Medieval Territories

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Edited by

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AN APPROACH TO THE STUDY
OF MEDIEVAL TERRITORIES

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Territory is the result of human action on the natural landscape with the clear purpose to occupy and exploit it. That is why territory is configured by human cultural and technological action, contextualized in diverse historical periods. Human activity has remained fossilized in the territory, depending on its grade of intensity, in the shape of buildings, names, production spaces, communication infrastructures, cultural boundaries, etc. These elements make up the identity of early societies, a detailed stratification of artefacts and vestiges produced over a specific period in the past. This accumulation of technological experience and cultural transformation has persisted as a legacy. They are the historical memory of a human community.

Studying territory means studying the environmental context, which is why both elements are encompassed in the landscape. To find the pioneers in studies about territory from a geological and environmental perspective, we have to go back to the prehistoric archaeologists. The concept of stratigraphy, borrowed from geology, begins to be experimented with during the second half of the nineteenth century, amidst the consolidation of Positivism.[1] In Italy, the first scholars of prehistory were educated in from an environmental perspective, following in the footsteps of Giuseppe Scarabelli, whose research focused on artefacts manufactured in the Paleolithic and Neolithic periods.[2]

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[1] Charles Lyell, *The geological evidences of the Antiquity of Man* (Cambridge: Cambridge University Press, 2009) (first edition 1863).

[2] Giuseppe Scarabelli, "Intorno alle Armi antiche di pietra dura che sono state raccolte nell'imolese", *Nuovi annali delle scienze naturali e rendiconto delle sessioni della Società agraria, e dell'Accademia delle scienze dell'Istituto di Bologna*, 3/2 (1850), pp. 258-266.

Moving the chronological context forward from the late nineteenth century to the 1950s, we find an archaeological interest in the geology and geography of territories, especially influencing cartography and topography.[3] It was not until after World War II, mostly with the emergence of the New Archaeology,[4] that archaeology accepted the need to integrate the different scientific disciplines with frameworks related to the natural environment. This way, the archaeologist gains a new perspective on territory and, of course, on landscape, and begins to experiment with studies of paleoenvironment, archaeometrics, archaeobotany and archaeozoology. With this new experience, the basis for a new discipline, geoarchaeology, has been established. Its objectives are to rebuild the formative processes of archaeological stratification, in relation to the geomorphological and paleoclimatical aspects. Therefore, geoarchaeological studies are not an end in themselves, but a means to rebuild the history of humanity from a social and economic perspective through an approach to the natural environment.[5]

Simultaneously, archaeological geography focuses on the connection between the natural environment and production spaces, especially the agrarian. French geoarchaeology projects are headed in this direction, bringing new conceptual frameworks such as 'ecofact' and 'manufact'. This scientific framework of French historiography, which associates history to geography, has been seen in the avant-garde studies of rural history and, evidently, in the contribution of the *Annales* School, well represented by Febvre, Braudel and Le Roy Ladurie.

Environmental Archaeology has also been in the spotlight in the study of territory, particularly in Europe and the United States. As of the 1970s, this discipline gained importance together with geoarchaeology, as a result of the importance of recognizing the formations of human culture and the corresponding archaeological repository. To study territories occupied by groups of humans without getting to know the natural environment seems meaningless. Karl Butzer (1982) incorporates the concept of an ecosystem

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[3] We emphasise the studies of John L. Myers in the UK [John L. Myers, *Geographical History in Greek Lands* (Oxford: Clarendon Press, 1953)], and the studies of Emilio Sereni in Italy [Emilio Sereni, *Storia del paesaggio agrario italiano* (Bari: Laterza, 1961)].
[4] Nicola Terrenato, "New Archaeology", *Dizionario di archeologia*, ed. by Riccardo Francovich (Bari: Editori Laterza, 2007), pp. 204-206.
[5] Karl W. Butzer, *Archaeology as a human ecology: Method and theory for a contextual approach* (Cambridge: Cambridge University Press, 1982).

defined as the space where a group of living organisms interrelate and coexist. He also acknowledges the concept that 'human ecosystem' refers to the interdependence between cultural and environmental variables.[6] Currently, archaeological field research is developing towards understanding territory and the elements that form it. So, observation on a local level is reaching for a global view of the elements that explain how territory is organized and exploited. In this circumstance, geoarchaeology allows us to go beyond static analysis to decipher the distribution of artefacts.

