in: Victoria Lenz-Wiedemann and Georg Bareth (eds.) (2011):
Proceedings of the ISPRS WG VII/5 Workshop, 18.-19.11.2011, Cologne:

PROSPECTION OF KARSTIC CAVES USING GIS AND REMOTE SENSING TECHNIQUES FOR GEOARCHAEOLOGICAL RESEARCH, NE-MOROCCO

A. Roeloffs[1], J. Linstädter[2], T. Wiatr[1], K. Reicherter[1] & G.-C. Weniger[3]
[1] Institute of Neotectonics and Natural Hazards, RWTH Aachen University, Aachen, Germany
[2] Institute of Prehistoric Archaeology, University of Cologne, Cologne, Germany
[3] Stiftung Neanderthal Museum, Mettmann, Germany
Anna.Roeloffs@rwth-aachen.de, joerg.linstaedter@uni-koeln.de

Abstract

Caves and rock shelters are important archives for archaeological research. Prehistoric men not only sheltered in caves but also set up camps in open-air locations. Over the last 15 years a joint research group, comprising INSAP (Institut National des Sciences de l'Archéologie et du Patrimoine du Maroc), KAAK (Kommission für Archäologie Außereuropäischer Kulturen, German Archaeology Institute) and the University of Cologne, has been carrying out surveys and excavations in the area of the Eastern Rif (NE-Morocco). Huge parts of the vast working area are poorly accessible and it is now realised that the whole area can only be covered using a remote sensing approach.The aim of this project is to integrate high resolution topographical, visual and geological data in order to develop models so that site locations can be predicted. Information from remote sensing (satellite image) and Geographic Information System (GIS) is used to identify an area in which carstic caves can occur and caves featuring archaeological remains may be located. The intersection of geological and topographical maps with QuickBird satellite imagery can then be used to quantify different features of identified caves. Based on the partially existing fans of sediment in front of the carstic caves, potential locations of caves in the defined area could be discovered.

Keywords: NE-Morocco, prehistoric occupation, remote sensing, GIS, carstic caves, limestone, predictive models for site location, sediment fan

1 Introduction

The preservation of archaeological sites is determined by environmental change, such as natural erosion, as well as the effects of human land use. The Collaborative Research Centre (CRC) 806 was launched to investigate human occupation sites and nearby environmental archives in order to study the dispersal of anatomically modern humans from Africa into Europe, the characteristics of regional developments, and the triggers for occupation and migration. The areas where humans have settled are widespread, partly inaccessible and, even in a limited area like NE-Morocco, often difficult to evaluate. In light of this problem, cooperation with other disciplines must be aimed for. A preliminary investigation using remote sensing and geological information can reduce the area to be surveyed, and archaeological field work can be concentrated on more specific areas (Siart et al. 2008). In fact, a large amount of modern archaeological research is dependent upon the accurate documentation of the distribution of raw material sources, water supply and geological and topographic requirements in order to establish the existence of archaeological sites. Robust predictions to locate archaeological sites require a geological perspective combined with remote sensing data to attain a higher efficiency in discovering caves, i.e. potential archaeological sites. Integrating GIS provides an interface between remote sensing, geomorphology and Digital Elevation Model (DEM) analysis (Alexakis et al. 2011).

"Morocco is located at a triple junction between a continent (Africa), an ocean (the Atlantic) and an active plate collision zone (the Alpine belt system)" (Michard et al. 2008: 1). As such, the geology of the region shows a long history of very active tectonics and sea level changes. A huge percentage of Moroccan geology is comprised of different types of limestone deposited in the Miocene, Barremien, Jurassic, Cretaceous and Lias.

The caves we are looking for are secondary, endogenous formations which developed following the diagenesis of limestone. Through corrosion in karstic rock, karstic caves develop in the presence of water, which infiltrates

in fugues and dissolves the rock (Bögli 1978). The development of caves is characterized by erosion, corrosion and weathering. Especially, the entrance of the cave is affected by weathering. Therefore, the cave ceiling is exposed to gradual weathering and the entrance increases in height. The deposited detritus forms a fan in front of the entrance (Fig. 1).

