Il Quaternario
Italian Journal of Quaternary Sciences
***18**(1), 2005 - Volume Speciale, 223-232*

GEOMORPHOSITES OF TOZEUR REGION (SOUTH-WEST TUNISIA)

Jo De Waele[1], Felice Di Gregorio[1], Nabil Gasmi[2], Maria Teresa Melis[1] & Mohamed Talbi[3]
[1]Department of Geology, Via Trentino 51, 09127 Cagliari - E-mail: geoam@unica.it
[2]Faculté de Sciences Humaines et sociales, 94, Bd. du 9 Avril 1938, 1007 Tunis - E-mail: nabil.gasmi@fshst.rnu.tn
[3]Institut des Régions Arides, Medenine, Route de Djorf Km 22.5, 4119 MEDENINE - E-mail: talbim@ati.tn

ABSTRACT: J. De Waele *et al.*, *Geomorphosites of Tozeur region (south-west Tunisia).* (IT ISSN 0394-3356, 2005).
Tozeur is the most important tourist town of south-western Tunisia, situated in between the two salt lakes Chott El Djerid to the south and Chott El Gharsa to the north. This area is known for its luxuriant oasis in the middle of the desert (Tozeur, Gafsa, Nefta etc.), the mountain chains to the north close to the border with Algeria with its villages and waterfalls (Tameghza, Chebìka, Midès), the mountain chain east of Tozeur (Jbel Morra etc.) with its arid canyons, and the wide salt plains (Chotts). Tourists usually visit the region rapidly without staying overnight, overlooking and ignoring the great geomorphologic and geological interesting places and landscapes.
Therefore, in the framework of a Research Project performed by the Department of Geology of the University of Cagliari in collaboration with the Institut des Régions Arides at Medenine and with the "Faculté de Sciences Humaines et sociales" of Tunis and financed by the Sardinian Regional Government (R.L. 11 Aprile 1996, n° 19), our multidisciplinary Research Team has studied twenty-one geosites and geological landscapes in the region of Tozeur, with the purpose of constituting a network of geosites in these arid and semi-arid areas.
Field work combined with remote sensing techniques have enabled to start preparing thematic maps of these geosites which, together with their description (genesis, evolution, state of conservation, proposals of valorisation, etc.) will be useful for obtaining financial aid for their protection and valorisation. The definition of morphostructural units landform analysis at a large/medium scale was performed by TeleGIS Laboratory, involved in these studies on southern Tunisia from 1997 in collaboration with the Institute des Régions Arides, applying remote sensing techniques on multi-spectral satellite images. During this project the interpretation keys for the image classification were created in the different steps of field observations and digital image processing. The radiometric and geometric responses were used for the discrimination of spectral units (lithological sequences) and textural units defined by photo-interpretation techniques (structural and landscape units like anticlines, fault-controlled valleys or forms like chevron, etc.).
Many of the studied geomorphosites are represented by canyons (Gorges de Ben Nebhana, Sidi Bou Helal, Thelja, En Negueb, Chaabet Es Sfa, Ben Hamed, Midès, etc.) and waterfalls (Grande Cascade and Cascade de l'Oasis at Tameghza, Cascade de Chebìka and its geological-structural features). Others are related to aeolian and meteoric processes (Barchan dunes of El Ghadayer, morpho-sculpture of Ong El Jmel, Yardangs of El Ghadayer, Nebkha fields of Chamsa). The remaining geosites are an ancient lacustrine coastline testified by a lumachelle with Cardium in the Jehim oasis near Tozeur, the anticline of Brikis close to Tameghza, and an ancient phosphate mine at Chouabin (Jbel Chouabin close to Redeyef), a representative part of Chott el Djerid, the Delta of Oued Mellah and the alluvial cone of Oued Foum el Khanga and the ancient oasis (*Corbeille*) of Nefta.
These sites and landscapes of geological and geomorphological interest represent the entire geological history of the Tozeur and the Chotts region fairly well. This history starts from Early Cretaceous, and the various sites narrate the sedimentary and tectonic events, the palaeo-environmental and palaeo-climate episodes, the birth, development and extinction of animal and plant species, the geomorphological processes and depositional events, explaining the present morphology, climate and landscape in a most interesting scientific and educational way.
The linking of all these places of geological and geomorphologic interest in networks of Geosites along a thematic issue (the "Living Desert" network with Nebkha and Barchan dunes, Yardangs and Aeolian sculptures, the "Rocks and Water" network with waterfalls, mountains and canyons, the "Earth's Memory" network across the canyons of Jbel Morra-Sidi Bou Helal passing through more than 100 million years of Earth's geological history, the “Phosphate Route” network with active and abandoned phosphate mines and their environmental impact and the “Changing Environment and Climate” network with salt pans, fossil shorelines and abandoned oasis) give an interesting opportunity of telling the history of the Earth, promoting geology and geomorphology to the local people and to the visitors. In fact, geological heritage can and should become a cultural and economical resource for the local people, and therefore these inhabitants should be taught understanding their natural and cultural environment, enabling them to use these elements in the framework of a touristic and sustainable development of their region.

RIASSUNTO: J. De Waele et al.*,* Geomorfositi della regione di Tozeur (Tunisia sud-occidentale)*. (IT ISSN 0394-3356, 2005).*
Tozeur è il principale centro turistico della Tunisia sud-occidentale, situato tra i due laghi salati dello Chott El Djerid a sud e lo Chott El Gharsa verso nord. Quest'area è rinomata per le sue belle oasi in mezzo al deserto (Tozeur, Gafsa, Nefta ecc.), le catene montuose con i villaggi, le oasi di montagna e le cascate a nord vicino al confine con l'Algeria (Tameghza, Chebìka, Midès), la catena di montagne con i numerosi canyon ad est di Tozeur (Jbel Morra, ecc.) e le grandi pianure salate (Chotts). In genere i turisti visitano la regione molto rapidamente senza poter conoscere ed apprezzare i caratteri essenziali dei paesaggi e dei numerosi siti d'interesse geologico e geomorfologici presenti.
Per questo motivo il gruppo di ricerca multidisciplinare, composto da ricercatori del Dipartimento di Scienze della Terra dell'Università di Cagliari, dell'Institut des Régions Arides di Medenine e della Faculté de Sciences Humaines et sociales dell'Università di Tunisi, ha predisposto un progetto finanziato dalla Regione Autonoma della Sardegna (L.R. 11 Aprile 1996, n° 19), che ha consentito di individuare e classificare 20 geomorfositi e paesaggi geomorfologici nella regione di Tozeur con lo scopo di creare un network di geomorfositi capaci di mettere in luce il valore del patrimonio geologico di quest'area desertica.
Il lavoro di rilevamento in campagna è stato combinato allo studio d'immagini satellitari per elaborare delle carte tematiche dei geomorfositi che, insieme alla loro descrizione (genesi, distribuzione, evoluzione, stato di conservazione, proposte di valorizzazione, ecc.) costituiscono un riferimento essenziale per la loro conservazione e valorizzazione. La definizione morfostrutturale delle diverse unità di paesaggio ad una scala medio-grande, mediante tecniche di remote sensing su immagini satellitari multispettrali, è stata eseguita nel laboratorio TeleGIS dell'Università di Cagliari coinvolto negli studi in Tunisia meridionale dal 1997 in collaborazione con l'Institut des Régions Arides. Le chiavi d'interpretazione per la classificazione delle immagini sono state create durante le campagne di rilevamento in loco e l'elaborazione delle immagini digitali in sede. Le risposte radiometriche e geometriche sono state utilizzate per la discriminazione delle unità spettrali (sequenze litologiche) e delle unità tessiturali definite attraverso tecniche di foto-interpretazione (unità strutturali quali anticlinali, valli controllate da faglie o forme come chevron ecc.).
Molti dei geomorfositi individuati e studiati sono dei canyon (Gorges de Ben Nebhana, Sidi Bou Helal, Thelja, En Negueb, Chaabet Es