Environmental archaeologists have been developing interesting contributions to the study of the configuration of territory, on the basis of paleoclimatic analysis. Climate, landscapes and inhabited areas are three closely related variables: in Mediterranean climate territories, populations settle in elevated lands, away from river courses, cliffs or torrents, to avoid floods that result from major storms, and to use sediments and water for irrigation afterwards. The indirect signs that allow us to rebuild past climates come from heterogeneous evidence, such as the growth rings of trees, pollen analysis, evolution of mollusks in terrestrial or marine contexts, and river sediments in their banks or deltas, among other factors.

The development of scientific disciplines for the study of territory that we have elucidated would not be possible without the application of field surveys, a set of techniques and implementations used to differentiate the elements that form a landscape (areas of production, settlements, and routes, among others).[7] The field survey is an essential instrument, although not the only one, for the reconstruction of past territories, visible or not, in the shape of cultural fossilized elements from the societies that created them. This work methodology is specifically related to Landscape Archaeology, the discipline which concerns itself with the study of territory from a more generic perspective or, in this case, a conceptual synonym, the landscape. This methodology offers a diachronic analytical point of view, an ideal perspective to understand the diverse historical and natural periods of the configuration of a territory or landscape. The work environment is the field itself, the places where history has manipulated natural elements and adapted them to every socio-economical context. The

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[6] Karl W. Butzer, *Archaeology as a human ecology* (Cambridge: Cambridge University Press, 1982).
[7] Franco Cambi and Nicola Terrenato, *Introduzione all'archeologia dei paesaggi* (Rome: Carocci, 1994); Colin Renfrew and Paul Bahn, *Archeologia. Teorie, metodi, pratica* (Bologna: Zanichelli, 1995).

field survey delves into history to detect those elements that give it identity and context.

In its most fundamental form, the field survey consists of a direct observation of a particular territorial space, in order to guarantee uniform and exhaustive coverage. These portions of land, which may coincide with croplands, are traversed by walking (field-walking) with the purpose of finding artefacts or other elements that allow the identification of archaeological sites or traces of past cultures. The typology of the field survey is developed in the project framework with an aim to finding non-visible remains of archaeological elements. However, field surveys can also be programmed with less intensive field work when the object of study has significant architectural elements on the surface, such as a medieval castle or monastery.

Without a doubt, the field survey must be supported by more studies that complete the archaeological field work. This is why it is important to ascertain the correct configuration of multidisciplinary teams, made up of historians of written sources, numismatists, geophysicists, anthropologists, ethnoanthropologists, etc. Archaeologists that work with sources obtained from aerial photography, satellite images[8] or remote sensing images deserve a special mention. It is unquestionable that remote sensing applied to field archaeology has experienced a huge qualitative improvement in the past few years. Experimentations with Lidar,[9] the widespread use of various Geographical Information System software, and new methods of quantitative and predictive archaeology[10] have opened new horizons for historical study and the appreciation of cultural heritage.

Studies on territory through landscape have experienced remarkable growth in the last decade, as a consequence of our society's interest in cultural landscapes. This interest is related to the higher social consciousness when facing present and future ecological challenges, and to the institutional support that stems from the European Landscape

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[8] Chris Musson, Rog Palmer and Stefano Campana, *In volo nel Passato: aerofotografía e cartografia archeologica* (Florence: All'Insegna del Giglio, 2005).

[9] *Topographic laser ranging and scanning: principles and processing*, ed. by Jie Shan and Charles K. Toth (Boca Raton: Chemical Rubber Company Press, 2008); *Interpreting archaeological topography*, ed. by Rachel Opitz and David Cowley (Oxford: Oxbow Books, 2013).

