# RECOGNITION AND ASSESSMENT OF SINKHOLES AS GEOSITES: LESSONS FROM THE ISLAND OF GOZO (MALTA)

Paola Coratza, Jorge Pedro Galve, Mauro Soldati, Chiara Tonelli

University of Modena and Reggio Emilia, Department of Earth Sciences, Modena, Italy

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Abstract. There is a wide literature on sinkhole or doline classification, formation and evolution. However, despite the fact that they are often characterised by spectacular morphological features, sinkholes are not normally described as geological resources which might be valuable for the society and worth of being promoted for their geomorphological importance. A series of sinkholes have been investigated in the Island of Gozo (Malta), some of which of notable size and high aesthetic interest. These sinkholes have been assessed applying a methodology which has been specifically set up with the aim of verifying whether any of them could be considered as geosites according to their scientific, additional (ecological, aesthetic, cultural) and use values. The paper shows the geosite assessment procedure and discusses its outputs, according to which 6 out of the 17 investigated sinkholes can be considered as geosites of geomorphological interest (geomorphosites). Finally, issues related to their enhancement and fruition are taken into account in the frame of potential geotourism strategies.

Key words: karst, sinkhole, geosite, geomorphosite, Malta, Gozo

*Mauro Soldati, Dipartimento di Scienze della Terra, Università di Modena e Reggio Emilia, Largo S. Eufemia 19, 41121, Modena, Italy, e-mail: mauro.soldati@unimore.it*

## 1. Introduction

Sinkholes or dolines are closed depressions with internal drainage which are typical features of karst landscapes. They display a wide range of morphologies (cylindrical, conical, bowl or pan-shaped) and can be up to several hundred metres across and deep (Williams 2003). There is a wide literature on sinkhole classification, formation and evolution (e.g., Williams 2003; Beck 2004; Waltham *et al.* 2005; Ford & Williams 2007; Gutiérrez *et al.* 2008b) and also on the possible hazards associated to these karst features (e.g., Buttrick & van Shalkwyk 1998; Cooper & Calow 1998; Paukstys *et al.* 1999; Zhou *et al.* 2003; Gutiérrez *et al.* 2008a; Galve *et al.* 2011).

Features ascribable to sinkholes have often had a great influence in the society: they have played important roles in legends (e.g., the *Il Maqluba* legend, a giant collapse thought to have occurred in Malta during the 14$^{th}$ century), provided inspiration to writers (e.g., the sinkholes of Ripon, in North Yorkshire, UK, thought to have inspired Lewis Carroll for the passage to the underworld in *Alice's Adventures in Wonderland*) and appeared in films (e.g., the sinkhole planet of *Star*

*Wars Episode III, Revenge of the Sith*). However, despite their attractiveness and the fact that they are often located in protected areas, sinkholes are not normally described as geological resources which might be valuable for the society, being of interest for visitors and worth of being promoted for their geomorphological characteristics and importance. It must be certainly emphasised that sinkholes attract tourists world-wide because of their peculiar, and sometimes spectacular, morphological features (e.g., Cenotes of the Yucatán Peninsula, Caribbean Blue Holes); however no specific literature have been found about the recognition and assessment of sinkholes as "geosites" (*sensu* Reynard 2004) or, more specifically, as "geomorphosites" (*sensu* Panizza 2001). During the last two decades, numerous scientific and legislative initiatives carried out in various parts of the World have demonstrated an increasing interest towards geoheritage and "geosites" – that is "portions of the geosphere that present a particular importance for the comprehension of the Earth history" (Reynard 2004) – and made the protection and conservation of geological and geomorphological features possible. Geosites of geomorphological interest that show scientific, cultural/historical, aesthetic and/or socio-economic value due to human perception or exploitation are defined as "geomorphosites" (Panizza 2001).

Within this frame, during recent geomorphological surveys carried out in the Island of Gozo (Malta), a series of sinkholes have been recognised and mapped in detail with the aim of investigating their evolution, both along the coast and inland (Fig. 1). Attention was specifically focused on the sinkholes depicted in the geological map of the island (Oil Exploration Directorate, 1993), some of which displaying features of notable size and high aesthetic interest. The sinkholes recognised have been qualitatively and quantitatively assessed applying a methodology which has been specifically set up on the basis of previous works (Reynard *et al.* 2007; Pereira *et al.* 2007; Zouros 2007). The aim was to see whether any of these sinkholes could be considered as geosites