Sfa, Ben Hamed, Midès, ecc.) e cascate (Grande Cascade e Cascade de l'Oasis a Tameghza, Cascade de Chebika e le sue eccezionali caratteristiche geologico-strutturali). Altri sono legati a processi eolici e meteorici (barcane di El Ghadayer, morfoscultura di Ong El Jmel, yardang di El Ghadayer, campi di nebkha di Chamsa). I restanti geomorfositi sono: un'antica linea di costa lacustre testimoniata dal livello sedimentario a lumachelle con Cardium nell'oasi di Jehim presso Tozeur, l'anticlinale di Brikis a Tameghza, un'antica miniera di fosfati a Chouabin (Jbel Chouabin nei pressi del villaggio di Redeyef), il delta dell'Oued Mellah, il cono fluvio-sedimentario dell'Oued Foum el Khanga, un settore paesaggisticamente rappresentativo dell'immenso Chott El Djerid e l'Oasi antica di Nefta (Corbeille).
Questi siti e paesaggi d'interesse geologico e geomorfologico rappresentano abbastanza compiutamente l'intera storia geologica della regione di Tozeur e degli Chott. Questa storia geologica inizia nel Cretaceo inferiore, ed i numerosi siti raccontano eventi sedimentari e tettonici, episodi paleo-ambientali e paleo-climatici, la comparsa, l'evoluzione e l'estinzione di specie animali e vegetali, i processi d'erosione e deposizione di sedimenti, che forniscono un quadro esauriente e completo della morfologia, del clima e del paesaggio attuale di elevato interesse didattico-culturale.
L'interconnessione di tutti questi siti di interesse geologico e geomorfologico in network tematici (il network "Deserto Vivente" con le nebkha, le barcane, gli yardangs e le sculture eolico-meteoriche, il network "Rocce ed Acqua" con montagne, cascate e gole, il network "La Memoria della Terra" con gli attraversamenti dei canyons del Jbel Morra-Sidi Bou Helal che consentono di percorrere nelle sequenze stratigrafiche più di 100 milioni di anni di storia della Terra, il network "Il Sentiero dei Fosfati" con miniere di fosfati attive ed abbandonate e il loro impatto sull'ambiente e il network "Il Clima e l'Ambiente che Cambia" con le antiche rive degli Chotts, le pianure salate attuali ed oasi abbandonate) consente di raccontare la storia della Terra, promuovendo la conoscenza dei fenomeni geologici e geomorfologici nei confronti sia della popolazione locale sia dei visitatori, in un ambiente semiarido ed arido dove sono limitate le possibilità di sviluppo. In tal senso, il patrimonio geologico può diventare una risorsa culturale ed economica di non trascurabile interesse per la regione. Per questo occorre rendere gli abitanti consapevoli della ricchezza del loro ambiente naturale e culturale, creando le opportunità per utilizzare queste risorse nel quadro di uno sviluppo turistico sostenibile della loro regione.

Keywords: Desert, Geomorphosite, Desertification, Remote sensing, Geotourism, Tozeur, Tunisia.

Parole chiave: Deserto, Geomorfosito, Desertificazione, Remote sensing, Geoturismo, Tozeur, Tunisia.

1. INTRODUCTION

The concepts "Geosite" and "Geological Heritage" became widely used since the beginning of the 90's and researchers from all over Europe started discussing on the conservation of geological sites and landscapes. The first important European meeting on Geo-conservation was organised at Digne-les-Bains (France) in 1991 and during this event the "International Declaration of the Rights of Earth's Memory" was ratified and a first attempt of cataloguing geosites was presented in order to start building a versatile data base (Barca & Di Gregorio, 1991a; 1991b). Since then our multidisciplinary research team has started inventorying geosites in Sardinia covering almost the whole regional territory (Barca *et al*., 1992; Panizza V. & Cannillo, 1994; Barca *et al.*, 1995; 1996; De Waele *et al.*, 1998; 1999; Ardau & De Waele, 1999; Arisci *et al*., 2001; 2002; De Waele *et al*., 2002; 2003a; 2003b; 2003c) and giving rise to a detailed work on geological heritage of the province of Cagliari (Barca & Di Gregorio, 1999).

All these researches have been carried out in the framework of international research programs such as "GEOSITES" of the International Union of Geological Sciences started in 1996 and "Geomorphological Sites", a working group found in 2001 by the International Association of Geomorphologists. The national studies have had a further impulse thanks to the Italian COFIN 2001-2003 project "Geosites in the Italian Landscape: research, evaluation and valorisation", in which framework two workshops have already been organised during which Italian and foreign researches have confronted and discussed their scientific results.

Geoconservation is not yet properly developed in the African continent, although the first attempts are starting to obtain some preliminary results especially in South Africa (Reimold, 1999). Our decennial experience on geosites and geomorphosites and starting from the concepts of Geomorphological Asset Evaluation as defined by Panizza M. & Piacente (1993) and Poli (2003), has brought our research team to start working also in north-African countries and thanks to several Research Projects financed by the Sardinian Regional Government we have commenced cataloguing sites of geological and geomorphological interest in the Middle Atlas of Morocco (De Waele *et al.*, 2003d) and in the Tozeur region in Tunisia (Di Gregorio *et al.*, 2002).

This paper describes the results of the researches on geomorphosites and geological heritage performed in the region of Tozeur (south-west Tunisia).

2. GEOLOGY OF THE REGION

Tozeur is located in south-western Tunisia, between the two salt lakes Chott El Djerid to the south and Chott El Gharsa to the north (Fig.1).

Fig. 1 - General location of the study area.
Localizzazione dell'area di studio.

Table 1 - Table of the identified and studied geomorphosites in the region of Tozeur, distinguished by their genetic process and degree of scientific and didactic-divulgation interest for geotourism and geoconservation purposes.