[10] Novelties in the field can be followed at the Computer Applications and Quantitative Methods in Archaeology annual conferences.

Convention of the Council of Europe, held in Florence in 2000.[11] Presently, we define 'landscape' as:

> *El trabajo humano el que crea los paisajes, al modificar la sucesión natural y mantener estados antrópicos intermedios convenientes y previsibles para los fines humanos. El paisaje es un algoritmo socioecológico. Sin intervención antrópica ni fines humanos no habría paisajes. Sólo ecosistemas.*[12]

Therefore, landscape is not defined by its natural agents: it is a socio-territorial reality. It ceases to be a natural landscape when it becomes a cultural landscape. History builds them through a long diachronic process over time. Its action has shaped territory in accordance with cultural needs:[13]

> *Los paisajes son esencialmente construcciones multidimensionales, resultado de la interacción de estructuras históricamente determinadas y de procesos contingentes. Como marco de la actividad humana y escenario de su vida social, el paisaje agrario, y los paisajes humanos en general, son una construcción histórica resultante de la interacción entre los factores bióticos y abióticos del medio natural. Cualquier interpretación histórica debe partir de la comprensión de esta dinámica. Es necesario, por tanto, que consideremos los paisajes como consecuencia de la coevolución socionatural a largo plazo.*[14]

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[11] *National Plan on Cultural Landscapes* ("Plan Nacional de Paisajes Culturales"). <http://www.mcu.es/patrimonio/MC/IPHE/PlanesNac/PlanPaisajes Culturales/PaisajesCulturales.html>, May 10th, 2017.

[12] "*Human work creates landscapes by modifying natural succession and maintaining anthropic intermediate states that are convenient and foreseeable for human ends. Landscape is a socio-ecological algorithm. Without anthropic intervention or human ends there would not be landscapes. Only ecosystems.*" (Enric Tello, "La formación histórica de los paisajes agrarios mediterráneos: una aproximación coevolutiva", *Historia Agraria*, 19 (1999), pp. 195-212).

[13] José Maria Martín Civantos, "Arqueología y recursos naturales", *Medio ambiente y arqueología medieval*, ed. by José María Martín Civantos (Granada: Alhulia, 2008), p. 26.

[14] "*In essence, landscapes are multidimensional constructions, a result of the interaction of historically determined structures and contingent processes. As a frame for human activity and the scenery for social life, the agrarian landscape, and human landscapes in general, are a historical construction, the product of the interaction between biotic and abiotic factors of the natural environment. Any historical interpretation must start with the understanding of these dynamics. Thus, it is necessary to consider landscapes as a consequence of long-term socio-natural coevolution.*" (Ramon Buixó, "Paisajes culturales y reconstrucción histórica de la

New perspectives on the study of territory imply changing theory and work methodology to increase the levels of complexity. These changes, already made during the development of field surveys, have been put into practice by Felipe Criado and the Landscape Archaeology research team from the University of Santiago de Compostela,[15] Almudena Orejas,[16] Gian Pietro Brogiolo from the University of Padua,[17] and Antonio Malpica from the University of Granada.[18] These proposals start with the idea that "*Human beings, unlike other living beings, do not only live in the environment, they also build their own environment to live or […] build their own socio-cultural environment*".[19] This trend is based on the concept of landscape proposed by Fernando González Bernáldez and mentioned by Enric Tello:

> *En tanto que construcción histórica el paisaje es como un palimpsesto que registra en el territorio las sucesivas huellas territoriales directas –y a una escala mayor, también la 'huella ecológica global- de las diversas sociedades que se han sucedido en el tiempo. Las formas y las escalas de tales huellas dependen de los flujos de energía y materiales extraídos, de los impactos y residuos resultantes de su procesamiento, y de la selección entre especies existentes o introducidas en el medio por la intervención humana voluntaria e involuntariamente.*[20]

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vegetación", *Ecosistemas. Revista científica y técnica de ecología y medio ambiente*, 1 (2006), p. 1).