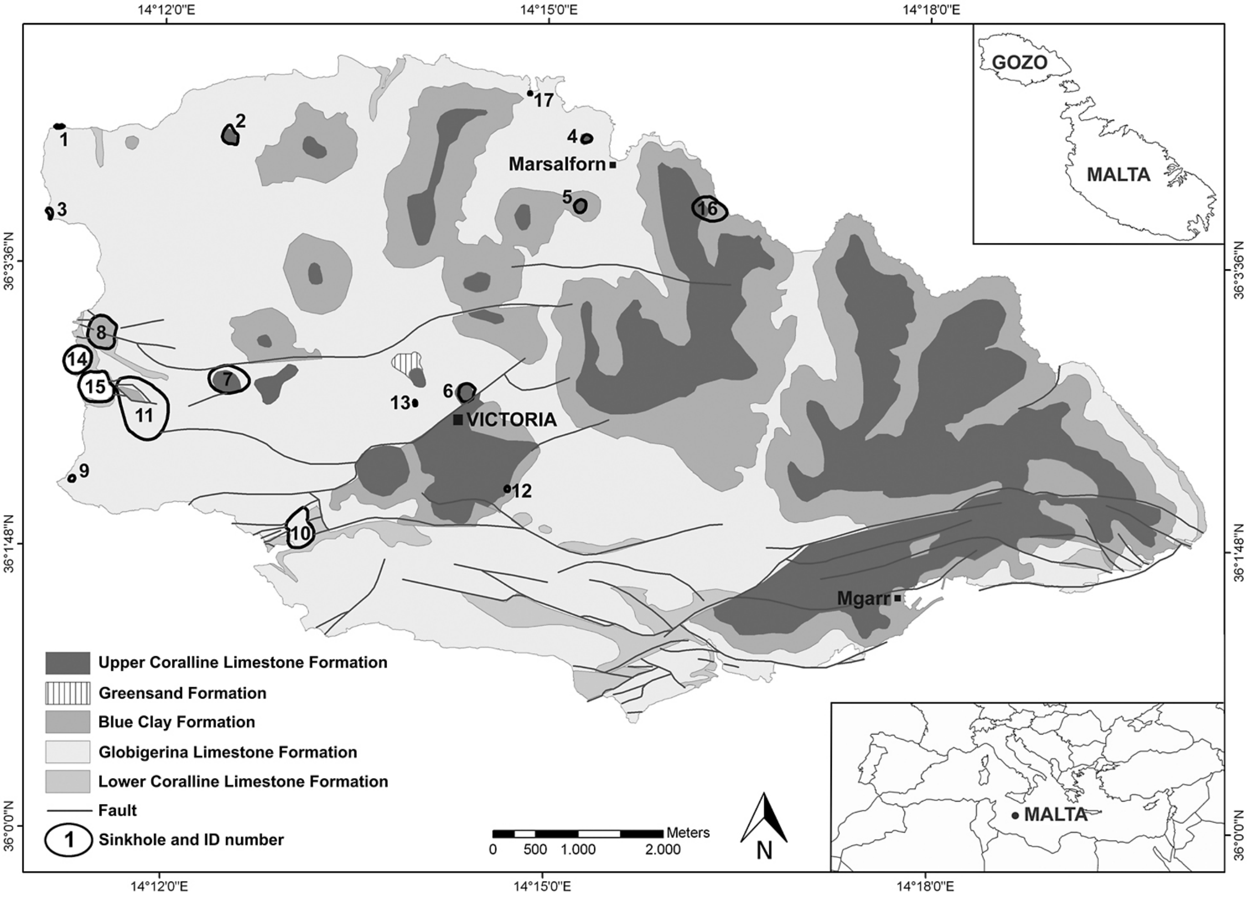


Fig. 1. Geological sketch map of the Island of Gozo and location of sinkholes.

of geomorphological interest (geomorphosites) according to three main values: scientific value, additional value and use value.

The paper shows the geosite assessment procedure and discusses its results. Finally, issues related to the enhancement and fruition of the sinkholes assessed as geosites are taken into account, also in relation to the fact that some of them have determined the location of past settlements (e.g., The Citadel of Victoria), showing a perfect example of integration between geomorphological features and cultural heritage (Soldati *et al.* 2008b). As regards the Maltese archipelago this issue was previously explored as for the Island of Malta (e.g., Soldati *et al.* 2008a), but this is the first attempt for the Island of Gozo.

