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Landscape units, Geomorphosites and Geodiversity of the Ifrane-Azrou region (Middle Atlas, Morocco)

Unità di paesaggio, Geomorfositi e Geodiversità della regione Ifrane-Azrou (Medio Atlante, Marocco)

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ABSTRACT – The concept of geomorphosites is relatively recent (PANIZZA, 2001), finding application in many European nations, but in Africa much research on geomorphological heritage has still to be done. The research group has started studying landscape units, geomorphology, geomorphosites and geological heritage in different North-African regions, with the aim of drawing thematic geomorphological maps. The choice of these arguments as main objectives of this research is determined by the absolute lack of specific researches on these topics in Morocco. Furthermore, the very interesting landscapes, very rich in geological and geomorphological sites, deserve to be better known, safeguarded and valorised. This research has allowed to realise the first example of Landscape and Geomorphosites Map in Morocco, compiled for the area of Ifrane and Azrou in the Middle Atlas (Central Morocco).
This region is already inserted in the classical tourist routes that connect Fes and Meknès with the South of Morocco and this fact, together with its geological and geomorphological variety, has suggested its selection for this type of applied research. The research carried out by means of the analysis of airborne- and satellite images and direct field observations have brought to the recognition of 14 landscape units in which 42 geomorphosites have been selected. These geomorphosites comprise springs, karst landforms (polje, dolines, caves, sinkholes, stone forests, cryptokarstic dolines), carbonate depositional landforms (travertines and waterfalls), fluvial landforms (meanders, canyons, palaeo-valleys, etc.), structural landforms (triangular facets, hogbacks, cuestas, residual outcrops, etc.), volcanic landforms (volcanoes, caldeira, pyroclastic cones, lava tube) and two geo-botanical sites.
The results of this research have been summarised in a geomorphological map, representing the various landscape units and the geomorphosites, and comprises a proposal for the valorisation of the geomorphological heritage by means of six itineraries. The Map, constructed upon a Landsat ETM+ image, is completed with some geological sketch maps and sections and several photographs of the geomorphosites with their scientific explanation.

KEY WORDS: Geomorphosites, Karst, Geotourism, Mapping, Middle Atlas, Morocco.

RIASSUNTO – Il concetto di geomorfosito è relativamente recente (PANIZZA, 2001) ed ha trovato applicazione in molti paesi europei, ma quasi tutto resta da fare sulla ricerca sui geomorfositi nel continente africano. Il Gruppo di Ricerca ha iniziato a studiare le unità di paesaggio, la geomorfologia, i geomorfositi e il patrimonio geologico in alcune regioni del Nord Africa, con lo scopo di redigere delle Carte Geomorfologiche tematiche. La scelta di questi argomenti come principali obiettivi delle ricerche fu determinata dalla quasi completa assenza di tali studi in Marocco. Inoltre, i paesaggi molto interessanti, in cui abbondano siti di interesse sia geologico sia geomorfologico, meritano di essere meglio conosciuti, salvaguardati e valorizzati. Questa ricerca ha consentito di realizzare il primo esempio di Carta dei Paesaggi e dei Geomorfositi per il Marocco, comprendendo l'area di Ifrane ed Azrou nel Medio Atlante (Marocco centrale).
Questa regione si trova attualmente già inserita in uno dei classici itinerari che collegano le città imperiali di Fès e Meknès con il Sud del Marocco. È proprio questa sua caratteristica, insieme all'abbondanza di siti di interesse geologico e geomorfologico, ad averne determinato la selezione per questo tipo di ricerca applicata.
La ricerca, svolta attraverso l'uso di immagini aeree e satellitari ed alcune campagne geologiche sul terreno, ha portato all'individuazione di 14 unità di paesaggio in cui 42 geomorfositi sono stati descritti e catalogati. Questi siti comprendono sorgenti, morfologie carsiche (polje, doline, inghiottitoi, paesaggi ruiniformi, doline criptocarsiche), morfologie carbonatiche di deposizione (travertini e cascate), forme fluviali (meandri, gole, paleovalli, ecc.), forme strutturali (facette triangolari, hogbacks, cuestas, forme residuali, ecc.), forme vulcaniche (coni vulcanici, caldeira, coni piroclastici, grotte di lava) e due località di interesse geobotanico.

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I risultati di questa ricerca sono stati riassunti in una Carta geomorfologica che rappresenta le varie unità di paesaggio ed i geomorfositi, e comprende una proposta di valorizzazione di questo patrimonio geomorfologico attraverso sei itinerari tematici. La Carta ha come base un'immagine Landsat ETM+, ed è completata da alcuni schemi geologici e diverse fotografie dei geomorfositi con loro spiegazione scientifica.

PAROLE CHIAVE: Geomorfositi, Carsismo, Geoturismo, Cartografia, Medio Atlante, Marocco.

1. – INTRODUCTION

Geoconservation and Geological Heritage are well-known in Europe since the first debates held in the late 80's and especially since the birth in 1993 of ProGEO (European Association for the Conservation of the Geological Heritage) from the previously instituted European Working Group for Earth Science Conservation. The European Project GEOSITES, promoted by the International Union of Geological Sciences (IUGS) has induced many European countries and regions to evaluate their geological heritage (AA.VV., 1998; WIMBLEDON *et alii*, 1995).

Also the term Geomorphological heritage or Geomorphological asset, even though much less common in scientific literature, has also been used since about ten years (BARCA & DI GREGORIO, 1999; CARTON *et alii*, 1994; PANIZZA & PIACENTE, 1993), while the term "Geomorphosite" has been coined only recently as "a landform with attributes which qualify it as a component of the cultural heritage" (PANIZZA, 2001; PANIZZA & PIACENTE, 2003). In practice, however, many previously described Geosites can often also be defined as Geological Monuments or Geomorphosites.

The whole of this cultural geological revolution has lead to the introduction of the term "Geodiversity" defined as "the range (or diversity) of geological (bedrock), geomorphological (landform) and soil features, assemblages, systems and processes" (GRAY, 2003; SHARPLES, 1995).

Geoconservation, Geological Heritage, Geosites, Geomorphosites and Geodiversity, however, are terms that are 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) and much more recently in some North African countries (DE WAELE *et alii*, 2005a; DE WAELE *et alii*, 2005b; OUANAIMI *et alii*, 2005).

One of the most interesting North-African countries from this point of view is Morocco, a country with a very rich geology, studied by several generations of earth scientists and recognised as one of the most interesting geological regions of the Mediterranean area by most of the modern geological scientific communities. The extraordinary geological succession, characterised by rocks of all sorts of types (igneous, sedimentary and metamorphic) dating from Precambrian up to Holocene, spread over a latitude range of 22-36° North and altitudes from sea level up to 4165 m a.s.l. at Mount Toubkal, have lead to a very rich geomorphological and geological landscape and a very high degree in geodiversity.

For this reason our research team has decided to start a scientific campaign on the Geomorphosites and the Geodiversity of Morocco choosing as a first test site the Middle Atlas of Ifrane-Azrou (EL WARTITI *et alii*, 2008; DE WAELE & MELIS, 2009) (fig. 1). This research has been carried out by the Laboratories of Environmental Geology and of Remote Sensing (TeleGis) of the Department of Earth Sciences (Cagliari University - Italy) in collaboration with the Laboratory of Applied Geology of the Science Faculty of the University Mohammed V-Agdal of Rabat (Morocco). This Project has benefited of the financial aid of the Sardinian Government (Regional Law 19/1996, cooperation with developing countries).