[15] Felipe Criado, *Del terreno al espacio: Planteamientos y perspectivas para la Arqueología del Paisaje* (Corunna: Universidad de Santiago de Compostela, 1997).

[16] Almudena Orejas, "El estudio del paisaje: decisiones desde la arqueología", *Arqueología Espacial*, 19-20 (1998), pp. 9-20.

[17] Gian Pietro Brogiolo, "Dall'Archeologia dell'Architettura all'Archeologia della complessità", *Pyrenae: revista de prehistòria i antiguitat de la Mediterrània Occidental*, 38/1 (2007), pp. 7-38.

[18] Antonio Malpica, "El agua en al-Andalus. Un debate historiográfico y una propuesta de análisis", *V Semana de Estudios Medievales: Nájera, 1 al 15 de agosto de 1994* (Logroño: Instituto de Estudios Riojanos, 1995), p. 74.

[19] Felipe Criado, *Del terreno al espacio*, p. 5.

[20] "*As a historical construction, landscape is like a palimpsest that records in territory the successive, direct territorial traces – and, on a larger scale, the global ecological footprint as well – of the diverse societies that have succeeded each other through time. The shapes and scales of such traces depend on the energy flows and extracted materials, on the impact and waste that result from its processing, and on the selection among existent species or species introduced in the environment by human intervention, willingly and unwillingly.*" (Enric Tello,

Therefore, territory and landscape are understood as a synthesis of social relations, and to study them we must understand them from the viewpoint of a macro-scenery or an extensive archaeological site. According to José María Martín Civantos, "*esto quiere decir que ese paisaje puede ser conocido y comprendido a lo largo de los diversos períodos por los que ha pasado y que de él se puede extraer información acerca de las distintas formaciones sociales que fueron dejando su huella*".[21] Certainly, this is an approach to the study of territory from a diachronic perspective, and from a geographic standpoint that is, delimiting the framework on the basis of features of the natural environment. That way, we will understand the diverse phases of its construction according to the historical society of that time.

From this viewpoint, it is true to say that studies on territory and mountain landscapes have been furthered, primarily on the dry lands in the Mediterranean area. Due to their environmental traits, these lands require an epistemological approach that encompasses all the artefacts and anthropic transformations, analysed from a holistic standpoint. Therefore, the diverse elements that form them – villas, fortresses, towers, wells, canals, routes, places of worship and burial, mines, crop fields, etc. – must be differentiated for to be better studied, but without forgetting the natural environment as a whole; its presence reminds us that we are looking at an archaeological macro-site.

The fragility of dry lands, due to aridity and erosion, is an additional difficulty for historians. The settlements there do not always show long-term occupation, perhaps as a consequence of the climate and environmental features. In dry lands, water is key to guaranteeing the survival of human groups. However, some climatic fluctuations have consequences in meteorology right away, in the form of more extreme temperatures or in pluviometric variability (increased droughts, stormy rains, etc.).

It is also important to mention that, in the Mediterranean area, these territories have not undergone great morphological transformations, if we

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"La formación histórica de los paisajes agrarios mediterráneos: una aproximación coevolutiva", *Historia Agraria*, 19 (1999), p. 197.

[21] "*This means that landscapes can be known and understood through their diverse periods, and information about the different social formations that left their trace can be extracted from the landscape.*" (Jose María Martín Civantos, "Arqueología y recursos naturales", p. 30).

compare them with peri-urban agriculture. Even if historians cannot find large amounts of data, it is certain that the data they do find do not experience major changes, due to the action of mechanised agriculture or the introduction of new irrigation systems, for example. Therefore, dry lands, because of their extent and importance to understanding human evolution in the Mediterranean, must be protected and, above all, must be understood by scientific historiography.

The intensity of the work accomplished thus far has been contributing to the progress of medieval archaeology and the study of landscapes, which have progressed immensely since their early days. With the purpose of promoting the exchange and discussion of research from the perspective of medieval archaeology and territory, various researchers doing archaeological work on medieval territories gathered for the 5th International Medieval Meeting Lleida, held at the University of Lleida on June 25 and 26, 2015.