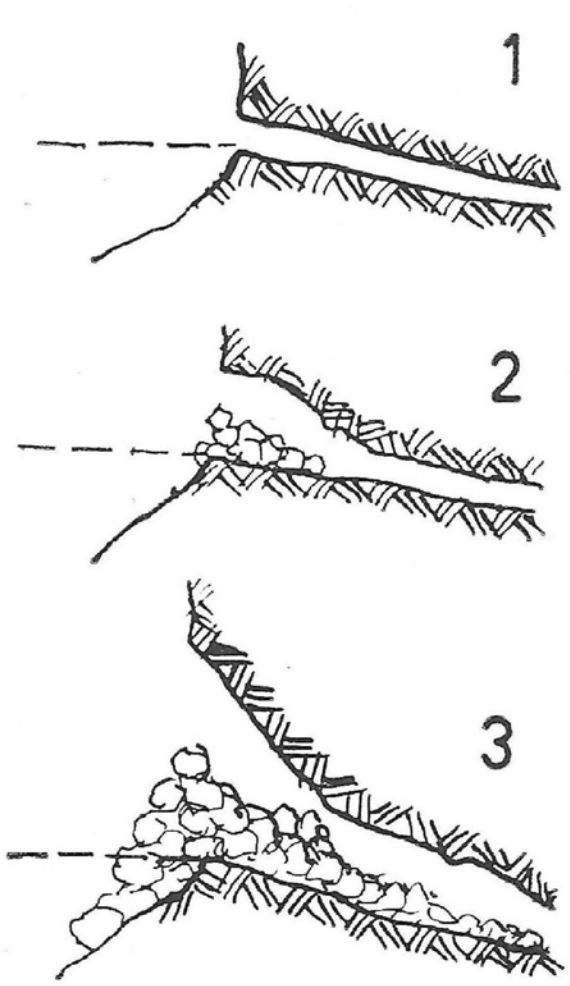


Fig. 1: Development of a cave entrance (Trimmel 1968)

The study area is located in north-eastern Morocco (Fig. 2). Geological and topographic maps show the coastal region of Morocco extending inland up to the Melilla peninsula. The topographic maps are available in the scale 1:50000 for the whole area under investigation (Fig. 3). The topographic maps include the regions of Nador, Taza, Ouida, Msoun, Mereda, El Agreb, Ain Zora, Saka, Melga el Ouidan, Driouch, Tistoutine, Taourirt, Mestigmer, Mechra Homadi, El Aioun, Hassi Berkane, Kebdani, Segangane, Kariat Arekmam, Melilla, Berkane, Martimprey du Kiss, Les Triffa and Saida du Kiss. For the topic of main interest, the geology, only the regions of Tistoutine, Segangane, Kebdani, Al Hoceima and Aknoul are obtainable in the scale 1:50000. The multispectral QuickBird2 satellite images have a resolution of 1.84 m to 2.44 m. The applied satellite images were taken of the region Kebdani (Fig. 4) on 2010-03-22, 2010-04-27, 2010-06-08 and 2010-08-26 (source of the QuickBird data: Digital Globe 2010a). The resolution of the multispectral Landsat ETM+ satellite images is 30 m. The images were taken on 2010-08-18 and 2010-08-26 (data source: GLCF 2010).

Remote sensing for archaeological surveys has become the routine in the course of the last 20 years, but today's high-resolution satellite images offer new perspectives (Scoller et al. 1990, Giardino 2010, Lasaponara & Masini 2011).

2 Archaeological Background

To reconstruct human settlement history or land use concepts of a region in prehistoric times, archaeological sites are the only source of information. These sites can be open-air locations or caves and rock shelters. Although cave sites were probably not the preferred location for settlement, a high percentage of open-air sites were probably exposed to natural erosion and human land use. Consequently, caves and rock shelters are almost the only places where prehistoric deposits are still preserved. Another advantage of cave sites is their relative stability. In general, they offer protection for several thousand years so that a single cave can contain deposits from very different periods (Fig. 4). Therefore, caves are also a highly

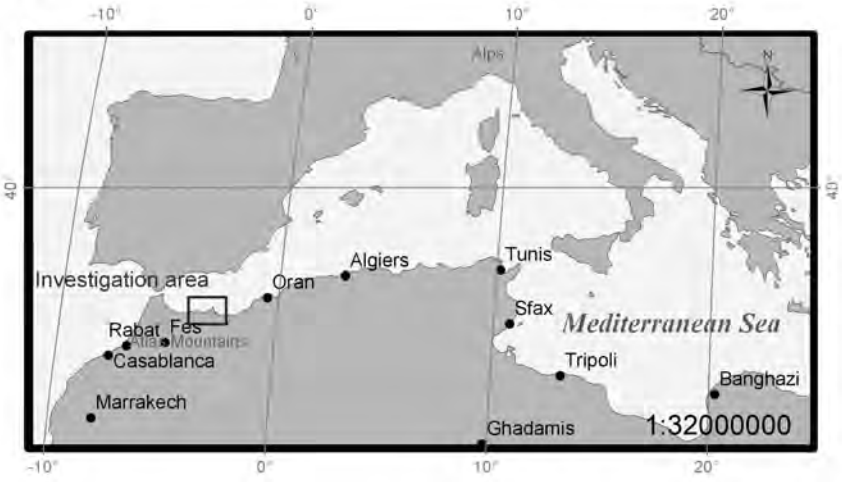


Fig. 2: Overview of Europe and the area under investigation (data source: ESRI)