2. – GEOGRAPHICAL AND GEOLOGICAL SETTING

The Middle Atlas is a SW-NE elongated mountainous chain located between the Atlantic Morocco to the West and the Moulouya plains to the East and forming a physical barrier that separates the Atlantic regions from the eastern parts of Morocco. Towards the South it is bordered by the high mountain ranges of the High Atlas, while to the

Fig 1 – Geographical location of the study area.
– *Ubicazione dell'area di studio.*

North it passes to the Saïss plain and the Rif mountains. From a morphological point of view the Middle Atlas can be subdivided in two main sectors: the northern and western parts are called the Middle Atlas *Causses*, while in the South and Southwest the "*Atlas Moyen Plissé*" (or Folded Middle Atlas) is located.

The Middle Atlas *Causses* are characterised by a series of high plains at altitudes ranging from 1800 m a.s.l. North of Oum Er Rbia to little over 1000 close to El Hajeb, more or less cut by valleys. In the Folded Middle Atlas the landscape is controlled by more or less broad synclines bordered by narrow ridges that can reach altitudes of more than 2000 meters, with a maximum of 2794 at Jbel Tichoukt. The study area is almost entirely located in the Middle Atlas *Causses* and comprises the villages of Ifrane, El Hajeb, Ain Leuh, Timahdite and Azrou.

This area is located not far South of the imperial cities of Fès and Meknès and covers a surface of more than 3500 square km. It is crossed by the national roads P21 connecting Meknès to Midelt and Ar-Rachidia and the P24 that links Fès to Beni Mellal and Marrakech and is thus one of the cross-roads used by foreign visitors to go from North to South Morocco. Furthermore, the area is already well-known for its Cedar forests and ski stations close to the tourist resort of Ifrane.

Climate is of Mediterranean type and is characterised by rainy winters and springs and a long period of drought with intense precipitation during late summer storms. Mean annual rainfall exceeds 900 mm (from 655 mm at El Hajeb – 1050 m a.s.l., over 827 mm at Azrou – 1250 m a.s.l. up to 1122 mm at Ifrane at 1635 m a.s.l.) and mean annual temperature is about 12 °C with very great differences between winter and summer (Ifrane: -4 - 30 °C, El Hajeb: 3-32 °C). Snow is present above 1500 meters of altitude during winter giving sometimes possibility of skiing (stations of Mischliffen and Jbel Hebri).

From a geological viewpoint the outcropping rocks are of metamorphic, sedimentary and volcanic origin and cover a lapse of time ranging from Silurian to Holocene (Martin, 1981; Michard, 1976; Piqué, 1994) (fig. 2). The oldest rocks of the area crop out in a vast territory West of the national road P21 between El Hajeb and Azrou in an erosion window. This interesting and scenographic

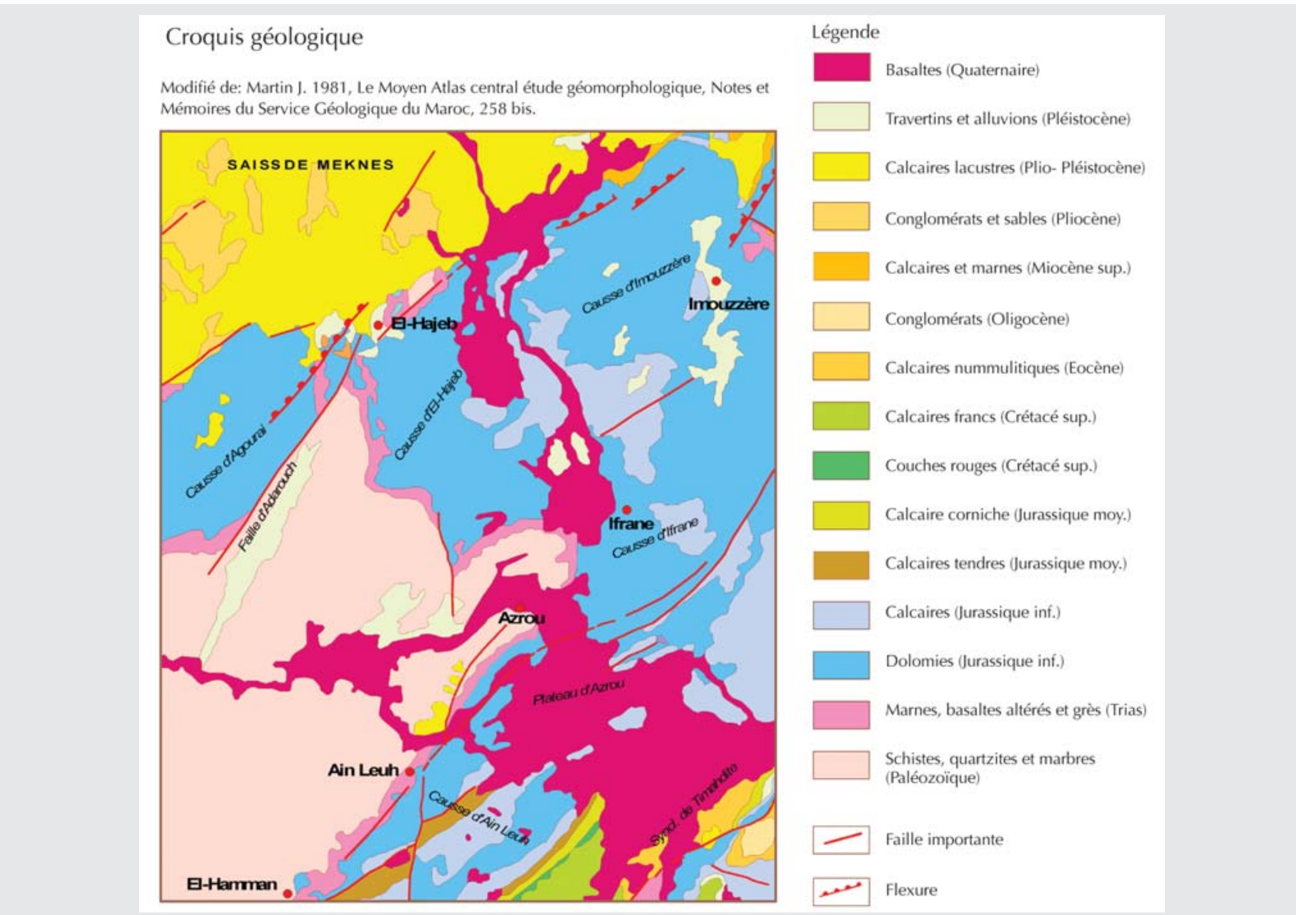

Fig. 2 – Geological sketch map of the study area (modified from Martin J., 1981).
– *Carta geologica semplificata dell'area di studio (modificata da Martin J., 1981).*

panorama on Palaeozoic rocks can be observed from the well-known *Balcon d'Ito*, one of the famous tourist stops of this part of Morocco. The Palaeozoic sequences are characterised by an alternation of soft (shales and phyllites) and hard rocks (marbles, sandstones and quartzites) intensively folded in typical Variscan NE-SW directions and ranging in age from Ordovician to Lower Permian. The structural control is clearly visible in the landscape with sharp and long rectilinear ridges and a subdendritic drainage pattern with valleys mainly directed NE-SW (AA.VV., 1975).