Their contributions were presented in specific sessions, such as the one organized by Carlo Citter, Antonio Porcheddu and Giovanna Pizziolo, 'Archaeological landscape evolution. Methods and applications I, II and III'; the sessions fostered by Juan Antonio Quirós, 'Social inequality in north-western Iberia: The archaeological markers' and 'The emergence of social complexity in Ebro villages'; '*Paisagens en mudança: cidades e territórios na Ida de Média*', organized by Raquel Martínez and Manuela Martins; and 'Primeros resultados de la necrópolis de Sant Joan de Caselles (Canillo, Andorra), organized by Albert Fortó. The conference also offered researchers the possibility of presenting their field work as free papers within the 'Archaeology' strand.

As an outcome of the sessions and papers presented individually at the 5th International Medieval Meeting Lleida, this book contains rich and interesting contributions on medieval territory from archaeological, historical, diachronic and transversal perspectives. The methodological developments in remote sensing exhibited by Antonio Porcheddu needed to be recorded after his study at the Ager Valley. Arianna Commodari presents the reconstruction of the past landscape of Pisa from Roman to Medieval times, from an archaeological viewpoint. Braga and its territory have been studied from a diachronic, multidisciplinary perspective by archaeologists Luís Fontes, Francisco Andrade, Raquel Martínez Peñín, and Manuela Martins. In addition, Mariña Bermúdez focuses on the study of the *Terrae* in Medieval Galicia through the thirteenth century. There are two further diachronic studies on the Sardinian territories of, Stintino and

Villanova Monteleone, carried out by Marta Diana and Rosanna Livesu, respectively. Juan Carlos García Cacho's research focuses on territory at monasteries and assemblies from Asturias and Leon in a specific chronology, through the years 860 to 999. Pau Turon presents a local study of Saint Esteve de Caulès and its environment from an archaeological perspective and the analysis of written documents. The multidisciplinary approach of Andrea Mariani contemplates analytical methods for the study of defensive architecture in the territory of the County of Milan. Catarina Almeida delves into the transition from the hermitage to the urban monastic building in Portugal and its effects in territory configuration. Pilgrimages were an alternative way to explore territory in the Middle Ages, hence the *Mudejar* routes between Castile and Mecca.

Territory continues to be seen from different perspectives, such as the one presented by Silvia Beltramo from friars in medieval towns in northern Italy. Changes in territory can also be of different kinds: Fabio Carminati and Andrea Mariani analyse the transition from ecclesiastical assets to private property in the Milan area in the fourteenth century. Marco Milanese, Maria Cherchi and Gianluigi Marras transport us to the study of the Sardinian medieval landscape from a multidisciplinary perspective, featuring new remote sensing techniques. Jesús A. de Inés Serrano studies territory from a local perspective, using Santillana as his starting point, between 1369 and 1445. Lastly, an urban analysis of Braga in the fourteenth and fifteenth centuries, is carried out by Maria Do Carmo Ribeiro, Manuela Martins, Fernanda Magalhães and Natália Botica.

The texts included in this book open new, innovative lines of research and suggest new methodologies for the study of the configuration of territory in diverse historical stages, and specifically in the Middle Ages, from their complexity.

Lidar for Landscape Archaeology: Detecting Archaeological Features in the Àger Valley[1]

Antonio Porcheddu
Universitat de Lleida

In 2014 the *Institut Cartografic i Geologic de Catalunya* ("Catalan Institute of Geology and Cartography") and the University of Lleida signed an agreement for the use of lidar data in archaeological research. The ICGC provided data from the Àger valley to be used as a test area for research on Landscape Archaeology. In the last fifteen years, lidar has become very useful for archaeological purposes because of the improving experience of researchers and better quality of data. This paper aims to assess the archaeological potential of the ICGC lidar data applied to some case studies of Landscape Archaeology in the Àger valley (Spain).