## 2. Sinkholes and geosites

Karst sinkholes have always been considered as distinctive landforms in many cultures. Normally specific or local terms to name these features are used in karst areas, although sinkhole and doline are terms used worldwide. Significant examples are: *Obruk* in Turkish, *Sima* in Spanish and *Cenote* in Maya language (Mexico). In areas where sinkholes are widespread and/or where large ones can be found, these features often became part of myths and legends grew up around them. Their mythological or mystic value, their historical importance in a broad sense and their scenic value have certainly favoured the designation of sinkholes and their surroundings as protected areas in numerous karst regions, in particular when they tend to form subcircular lakes (e.g., Lewis 2008; Kiernan 2010; Vdovets *et al.* 2010; Fassoulas *et al.* 2012). The most remarkable protected area in the World directly associated with sinkholes is the Bottomless Lakes State Park of New Mexico (USA). This State Park includes an area with large sinkholes generated in a particular hydrogeological setting. These landforms are clear examples of sinkholes developed in discharge areas with upward flow of the groundwater. The Bitter Lakes National Wildlife Refuge (New Mexico, USA) is a protected area related to the latter. It protects a group of sinkholes and associated subsidence depressions filled by saline groundwater. Although the protection of that area is mainly based on its ecological value, the karst landforms and their hydrogeochemical characteristics are essential to the ecosystem developed in that place. The Leon Sinks Geological Area in Florida (USA) is a regional park focused on sinkholes, landscape features very common in the peninsula of Florida. *Lagunas de Cañada del Hoyo* is a regional park in Spain also devoted exclusively to sinkholes. In Croatia, a large sinkhole more than 520 m in depth called *Modro Jezero* (Red Lake) has become an important tourist attraction. Also the *Cenotes*, the famous subcircular collapse sinkholes of the peninsula of Yucatán (Mexico), have been intensively exploited for tourism purposes. In the Caribbean region, submarine sinkholes called *Blue Holes* have become singular places for diving practices and their aerial images are known all over the World.

It should be mentioned that several geosites of geomorphological interest include or correspond to karst areas where sinkholes are noteworthy, such as in the case of the Global Geosites project, an initiative of the International Union of Geological Sciences (IUGS), and of several national geosite lists. In particular, in the geosite list compiled by the Spanish Geological Survey, more than 50% of the geosites of geomorphological interest are located in karst areas.

Concerning the Maltese archipelago, documentation about the karst morphologies has been treated (Paskoff & Sanlaville 1978; Marmarà 2004; Saliba 2008; Calleja 2010), but specific research for the identification of sinkholes as geomorphosites was carried out only at Il-Majjistral Nature and History Park where some dissolution subsidence landforms have been recognised and assessed as geomorphosites (Coratza *et al.* 2011).

## 3. Sinkholes in Gozo

The Island of Gozo is part of the Maltese archipelago which is located in the Mediterranean Sea, about 90 km south of Sicily and 290 km northeast of Tunisia. From a geological viewpoint, the islands are composed of a Late Oligocene (Chattian) to Late Miocene (Messinian) succession of sedimentary rocks, mainly limestones (cf. Oil Exploration Directorate 1993; Pedley *et al.* 2002). The rock sequence is divided into four main lithostratigraphical units whose different resistance to erosion controls the Maltese landscape. The tectonic setting is characterised by two intersecting fault trends: the NW-SE-trending Pantelleria Rift and the ENE-WSW graben system. Although the four lithostratigraphical units are displaced by several faults, they lie almost horizontally across the islands creating a landscape of plateaus, mesas, buttes and canyons (Pedley *et al.* 1978; Illies 1981; Alexander 1988; Pedley *et al.* 2002). Classical literature mainly deals with the geological features and evolution of the Maltese Islands whilst detailed geomorphological research has only recently been carried out and documented, with particular reference to mass movements and karst landforms and processes (Dykes 2002; Marmarà 2004; Farrugia 2008; Magri *et al.* 2008; Saliba 2008; Magri 2009; Calleja 2010; Coratza *et al.* 2011; Tonelli & Galve 2011; Devoto *et al.* 2012).

Karst processes play an important role in the Maltese archipelago due to the extensive presence of limestones, which has favoured the development of an interesting karst system on the islands and the surrounding submarine area.

The effects of karst processes through time are particularly evident in Gozo, where 17 sinkholes have been recognised (Fig. 1). According to the classification proposed by Gutiérrez *et al.* (2008b), all of them can be described as caprock collapse sinkholes. The majority of the Gozitan sinkholes still show their original infill deposited during the subsidence or afterwards. Some of these karst features reach a few hundreds of metres in diameter and depth, and display different geomorphic expressions depending on the resistance to erosion of the lithotypes outcropping inside and outside the structures. Circular depressions, such as Qawra and Xlendi sinkholes (Fig. 1, ID 8 and 10), have formed due to differential erosion of soft sediments collapsed into more resistant limestones. When located along the coast, these depressions have controlled the development of subcircular bays, such as in the case of Dwejra North and Dwejra Bay sinkholes (Fig. 1, ID 14 and 15). Where the rocks capping the collapsed block are more resistant than the country rock, rounded buttes or mesas are created due to differential erosion, such as at Tas Salvatur and Ghajn Abdul sinkholes (Fig. 1, ID 5 and 7). The latter make up significant examples of relief inversion; in fact, buttes can be observed in areas once forming karst depressions.