The first sediments deposited upon this basement complex are Triassic sandstones and red clays followed by weathered doleritic basalts that can be traced along the entire western margin of the *Causses* (PIQUÉ & LAVILLE, 1993). These outcrops, clearly recognisable by their colours, from the reddish of the clays to the dark brownish of the volcanic rocks, have been eroded by surface drainage forming a concave and gentle slope towards the underlying Palaeozoic rocks (MARTIN, 1981). But the most important rock types that characterise more than 50 % of the study area are the Jurassic carbonate rocks of the *Causses*. These are composed of dolostones, calcareous dolostones and limestones that have been deposited in a more or less shallow sea from Sinemurian up to Bathonian (COLO, 1964; MARTIN, 1981). The entire series is easily distinguishable in two major facies: a lower dolomitic one easily recognisable for its greyish colour and ruin-like morphologies, and an upper facies where limestone is predominant.

Towards the end of the Middle Jurassic the whole area emerged from the sea giving rise to a long and intense erosion period that lasted from Upper Jurassic until part of Lower Cretaceous. The first post-Jurassic sediments are composed of red marls and clays with conglomerate intercalations attributed with some doubts to the Cenomanian. These sediments crop out on the border of the large syncline of Bekrite-Timahdite. These are followed by pure and marly limestones of Upper Cretaceous, followed by a thick sequence of sandstones, gypsum and claystones of Palaeocene and ending with the fossiliferous limestones of Eocene age that form a platform and cliffs near the village of Timahdite (RAHHALI, 1970).

The sedimentary sequence of the study area ends with the lacustrine limestones, sands and conglomerates of Plio-Quaternary age that have infilled the Saïss plain and travertines that locally crop out along the border of the *Causses* (e.g. El Hajeb).

During Pleistocene also an important alkaline volcanic phase has taken place leaving over 400 square km of basalts with beautiful cones and calderas on the plateau d'Azrou (HARMAND & CANTAGREL, 1984; HARMAND & MOUKADIRI, 1986). K-Ar Age of these basalts ranges between 0.6 and 1.8 Ma (EL AZZAB & EL WARTITI, 1998), but the fresh landforms suggest an even younger age for some of these volcanoes.

3. – GEOMORPHOLOGY

The overall geomorphology of the Middle Atlas Causses is the product of a combination of mostly inherited and some active landforms.

The topography of the summits of the *Causses* designates an important palaeo-surface (denudation plain) that has been dated back to Eocene. This testifies a long period of tectonic stability, with the Eocene sea submerging most of the Mesozoic carbonates. Subsequently tectonic activity reactivated during Oligocene and dislocated the different plateaus of the *Causses*. Another period of tectonic stability occurred during Middle Miocene producing another denudation plain that did however leave the higher summits and the Eocene palaeo-surface in place (MARTIN, 1981). During this continental period karst corrosion processes begin to play an important role.

During Late Miocene-Pliocene erosion processes start building up the present landscapes, with the slow uplift of the *Causses* and the formation of the Northern and Western tectonic escarpments: the first clearly divides the Saïss plain and Rif from the Middle Atlas *Causses* while the second separates the *Causses* from the Palaeozoic outcrops (BEAUDET & MARTIN, 1967). The presence of important deposits of travertines in the Saïss plain and along the north-western border of the *Causses* testifies important karst corrosion of the Liassic dolo- and limestones during this period. Erosion processes accelerate with the rapid incision of the Oued Sebou gorge on the Pliocene-Quaternary boundary leading to the final shaping of the present landforms and landscapes.

During Quaternary this landscape is disrupted by volcanic activity that give rise to several edifices and lava flows. The volcanic landforms appear very fresh and unaltered, especially on the Azrou plain, and comprise lava flows (pahoehoe lava), lava tubes, hornitos, spatter cones, caldera, explosion craters etc. The fact that these lava flows cover a karst topography has led to a convergence of forms with big collapse cryptokarstic dolines sometimes due to the presence of underlying lava tubes, but generally related to the collapse in depth of karst tunnels in limestones of Lias (MARTIN, 1981).

The present landscape of the *Causses* is disseminated with more or less active karst landforms, mainly present on the dolo- and limestone outcrops at different altitudes, but minor forms have also been observed in the Palaeozoic marbles of the Tizra hogback. Many of the bigger landforms, such as poljes, macrodolines and uvalas, are related to the intense karst phases of Mio-Pliocene and are now almost completely inactive. They are generally located in structurally favourable areas such as intersection of faults or synclines. Some of these (Dayet Ifrah, Aguelmam Azigza etc.) still contain temporary lakes but lack springs and ponors. Their base level, very close to the aquifer, is slowly filling up with sediments and corrosion is no more active on their bottoms and their flanks.

The very large macrodolines such as Moutferraoun (1.5 km wide and 110 m deep) and Trou de la Panthère are big collapse structures in the Lower Lias dolostones that do not appear to be related to faults. Their origin is most probably due to the dissolution of salt in the underlying Trias, leading to relatively fast collapse (El Khalki & Akdim, 2001; Martin, 1981).

The same dolostones display a wide variety of ruin-like forms, creating strange landscapes of rocky mushrooms, pinnacles and towers of several meters high, cut by rectilinear troughs and trenches. Very beautiful examples are located at Tidrine, near Ifrane, and at Tisfoula, along the road to the springs of Oum-Er-Rbia.

Karren landforms are widely represented especially in the dolostone facies in association with these ruin like landforms, but also occur in limestones of the *Causses* and in the marbles of Tizra. In some places, at high altitudes and on the northern slopes, their rounded forms probably reflect their corrosion under snow or beneath a soil cover. Besides all kinds of normal and rounded clints also solution pans (*kamenitze*) are well represented.

The influence of snow on the karst forms is also well displayed above 1,700 m of altitude in the asymmetric shape of the dolines, with a preferential dissolution of their protected inner slopes. A similar phenomenon also occurs in the High Atlas karst of Ait Abdi (Perritaz, 1996).

Despite the well developed surface karst only few caves are known in the Middle Atlas mountains. This is due to the scarceness of thick pure limestone beds, often intercalated with marly limestones, and the abundance of highly fractured dolostones that convey surface waters directly to the underlying Trias through cracks and fissures (Martin, 1981). One of the best examples of true karst caves is Ifri-ou-Berrid, a sinkhole located at the end of a blind valley and with an underground development of approximately 100 meters, ending in a drowned passage.

Landscape development during Quaternary is characterised by the mechanical and chemical cutting of valleys during the wetter periods and the deposition of travertines and alluvial sediments during periods with diminished flow rate and higher temperatures. Now these valleys are mostly dry, except from the ones fed by springs (e.g. Oum-Er-Rbia) and are the relict of the drainage network of the pluvial periods.

Present morphodynamics is mainly correlated to karst denudation processes, weathering of the alkaline basalts and slope dynamics (especially on soft rock-types, e.g. Triassic marls and altered dolerites), enhanced by heavy sheep-breeding activities, with formation of badlands, gullies, creep and solifluction phenomena etc.

