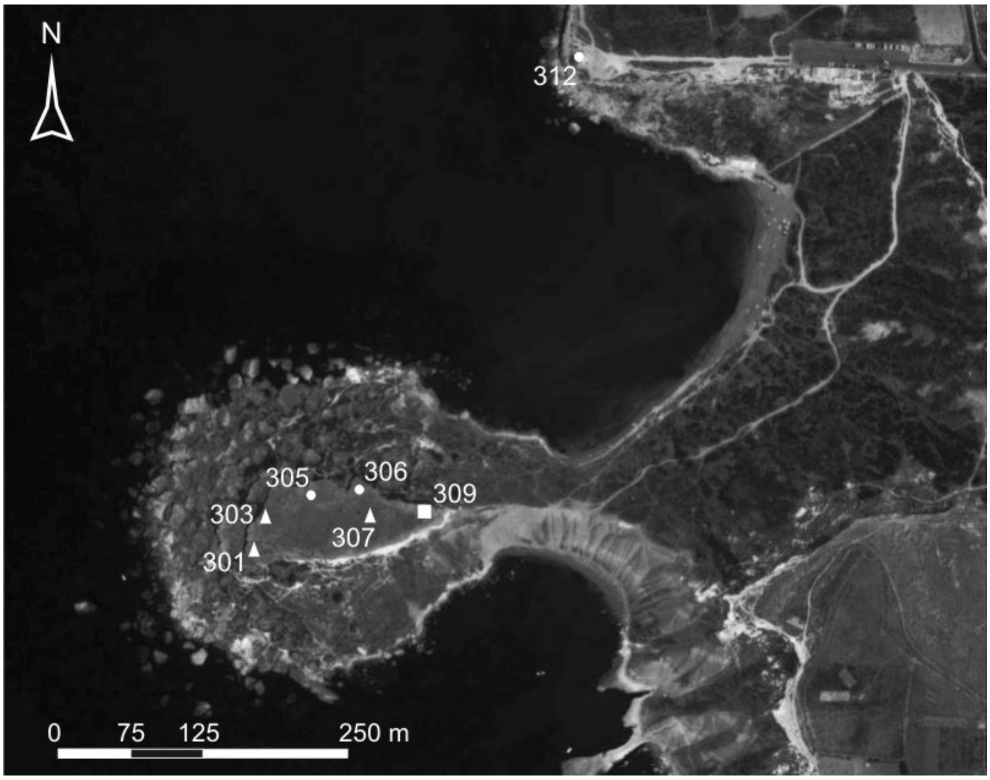

FIG. 7 - Satellite image of Il-Qarraba and the coastal tower overlooking Ghajn Tuffieha Bay: benchmarks that recorded significant planar displacements are indicated with a triangle symbol, those which have moved during the wet period are indicated with a circle symbol and those which have moved during the dry period are indicated with a square symbol.

FIG. 8 - Satellite image of Il-Prajjet: benchmarks that recorded significant planar displacements during the wet period are indicated with a circle symbol and those which have moved during the dry period are indicated with a square symbol.

ber 2005 and October 2007 give a displacement range between 0.54 cm to 1.73 cm. Deformation is occurring at a rate between 1 mm to 3 mm per month. It should also be noted that rainfall does play an important role since measurements have indicated that during the wet period six benchmarks have moved in comparison to the three benchmarks which were displaced during the dry period. No temporal continuation has been observed with regards to the deformations and displacement vectors do not maintain the same direction throughout the surveys.

Although the data presented in this study constitute the preliminary results over a two-year period, trends in landslide displacements can still be observed. The significance of these results is enhanced when considering their broader implications with regards to the elements of hazard and risk exposed to locals and tourists who frequent this area. The north-west coast, being the focal area of this study, is endowed with structures which enrich the cultural heritage of the Maltese Islands, such as the defence tower overlooking Ghajn Tuffieha Bay which is in danger of collapse due to the retreating cliff. Moreover this coastal region is especially sought after for outdoor activities, such as hiking and country-walking and highly promoted for tourism, due to the aesthetic qualities of the natural rural and coastal landscape. The latter has remained largely pristine and undeveloped, although some infrastructural and touristic developments have taken place in recent years. Consequently, research activities along the north-west coast of Malta have been undertaken during the past three years, which address landslide hazard assessment and mitigation, especially through the monitoring of landslide displacements. The ultimate objectives are to protect the cultural heritage and carry out tourism and outdoor activities in safe conditions for the benefit of the local population and the tourists who visit the Maltese Islands.

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