According to Pedley (1974) the largest Gozitan sinkholes have formed in the Miocene; however, so far their origin has not yet been completely clarified. Trechmann (1938) and Pedley (1974) theorize about their origin being caused by a cavern roof collapse. Pedley (1974), carrying out a detailed study of the sinkholes and their infill, indicates that these solution subsidence structures (as the Author named them), were formed due to a collapse in submarine conditions of the roofs of a cavern system developed in early Tertiary. Another model of formation based on the collapse of caprock above dissolved salt diapirs is proposed by Illies (1980). Alexander (1988) suggests to investigate the relations between surface hydrology and vertical tectonics since the previous theories show some incongruities between their paleogeographical models and the Miocene sea levels.

## 4. Methods

Numerous methods, both qualitative and quantitative, for assessing geomorphosites are available in scientific literature (Reynard 2009 and references within). The methodology here applied is developed on the basis of previous works (cf. Panizza & Piacente 1993; Reynard *et al.* 2007; Pereira *et al.* 2007; Zouros 2007; Coratza *et al.* 2011) and based on three sets of values (scientific value, additional value, use value) and on the assessment criteria reported in Tab. 1.

The assessment of the *scientific value* is based on four criteria (Tab. 2) which mainly reflect those suggested by Reynard *et al.* (2007): *palaeogeomorphological model* refers to the importance of the site for Earth climate or history; *rareness* refers to its rarity with respect to a reference space; *representativeness* refers to its exemplarity with respect to a reference space; finally, *integrity* refers to its state of conservation which depends on both natural and anthropogenic factors.

The *additional values* take into account ecological, aesthetic and cultural aspects (cf. Panizza & Piacente 1993) (Tab. 3). This parameter highlights possible links between geomorphological features and other natural and cultural aspects. The *eco-*

Table 1. Value and criteria of sinkholes assessment methodology.

| Value | | Criteria |
|---|---|---|
| Scientific value | | Palaeogeomorphological model |
| | | Rareness |
| | | Representativeness |
| | | Integrity |
| Additional values | Ecological value | Ecologic support role |
| | | Protected site |
| | Aesthetic value | Panoramic quality |
| | | Colour diversity |
| | | Vertical development |
| | | Naturalness |
| | Cultural value | Religious importance |
| | | Historical importance |
| | | Artistic importance |
| Use value | | Accessibility |
| | | Visibility |
| | | Services |
| | | Importance for education |

*logical value* takes into account the geomorphosite importance for its ecological implications (exclusive habitat of a particular fauna and vegetation) and with reference to existing protection rules for ecological reasons. The *aesthetic value* takes into account the perception of the landscape beauty and therefore its evaluation is the most subjective one (Regolini-Bissig 2010). For this reason, in order to reduce the subjectivity involved – based on Reynard *et al.* (2007), Pralong (2005), Coratza *et al.* (2011) – a series of objective parameters has been introduced in the assessment. These consist of:

i) panoramic quality in terms of the visibility of a site;
ii) colour diversity (e.g., contrast due to lithological changes);
iii) vertical development and iv) naturalness of the site.

Table 2. Numerical range of criteria used for the assessment of scientific value.

| Scientific value (maximum 4) | |
|---|---|
| 0–1 | Palaeogeomorphological model |
| 0–1 | Rareness |
| 0–1 | Representativeness |
| 0–1 | Integrity |

Table 3. Numerical range of criteria used for the assessment of additional value.

| Additional value (maximum 3) | |
|---|---|
| Ecological value | |
| 0–0.5 | Ecologic support role |
| 0–0.5 | Protected site |
| Aesthetic value | |
| 0–0.25 | Panoramic quality |
| 0–0.25 | Colour diversity |
| 0–0.25 | Vertical development |
| 0–0.25 | Naturalness |
| Cultural value | |
| 0–0.33 | Religious importance |
| 0–0.33 | Historical importance |
| 0–0.33 | Artistic importance |

The *cultural value* includes different sub-criteria (cf. Panizza 1996):

i) religious importance;
ii) historical importance in a broad sense including archaeology, prehistory and history;
iii) artistic importance which concerns the presence of the site in artistic realisation. The additional values, due to their heterogeneity, in this study have been assessed based on the bibliographical information available, since they cover a large spectrum of disciplines (biology, zoology, history etc.).

