Paleorelief detection and modelling – a case of study in eastern Languedoc (France)

OŠTIR Krištof,[1] NUNINGER Laure,[2]

[1] Scientific Research Centre of the Slovenian Academy of Sciences and Arts (Slovenia)
[2] Chrono-Ecology, UMR 6565 CNRS/University of Franche-Comté (France)

1 Introduction

The main objective of the paper is paleo digital elevation model (paleoDEM) detection and modelling, a multi-disciplinary approach involving geodesy, archaeology, and paleoenvironmental studies. The digital elevation model (DEM) is an important data layer to understand settlement pattern and socioenvironmental contexts and evolution that archaeologists are using together with GIS analysis. It can, for example help to analyze viewsheds, to define travel time between places, to simulate ancient paths, etc. Considering a period of several millennia, some topographical areas can be considered without fundamental change. Within littoral zones or fluvial areas, however, the situation is different. Sedimentation and erosion change the relief permanently, due to alluvial and sea level dynamic. A nowadays-flat area could be hilly in prehistoric times and the application of present DEM for the analysis is therefore unsuitable, since it would distort the expected result completely.

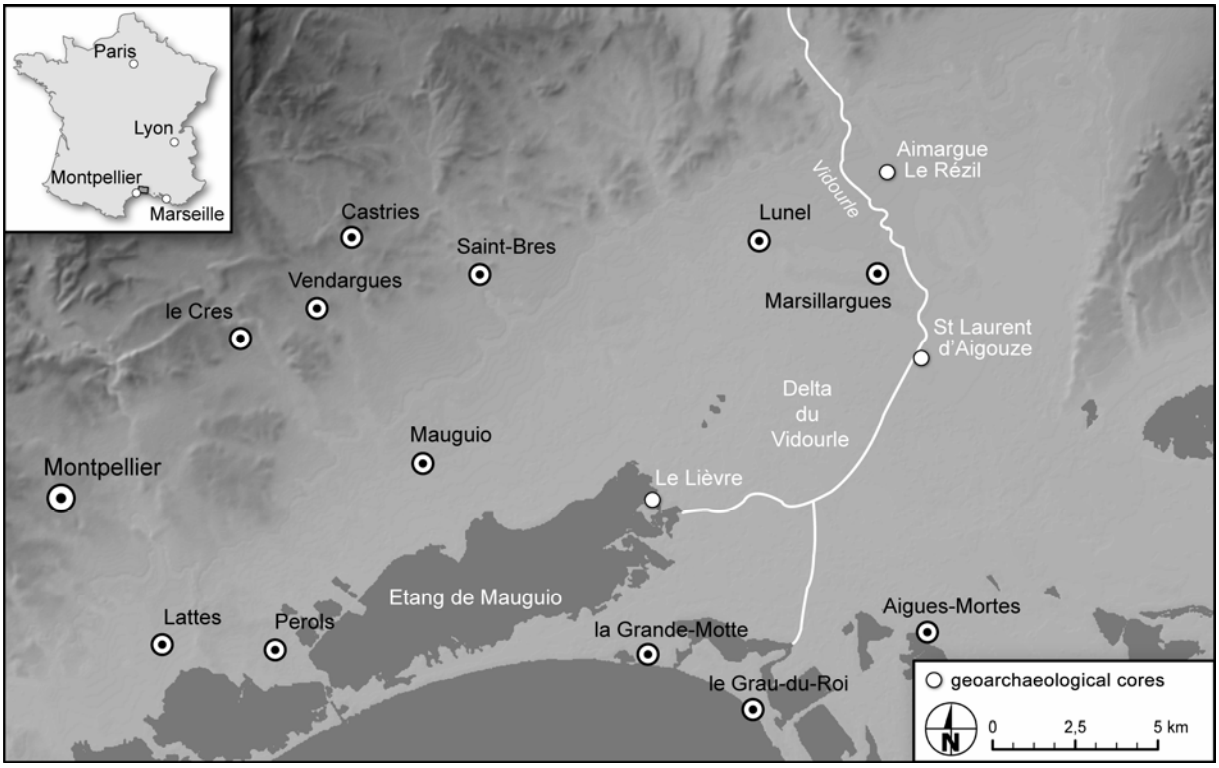

Fig. 1. Location of the study area.