4. – METHODS

The adopted methodology is based on the experience acquired during the past couple of years in two National Research Projects (PRIN 2001-2003 on Geosites in the Italian Landscape and PRIN 2004-2006 on Geotourism in Italy) and especially during a Co-operation Project, financed by the Sardinian Regional Government, in which our team has collaborated with the Institute des Regions Arides of Medenine (Tunisia) aiming to define the geological heritage of the region of Tozeur in South Tunisia (De Waele *et alii*, 2005b; Di Gregorio *et alii*, 2002). This method is based on the preliminary consultation of scientific and geographic literature and topographical, geological and tourist maps that have lead to a first selection of sites and landscapes of geological and geomorphological interest. For this purpose the detailed and magnificent PhD work of Jacques Martin, presented in 1977 at the Université de Paris VII (Martin, 1981), has been of enormous value, giving lots of suggestions on sites and landscapes of possible geo-tourist attraction.

Several field campaigns have been organised to study more in detail the selected 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). During these trips several other geomorphosites, previously ignored, have been added to the list and have also been studied in detail.

For the description of these sites in 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) also data on accessibility, visibility, geology and geomorphology, use and state of conservation are reported. Contents of such a sheet file, similar to the one adopted by our research team in Tunisia, is reported in figure 3.

Nom du Géosite: **Numéro**

1. IDENTIFICATION
- *Gouvernorat*:
- *Commune*:
- *Localité*:
- *Références cartographiques* (1:50.000 ou 1:100.000):
- *Coordonnées métriques centrales* (U.T.M.):

Localisation (sur une carte du Maroc) *Itinéraire (sur Carte routière 1.1.000.000)*	*Extrait de la Carte topographique et localisation (échelle 1:100.000 ou 1:50.000)*

Description géométrique *(Surface, Longueur, Profondeur, Largeur, Hauteur, Epaisseur, etc.)*
- Longueur : - Largeur : - Epaisseur :

Accessibilité *Facile (proche d'une route)* *Difficile (loin de la route)* *Très difficile*

Point panoramique Qui Non

Visibilité de loin Qui Non

Saison conseillée pour la visite *H* *P* *E* *A* *T*

2. DESCRIPTION
Géologie-stratigraphie
Géomorphologie, genèse et évolution

3. CLASSIFICATION GENETIQUE
Processus génétique principal **Processus génétique secondaire**

Actif Inactif Actif Inactif

Définition de la Forme

4. UTILISATION ET CONSERVATION
Utilisation actuelle du monument et du territoire limitrophe
Etat de conservation
Mesures de conservation existante (Lois, Parcs, etc.)
Menaces et/ou perturbations au paysage
Propositions de conservation et de valorisation

5. REFERENCES BIBLIOGRAPHIQUES

6. CARTOGRAPHIE GEOLOGIQUE, GEOMORPHOLOGIQUE ET ESQUISSES DU SITE

7. REFERENCES PHOTOGRAPHIQUES

Fig. 3 – Example of the sheet file, in French, used in the field for the cataloguing of the Geomorphosites.
– *Esempio di una scheda da rilevamento, in lingua francese, utilizzata in campagna per l'inventariazione dei geomorfositi.*

For the identification, classification and the graphical representation of the geomorphosites a Landsat ETM+ Image has been used. The different lithological units outcropping in the area have been recognised by means of the creation of interpretation keys based on field surveys using the medium-infrared band combinations. Lithology, tectonics, drainage pattern, land cover and topography have then been analysed to characterise the general morphology of the study area. 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. Where the vegetation is lacking or relatively scarce the spectral response of the different lithologies can easily be observed, while the distinction of topography has been enhanced introducing shadow analysis. Directional filters associated with spectral analysis have allowed to recognise the general structure of the area and the most important faults and alignments.

All the bibliographical, field and remote sensing data have been summarised in a geomorphological map superimposed on the satellite image (fig. 4).

The next step was to define the different landscape units based on a complex geomorphological and environmental analysis of the different parts of the study area. This landscape analysis allows to subdivide the territory in homogeneous units, differing in morphology, lithology or land-use and classified according to a hierarchic scheme.

Subsequently, the singles sites have been positioned on the satellite image and the links between the single geomorphosites and geosites (intrinsic values) and the surrounding landscape (overall value) have been defined in order to have a complete perception of the importance of geological heritage in the region.

This applied geomorphological interpretation of the Middle Atlas of Ifrane-Azrou allows to summarise the geological and geomorphological heritage of the area in which the single sites, because of their easy perception (recognisability), their characteristic form (completeness), their state of conservation (exemplarity) and their effective possibility of visit (accessibility) (POLI, 2003), are integrated in a global landscape and constitute the foundation for a sustainable geotouristic development. For a more direct understanding of this geomorphological heritage the geomorphosites and geosites are grouped in networks, according to similar geomorphological processes and differentiated by colours. This distinction in thematic networks of geosites and geomorphosites makes it also easier to define coherent actions of planning, valorisation and conservation.

5. – LANDSCAPE UNITS

Landscape units are territorial ambits with specific, distinctive and homogeneous characteristics regarding their genesis, constitution and evolution due to both natural and human interactions (BERTRAND, 1970; DI GREGORIO, 1987; ROMANI, 1986). In general a Landscape Unit is a geographically distinct portion of an area that has a particular visual character.

The identification of the single Landscape Units has been carried out by means of the analysis and the classification of a complex series of characterising and significant elements (geological constitution, geomorphological elements, altitude, climate and microclimate and other physical and geographical elements, vegetation, material expressions of the human presence etc.). These elements also allow to define the originality, the scientific interest and the perceptive quality of the landscape according to the European Landscape Convention (ECC Treaty n° 176, October 20^{th} 2000) (DI GREGORIO, 2003).