The *use value* of a site is defined on the basis of four main criteria: *accessibility*, *visibility*, *services* (in terms of the presence of equipment and support services in the nearby) and *importance for education* (school, universities) (Tab. 4).

The total value of a geomorphosite can therefore result from the sum of the scores of all criteria, with 10 being the highest score attainable. As regards the weighting of results, it is clear that the most important parameter is the scientific value and, actually, the weight assigned to it has

Table 4. Numerical range of criteria used for the assessment of use value.

| Use value (maximum 3) | |
|---|---|
| 0–0.75 | Accessibility |
| 0–0.75 | Visibility |
| 0–0.75 | Services |
| 0–0.75 | Importance for education |

the highest score (4). Nevertheless, according to the need of selecting sinkholes useful for educational and tourism purposes, significant values have also been assigned to the other parameters; in fact, additional and use values sum up 3 points each.

## 5. Sinkhole assessment

All 17 sinkholes recognised in Gozo have been assessed and the results are summarized in Tables 5 and 6. The outline of the scores enables comparisons of value distribution to be made.

Nevertheless, it should be noted that the selection and assessment procedure has also been aiming at the promotion and enhancement of the rich geoheritage of the island. For this reason a *tourism rating* (Feuillet, Sourp 2011) has been calculated as the arithmetical sum of the additional value and the use value. The results are presented in Table 7 and Fig. 2 where the total scientific value and the tourism rating are shown. This scoring has been used to establish a classification, which has allowed us to define the most valuable sinkholes, both in terms of scientific interest and tourism promotion (Feuillet & Sourp 2011).

As outlined in Table 7, 10 sites display a high scientific value, but 4 of these show a lower score in tourism rating. The Il-Maxell sinkhole (Fig. 1, ID 3) shows a good preservation of the sedimentary infill, and therefore has a high scientific interest, but a low use value due to its inaccessibility and lack of historic, aesthetic or cultural values. Qolla s-Safra, Xlendi, Tal Harrax (Fig. 1, ID 4, 10, 11) are also very important from a scientific point of view because of their good state of conservation, but they may be of difficult recognition on the field for the public.

Among the 17 sinkholes, 6 have finally been assessed as geomorphosites scoring highest in total scientific value and in tourism rating. Three sinkholes (The Citadel, Qawra and Dwejra Bay; Fig. 1, ID 6, 8, 15; Fig. 3e, a, c) are already exploited as tourist sites, but not for their geomorphological significance (there is not a real scientific fruition).

Qawra (Fig. 3a) is a large depression more than 400 m in diameter, with an "inland sea" connected to the open sea by a narrow tunnel through

Table 5. Quantitative assessment of scientific value of sinkholes.

| Sinkholes | | Scientific value | | | | |
|---|---|---|---|---|---|---|
| ID | Name | Paleogeomorphological model | Rareness | Representativeness | Integrity | Total |
| 1 | San Dimitri Point | 0.25 | 0.50 | 0.25 | 0.25 | 1.25 |
| 2 | Tal-Lexuna | 0.25 | 0.50 | 0.25 | 0.25 | 1.25 |
| 3 | Il-Maxell | 0.75 | 0.50 | 0.50 | 0.50 | 2.25 |
| 4 | Qolla s-safra | 0.50 | 0.50 | 0.50 | 0.50 | 2.00 |
| 5 | Tas-Salvatur | 0.75 | 0.50 | 0.75 | 0.75 | 2.75 |
| 6 | The Citadel | 0.75 | 0.50 | 0.75 | 0.75 | 2.75 |
| 7 | Ghajn Abdul | 0.75 | 0.50 | 0.75 | 0.75 | 2.75 |
| 8 | Qawra | 0.75 | 0.50 | 0.75 | 0.50 | 2.50 |
| 9 | Wardija Point | 0.25 | 0.50 | 0.25 | 0.25 | 1.25 |
| 10 | Xlendi | 0.75 | 0.50 | 0.50 | 0.50 | 2.25 |
| 11 | Tal Harrax | 0.75 | 0.50 | 0.25 | 0.50 | 2.00 |
| 12 | It-Taflija | 0.25 | 0.50 | 0.25 | 0.25 | 1.25 |
| 13 | S of Gelmus | 0.25 | 0.50 | 0.25 | 0.25 | 1.25 |
| 14 | Dwejra North | 0.50 | 0.50 | 0.50 | 0.50 | 2.00 |
| 15 | Dwejra Bay | 0.50 | 0.50 | 0.50 | 0.50 | 2.00 |
| 16 | Ghajn Barrani | 0.25 | 0.50 | 0.25 | 0.25 | 1.25 |
| 17 | Xwieni Bay | 0.50 | 0.50 | 0.25 | 0.25 | 1.50 |