Our case of study area is situated in Languedoc (France), on the littoral plain of Mauguio between the cities of Montpellier to the west and Nîmes to the north (Fig. 1). This area covers around 250 km^2. From an archaeological point of view, the zone is very well explored with almost 350 sites inhabited from Bronze Age to Middle Ages, showing also land division evidences obtained from aerial photo interpretation. In addition, in 1990s several geoarchaeological surveys were done in the main deltas of Lez and Vidourle rivers. Unfortunately the geo-archaeological coring, performed to understand paleochannel profiles in the Vidourle delta, is concentrated in three zones only. Considering a regional scale, only three average points could be used in further analyses. The geoarchaeological approach in itself brings indices about paleorelief but since the measurements are represented as points they are not adequate to produce a proper historical DEM. Additionally the approach is slow and relatively expensive. We have therefore used remote sensing, optical image processing and radar interferometry, in combination with spatial analysis to detect the paleorelief.

The first step was to create an accurate present DEM with a resolution suitable for analyses. Afterwards, the DEM, as well as SPOT and Landsat satellite images, was processed with several filtering techniques to detect "paleofeatures" – evidences of paleorelief. Features were digitalised and their spatial distribution was statistically tested according to archaeological data distribution. At last, we compared and tried to qualify the paleofeatures with the results obtained by photo-interpretation, classification and simulation.

2 Paleorelief interpretation

Existing technology does not allow a direct detection of paleorelief. Nevertheless, satellite imagery and current digital elevation models can be used to detect the "paleo-features" and to relate them to past relief.

The digital elevation model of the study area has been made as a combination (weighted sum) of all available sources (Podobnikar et al. 2000). Firstly, a DEM has been produced with radar interferometry (InSAR, Oštir et al. 2004) from two ERS radar images, acquired on 1996-04-04 and 1996-04-05. The images were acquired in tandem mode by ERS-1 and ERS-2 with a time difference of only one day. The coherence of the image pair is very high in the whole study area, with exception of water bodies (sea, rivers, channels, etc.). Interferometric processing produced a digital elevation model with a resolution of 25 m. The vertical accuracy of the relief is approximately 8 m and the positional accuracy is almost 5 m (one fifth of pixel size). The model has been only moderately filtered and prepared for combination with other DEMs.

Additionally the following DEMs were used: IGN DEM (with the resolution of 50 m, provided by IGN), Aster DEM (30 m, made from Aster stereo satellite images), SRTM DEM (90 m, produced with radar interferometry from the Shuttle Radar Topography Mission data). These models have different resolution and different coverage of the area: from ~60% for Aster to almost 100% for InSAR and SRTM (both are produced with interferometry and contain some areas with missing data) and complete for IGN. Standard deviations of all DEMs for the study area are less than 10 m (Table 1); Aster and InSAR are systematically higher because they include vegetation cover.

The final (combined) model is a weighted sum of partial models (Podobnikar et al. 2000). It takes the rough shape of IGN DEM and adds details of others, particularly InSAR. Its resolution is 25 m and it is very close to the control points (-0.2 m, standard deviation 3.7 m, Table 1, Fig. 1). The model is rather homogenous and could be used for further analysis and paleorelief interpretation.