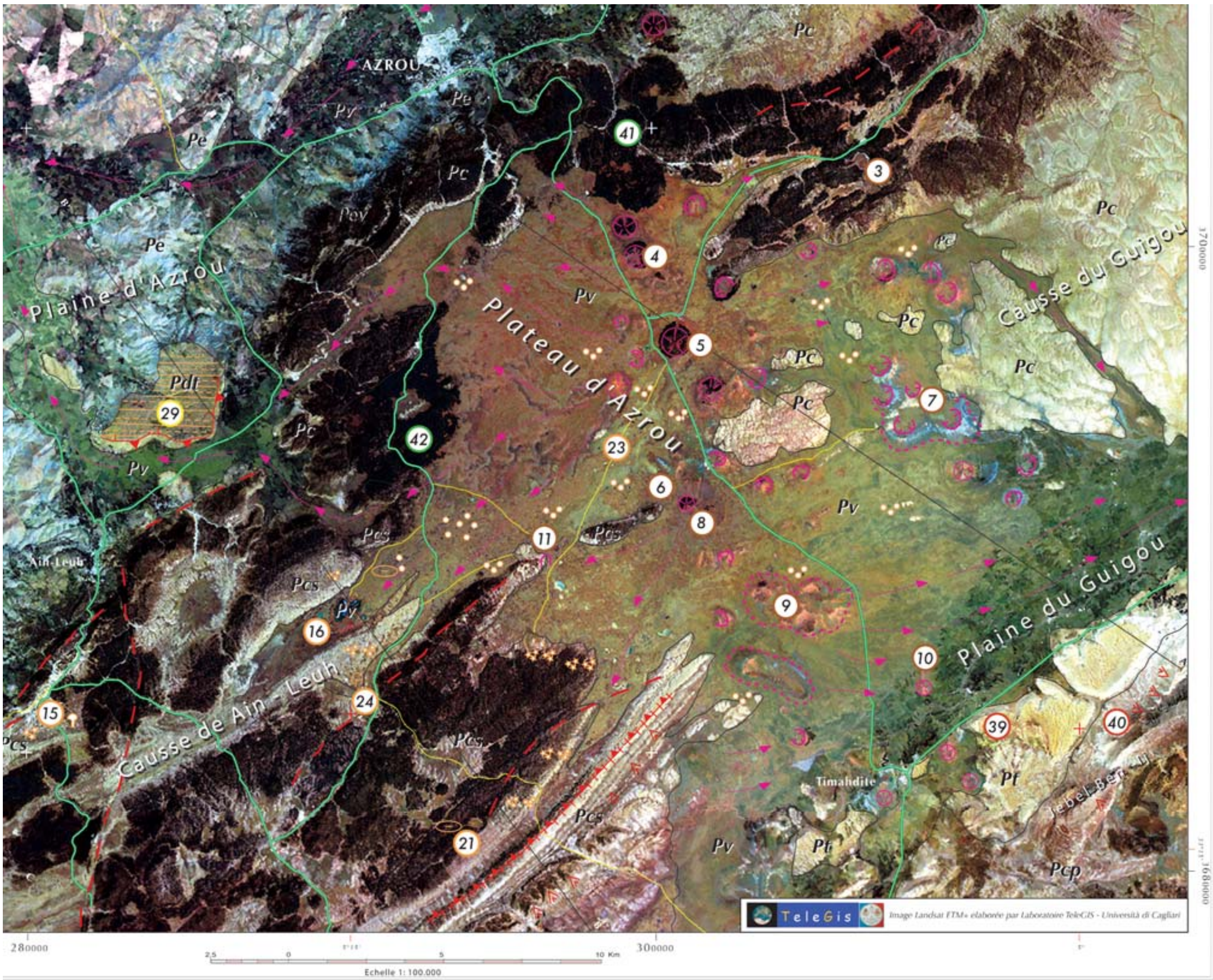

Fig. 4 – Extract of the map of Landscape Units and Geomorphosites of the Ifrane-Azrou region. The represented area is the basaltic plateau of Azrou, one of the landscape units with the highest geodiversity. For the legend see attached Map.
– *Stralcio della Carta delle Unità di Paesaggio e dei Geomorfositi della Regione di Ifrane-Azrou. L'area rappresentata è l'altopiano basaltico di Azrou, una delle unità di paesaggio con la più alta geodiversità. Per la legenda si rimanda alla Carta allegata in tasca di copertina.*

This subdivision of the study area in Landscape Units allows to:

- construct a territorial matrix useful as a spatial reference for the identified elements (natural sites, cultural heritage, human settlements and infrastructures, vegetation etc.);
- to interconnect in an organic way the different components in categories, classes and types and to better understand the relationships between the single sites and the surrounding landscape;
- to describe the determinant characters of more or less extensive homogeneous areas;
- to classify, plan and manage together the single components of the landscape, orienting the actions and interventions towards a shared goal – conservation or transformation – respecting the principles of sustainability.

The subdivision of the Ifrane-Azrou region in Landscape Units has been carried out using several types of thematic maps (topographical, geological, geomorphological) at different scales (from 1:50.000 to 1:250.000), interpreting aerial photographs and satellite images (Landsat ETM+) and carrying out surveys and controls in the field. Landscape units differ in terms of geomorphology, with different landforms in relation with the geological and structural settings, and land-use. Sheep-breeding is abundant on the steep slopes, on the *Causses* and on the basaltic plateaus while agriculture characterises the lower plains where irrigation is practiced since a long time. The recognised Landscape Units could be subdivided in smaller landscape facies with a detailed analysis at larger scales (TRICART & KILIAN, 1985), according to different natural and/or human components. Several Landscape Units can also be grouped together to form Landscape Systems that describe the territory in a much more general but nevertheless characterising way. In the study area a total of five Landscape Systems have been recognised: the carbonatic *Causses*, the sedimentary and agricultural Lower Plains, the Plio-Quaternary Volcanic landscape system, the Palaeozoic Central Massif and the Transitional systems. The landscape has then further been subdivided in fourteen easily recognisable different Landscape Units. The main characteristics of the Landscape Systems and Units are resumed in table 1.

6. - GEOSITES, GEOMORPHOSITES, LANDSCAPES AND ITINERARIES

A total of 42 sites of geological and/or geomorphological interest have been identified, studied and classified and represent the essential reference for the construction of the thematic itineraries (tab. 2). Geomorphosites have been classified according to their genesis in volcanic, dissolution karst, deposition karst, fluvial, structural and polygenetic landforms, at which two geobotanical sites have been added. The same genetic

Tab. 1 – *Landscape systems and units of the Azrou-Ifrane area and their main characteristics.*
– Sistemi ed Unità di Paesaggio dell'area di Ifrane-Azrou e loro principali caratteristiche.

Landscape System (LS)	**Acronym**	**Landscape Unit**	**Description (main characteristics)**	**General morphology**	**Main lithologies**
Causses	Pc	Tabular *Causses*	Tabular carbonate plateaus (*Causses*) of El Hajeb, Immouzer, Ifrane, Guigou, Ain-Leuh	Sub-horizontal bedded dolo- and limestone plateaus with typical karst features	Liassic dolostones, dolomitic limestones & limestones
	Pcp	Slightly folded *Causses*	Folded Middle Atlas SE of Timahdite	Folded dolo- and limestones with karst features and cuestas	Liassic dolostones & limestones
	Pca	*Causse* d'Agourai	*Causse* d'Agourai	Slightly NW-tilted carbonate plateau	Liassic dolostones & limestones
	Ps	Timahdite (Bekrite) Syncline	Syncline W of Timahdite	Large syncline with Cretaceous core and basalt infilling	Cretaceous limestones and Plio-Pleist. basalts
	Pt	Timahdite balcony	Eocene limestone plateau of Timahdite	Eocene limestone balcony eroded by Oued	Eocene limestones
Lower Plains	Ptq	Saïss plain	Low plains N of Middle Atlas *Causses*	Agricultural plains and human landscape with the cities of Fès and Meknès	Plio-Quat. lacustrine sediments
Volcanic	Pv	Lavaflows	Plio-Pleistocene lava flows	Lava flows up to 40 km long	Plio.Quaternary basalts
	Pv	Volcanic plateau	Plateau d'Azrou	Plateau basalt with various types of volcanoes	Plio.Quaternary basalts
	Pv	Single volcanoes	El Koudiate, Jbel Outgui	Single volcanoes	Plio.Quaternary basalts
Central Massif	Pes	Structural landscape	Wide lower complex plain W of *Causses* d'El Hajeb	Hogbacks and syncline valleys	Palaeozoic marbles and quartzites
	Ped	Hills with dentritic drainage	Azrou plain	Smooth and rounded hills in mostly tender rocks	Palaeozoic shales and phyllites
	Pev	Reddish altered slopes	Western border of the *Causses* d'Agourai, El Hajeb & Ain-Leuh	Concave slopes in tender rocktypes	Triassic sandstones, clays & altered basalts
Transitional systems	Pd	Piedmonts	Slope deposits	More or less steep slopes	Plio-Quaternary slope debris
	Pdt	Travertines	Travertine terraces and balconies along the borders of the *Causses*	Step-like travertine terraces or plateaus	Plio-Quaternary travertines

Tab. 2 – *Geosites, geomorphosites and geological landscapes of the Azrou-Ifrane area.*
– Geositi, geomorfositi e paesaggi geologici della area di Ifrane-Azrou.