Table 6. Quantitative assessment of additional and use values of sinkholes.

| Sinkholes | | Additional value | | | Use value | Total |
|---|---|---|---|---|---|---|
| ID | Name | Ecological value | Aesthetic value | Cultural Value | | |
| 1 | San Dimitri Point | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2 | Tal-Lexuna | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 3 | Il-Maxell | 0.00 | 0.50 | 0.00 | 0.50 | 1.00 |
| 4 | Qolla s-safra | 0.00 | 1.00 | 0.00 | 0.50 | 1.50 |
| 5 | Tas-Salvatur | 0.00 | 0.50 | 0.75 | 1.00 | 2.25 |
| 6 | The Citadel | 0.00 | 1.00 | 0.50 | 2.50 | 4.00 |
| 7 | Ghajn Abdul | 0.00 | 0.75 | 0.50 | 2.50 | 3.45 |
| 8 | Qawra | 0.50 | 1.00 | 0.00 | 2.50 | 4.00 |
| 9 | Wardija Point | 0.00 | 0.75 | 0.00 | 0.50 | 1.25 |
| 10 | Xlendi | 0.00 | 0.25 | 0.00 | 1.00 | 1.25 |
| 11 | Tal Harrax | 0.50 | 0.00 | 0.00 | 0.50 | 1.00 |
| 12 | It-Taflija | 0.00 | 0.00 | 0.00 | 0.50 | 0.50 |
| 13 | S of Gelmus | 0.00 | 0.00 | 0.00 | 0.50 | 0.50 |
| 14 | Dwejra North | 0.50 | 1.00 | 0.00 | 2.00 | 3.50 |
| 15 | Dwejra Bay | 0.50 | 1.00 | 0.75 | 2.50 | 4.75 |
| 16 | Ghajn Barrani | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 17 | Xwieni Bay | 0.00 | 0.25 | 0.00 | 0.50 | 0.75 |

Table 7. Final quantitative assessment of sinkholes (sinkholes assessed as geomorphosites are outlined in bold).

| Sinkholes | | Total scientific value | Total additional and use value | Total |
|---|---|---|---|---|
| ID | Name | | | |
| 1 | San Dimitri Point | 1.25 | 0.00 | 1.25 |
| 2 | Tal-Lexuna | 1.25 | 0.00 | 1.25 |
| 3 | Il-Maxell | 2.25 | 1.00 | 3.25 |
| 4 | Qolla s-safra | 2.00 | 1.50 | 3.50 |
| **5** | **Tas-Salvatur** | **2.75** | **2.25** | **5.00** |
| **6** | **The Citadel** | **2.75** | **4.00** | **6.75** |
| **7** | **Ghajn Abdul** | **2.75** | **3.45** | **6.20** |
| **8** | **Qawra** | **2.50** | **4.00** | **6.50** |
| 9 | Wardija Point | 1.25 | 1.25 | 2.50 |
| 10 | Xlendi | 2.25 | 1.25 | 3.50 |
| 11 | Tal Harrax | 2.00 | 1.00 | 3.00 |
| 12 | It-Taflija | 1.25 | 0.50 | 1.75 |
| 13 | S of Gelmus | 1.25 | 0.50 | 1.75 |
| **14** | **Dwejra North** | **2.00** | **3.50** | **5.50** |
| **15** | **Dwejra Bay** | **2.00** | **4.75** | **6.75** |
| 16 | Ghajn Barrani | 1.25 | 0.00 | 1.25 |
| 17 | Xwieni Bay | 1.50 | 0.75 | 2.25 |

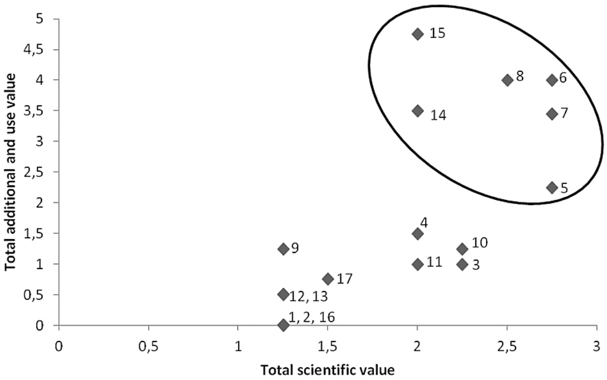


Fig. 2. Relationship between total scientific value and total additional and use value (tourism rating). Encircled are the top-rated sinkholes which have been assessed as geomorphosites.

the cliffs which allows the transit to small boats. It is considered one of the best dive sites of Malta and hosts a large number of visitors every day. It is also very important for scientific issues because is one of the most preserved sinkholes and shows geological and geomorphological evidence useful to investigate the collapse triggering factors.