Tabella dei geomorfositi identificati e studiati nella regione di Tozeur, distinti in base al processo genetico e al livello di interesse scientifico e didattico-divulgativo ai fini del geoturismo e della geoconservazione.

N°	Géomorphosite name	Province	Commune	Genetic process	Age of rocks	Level of interest
1	Midès canyon	Tozeur	Tameghza	Ft	Cm	***
2	Brikis anticline	Tozeur	Tameghza	T	Cm	*
3	Grande Cascade waterfall	Tozeur	Tameghza	Ft	Eoc	**
4	Cascade de l'Oasis waterfall	Tozeur	Tameghza	Ft	Eoc	***
5	En Negueb canyon	Tozeur	Tameghza	Ft	Cup-Eoc	***
6	Chebika canyon and waterfall	Tozeur	Tameghza	Ft	Cup-Ol	***
7	Ancient mine of Chouabin	Gafsa	Redeyef	A	Eoc	**
8	Thelja canyon	Gafsa	Metlaoui	Ft	Cup-Ol	***
9	Oued Foum el Khanga alluvial fan	Tozeur	Tameghza	F	Q	**
10	Oued Mellah delta	Tozeur	Hamma	F	Q	*
11	Ong El Jemal aeolian sculpture	Tozeur	El Hamma du Jerid	M	Plio-Q	**
12	El Ghadayer yardangs	Tozeur	Nefta	W	Q	*
13	El Ghadayer barchan dunes	Tozeur	Nefta	W	Q	*
14	Chamsa nebkha fields	Tozeur	Tozeur-Nefta	Wb	Q	*
15	Cardium Lumachelle of Jehim	Tozeur	Tozeur	S	Q	*
16	Chaabet Es Sfa canyon	Tozeur	Degueche	Ft	Cup	***
17	Sidi Bou Helal canyon	Tozeur	Degueche	Ft	Cup	***
18	Ben Nebhana canyon	Tozeur	Degueche	Ft	Cup	**
19	Ben Hamed canyon	Tozeur	Degueche	Ft	Cup	***
20	Chott El Jerid salt pan	Tozeur	Degueche	Ts	Q	***
21	Corbeille de Nefta oasis	Tozeur	Nefta	A	Mio-Plio	**

The main genetic processes that are responsible for the formation of the geomorphosites are: Ft = Fluvial-Tectonic; T = Tectonic; A = Anthropic; F = Fluvial; M = Meteoric ; W = Aeolian ; Wb = Aeolian-Biological ; S = Sedimentary ; Ts = Tectonic-Sedimentary.
The age of the rocks : Cm = Middle Cretaceous ; Cup = Upper Cretaceous ; Eoc = Eocene ; Ol = Oligocene ; Mio = Miocene; Plio = Pliocene ; Q = Quaternary.
Level of Interest : * = moderate ; ** = high ; *** = very high.

The region of Tozeur is part of the Atlas fold and thrust belt that extends from Morocco over Algeria right up to west Tunisia. To the east of the Tunisian Atlas lies a north-south trending mountain range corresponding to the major fault zone that divides the Atlas from the eastern Sahel Block. The region of Tozeur belongs to the southern Tunisian Atlas in which are distinguished the Gafsa zone in the north, characterised by a series of anticlinal east-west trending mountain ranges mainly composed of Late Mesozoic carbonate sediments, and the southern Chotts Trough region composed of a since Late Carboniferous subsiding sedimentary basin.

The Gafsa zone can be subdivided in the Metlaoui Chain, composed of an east-west trending tight anticline with an overturned forelimb and gently dipping (30°) backlimb, separated from the structurally similar "Chaine des Chotts" (east of Tozeur) by a large box syncline (Outtani *et al*., 1995). According to Ben Ferjani (1990) the "Chaine des Chotts" is located on a Jurassic graben and corresponds fundamentally to the inversion of this inherited structure. The tectonic events, probably active at least since Middle Pleistocene (since lower Quaternary sediments are involved in the fold-thrust structures along the mountain fronts), have involved only the upper part of the sedimentary cover (the basal décollement would be identified in the Cretaceous stratigraphic levels) that has been folded as a sheet upon the rigid basement (Outtani *et al*., 1995; Fakhraoui, 1999).

Subsidence in the Chotts area occurred mainly during Middle Triassic-Jurassic as a consequence of the separation between Europe and Africa and has continued during Miocene-Early Pleistocene related to the compression associated with the Atlas orogeny (Burrolet, 1956; 1991; Zargouni, 1984; 1985; 1986; Swezey, 1996; Patriat *et al.*, 2003).

Many of the east-west oriented anticlines and synclines in the Gafsa zone are cut by northwest striking right-lateral strike slip faults among which the Gafsa fault and the Negrine-Tozeur fault have to be mentioned. The first is the most important one, having direction N 120°-130° (Boutib & Zargouni, 1998) and

showing a lateral offset of 1 km, and seismological and stratigraphical data (Chihi, 1979) together with the presence of thermal hot springs along the fault (Coque, 1962) indicate that it is still active today.

The oldest outcropping rocks of the region are of Upper Cretaceous age. At J. Bou Helal the outcropping sequence starts with the evaporites of Beida containing rare ostracods of Middle Turonian, followed by a sequence of marls, whitish dolostones and limestones with abundant fossils such as foraminifers, ostracods, echinoids and ammonites of Lower-Middle Coniacian age. This sequence is characterised by the presence of a hardground encrusted by oysters at the foot of the upper limestone levels (Abdallah, 1987; Abdallah *et al.*, 1995). Santonian starts with 40 m of greyish clays and marls (with Santonian ostracods, echinoids and foraminifers) followed by ammonite containing limestone beds. Campanian is characterised by greenish marls and marly limestones (with abundant fossil oysters) followed by white ammonite and echinoid-bearing limestone beds with clear evidence of emersion episodes. Maastrichtian is dominated by massif and locally fossiliferous limestone beds dated on the basis of foraminifers, nautiloids and ostracods. At the end of Cretaceous a short continental period interrupts sedimentation, immediately followed by dark gypsum-rich clays with phosphate levels deposited in a lagoonal basin (Bensalem, 2002). This sequence has been grouped in the about 70 meters thick Thelja Formation that surmounts a silicified horizon (Burrolet, 1956; Chaabani, 1978). The economic phosphate deposits have been discovered in 1885 by Philippe Thomas at Thelja gorge and underground mining started at Metlaoui in 1899. The phosphate levels, alternated with bioturbated clays, belong to the Ypresian and contain shark teeth and tortoise carapaces (Sassi, 1974). Phosphate levels are followed by two limestone beds with silex nodules (Ypresian-Lutetian) and carbonate-rich clays with gypsum levels (Priabonian). During Oligocene sedimentation becomes continental characterised by conglomerates with carbonate and clayey cement (Fakhraoui *et al.*, 1995; Regaya *et al.*, 2001). Neogene is mainly characterised by coarse and fine sandy continental deposits dated from Middle Miocene up to Villafranchian, this last constituted of sediments with *Cardium*. The actual morphology has been defined during Quaternary with the emplacement of several mostly continental deposits. In particular at least three generations of terraces have been recognised, all characterised by silty yellowish and more or less reddish sediments with intercalations of conglomerates and gypsum crusts. These terraced sediments cover unconformably the slightly tilted Miocene sequences and have been dated respectively Middle Pleistocene, Upper Pleistocene and Holocene (Ben Ouezdou et al., 1996). During Holocene sediments of aeolian origin have been deposited, mostly captured in nebkhas and sometimes forming barchan dunes. Also the sebkha soils of the Chotts cover wide extensions of territory in the region of Tozeur, characterised by fine wet sediments and brines in winter and mud cracked surfaces with salt and gypsum crusts in summer. Finally the recent alluvium has to be mentioned, with more or less fine sediments depending on the distance from the jebels. Among these transported sediments also the phosphate silts deriving from the mine industry can be classified, such as the ones of the Oued El Mellah.