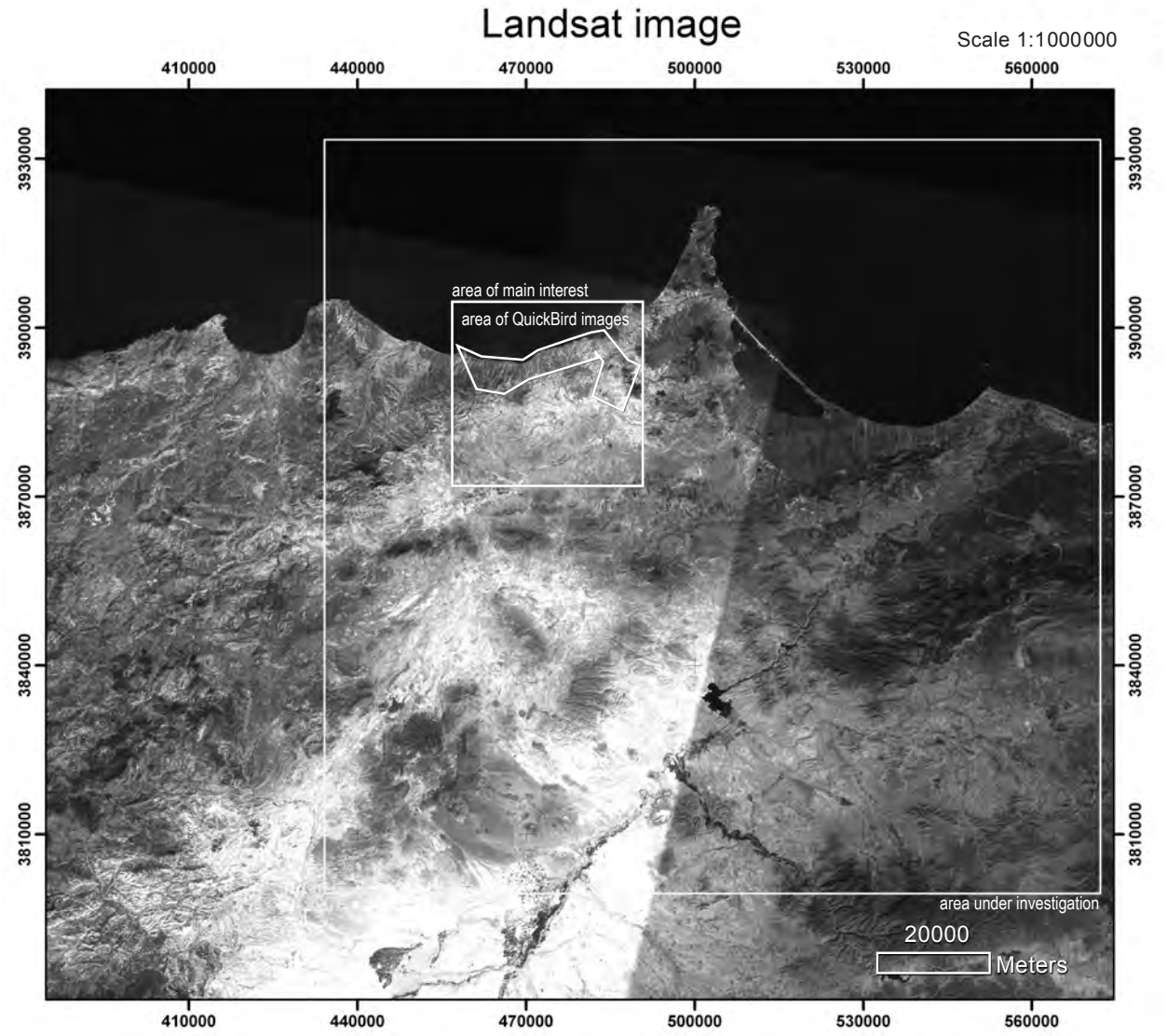


Fig. 3: Landsat satellite image of the area under investigation, area of main interest and area of QuickBird satellite image

Fig. 4: Ifri N'Sascha: This site was discovered in 2008 during an intensive survey conducted on foot. Height of the left rock shelter is about 5 m.

suitable location to study very interesting transitional phases, e.g. the Neolithisation of the Mediterranean Maghreb in the 8th millennium cal BP.

Systematic archaeological research of the Eastern Rif area south of the Melilla Peninsula was initiated in 1995 as a joint research project of the Institut National des Sciences de l'Archéologie et du Patrimoine (INSAP, Rabat), Morocco, the German Archaeological Institute (DAI, Bonn), Germany, and the University of Cologne, Germany (Moser 2003, Nami 2007). In the last 16 years of the project activities, a total of 378 sites have been discovered, covering a time span from the Lower Palaeolithic (Jebb 2008) up to the Islamic Period (Linstädter et al. 2011a). The sites include grave mounds, single finds, raw material sources and occupation sites in caves and rock shelters as well as open-air sites. Undisturbed and stratified deposits which are of particular interest for archaeologists, are rather rare. Epipalaeolithic and Early Neolithic sites are in the focus of recent research of the University of Cologne (CRC 806). Only twelve sites fulfil the latter mentioned conditions and show remarkable and relatively untouched deposits (Linstädter 2011).