Table 1. Statistical comparison of available DEMs and the final combined DEM

	Control points	IGN DEM 50	Aster DEM	SRTM DEM	InSAR DEM	Combined DEM
Number	110	110	67	108	105	110
Percentage	100%	100%	61%	98%	95%	100%
Average	81.4	80.9	82.4	81.6	90.0	81.2
Min Diff		-13	-13	-25	-15	-15
Max Diff		8	24	11	29	8
Average Diff		-0.5	9.1	-1.2	4.7	-0.2
StdDev Diff		3.7	8.4	5.0	7.8	3.7

Optical satellite images were an additional important interpretation source. A panchromatic image acquired by SPOT 4 in 1999-04-08 and a Landsat 7 ETM+ image from 2001-08-13 were used. Optical images (Landsat and SPOT) were enhanced prior interpretation. We have been trying to observe paleofeatures indirectly through detection of edges, particularly related to humidity and vegetation anomalies. Landsat with its seven bands gives much better spectral information than SPOT while SPOT has a better spatial resolution (SPOT 4 pan with 10 m resolution has been used only).

Simple and advanced edge detection has been performed, including Sobel and high-pass filtering supplemented with edge thresholding. Special attention has been given to filtering in the direction of the Sun to expose small variations in the direction of incidence radiation. The position of the Sun has been computed from the image acquisition time and the filter has been oriented in the selected direction.

To increase the spatial and preserve spectral resolution of Landsat resolution merge of panchromatic and selected multispectral channels has been performed (Švab and Oštir 2006). A similar procedure has been repeated with panchromatic SPOT and multispectral Landsat data. It has to be mentioned the huge difference between 15 m resolution of panchromatic Landsat and 10 m of SPOT. The latter is much sharper, what is probably the influence of different sensor types, simplifying the observation of anomalies.

The pre-processed DEM and satellite imagery enabled paleofeature delineation. Manual on screen digitalization has been performed and all possible features have been included. The following data has been mainly used to digitalize potential features (Fig. 2):

- panchromatic and edge filtered SPOT,
- multispectral and pan-sharpened Landsat, edge filtered panchromatic Landsat, and
- shaded and edge filtered combined DEM.

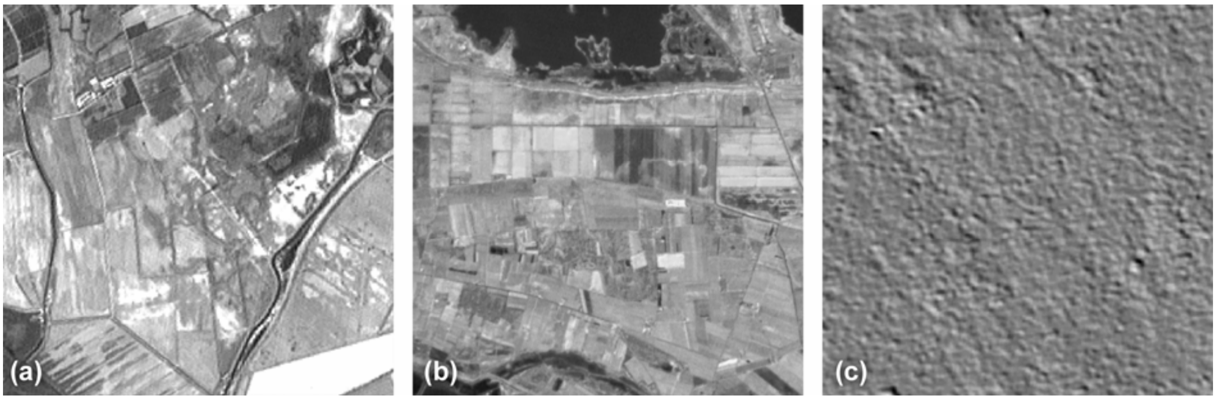

Fig. 2. Enhanced SPOT (a) and Landsat (b) satellite images were used together with DEM (c) to detect paleofeatures.