3. METHODOLOGY

The geomorphosites of Tozeur region have been chosen on a preliminary basis using existing geographical and geological maps and scientific papers on geology and geomorphology, but also tourist maps and guide-books. Several field campaigns have been organised to identify and classify interesting geosites and geomorphosites, to verify the collected bibliographical data and to make detailed observations and gather further documentation (e.g. geological sketches, geomorphological processes, photographs). According to Panizza M. (2001) a geomorphosite is “a landform with attributes which qualify it as a component of the cultural heritage”.

On the field a sheet file has been compiled in which, together with the data of identification of the site (e.g. commune, locality, co-ordinates, altitude, etc.) also data on accessibility, visibility, geology and geomorphology, use and state of conservation are reported. An example of such a sheet file, adopted by our research team also in other north-African countries, is reported in figure 2.

The identification, classification and graphical representation of the geomorphosite networks have been completed using remote sensing techniques. The satellite image interpretation has been performed using a legend in which the lithological units and the main morphologies have been classified. The choice of the legend classes has been focussed in particular on the geomorphological systems in which the chosen geomorphosites are located.

The analysis of medium-infrared band combinations has allowed to recognise in a preliminary phase the different lithological units, by means of the creation of interpretation keys based on field surveys. The following data have then been analysed to characterise the morphology of the study area: lithology, tectonics, drainage pattern, land cover and topography. The use of satellite images has proven to be an ideal instrument for the recognition of the main landforms, guiding the field campaigns in a remarkable way. The almost complete absence of vegetation enhances the recognition of the different lithologies that can easily be revealed by their spectral response, and the distinction of topography has been enhanced introducing shadow analysis.

The general structure of the area and the most important faults and alignments have been put in evidence by image elaboration techniques using directional filters associated with spectral analysis. Remote sensing analysis has also been a powerful tool to study vast depositional systems such as the Delta of Oued El Khanga, an inactive river fan, relic of much wetter periods, that flows into the Chott El Gharsa crossing transversally the ridge of El Manndra-Bliji. This fan has also been cut by neotectonic faults, clearly evidenced also by recent fluvial deviations, and visible using satellite images.

The result of the remote sensing analysis, combined with terrain work, has enabled to compile the “Map of Geosites and Geomorphosites of the Region of Tozeur” in which structural, lithological and geo-

Name of the Géosite: **Sidi Bou Helal Canyon** | Number: **17**

1. IDENTIFICATION

- *Province*: Tozeur
- *Commune*: Degueche
- *Locality*: Jebal Sidi Bou Helal (Versant Sud)
- *Map references*: Feuille topographique 1/100.000 (El Hamma du Jerid)
- *Co-ordinates* (U.T.M.):

General location and itinerary (on a Road Map 1.1.000.000 and on Topographic Maps in Scale 1:100.000 or 1:50.000)

Geometrical description *(Surface, Length, Depth, Width, Height, Thickness, etc.)*

Linear form : - 2 x 500 m long
- 5 m to 25 m width
- 2 m to 100 m depth

Accessibility *Easy (close to roads)* [X] *Difficult (far away from roads)* [ ] *Very difficult* [ ]

Panoramic point Yes [ ] No [X]

Visible from distance Yes [X] No [ ]

Best season for visit

W	*Sp*	*Su*	*F*	*Y*

2. DESCRIPTION

Geologie-Stratigraphy

Located at the western extremity of the northern Chain of the Chotts the Sidi Bou Helal gorge cuts the southern limb of the homonymous anticline. The outcropping sedimentary facies correspond to Upper Senonian limestones and dolostones and evaporitic rocks (gypsum) followed by Coniacian dolostones, gypsum rich marls and greenish clays, Santonian clays and limestones and Campanian marly and pure limestones locally very rich in fossils (Ostracods, Oysters, Gastropods and Echinoids). Towards the Chott the sedimentary sequence comprises also Miocene, Pliocene and Quaternary sediments.

Geomorphology, genesis and evolution

The Sidi Bou Helal gorge is one of the many canyons that has its origin on the El Guebgueb ridge. Its morphology depends on tectonic and lithological factors. It is formed in the dissymmetric anticline of Jebal Sidi Bou Helal with a gently dipping northern flank (15°) and a southern much steeper one (40°). The canyon crosses a thick sedimentary sequence in which hard rocks (limestones and dolostones) alternate with softer ones (clays and marls) creating several different morphologies. Aside typical fluvial landforms (meanders, giant's kettles, etc.) also meteorological forms (tafoni, mushroom-like rock sculptures, etc.) are well represented. The depth and width of the canyon mostly depends on the rock type (differential erosion).

3. GENETIC CLASSIFICATION

Main genetic process	Secondary genetic process
Fluvial	Tectonics
Active [X] Inactive [ ]	Active [ ] Inactive [X]

Definition of the Form

Canyon

4. UTILISATION AND CONSERVATION

Actual utilisation of the monument and of the surrounding territory

Sheep-breeding (there is a small spring in the western canyon)
Religious function (two marabous)

State of conservation

Very good

Existing protection measures (Laws, Parks, etc.)

None

Menaces or deteriorations of the Landscape

None

Conservation and valorisation proposals

The canyon could represent an important geosite for the explanation of the different lithologies that outcrop in the region. Moreover it is possible to see fossils (Ammonites, Gasteropods, etc.) that give the possibility to explain the process of fossilisation.

5. REFERENCES

Abdallah H. (1987) - Le Crétacé superieur de la chaîne Nord des Chotts : Biostratigraphie, sédimentation, diagenès. Thèse de 3^{e} Cycle, Univ.Bourgogne, Dijon, 205 p.

Ben Ouezdou H., Gasmi N., Bouassida L. (1996) - Contribution à l'étude géomorphologiqe du Jebel Sidi Bouhlel et ses environs (Sud-Ouest de la Tunisie). Revue Tunisienne de Géographie 30, pp. 53-80.