On the base of these sites, a regional chronology of the Early to Mid Holocene could be reconstructed. The Epipalaeolithic culture of the Eastern Rif is clearly rooted in the foregoing Iberomaurusian of the Late Pleistocene. The Epipalaeolithic commences with the beginning of the Holocene at about 11000 cal BP (Linstädter 2008). As their typical lithic industry shows, these Epipalaeolithic hunter gatherers continue at least until the end of the 7th millennium cal BP (Linstädter 2004). In the mid of the 8th millennium cal BP, Neolithic pioneer groups reached the Mediterranean coast of modern day eastern Morocco (Linstädter 2010). These people brought with them domesticated animals and plant species as well as pottery. The pottery shows parallels to Early Neolithic ceramics from south-eastern Spain, indicating intercontinental contacts at that time. The indigenous populations seem to have adopted Neolithic innovations step by step, resulting in a Neolithisation of the interior which was not completed until the 6th millennium cal BP.

Of the twelve sites mentioned, four are open-air sites and eight are caves or rock shelters. Open-air sites are noted exclusively in the alluvial deposits of the Moulouya River (Linstädter et al. 2011b). In the up to 15 m high sections, these sites are weathered, exposed by lateral erosion of the modern Moulouya River (Ibouhouten et al. 2010). Not a single surface site comes from the area outside the Moulouya flood plain. Due to intensive wood cutting and grass farming in the last centuries, the slopes of the Eastern Rif are heavily eroded and potential sites have been washed away. Therefore, the cave sites and rock shelters are the most important data sources for prehistoric archaeology in the area, and for this reason they are in the focus of all survey activities.

3 Methods

Topographical and geological maps (1:50000), QuickBird images, and the locations of already discovered cave sites are the basis for GIS analyses with ArcGIS. To integrate all these data the following procedure was carried out:

a) First, topographical and geological maps were collected, superimposed and geo-referenced using the UTM WGS 1984 30N coordinate system. Topographical and geological maps are required without legends. Using the software Photoshop CS4, the maps were cut out and orientated. Without geo-referencing, the maps lack spatial location. The coordinate system can be chosen in the menu: View → Data Frame Properties → Register: Coordinate System → Select a coordinate system: Predefined → Projected Coordinate Systems → UTM → WGS 1984 → WGS 1984 Zone 30N. Using the tool Georeferencing, four points were plotted on the topographical and geological maps and control points (coordinate points) were set: Geo-referencing (Layer: topographical or geological maps) → Add Control Point → „Input X and Y". Landsat images can be used to control the coordinate points.

b) Limestone outcrops were digitized from geological maps. Due to the spatial extension of the limestone layers, these were processed as spatial information. A new shapefile was generated in ArcCatalog: Open ArcCatalog → File → New → Shapefile → Polygon shapefile with coordinate system (WGS 1984 Zone 30N) and filename (Limestone). Using the Editor–Tool, the layers of limestone were created as a polygonal surface: Editor Toolbar → Start Editing (Task → Create New Feature, Target: Limestone).

c) Archaeological sites were plotted and QuickBird images were added. The archaeological sites were digitized by creating a table in Microsoft Access, where sites in connection with Global Positioning System (GPS) coordinates were added and exported as a file. This file was added in ArcMap. The sites were plotted as point information. Where QuickBird

images and limestone outcrops overlapped, potential cave sites could be identified by sediment fans in front of the cave entrance. This was further simplified by using satellite images of already discovered sites as a reference (Fig. 5).

The plotting of the already known sites on the digitized limestone outcrops could be used as a test of our hypothesis, i.e. that cave sites occur exclusively within the outcrops. Only a few sites are located outside. Here, we suggest that mapping of the deposits is not accurate