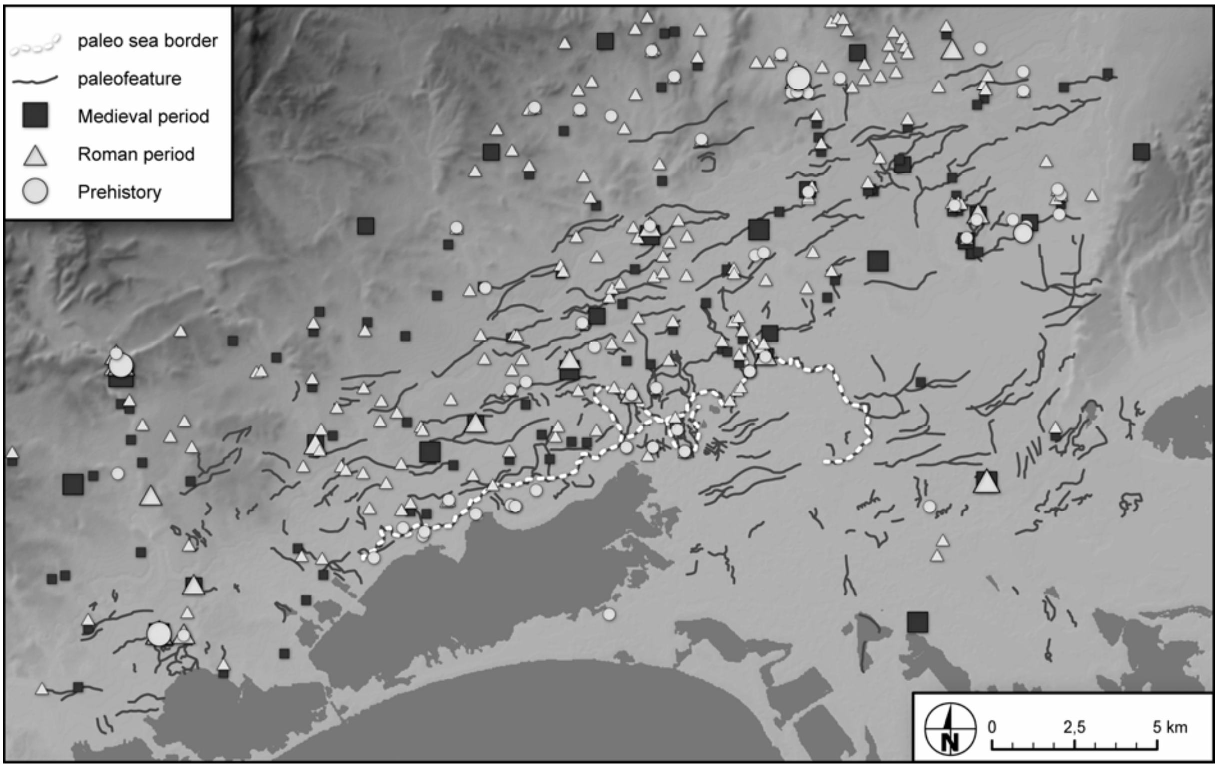

Fig. 3. Digitized and cleaned paleofetures are shown in relation to archaeological sites.

All possible anomalies have been considered and the features have been over-digitalized and later cleaned (Fig. 3). In the iterative procedure different images were used to digitize and recognize features. Maps in the scale 1:25.000 were used to verify all the vectors by eliminating existent relief characteristics (roads, buildings, etc.) and water courses (rivers, channels, etc.). SPOT and shaded combined DEM were most useful in feature delineation and all other layers were used only to update or check the results. Much better results are expected with a digital elevation model produced from lidar imaging (Challis 2006) that is scheduled for December 2006.

3 Thematical identification

To test if the detected paleofeatures can be linked to real paleorelief, an analysis of archaeological sites in the area has been performed (Fig. 3). The distribution of sites in relation to the features (buffer zones, site proximity analysis) has been observed for Prehistory, Roman period and medieval period. The sites were compared to random point distribution. For all known sites the distance from digitalized paleofeatures has been determined. Only sites that are less than certain distance (2.5 km) from the features have been considered. It has been statistically proven that the average distance of sites for all periods, especially for Prehistory, is smaller than for random points (Fig. 4a). For Prehistory the average distance is only approximately 450 m, while for random points it is more than 800 m, almost twice as large. One can also observe that the majority of the sites lie less then 500 m from the detected features (Fig. 4b).