Dwejra North and Dwejra Bay (Fig. 1, ID 14 and 15; Fig. 3d, c) are two subcircular bays formed by differential erosion of the soft infill sediments by the sea. Dwejra North shows a suggestive landscape formed by the contrast between the soluble rocks and the sea. Dwejra Bay is surrounded by high calcareous cliffs and it is partially closed in its western side by a small island called Fungus Rock. This island hosted a rare tuber, the *Cynomorium coccineum*, apparently discovered by the Knights of St. John who used it as a curative plant.

The Citadel (Fig. 1, ID 6; Fig. 3e) is an ancient fortification located in the northern part of Victoria, the capital of Gozo. It is built on the hard infill of a sinkhole, emerging from the ground in positive relief. It is an example of relief inversion: the sinkhole was originally a depression and then the differential erosion removed the surrounding clays leaving the harder calcareous infill in positive relief. It is interesting to note that this positive relief was a key feature for the choice of the safer place in which to build the ancient city.

Ghajn Abdul (Fig. 1, ID 7; Fig. 3b) is another sinkhole showing positive relief. It is a large calcareous mesa emerging from the surrounding clays. Its scientific value is due to the presence of a well-exposed sedimentary infill. Ghajn Abdul also shows a high historical value: it is thought that the people who first colonised Gozo in the Neolithic period lived in caves on Ghajn Abdul plateau.

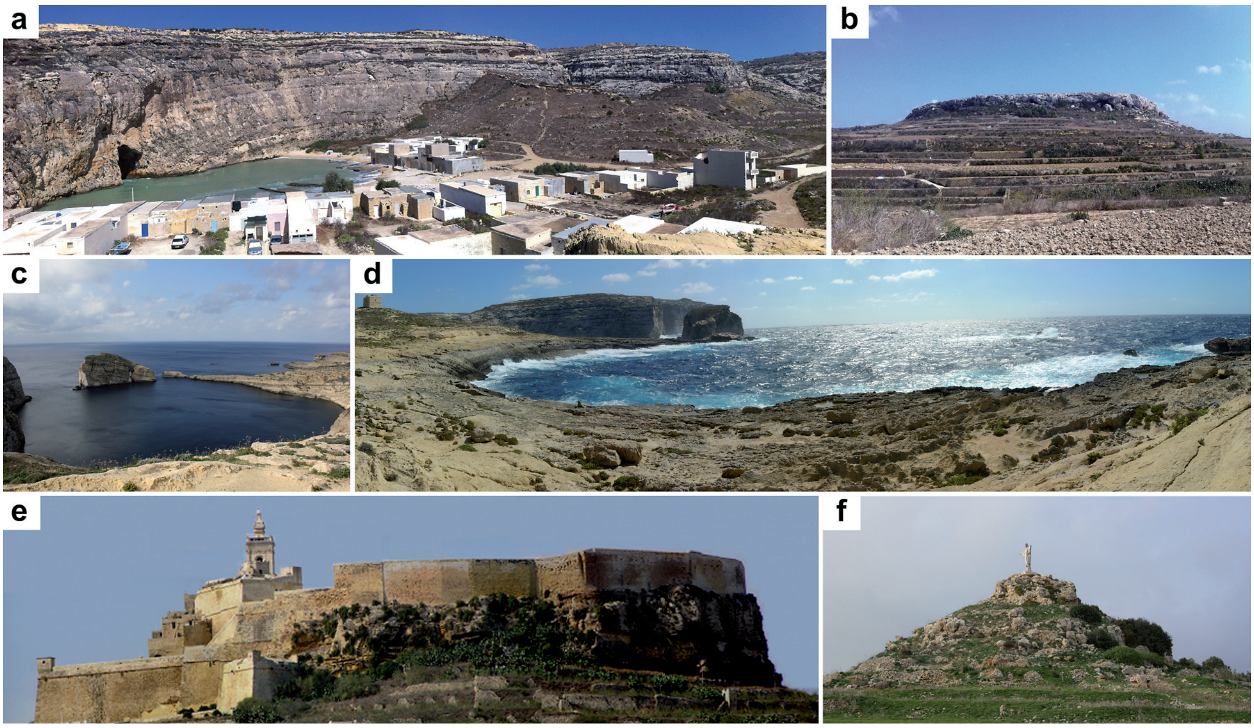


Fig. 3. Images of the sinkholes assessed as geomorphosites: a – Qawra (ID 8), b – Ghajn Abdul (ID 7), c – Dwejra Bay (ID 15), d – Dwejra North (ID 14), e – The Citadel (ID 6) (courtesy of I. Calleja), f – Tas-Salvatur (ID 5).