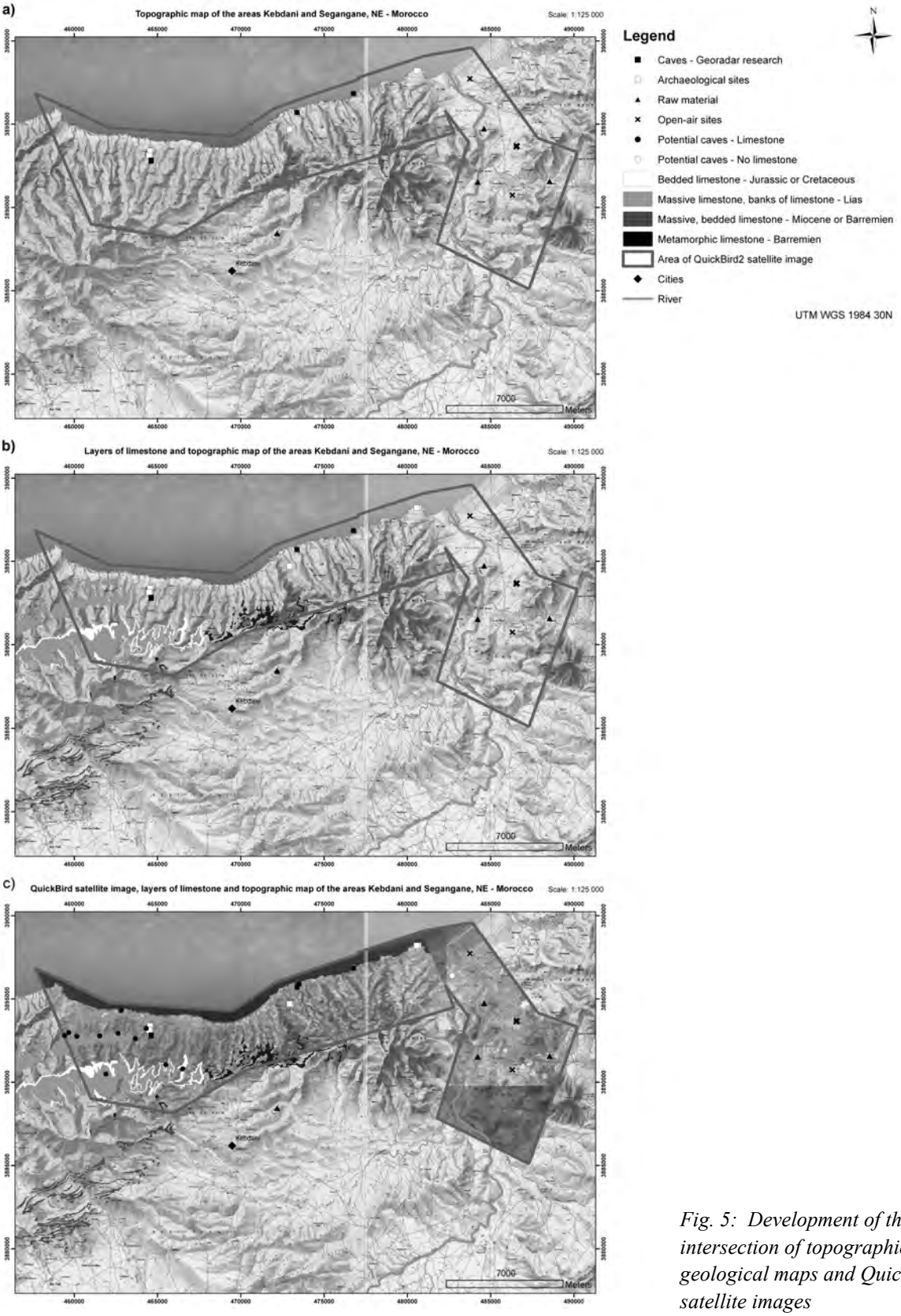


Fig. 5: Development of the intersection of topographic maps, geological maps and QuickBird satellite images

enough and further surveys are planned to substantiate this.

Finally, a DEM was created on the base of Shuttle Radar Topography Mission (SRTM) data (CGIAR-CSI 2010). With the help of GIS, watershed areas of rivers are generated. As a secured drinking water supply is crucial for any settlement site, the distance to a watercourse is an important factor for selecting a place to live.

4 Discussion and Results

Predictive modelling and definition of the survey area

With the help of the digitized geological maps the area where caves and rock shelters could have developed, i.e. their detection can be expected, was reduced considerably. The different limestone deposits cover only 5.5 % of the research area. Therefore the investigation area also decreased to 94.5 % of its former extent.

The distribution analysis of known sites

Three areas are differentiated in the geographical frame (Fig. 3): the area of investigation (see above), the area of main interest (ongoing archaeological surveys), and the area where QuickBird data is available. All analyses of known sites refer to the first area. A total of 74 cave sites have already been discovered here. The GIS analysis allows for a) information regarding different types of limestone; consequently we can verify whether caves and rock shelters can form in every type of limestone; and b) the information if caves and rock shelters are exclusively connected to limestone in general. In fact, 74 % are located within limestone deposits (Fig. 6). Due to the inaccuracy of the geological map (1:50000), it is likely that some, if not all, other sites are also located within limestone outcrops. This hypothesis can only be verified by further field work

Remote survey of potential cave sites

The 30 m resolution of the Landsat satellite images is too low for the detection of sediment, erosional or alluvial fans. However, the QuickBird resolution is already sufficient to detect fans of sediment, even if they show a low contrast in colour compared to the surrounding rocks. The approach is comparable to attempts done to detect ancient walls made of rock from in-situ deposits (de Laet et al. 2007).

In contrast, sediment fans of anthropogenic material are characterized by a high organic component and can be identified as grey to black deposits at the entrance of the cave. However, even these fans, which were degraded by erosion, are generally hard to identify. There are methods of computer-based detection of these contrasts by satellite sensors as used at the Sarasvati River, India, (Rajani & Rajawat 2010). However, a visual interpretation presents better results than automatic extraction techniques (de Laet et al. 2007).

In total, 13 potential caves were detected by the described method, all located in the area covered by QuickBird data. Almost all of these potential caves are located within limestone deposits and in close proximity to watercourses (Fig. 7).