N°	Nom Géosite	Commune	Typologie	Lithologie	Age
1	Jbel Outgui	El Hajeb	Cône Volcanique	Basaltes	Plio-Pleistocène
2	El Koudiate	Ifrane	Cône Volcanique	Basaltes	Plio-Pleistocène
3	Mischliffen	Azrou	Cratère d'explosion	Basaltes	Plio-Pleistocène
4	Jbel Habri	Azrou	Cône Volcanique	Basaltes	Plio-Pleistocène
5	Jbel Hebri	Azrou	Cône Volcanique	Basaltes	Plio-Pleistocène
6	Tit Ouagmar	Azrou	Volcan complexe	Basaltes	Plio-Pleistocène
7	Bou Ibalrhatene	Azrou	Cratère d'explosion	Basaltes	Plio-Pleistocène
8	Chedifat-Tit Ouagma	Azrou	Volcan complexe	Basaltes	Plio-Pleistocène
9	Bou Teguerouine	Azrou	Volcan complexe	Basaltes	Plio-Pleistocène
10	Sidi Aziz	Azrou	Cône Volcanique	Basaltes (pyrocl.)	Plio-Pleistocène
11	Trou de Ifri-Ouska	Azrou	Tunnel de lave	Basaltes	Plio-Pleistocène
12	Dayet Aoua	Ifrane	Lac et Barrage tectonique	Calcaires dolom.	Lias inf.
13	Tidrine	Ifrane	Paysage ruiniforme	Dol. + Calcaires	Lias moyen
14	Dayet Hachlaff	Ifrane	Paysage ruiniforme	Dolomies	Lias inf.
15	Tisfoula	Ifrane	Paysage ruiniforme	Dolomies	Lias inf.
16	Afennourir	Ifrane	Synclinale + lac + dolines	Dol. + calcaires	Lias
17	Dayet Ifrah	Azrou	Polje + lac karstique	Dol. + Calcaires	Lias
18	Polje de Ouiouane	El Hammam	Polje, hum et lacs	Calcaires	Lias
19	Bassin de Agoulmam	Sefrou	Macrodoline + lac	Calcaires dolom.	Lias inf.
20	Doline de Moutferraoun	Sefrou	Macrodoline d'effondrement	Dolomies	Lias inf.
21	Trou de la Panthère	Azrou	Doline d'effondrement	Dolomies	Lias
22	Aguelmam Azigza	El Hammam	Doline avec lac	Calcaires	Lias
23	Tichilite	Azrou	Dolines Cryptokarstiques	Calc. + Basalts	Lias + Quat.
24	Ifri-ou-Berid	Azrou	Ponor + vallée aveugle	Calcaires	Lias
25	Sources Oum- Er- Rbia	Khenifra	Sources + Cascades	Dol. + travertins	Lias + Quat.
26	Cascades des Vierges	Ifrane	Cascades	Travertins	Quaternaire
27	Ifrane Zaouia	Ifrane	Cascades	Travertins	Plio-Pleistocène
28	Terrasses d'El Hajeb	El Hajeb	Dépots de travertins	Travertins	Pleist. inf-moy.
29	Jbel Irhoud	Azrou	Plateau de Travertins	Travertins	Pliocène
30	Source Vittel	Ifrane	Sources karstiques	Calcaires + travertins	Lias + Quat.
31	Gorge de l'Oued Tizguite	El Hajeb	Gorge fluviale	Calcaires + basaltes	Lias + Plio-Quat.
32	Méandre Oued Akkous	El Hajeb	Méandre fluvial	Basalts + trav.	Pleist. inf-moy.
33	Gorge de l'Oued Defali	El Hajeb	Gorge fluviale	Dolomies	Lias
34	Village perché Bou Youssef	El Hajeb	Village sur travertins témoins	Travertins	Plio-Pleistocène
35	Mohamed ou Messaoud	El Hajeb	Paysage plurigénétique	Scistes+ marbres	Paléozoïque
36	Paysage d'Ito	El Hajeb	Paysage plurigénétique	Scistes + Arenites	Paléozoïque
37	Crête de Tizra	El Hajeb	Hogback	Marbre	Ordovicien
38	Tammeroit	Ifrane	Butte	Conglomerates	Pliocène ?
39	Balcon de Timahdite	Timahdite	Synclinale	Calcaires	Eocène
40	Chevrons de Timahdite	Timahdite	Chevrons	Calc. + dolomies	Lias
41	Cèdre Gouraud	Azrou	Site géobotanique	Calcaires	Lias
42	Paysage des Cèdres	Azrou	Paysage géobotanique	Calcaires + basaltes	Lias + Plio-Quat.

relationships have lead to the definition of the six itineraries that are based on genetic relationships between the different geomorphosites and exemplify the major genetic concepts of the landscape: volcanic, karst (dissolution and deposition), fluvial, structural and geobotanical.

The geomorphosites, in different colours according to their genetic relationships, the networks (grouping the geomorphosites of the same colours) and the landscape units are represented in the Geomorphosites Map of the region of Ifrane-Azrou, in scale 1:100.000. This map is the graphical summary and is the final product of this research. An extract of the Map is shown in figure 4.

This thematic map has been designed upon a Landsat ETM+ image and also reports infrastructural information (roads, villages etc.) and the main landforms and morphologies.

The geographical distribution of the geomorphosites in this map shows a greater concentration of sites of geomorphological and/or geological interest in the Landscape Units of the Tabular *Causses* (Pc) and on the volcanic Plateau d'Azrou (Pv). These

Landscape Units are the ones with the greatest degree in Geodiversity (GRAY, 2003).

The six itineraries, reported in different colours, group the geomorphosites with similar genetic characteristics and have been given the following names: *La petite Auvergne* (small Auvergne), connecting 11 volcanic sites and named after the famous French volcanic region, *L'eau qui dissoud les roches* (the water that dissolves the rocks) grouping the 14 karst sites, *L'eau constructrice des roches* (the water that builds the rocks) comprising the 4 travertine sites, *L'eau constructrice des paysages* (the water that sculpts the landscapes) comprising 4 fluvial geomorphosites, La Terre vivante (the Living Earth) connecting 7 structural and tectonic landscapes and, finally, the 2 geobotanic sites. These networks have been reported in a miniature extract of the Map (bottom left) and reports, besides the geomorphosites (in different colours) also the landscape units and the road network. This extract is shown in figure 5.