Coque R. (1962) - La Tunisie présaharienne (Etude géomorphologique). Ed A. Colin Paris. 476 p.

Fakhraoui M. (1999) - Etude stratigraphique et structural des chaînes des chott : Evolution géométrique et cinématique liée à l'accident sud Atlasique. Thèse deDoctorat de 3^{e} Cycle, Univ.Tunis II, 243 p.

Fakhraoui M., Mahjoub K., Charni T. (1995) - Notice explicative de la carte géologique de Hamma El Jerid. O.N.M., Tunis, 25 p.

Gasmi N. (1997) - Le Jebal Sidi Bouhelal et ses environs : Levés et commentaire de la carte géomorphologique au 1/50.000. Memoire de DEA en géographie physique. Université de Tunis 1.122 p. + carte au 1 /50.000.

6. GEOLOGICAL, GEOMORPHOLOGICAL MAPS AND SCHEMES OF THE GEOSITE

7. PHOTOGRAPHIC REFERENCES

Fig. 2 - Example of sheet file used for the survey, description and classification of the geomorphosites.
Esempio della scheda di rilevamento, descrizione e classificazione dei geomorfositi utilizzata.

morphological data are resumed.

The main purpose of these geomorphological training and research activities was to make the link between the single geomorphosites (intrinsic values) and the surrounding landscape (overall value) to form a complete perception of the importance of geological heritage in the region. In fact, only by means of a rigourous process of scientific awareness of this heritage it will become possible to create the basis for a conscient use in a context of sustainable development and valorisation through Geotourism. This type of cultural tourism can be explicated very well in semi-arid and arid regions, because the landscape observation and analysis are favoured, and can become a good opportunity of economical growth.

Because of their easy perception (recognisability), their characteristic form (completeness), their state of conservation (exemplarity) and their effective possibility of visit (accessibility) geomorphosites can be defined ideal for valorisation and for geotourism (Poli, 2003).

A particularly significant and innovative aspect of this research is the proposal of networks, in which geomorphosites and geosites are linked by similar geomorphological processes, making their identification and recognition easier. This distinction in thematic networks of geosites and geomorphosites makes it also easier to define coherent actions of planning, valorisation and conservation.

4. GEOMORPHOSITES

For the moment a total of twenty-one geomorphosites have been chosen in the region of Tozeur and are reported in Table 1. These sites, in the prevision of their valorisation though geotourism, have been grouped in thematic circuits according to their geographical, geological, geomorphological and genetical characteristics. These circuits are: the "Living Desert", the "Rocks and Water", the "Earth's Memory", the "Phosphate Route" and the "Changing Environment and Climate" networks (Fig.3).

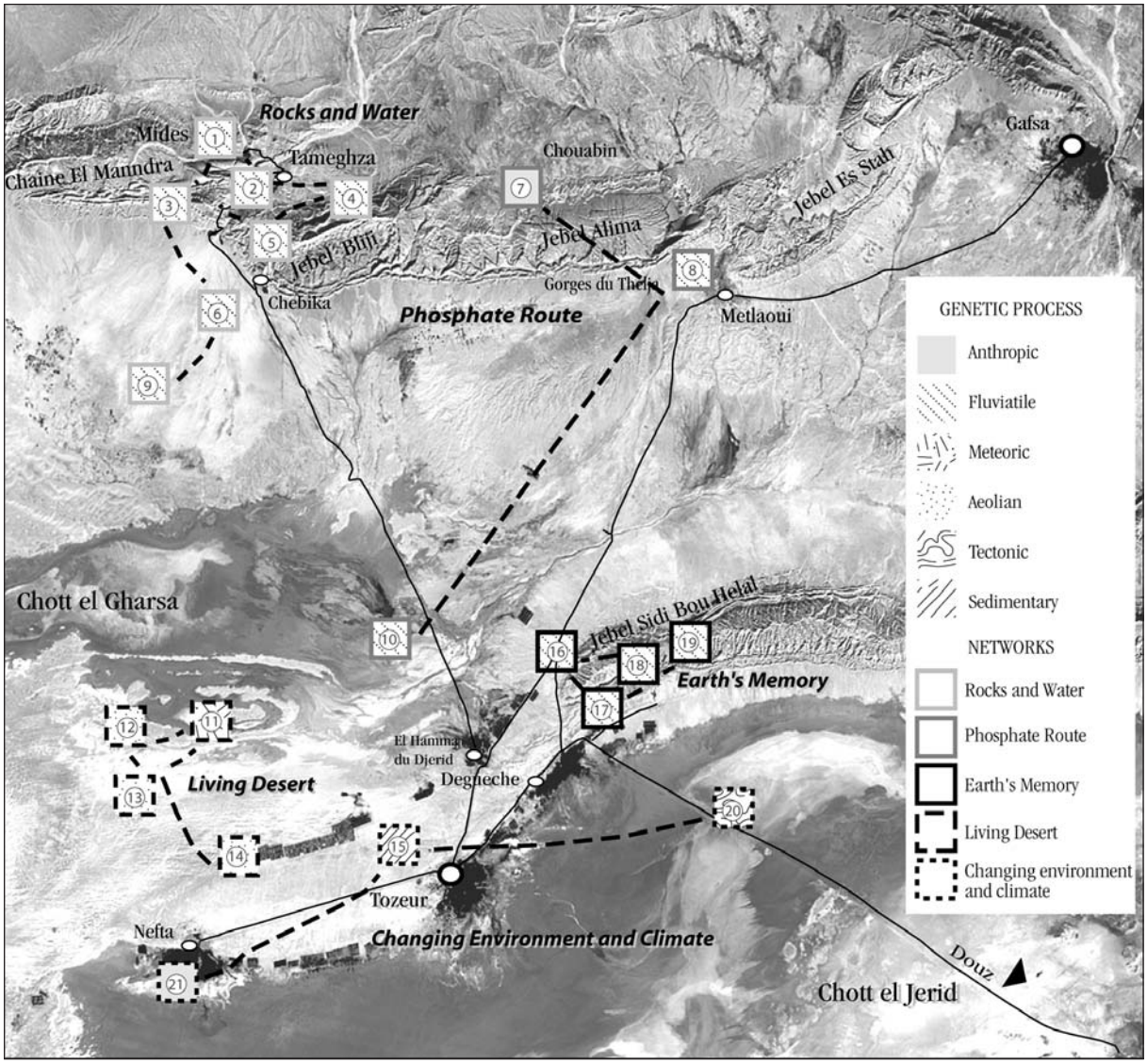

Fig. 3 - Proposed network of geomorphosites organised in thematic itineraries related to prevalent genetic processes.
Rete di geomorfositi proposti organizzata per itinerari tematici legati ai processi genetici prevalenti.