Reconstruction of catchment areas

The resolution of SRTM-data is 90 m. Consequently, it was not possible to generate watershed areas for rivers by using GIS. This problem was previously addressed by Harrower (2010) who tried to generate the local hydrology in the Wadi Sana, Yemen. SRTM data are not

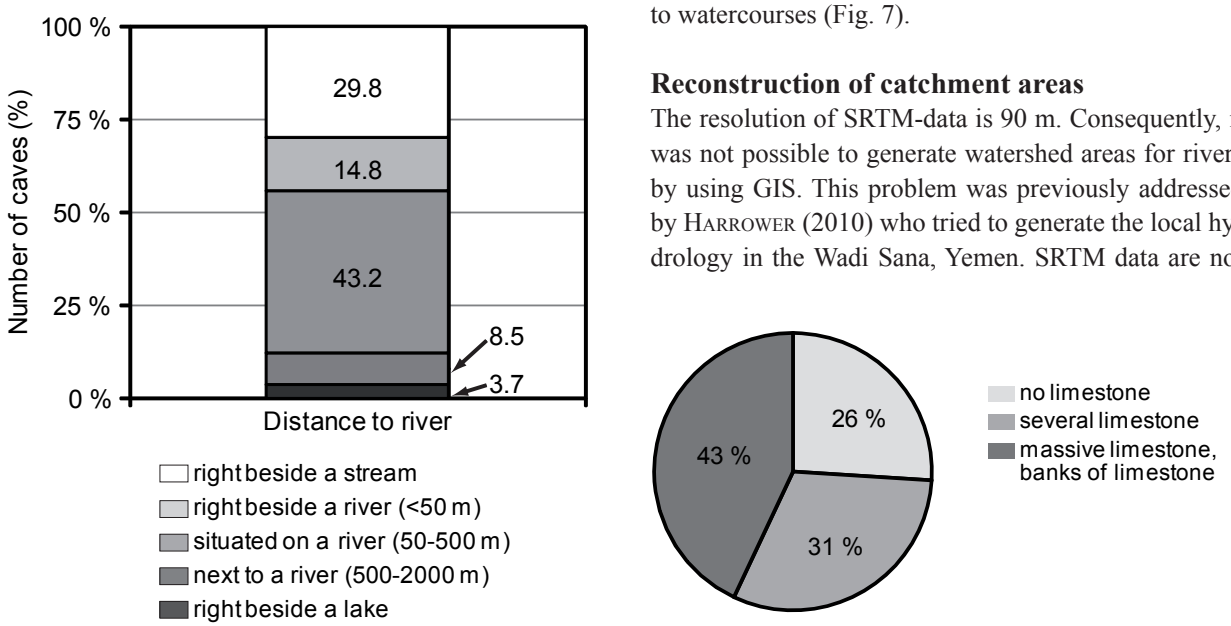


Fig. 6: Analysis of discovered caves: 1) The distance between the archaeological sites and rivers (left); 2) the relation between different types of limestone (right)

suitable for studying the location of settlements as a function of permanent access to drinking water.

However, the distance between an archaeological site and a stream could be determined by GIS. The majority of known caves lie at a distance of between 50 m and 500 m of the next watercourse. The reason for this spatial pattern might be related to the access to drinking water, but future work is needed on this topic.

5 Conclusions

Due to the combination of remote sensing and geological information, the extent of the survey area can be reduced considerably and the archaeological field work can be concentrated on specific areas. In total, 74 % of known caves and rock shelters are located within limestone deposits. Therefore the hypothesis that most of the caves are linked to layers of limestone was confirmed.