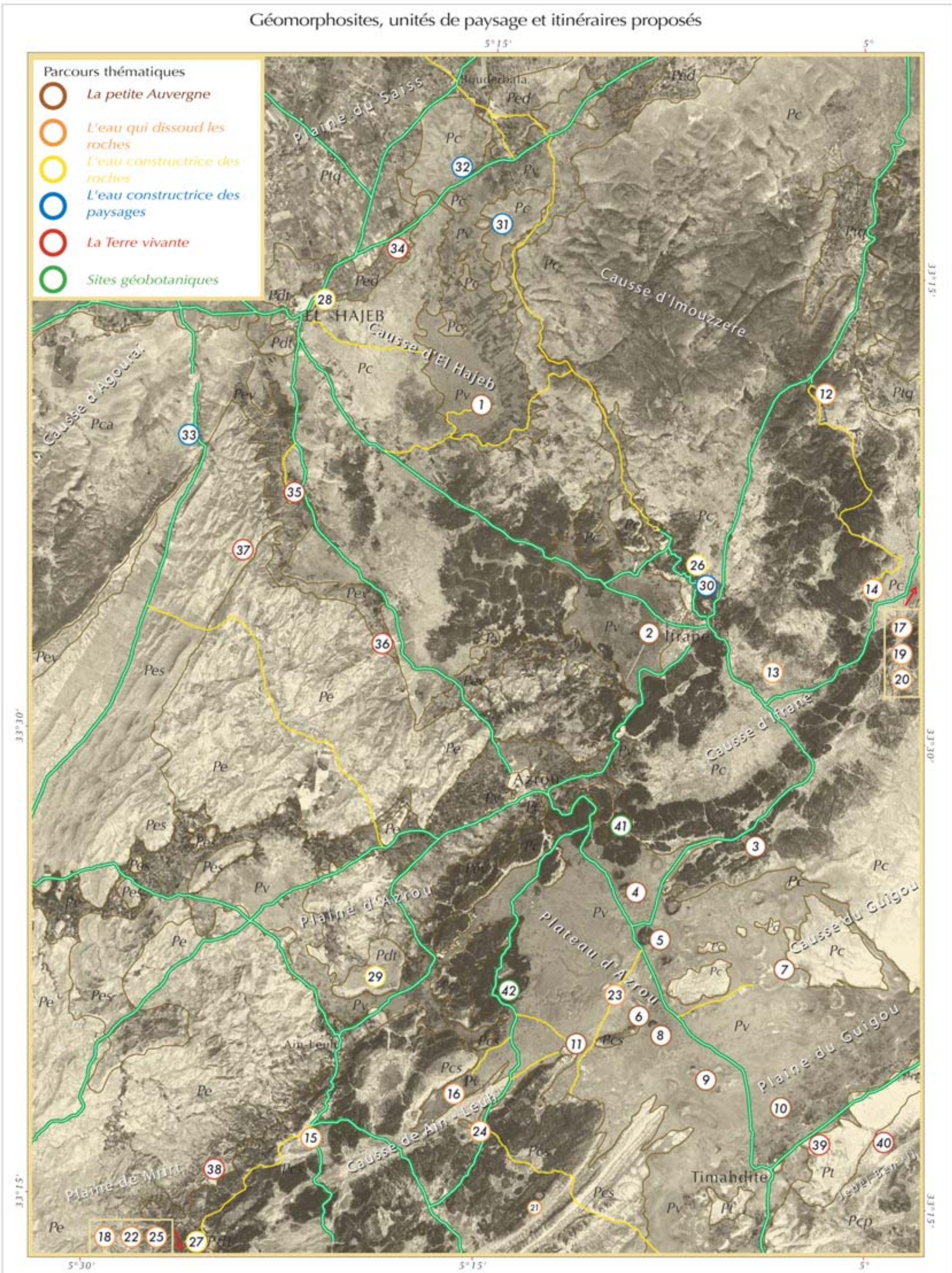

Fig. 5 – The itinerary map, in French, with the proposal of six thematic itineraries (left upper corner). In this miniature map all geomorphosites (circled numbers), the landscape units (in black italic letters) and the main roads are also summarised.
– *La Carta degli Itinerari, in lingua francese, con la proposta di sei itinerari tematici (angolo superiore sinistro). In questa piccola mappa sono segnalati tutti i geomorfositi (numeri cerchiati), le unità di paesaggio (in lettere nere corsive) e le strade principali.*

For every itinerary a series of photographs of the most important geomorphosites with exhaustive explanations are given on the right side of the Map, two examples of which is given in figures 6 and 7.

7. - CONCLUSIONS

Research on geological and geomorphological sites is a completely new branch of earth science in Morocco, despite the fact that it is one of the most important North African countries for what concerns geology, geomorphology and landscape. Morocco, in fact, has both Atlantic and Mediterranean coastlines, several mountain chains (Rif, Middle Atlas, High Atlas, Anti-Atlas), a wide variety of ecosystems ranging from Mediterranean forests over high mountain meadows to plain deserts and plenty of other geo-ecosystems.

This paper is one of the first attempts of popularising geology and geomorphology to the local communities by means of a Geo-tourist Map that reports the essential sites of geomorphological sites and landscapes and also gives information on geology, geomorphology and geodiversity of the region of Ifrane and Azrou in the Middle Atlas. The Map, designed on a Landsat ETM+ image and written in French, describes this region in a scientific way but in the meantime uses a simple and direct language that has the purpose of bring-