The "Living Desert" network is situated in the Chott El Gharsa region and can be reached departing from the ancient oasis of Tozeur and following the road that leads to the famous Ong El Jmel natural sand sculpture. This network combines four geomorphosites: the nebkha fields of Chamsa, the barchan dunes of El Ghadayer, the yardangs of El Ghadayer and the above mentioned Ong El Jmel geomorphosite. This network explains the products of aeolian processes in semiarid regions, the evolution of sand dunes, from young nebkha dunes over mature barchan dunes ending up with partially demolished dunes (yardangs). Also the famous Ong El Jmel sand sculpture is inserted in this network, being an residual erosion form assuming the silhouette of a sitting dromedary, related to morphoselective meteoric processes. Even though these single landforms are not easily readable on Landsat images, because of their relatively small dimensions, on the most western side of the study area the greatest of the barchan dunes can be distinguished, reaching almost 150 meters of width.

The "Rocks and Water" network, showing the landscape modelling and evolution through fluvial processes, is located in the Chebika and Tameghza mountains and combines seven geomorphosites: the canyons of Midès and En Negueb, the waterfalls of Tameghza (“Grande Cascade” and “Cascade de l’ Oasis”), the anticline of Brikis, the canyon, geological structures and waterfall of Chebika (Fig. 4) and the alluvial cone of Oued Foum el Khanga (Mamou, 1981). These seven sites represent the geomorphologic evolution of river profiles: water slowly erodes the outcropping rocks, accelerating the process during uplifting episodes (the tectonic evolution of the Tameghza mountains can easily be explained showing the Brikis anticline), and the alternation of hard and soft rocks causes differential erosion, formation of waterfalls and alternation of narrow canyon passages with larger riverbeds. At the end of the voyage the water flows out of the narrow gorges and enters the wide subsiding plains forming great alluvial fans. The satellite image, as said before, clearly puts in evidence the alluvial fan and the neotectonic movements, but also reveals wide and important structures such as chevrons, the smaller of which can also be easily distinguished on the field.

Close to Tozeur, in the “Chaine des Chotts” mountains, the "Earth’s Memory" network is located comprising four canyons passing transversally through most of the Cretaceous sedimentary sequence. In fact, the three canyons of Sidi Bou Helal, Ben Nebhana and Ben Hamed cut the mountain range in its southern flank, while the Chaabet Es Sfa canyon crosses the northern flank instead (Ben Ouezdou *et al*., 1996; Gasmi, 1997). In these canyons the didascalic Cretaceous sequence of this region can be observed in good exposure, showing many fossiliferous beds with ammonites, echinoids, oysters and gasteropods, allowing the visitors to go through 100 million years of Earth’s history. Also morphoselective meteoric processes have shaped interesting forms in the calcarenites, such as the mushroom-like rock sculptures in the Ben Hamed gorge (Fig. 5). Furthermore in some canyons of the southern flank ancient human settlements (Roman dams and quarries, abandoned oasis, etc.) enrich these geomorphosites and the network in a whole.

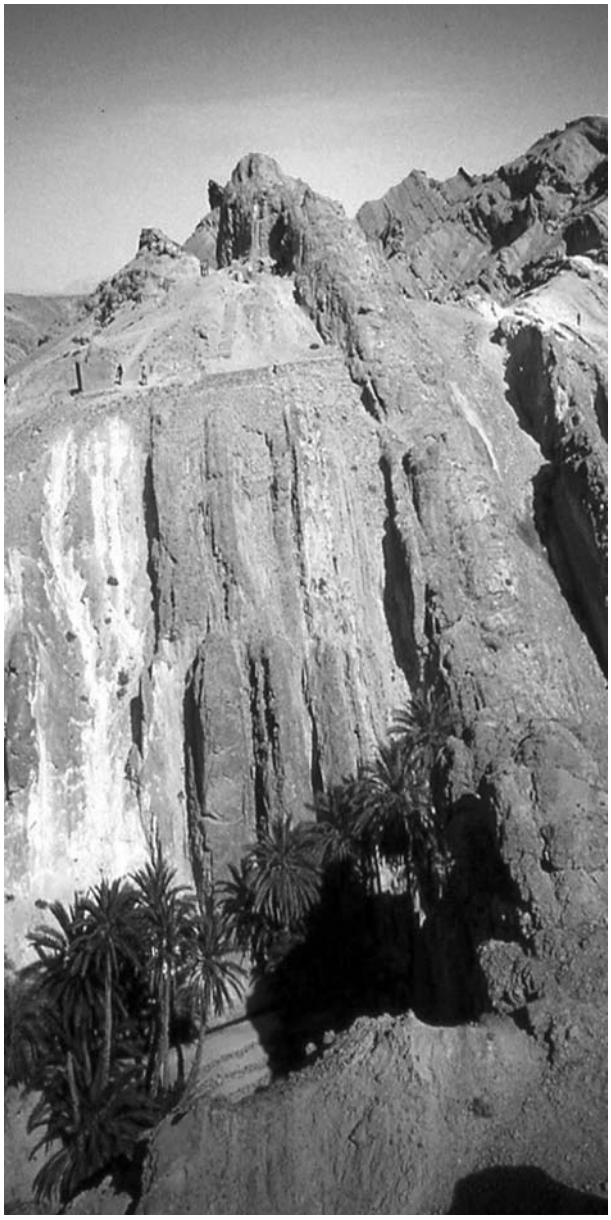

Fig. 4 - Eocene sedimentary sequence in almost vertical attitude in which the softer clay beds are in negative relief respect to the silicificated limestone beds.

Sequenza eocenica in giacitura subverticale nella quale gli strati argillosi teneri risultano più intaccate rispetto ai banchi silicizzati.

The “Phosphate Route” is of a more “human dimension” showing an abandoned underground phosphate mine near Chouabin, the immense active phosphate mines (underground and open pit cultivation) and their environmental impact (tailings, sterile heaps, excavations, phosphate mud in the draining rivers, etc.) on the immediate environs but also at greater distance such as at the Thelja gorge or at the Oued El Mellah delta. The analysis of satellite images clearly puts in evidence the dispersion of dust and phosphate muds, with a unique spectral response.

Finally the “Changing Environment and Climate” network comprises three geomorphosites close to

Tozeur: a small outcrop of Quaternary littoral sediment very rich in *Cardium* in the oasis of Jehim testifying an ancient shoreline of the Chott el Djerid, the actual salt plain itself (Ben Ouezdou, 1999) and the *Corbeille* of Nefta with the ancient spring sites that are dried up due to overexploitation of the aquifer.

Fig. 5- Beautiful example of mushroom-like meteoric selective erosion rock sculpture in the Ben Hamed gorge.

Bell'esempio di roccia a fungo d'erosione meteorico-selettiva nella Gorge di Ben Hamed.

5. CONCLUSIONS

Geoconservation and geotourism are widely used and accepted terms in Europe and north-America, but are new concepts for Tunisia. Although geological heritage in Tunisia is well known and many areas have been thoroughly studied by geologists, this geological and geomorphological knowledge is still restricted to few people, and should be diffused to a wider public.