Tas-Salvatur (Fig. 1, ID 5; Fig. 3f) is located in the northern part of Gozo, south of Marsalforn. Due to its positive relief, it emerges from the surrounding landscape as a 65-m high hill. The butte's visibility is increased by the presence of a statue of Jesus Christ on its top which is a scaled down version of the more famous one located on the Corcovado hill in Rio de Janeiro (Brazil). Due to the particular shape of the hill, different legends developed; the most famous one considered the hill a dormant volcano.

## 6. Final remarks

Travel and recreation are nowadays mostly linked to cultural and historical aspects, civilization's heritage elements, natural elements and leisure infrastructures. However, geomorphology is rarely considered as a major tourist element of attraction.

Tourism development in the Maltese archipelago has grown to be one of the most important economic activities on the islands. The sun-and-sea tourism plays a major role in Maltese tourist offer. Nevertheless, the positive contribution of this type of tourism to the national economy is often accompanied by negative effects on coastal resources, such as marine and air pollution, loss of natural habitats, impact on marine resources, land degradation, urbanisation etc. (Trumbic 2004). Tourism in the Maltese archipelago is also linked to outstanding cultural assets and to the pristine rural and natural environment. The latter is well-preserved and widespread especially in Gozo. The ever-growing consolidation of this kind of tourism focused on environmental elements implies an important challenge: the development of a sustainable tourism. In this case, sustainable tourism in the Maltese Islands could certainly correspond to "geotourism" as defined by Hose and Vasiljevic (2012), that is "the provision of interpretative and service facilities for geosites and geomorphosites and their encompassing topography, together with their associated in situ and ex situ artefacts, to constituency-build for their conservation by generating appreciation, learning and research by and for current and future generations".

The issue of geotourism can be tackled with a positive attitude towards success especially in Gozo, by favouring a good understanding and comprehension of its pristine landscape. This kind of tourism would certainly be enhanced if geomorphological issues were taken into account and exploited in tourism management and promotion. This may perfectly apply to the case of the spectacular sinkholes which have been assessed as geomorphosites within this study. In fact, they show a high scientific value (they are a key for understanding and reconstruct the geological history of Gozo since the Miocene) and ecological, aesthetic, cultural and use values which provide the sites with a tourist appeal. The original contribution of this study is to show that sites of geomorphological interest, such as sinkholes, can become part of a culturally accessible and shared heritage, making them a resource for social and economic development in their own territory. Indeed, the sinkholes selected as geomorphosites in Gozo can be considered as new elements that can catalyse the potential of a territory which is often neglected or pass unnoticed. Arranging tourist integrated-type proposals – based on classic, well-tried itineraries which include geological elements to support or complete the themes usually considered (e.g., archaeology, architecture, flora and fauna) – could help to disseminate awareness of geomorphology as a key factor of tourist attraction.

The assessment carried out has brought to light that some places already carrying a cultural and/or tourist significance in Gozo also show peculiar scientific aspects worth of enhancement. This is the case not only of the well-known sites of Qawra, Dwejra and The Citadel, but also of Tas-Salvatur and Ghajn Abdul. The local geological setting has conditioned the development of singular landforms used by the Gozitan people as dwelling in Neolithic times (caves of Ghajn Abdul), as fortress (butte of The Citadel) or as a site where a tuber with medical properties (*Cynomorium coccineum*) was exploited by the Knights of St. John (Fungus Rock at Dwejra) and finally as a remarkable religious destination (Tas-Salvatur). This relationship between the human activities and the natural/geological environment is worth mentioning as a significant added value to promote these sites.

This multi-spectral approach can guarantee a conscious tourist fruition which could be knowledge-based and without seasonal constraints. This approach would be a correct mean of awakening public opinion to environment, an unquestionable premise for a sustainable and safe fruition of environment itself. At the same time, it would be a solid mean to implement and stimulate the need of knowledge of the different environmental components, including geomorphology.

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