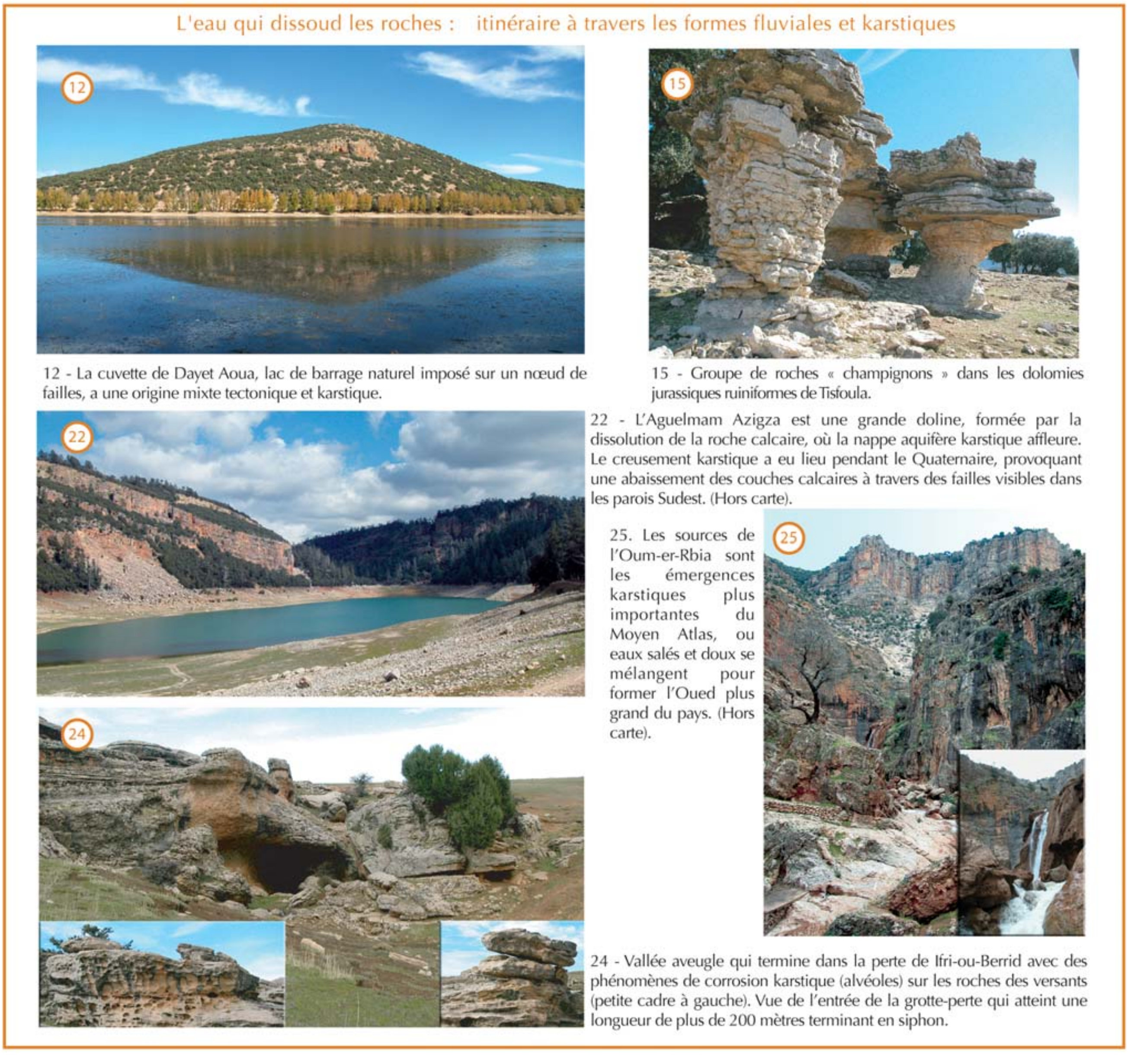

Fig. 6 – The "Water that dissolves the rocks" itinerary, in original French language, shows 5 of the most important karstic geomorphosites of the *Causses* region.
– L'itinerario "L'acqua che dissolve le rocce", in lingua originale francese, comprende 5 dei più importanti geomorfositi carsici della regione dei Causses.

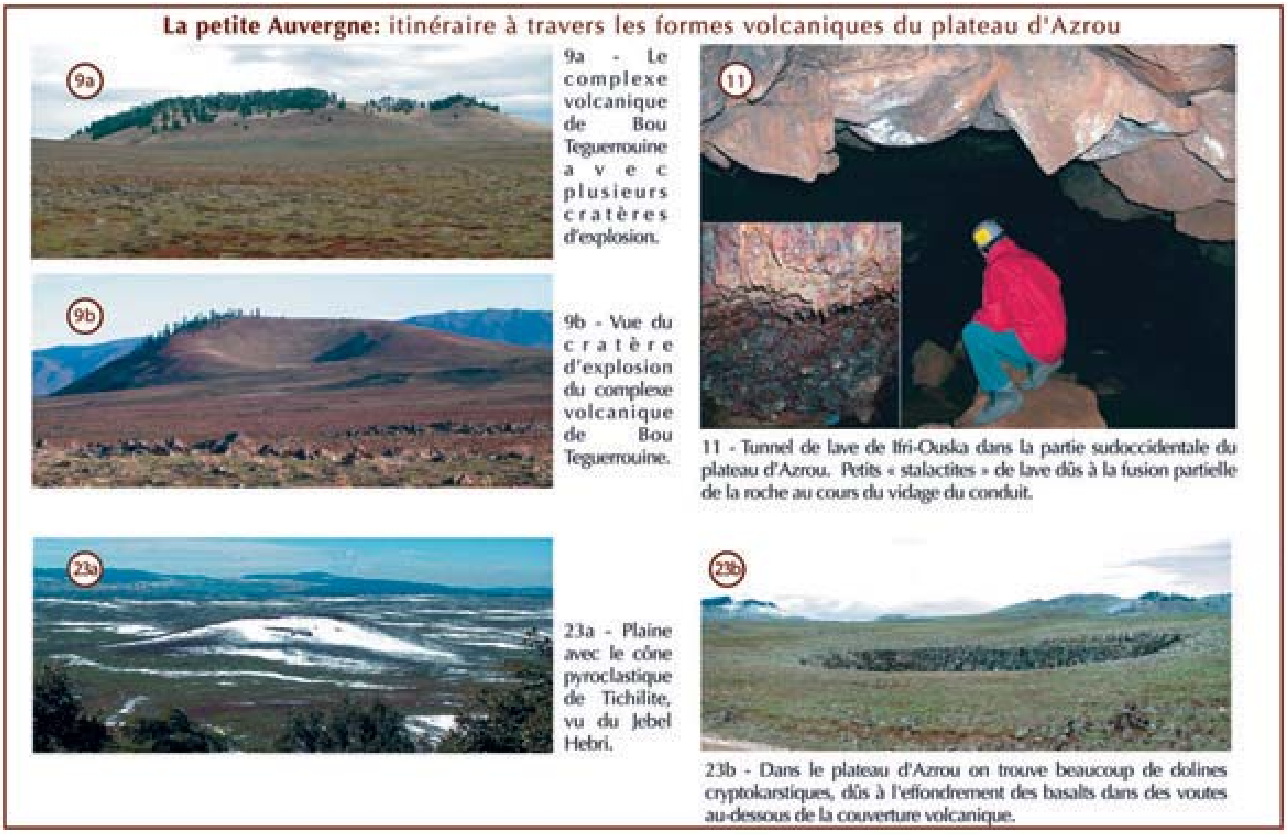

Fig. 7 – The "Small Auvergne" itinerary, in original French language, illustrates typical landforms related to volcanic processes of the Azrou Plateau.
– *L'itinerario "Piccola Alvergna", in lingua originale francese, illustra alcuni dei più tipici geomorfositi legati all'attività vulcanica dell'Altopiano di Azrou.*

ing also local people, unfamiliar with science, closer to the geological and geomorphological significance of the landscape in which they live. The Map is particularly designed for tourists, that often rush through this area in their travel to South Morocco, in the hope that they will decide to stay a while in the region to visit the geomorphosites suggested and described in the map. The use of photographs, showing the remarkable geological and geomorphological heritage of this region, is aimed to attract people to visit these sites.

The quantitative evaluation of the geological and geomorphological heritage of the region, following the guidelines proposed by several authors (BARCA & DI GREGORIO, 1991; BRUSCHI & CENDRERO, 2005; CORATZA & GIUSTI, 2005), in order to give a valuable tool for Environmental Impact Assessment studies (BONACHEA *et alii*, 2005) could be a further development of this research.

Finally, it must be stressed that the implementation of tourist pressure on some of these geomorphosites, representing a logical consequence of the publication of geo-tourist maps such as the one presented in this paper, could compromise their integrity. Therefore it is becoming increasingly important to inform the local population and especially the local stakeholders that manage the geomorphological heritage in order to raise awareness on the uniqueness of their landscape and the geosites and geomorphosites contained in it. The understanding that this heritage is an important part of the cultural identity of their territory (PANIZZA, 2003) should make conservation and valorisation much easier.

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