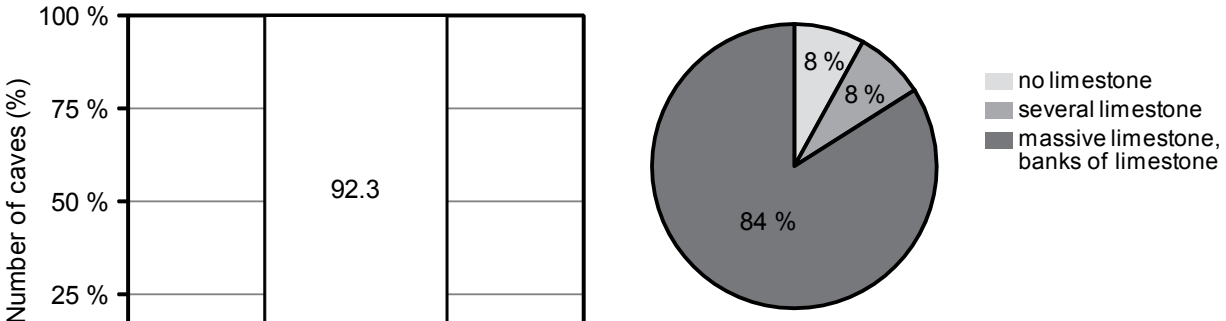
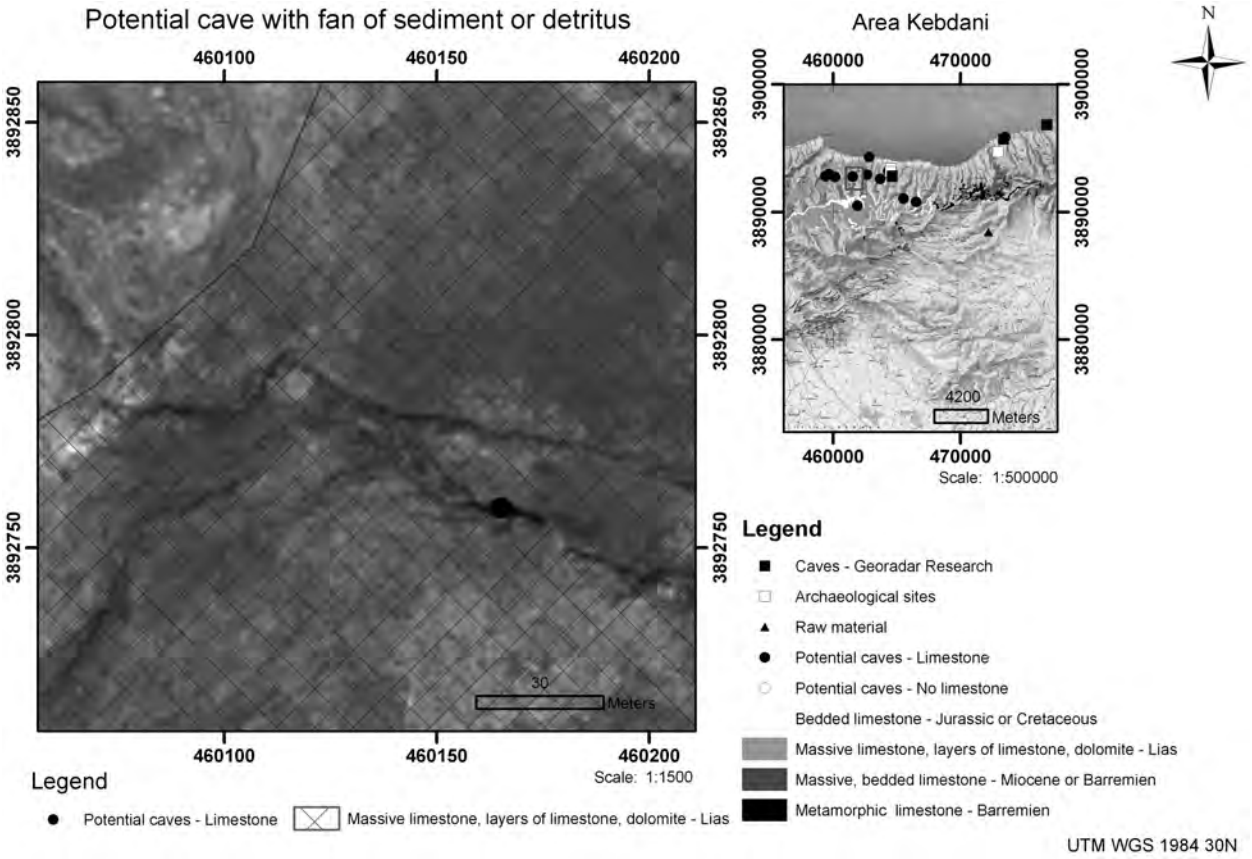


Fig. 7: Analysis of potential caves: 1) The distance between the potential caves and rivers (left); 2) the relation to different types of limestone (top)

Fig. 8: QuickBird satellite image of a potential cave (source: Digital Globe 2010b) (bottom)



Due to the inaccuracy of the geological map (1:50000), it is likely that the precise positions of determined cave sites still require some modification, i.e. caves may be in fact situated in nearby limestone outcrops.

The available QuickBird images were surveyed in order to find potential caves. The sites are characterized by a sediment fan or detritus, which is barely distinguishable from the in-situ soil (Fig. 8). In total, 13 potential sites could be identified and localized within the limestone outcrops and close to seasonal watercourses.

Catchment areas could not be modelled due to the insufficient resolution of the available SRTM data. Nevertheless, the distances between archaeological sites and watercourses could be determined showing a distance of 50 m to 500 m. The reason for this spatial pattern might be related to the access to drinking water.

Acknowledgements

We would like to express our gratitude to Andreas Bolten for his continual support and discussions. We also extend our thanks to Abdessalam Mikdad from INSAP (Institut National des Sciences de l'Archéologie et du Patrimoine) in Rabat, Morocco, and to Josef Eiwanger, DAI (Deutsches Archäologisches Institut), Bonn, Germany, for providing QuickBird images and site data.

References

Alexakis, D.; Sarris, A.; Astaras, T. and Albanakis, K. (2011): Integrated GIS, remote sensing and geomorphologic approaches for the reconstruction of the landscape habitation of Thessaly during the Neolithic period. Journal of Archaeological Science, 38(1), pp. 89-100.

Bögli, A. (1978): Karsthydrographie und physische Speläologie. Berlin.

CGIAR-CSI (2010): SRTM Data Selection Options. http://srtm.csi.cgiar.org/SELECTION/inputCoord.asp. 2010-08-26.

De Laet, V.; Paulissen, E. and Walekens, M. (2007): Methods for the extraction of archaeological features from very high-resolution Ikonos-2 remote sensing imagery, Hisar (southwest Turkey). Journal of Archaeological Science, 34(5), pp. 830-841.