1. Lidar Principles and the ICGC Lidar Dataset

Lidar is a form of technology derived from laser scanners and is applied to a wide surface area, using an aircraft as a vector for the instrument. The acronym, Light (sometimes laser) Detection and Ranging, exposes that the main principle of lidar is to measure distances using precision light (laser). The distance is measured from the scanner to the hit surface using time and the angle of return of the echo of the emitted pulse.

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[1] Abbreviations used: ICGC, Institut Cartografic i Geologic de Catalunya; Lidar, Light, Detection and Ranging; GPS, Global Positioning System; IMU, Inertial Measurement Unit; DEM, Digital Elevation Models; DTM, Digital Terrain Model; DSM, Digital Surface Model; GIS, Geographic Information System; PCA, Principal Component Analysis; LRM, Local Relief Model; LiVT, Lidar Visualisation Toolbox; SVF, Sky View Factor.

Other parameters such as flying data (IMU) and GPS data are used to refine the correct position of each point.

The resulting points are stored as R^3 coordinates and constitute the so-called points cloud. By interpolating these points, it is possible to digitise some surfaces as Digital Elevations Models (DEM). The points can also be classified in order to correspond to an object of the real surface (buildings, low vegetation, high vegetation, etc.) and then filtered to retain the desired features. An important use of this property is to filter the vegetation in order to obtain the surface of the bare earth, the Digital Terrain Model (DTM).

The lidar data available from the Catalan Institute of Cartography and Geology were collected between 2008 and 2011 during the LIDARCAT project. This project started in 2006 with the objective being to scan the entire surface of Catalonia with lidar. As stated in a presentation in 2009, the ICGC processed the lidar point cloud in order to obtain precision but also to avoid huge time consuming procedures. This means that the low points were not revised, and they were classified without a manual classification.[2]

This kind of data was used by the ICGC for other research projects, in geography, geology, and environmental science, but this is the first time in Catalonia that the ICGC lidar has been used for archaeological purposes.[3]

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[2] The entire procedure of the data processing of the lidar point cloud performed by the ICGC is published on the official web page of the institution, and the document is downloadable at the following URL:
<http://www.icc.cat/content/download/9800/31328/file/disponibilitat_dades_lidar.pdf>

[3] Antonio Ruiz, "Aportación del lídar aerotransportado al cálculo de cambios en las playas tras temporales", *Revista Catalana de Geografia*, 14/37 (2009), pp. 54-61; Marc Coromines, Antonio Ruiz and Ester Blanco, "Aplicación de la tecnología lidar al estudio de la cubierta vegetal", *Cuadernos de la Sociedad Española de Ciencias Forestales*, 19 (2005), pp. 71-77; Antonio Ruiz, Oriol Viñas, Albert Domingo and Valentí Marco, "Tree Species Classification from Aerial Images and Lidar in Agricultural Areas",
<https://www.researchgate.net/publication/236329615_TREE_SPECIES_CLASSIFICATION_FROM_AERIAL_IMAGES_AND_LIDAR_IN_AGRICULTURAL_AREAS>, 15th March 2015.

Figure 1. The ICGC aircraft used with the lidar installed on board (photo from www.icgc.cat)

2. Lidar in Archaeology

Researchers in Archaeology consider lidar as one of the most useful tools for archaeological prospection in the present day, which is demonstrated by the growing number of publications and projects related to it.[4] Even though very effective techniques, such as geophysics, exist and can generate extremely precise results in the prospections of archaeological sites, lidar is the perfect tool for surveying large areas, which is why it has become essential for Landscape Archaeology. In particular, what has made it so popular for archaeologists is the ability to derive a reliable high resolution digital terrain model from the point cloud. This means that, by classification and filtering processes from the point cloud, it is possible to separate different objects of the landscape and to retain the desirable ones. In this case, archaeologists are interested in the surface of the terrain because here it is possible to detect archaeological features, especially in those areas where other sources of data are less useful, such as aerial photography of a forested landscape. Lidar allows a DTM of the surface under the vegetation canopy to be generated, thanks to a number of points that hit the terrain. This fact is one of the most important achievements of lidar for archaeology: for the first time it has

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[4] As lidar is becoming more and more accessible to researchers, they are increasingly using it to support their research throughout the world. Some of the most important projects are in the United Kingdom, where Historic England uses lidar to support the Heritage List project.
(https://historicengland.org.uk/research/approaches/research-methods/airborne-remote-sensing/lidar/). For a general review of lidar's use in archaeology see: Rachel Opitz and David Cowley, *Interpreting archaeological topography: 3D data, visualisation and observation* (Oxford: Oxbow Books, 2013).

been possible to remove the vegetation canopy and to discover dozens of new archaeological evidences.