(a)

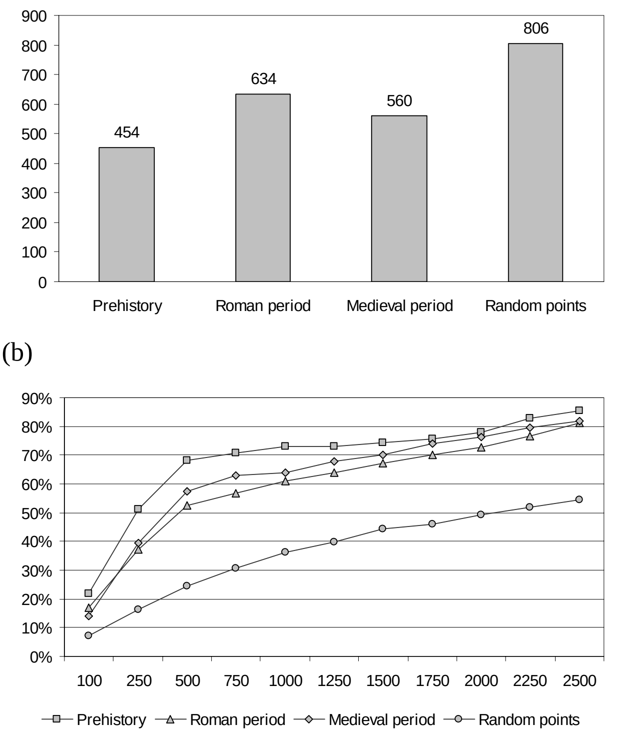

Fig. 4. Average distance to of archaeological sites to paleofeatures for different periods (a) and percentage of the sites within certain distance (b) compared with random points.

Despite of the connection between evidence of paleofeatures and archaeological sites, we do not know their exact nature. Three different approaches were performed to define types of paleofeatures. First, the digitized layer was overlaid with geology, pedology, cadastre with contour lines at 1 m interval, and historical aerial photography (from allied missions in 1944). By observation of small areas chosen as test sites, several paleofeatures were identified as paleochannels, edges of natural paleodepressions, ancient roads, terraces, dried valleys etc. Nevertheless, it was noticed that some of the features are still related to the artefacts observed on the IGN DEM (stages caused by contour line interpolation) and some features remain unresolved.

The second approach was related to paleocoastline or sea border (Fig. 3). To ascertain if any of the features can be interpreted as coastline, we used simulations taking into account geoarchaeological information. A small number of cores with an acceptable spatial distribution permitted the generation of a very basic model with an approximated subsiding of the alluvial floor (Nuninger and Oštir 2005). The result shows a rather good general connection and by adding archaeological sites distribution, we were able to notice a relation between chronology and local variation. In fact, reconstitution of paleo-shore during antiquity suggests that the sea-level was approximately 1 m above the present level. However, the archaeological site locations suggest less elevated paleo-shore which is better connected to detected paleofeatures. Even if the scale of layers is different, we have to consider the local variation of sea level, due to hydro sedimentary dynamics. Thus, features detected (Fig. 5) show two steps of shore evolution from Bronze Age to Antiquity. In this case, a shore seems to have moved back until Antiquity and Bronze Age settlements were probably under water during that time.