Digital Globe (2010a): QuickBird2 images (2010-03-22, 2010-04-27, 2010-06-08 and 2010-08-26). http://www.digitalglobe.com. 2010-09-10.

Digital Globe (2010b): Basic satellite image. http://www.digitalglobe.com/index.php/48/Products?product_id=1. 2010-09-10.

Giardino, M.J. (2010): A history of NASA remote sensing contributions to archaeology. Journal of Archaeological Science, doi:10.1016/j.jas.2010.09.017, (in press).

GLCF (2010): Landsat imagery (2010-08-18 and 2010-08-26). http://glcf.umiacs.umd.edu/data/landsat/. 20100910.

Harrower, M.J. (2010): Geographic Information Systems (GIS) hydrological modelling in archaeology: an example from the origins of irrigation in Southwest Arabia (Yemen). Journal of Archaeology Science, 37(7), pp. 1447-1452.

Ibouhouten, H.; Zielhofer, C.; Mahjoubi, R.; Kamel, S.; Linstädter, J.; Mikdad, A.; Bussmann, J.; Werner, P.; Härtling, J.W. and Fenech, K. (2010): Archives alluviales holocènes et occupation humaine en Basse Moulouya (Maroc nord-oriental). Géomorphologie – Relief, Processus, Environnement, 1/2010, pp. 41-56.

Jebb, M.D. (2008): The Lower Paleolithic of northern Morocco: bifaces and other stone tools from the open air sites of Ammorene I and Ammorene II. Magister Artium Thesis. Eberhard-Karls Universität Tübingen, Tübingen, Germany.

Lasaponara, R. and Masini, N. (2011): Satellite Remote Sensing in Archaeology: past, present and future perspectives. Journal of Archaeological Science, doi:10.1016/j.jas.2011.02.002, (in press).

Linstädter, J. (2004): Zum Frühneolithikum des westlichen Mittelmeerraumes. Die Keramik der Fundstelle Hassi Ouenzga. Archäologisches Nachrichtenblatt, 9, pp. 205-209.

Linstädter, J. (2008): The Epipalaeolithic-Neolithic-Transition in the Mediterranean region of Northwest-Africa. Quartär, 55, pp. 41-62.

Linstädter, J. (2010): Recherches récentes sur les sites en grotte du Néolithique ancien dans l'Ouest marocain. In: Manen, C. et al. (eds.): Proceedings of Organisation et fonctionnement des premières sociétés paysannes – structure de production céramique. May 2007, Toulouse, France, pp. 227-235.

Linstädter, J. (2011): The Epipalaeolithic-Neolithic Transition in the Eastern Rif Mountains and the Lower Moulouya valley, Morocco. In: Juan F. Gibaja Bao, J. F., Carvalho, A. F.& N. F. Bicho (eds.): Proceedings of the work shop The last hunter-gatherers and the first farming communities in the south of the Iberian Peninsula and north of Morocco. November 2009, Faro, Potugal, pp. 89-100.

Linstädter, J.; Fili, A.; Amarir, A. and Mikdad, A. (2011a): Bouchih, un site almoravide sur la rive ouest de Moulouya (Rif oriental). Bulletin de l'Archéologie Marocain (in press).

Linstädter, J.; Aschrafi, M.; Ibouhouten, H.; Zielhofer, C.; Bussmann, J.; Deckers, K.; Müller-Sigmund, H. and Hutterer, R. (2011b): Flussarchäologie der

Moulouya-Hochflutebene, NO-Marokko. Madrider Mitteilungen, 52 (in press).

Michard, A.; Saddiqi, O.; Chalouan, A. and Frizon de Lamotte, D. (2008): Continental Evolution: The Geology of Morocco. Heidelberg.

Moser, J. (2003): La Grotte d´Ifri N´Ammar. Tome 1: L´Ibéromaurusien. Cologne.

Nami, M. (2007): Les techno-complexes ibéromaurusiens d´Ifri El Baroud (Rif Oriental, Maroc). Zeitschrift für Archäologie Außereuropäischer Kulturen, 2.

Rajani, M.B. and Rajawat, A.S. (2010): Potential of satellite based sensors for studying distribution of archaeological sites along palaeo channels: Harappan sites a case study. Journal of Archaeological Science, doi:10.1016/j.jas.2010.08.008, (in press).

Scoller, I.; Tabbagh, A.; Hesse, A. and Herzog, I. (1990): Archaeological Prospecting and Remote Sensing. Journal of Archaeological Science, 19(2), pp. 231-232.

Siart, C.; Eitel, B. and Panagiotopoulos, D. (2008): Investigation of past archaeological landscapes using remote sensing and GIS: a multi-method case study from Mount Ida, Crete. Journal of Archaeological Science, 35(11), pp. 2918-2926.

Trimmel, H. (1968): Höhlenkunde. Braunschweig.

Contact information
Anna Roeloffs
RWTH Aachen University
Institute of Neotectonics and Natural Hazards
Lochnerstrasse 4-20
D - 52056 Aachen
Germany
Anna.Roeloffs@rwth-aachen.de
+49 (0)241 80 95 722