The Author's attempt is to explain the geological and geomorphological characteristics of the region of Tozeur to the local people and to the visitors, enriching the already existing tourist offer with new themes of interest that are based on the geological and geomorphological resources that are particularly well represented in the region. In fact, many of the geomorphosites included in this paper are well-known tourist attractions, but the geological and geomorphological significance of these sites is never explained.

The connection of several of these geomorphosites in circuits (or networks) has the purpose of explaining the geological and geomorphological evolution of these sites, giving a more educational explanation of sometimes complex and slowly developing phenomena.

In the framework of the valorisation of the territory it is also important to make a link between natural processes and human activities: in many geomorphosites presented here also the human presence is clearly visible with archaeological remains (Prehistoric graffiti, Roman dams, abandoned oasis and settlements, etc.) or historical-technological curiosities (the "Lezard Rouge", a tourist train along the suggestive ancient phosphate mine railtracks, abandoned and still operating phosphate mines, etc.).

Aside all these sites of geological or geomorphological interest many other important localities exist (e.g. the restored oasis or "Corbeille" of Nefta dried up due to human intervention and global change, museums, experimental date palm tree plantations etc.) and the integrated tourist development of all these natural and cultural resources can give new economic opportunities to this arid and semiarid region.

ACKNOWLEDGEMENTS

This study has been carried out with the financial aid of the Sardinian Regional Government in the framework of the Project "Identification, classification and valorisation of important landscapes and geosites in south Tunisia" (Responsible Prof. Felice Di Gregorio) (Regional Law n°19/1996). For the conceptual part of this work reference has been made to the National Project COFIN 2001-2003 "Geomorhosites in the Italian Landscape", National coordinator Prof. Sandra Piacente, Responsible of the Local Research Unit Prof. Antonio Ulzega and Prof. Felice Di Gregorio.

The Authors would like to thank Mario Panizza and Sergio Ginesu for their critical advice.

REFERENCES

Abdallah H. (1987) - *Le Crétacé supérieur de la chaîne nord des Chotts (Sud tunisien): biostratigraphie-sédimentation-diagenèse* - Phd thesis, Université de Bourgogne, Dijon, 255 pp.

Abdallah H., Memmi L., Damotte R., Rat P. & Magniez-Jannin F. (1995) - *Le Crétacé de la chaîne nord des Chotts (Tunisie du centre-sud): biostratigraphie et comparaison avec les régions voisines* - Cretaceous Research, **16**, pp. 487-538.

Ardau F., De Waele J. (1999) - *Geosites of the Tacchi area (central-east Sardinia, Italy)* - In: D. Barettino, M. Vallejo & E. Gallego (eds.), *Towards the Balanced Management and Conservation of the Geological Heritage in the New Millenium*, pp. 87-93.

Arisci A., De Waele J., Di Gregorio F., Ferrucci I. & Follesa R. (2001) - *Geosites and touristic development of the karstic coastline of southwest Sardinia* - In: E. Ozhan (ed.), *Medcoast 01: Proceedings of the Fifth International Conference on the Mediterranean Coastal Environment, 23-27 October 2001, Hammamet, Tunisia*, Middle East Technical University, Ankara, Turkey, Vol. 1, pp. 302-314.

Arisci A., De Waele J., Di Gregorio F., Ferrucci I., Follesa R. & Piras G. (2002) - *The Human Factor in Natural and Cultural Landscapes: the Geomining Park of Sardinia* - Proceedings of the International Conference on "Natural and Cultural Landscapes

the Geological Foundation", Dublin, 9-11 September 2002 (in print).

Barca S. & Di Gregorio F. (1991a) - *Conservation et valorisation du patrimoine géologique de la Sardaigne: une proposition methodologique* - 1er Symposium international sur la protection du patrimoine geologique, Digne-les-Bains, France 10-16 Giugno 1991, pp. 84-92 .

Barca S. & Di Gregorio F. (1991b) - *Proposta metodologica per il rilevamento dei monumenti geologici e geomorfologici* - Bollettino dell'A.I.C., **83,** pp. 25-31.

Barca S. & Di Gregorio (1999) - *Paesaggi e Monumenti geologici della Provincia di Cagliari* - Saredit Cagliari, 421 pp.

Barca S., Di Gregorio F. & Mulas G. (1995) - *Natural rock arches of the Orosei Gulf, Sardinia, Italy* – In: E. Ozhan (ed.), Medcoast 95: *Proceedings of the Second International Conference on the Mediterranean Coastal Environment, 24-27 October 1995, Tarragona, Spain*, Middle East Technical University, Ankara, Turkey, Vol. 1, pp. 217-229.

Barca S., Di Gregorio F. & Cannillo C. (1992) - *Rilevamento e valutazione dei monumenti geologici e geomorfologici del Meilogu- Logudoro (Sardinia N-W)* - Bollettino dell'A.I.C., **86,** pp. 71-84.

Barca S., Di Gregorio F., Floris C. & Montis M. (1996) - *Rilevamento e valutazione dei monumenti e delle aree di rilevante interesse geologico e geomorfologico nei monti del Sulcis (Sardegna S.O.)* - In: L. D'Arienzo (ed.), *Studi di geografia e storia in onore di Angela Terrosu Asole*, pp. 189-335.

Ben Ferjani A., Burollet P. & Mejri F. (1990) - *Petroleum geology of Tunisia* - ETAP, Tunis, 194 pp.

Bensalem H. (2002) - *The Cretaceous-Paleogene transition in Tunisia: general overview* - Paleogeography, Paleoclimatology, Palaeoecology, **178**, pp. 139-143.

Ben Ouezdou H. (1999) - *Chott el jerid et les oasis* - Editions Tozeur, 47 pp.

Ben Ouezdou H., Gasmi N. & Bouassida L. (1996) - *Contribution à l'étude géomorphologiqe du Jebel Sidi Bouhlel et ses environs (Sud-Ouest de la Tunisie)* - Revue Tunisienne de Géographie, **30**, pp. 53-80.

Boutib L. & Zargouni F. (1998) - *Disposition et géométrie des plis de l'Atlas centro-méridional de Tunisie : découpage et cisaillement en lanières tectoniques* - C. R. Acad. Sciences Paris, Sciences de la Terre et des Planètes, **326**, pp. 261-265.

Burrolet P.F. (1956) - *Contribution à l'étude stratigraphique de la Tunisie centrale* - Ann. Min. Géol. Tunisie, **18**, pp. 1-240.

Burrolet P.F. (1991) - *Structures and tectonics of Tunisia* - Tectonophysics, **195**, pp. 359-369.

Chaabani F. (1978) - *Les phosphorites de la coupe de Foum Thelja. Une série sédimentaire séquentielle à évaporites du Paléocène* - Phd thesis, Université Louis Pasteur, Strasbourg, 151 pp.