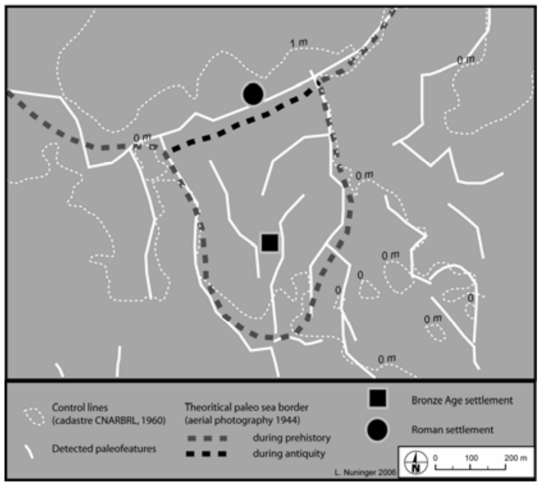

Fig. 5. Evolution of paleo sea border from Bronze Age to Antiquity

At last, in order to automatically classify the detected evidence of paleorelief, a multivariate analysis (factor analysis with classification[1]) was processed (Coulon 2006). First, the detected features were rasterised and filtered to delete each cells corresponding to DEM artificial stages and thus to avoid noise due to IGN DEM artefacts. Remaining cells were grouped as new entities (1020) according to neighbourhood and their thematic homogeneity (mostly soils). Then, each entity was described by several criteria:

- Archaeological density was calculated as kernel density taking into account duration of occupation (settlements). E.g. 1 settlement occupied during period 100 to 199 AD and period 200 to 299 AD counts as 2 occupations for density calculation.

- Compactness is a criteria linked to morphological shape of checked palaeorelief. Entities with strong compactness can reflect geomorphological types as depression, micro-reliefs (small hills). Entities with low compactness trend to show linear shapes as terrace, embankment, dried valley or road for example.
- Aspect is based on slope calculation. This criterion is important to detect entities linked to the general morphology of the littoral plain having a dip north-east / south-west.
- Soil types were grouped in 4 classes according to their age and potential accumulation. Recent alluvial soils, from flood plain of major streams, were isolated since they count almost no detected features. In addition, few features connected to this type of soil are probably due to artefact of DEM or imagery noise, recent sedimentation being very dip in such area.

The factor analysis results grouped the detected paleofeatures in 7 classes for 1020 entities. We will focus to the most significant only. In spite of containing dip 6% of all entities, class 1 is very interesting. It groups features with a strong archaeological density, a very strong compactness, a principal aspect to the east and a concentration on the oldest soils (61% “fersiallitiques”). Features from this class can be interpreted as micro-knoll with a high probability. Class 7 and 8 (14% and 6%) can be interpreted as class 1 with lower probability. On the contrary within class 6 (12%), one can observe a weak archaeological density (78% from null to mean value), a weak compactness (88%), principal aspect to north or north-east (67%) and most recent soils (70%). Features from this class are probably in connection with alluvial terrace or dried valley. At last, the class 5 (10%) is represented mostly by no archaeological occupation (82%), a very strong compactness (70%) and most recent soil (85%), especially soils with hydromorphological characteristics (41%). This class should bring together small depressions and paleomeanders.

The multivariate analysis is a first stage to sort automatically the detected paleofeatures. Nevertheless, such assumptions should be verified by control on the original data (IGN map, cadastre, aerial photograph) and in the field. Then, if the classification can be validated, criteria should be integrated directly within the process of detection.

4 Conclusions

With the case study we have proven that remote sensing can help in the detection of paleorelief. While it is not possible to detect past environment directly, several data layers – in our case most successfully the enhanced panchromatic SPOT 4 and the combined DEM – can be used to observe paleofeatures and to relate them to relief. The described approach will not replace precise work of archaeological and paleoenvironmental investigation, but can simplify the interpretation.

The results obtained present a first step and should be improved with further processing and additional data. The project will continue with advanced processing of high resolution satellite imagery and aerial photography. Furthermore, lidar scanning is scheduled to provide better elevation data in the flat areas.

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[1] The factor analysis and classification used are an « Analyse Factorielle des Correspondances - AFC » with a « Classification Ascendante Hiérarchique – CAH »