Chihi L. (1992) - *Seismotectonic study in Central and southern Tunisia* - Tectonophysics, **209**, pp. 175-178.

Coque R. (1962) - *La Tunisie présaharienne : étude géomorphologique* - Ed A. Colin Paris. 476 pp.

De Waele J., Di Gregorio F., Follesa R. & Piras G. (2002) - *I geositi dell'uomo nel Parco Geominerario Storico Ambientale della Sardegna: alcuni esempi del Sulcis-Iglesiente (Sardegna sud-occidentale)* - Proceedings of the National Conference "La Geologia Ambientale: strategie per il nuovo millennio", Genova 27-29 giugno 2002 - Geologia dell'Ambiente 11(1), pp. 192-197.

De Waele J., Di Gregorio F., El Wartiti M., Fadli D., Malaki A. & Melis M.T. (2003d) - *Geomorphosites and Geodiversity of the Ifrane region (Middle Atlas, Morocco)* - Proceedings of the Workshop "Geomorphological Sites assessment and mapping", Cagliari 1-5 ottobre 2003, Abstract volume.

De Waele J., Di Gregorio F., Follesa R. & Piras G. (2003a) - *Geosites and landscape evolution of the "Tacchi": an example from central-east Sardinia* - Proceedings of the Workshop "Geomorphological Sites research, assessment and improvement", Modena 19-22 giugno 2002 - Il Quaternario (this volume) (in print).

De Waele J., Di Gregorio F. & Pala A. (2003b) - *Karstic geomorphosites of Monte Albo (north-east Sardinia)* - Proceedings of the Workshop "Geomorphological Sites assessment and mapping", Cagliari 1-5 ottobre 2003 - Il Quaternario (this volume) (in print).

De Waele J., Di Gregorio F. & Panizza V. (2003c) - *Geomorphosites at risk: some examples from Sardinia (Italy)* - Proceedings of the Regional Geomorphology Conference Mexico 2003, Mexico City, 27 October - 2 November 2003 (in print)

De Waele J., Di Gregorio F. & Piras G. (1998) - *Geosites inventory in the Paleozoic karst region of Sulcis-Iglesiente (south-west Sardinia, Italy)* - International Congress PROGEO '98, 7-13 june 1998, Belogradchik, Bulgaria - Geologica Balcanica **28(3-4)**, pp. 173-179.

De Waele J., Di Gregorio F. & Piras G. (1999) - *The twenty most important karstic geosites of Sardinia* - In: D. Barettino, M. Vallejo & E. Gallego (eds.), *Towards the Balanced Management and Conservation of the Geological Heritage in the New Millenium*, pp. 155-161.

Di Gregorio F., Talbi M., Melis M.T., Piras G., Gasmi N., Marini A., De Waele J. & Follesa R. (2002) - *Progetto di Ricerca per l'inventario, la tutela e la valorizzazione dei geositi in ambiente arido e semiarido nella regione di Tozeur e di Gafsa (Tunisia)* - Proceedings of the National Conference "La Geologia Ambientale: strategie per il nuovo millennio", Genova 27-29 June 2002 - Geologia dell'Ambiente, **11(1)**, pp. 198-203.

Fakhraoui M. (1999) - *Etude stratigraphique et structural des chaînes des chott : Evolution géométrique et cinématique liée à l'accident sud Atlasique* - Thèse de Doctorat de 3e Cycle, Univ.Tunis II, 243 pp.

Fakhraoui M., Mahjoub K. & Charni T. (1995) - *Notice explicative de la carte géologique de Hamma El Jerid* - Office Nationale des Mines, Tunis, 25 pp.

Gasmi N. (1997) - *Le Jebal Sidi Bouhelal et ses environs: Levés et commentaire de la carte géomorphologi-*

que au 1/50.000 - BSc. Thesis in Physical Geography. Université de Tunis,122 pp., map 1/50.000.

Mamou AH. (1981) - *Etude géologique et hydrogéologique de la région de Tamerhza. Possibilités de création de retenues souterraines au Nord de jebal El Ardhia* - Phd Thesis, Institut de Recherche de Géologie et de Mécanique, U.S.M. Grenoble, 185 pp.

Outtani F., Addoum B., Mercier E., Frizon De Lamotte D. & Andrieux J. (1995) - *Geometry and kinematics of the south Atlas front, Algeria and Tunisia* - Tectonophysics, **249**, pp. 233-248.

Panizza M. (2001) - *Geomorphosites: concepts, methods and examples of geomorphological survey* - Chinese Sci. Bull., **46**, pp. 4-6.

Panizza M. & Piacente S. (1993) - *Geomorphological asset evaluation* - Zeitschrift fur Geomorphologie N.F., **87**, pp. 85-117.

Panizza V. & Cannillo C. (1994) - *Rilevamento e valutazione di beni geografico-fisici di tipo geologico e geomorfologico in un'area della Sardegna nord-occidentale* - Riv. Geogr. Ital., **101**, pp. 545- 576.

Patriat M., Ellouz N., Dey Z., Gaulier J. M. & Ben Kilani H. (2003) - *The Hammamet, Gabès and Chotts basins (Tunisia): a review of the subsidence history* - Sedimentary Geology, **156**, pp. 241-262.

Poli G. (2003) - *Dalla stanza delle meraviglie alle meraviglie della Terra* - In: S. Piacente & G. Poli (eds), *La Memoria della Terra. La Terra della Memoria*, L'Inchiostro Blu Ed., Bologna, pp. 28-40.

Regaya K., Ben Mamou A., Ben Youssef M. & Ghanmi M. (2001) - *Notice explicative de la carte géologique de Metlaoui* - Office Nationale des Mines, Tunis, 31 pp.

Reimold W. U. (1999) - *Geoconservation - a southern African and African perspective* - Journal of African Earth Sciences, **29(3)**, pp. 469-483.

Sassi S. (1974) - *La sédimentation phosphatée du Paléocène dans le Sud et le Centre ouest de la Tunisie* - Thèse des Sciences, Univ. Paris Sud-Orsay, 304 pp.

Swezey C.S. (1996) - *Structural controls on Quaternary depocentres within the Chotts trough region of southern Tunisia* - Journal African Earth Sciences, **22(3)**, pp. 335-347.

Zargouni F. (1984) - *Style et chronologie des déformations des structures de l'Atlas tunisien méridional. Evolution récente de l'accident Sud-atlasique* - Comptes Rendus Académie Sciences, **299**, pp. 71-76.

Zargouni F. (1985) - *Tectonique de l'atlas méridional de Tunisie. Evolution géométrique et cinématique des structures en zone de cisaillement* - Thèse des Sciences, Strasbourg, 292 pp.

Zargouni F. (1986) - *Tectonique de l'Atlas Méridionale de Tunisie. Evolution Géométrique et cinématique des structures en zone de cisaillement* - Revue des Sciences de la Terra, Mémoire **III**, Tunis, 304 pp.