Another useful characteristic of lidar-derived digital terrain models is the precision in determining altitude variations. This means that it is possible to determine micro relief variations that often may hide features of archaeological interest. For example, fossil agrarian parcels, remains of roads or buildings and little motte-and-bailey castles.[5]

3. The General Study Area and the Test Areas

The choice of the Àger study area was based on research interests. The *Consolidated Medieval Studies Research Group* of the University of Lleida exhibited a strong interest in this area, carrying out several research tasks. In particular, these included developed studies on the Middle Ages period based in documental history, art history, architecture, archaeological excavations and prospections.[6] This last subject is the one in which lidar data is supposed to contribute the most.

The Àger valley is an area of barely 50 square kilometres located in the pre-Pyrenees to the north of Lleida. It is surrounded to the north and south by middle-altitude mountains (the Montsec and the Montclús). The east and west sides are delimited by two rivers, the Noguera Pallaresa and the

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[5] Benoît Sittler and Sabine Schellberg, "The Potential of LIDAR in Assessing Elements of Cultural Heritage Hidden Under Woodland Canopies. Possibilities and Limits in Detecting Microrelief Structures for Archaeological Surveys", *From Space to Place. 2nd International Conference on Remote Sensing in Archaeology*, ed. by Stefano Campana (Oxford: British Archaeology Reports, 2006), pp. 4-7; Rosa Lasaponara and Nicola Masini, "On the processing of aerial LiDAR data for supporting enhancement, interpretation and mapping of archaeological features", *Computational Science and Its Applications*, ed. by Beniamino Murgante, Osvaldo Gervasi, Andrés Iglesias, David Taniar and Bernardy O. Apduhan (Berlin: Springer, 2011), pp. 392-406.
[6] Francesc Fité, *Reculls d'història de la Vall d'Ager. Període Antic i Medieval* (Àger: Centre d'Estudis de la Vall d'Àger, 1985); Flocel Sabaté, "Las tierras nuevas en los condados del nordeste peninsular (siglos X-XII)" *Studia historica. Historia medieval*, 23 (2005), pp. 139-170; Antonio Porcheddu, "Predicting and Postdicting a Roman Road in the Pre-pyrenees Area of Lleida (Spain)", *CAA2015 KEEP THE REVOLUTION GOING, Proceedings of the 43rd Annual Conference on Computer Applications and Quantitative Methods in Archaeology*, ed. by Stefano Campana, Roberto Scopigno, Gabriella Carpentiero and Marianna Cirillo (Oxford: Archaeopress, 2006) pp. 599-604.

Noguera Ribagorçana. The entire area presents a huge variability in both vegetation canopy and orography that makes it interesting to test and compare the results over areas of different characteristics (plain, highly steeped, densely and scarcely vegetated areas).

The first test area is a little monticule near the medieval tower Torre dels Moros or Masos de Millà, a village south-east of Àger. There, some circles are visible from the aerial photograph. The main aim is to evaluate if lidar could help us to understand the nature of these circles better. From the aerial view they appear as crop marks, but no more information can be obtained about their relief. The second test area is a flat open area near the village of Àger, where we would like to test the level of precision of the data to enhance micro relief features. This area is characterized by agrarian fields with division marks consisting of secondary roads, trenches and hedges. The third area is a heavily wooded, uncultivated slope, located on the southern face of the Montsec. In this area, we would like to understand by which measures our data can visualize the terrain under the vegetation canopy and what features can be mapped. It is important to take this into consideration when extracting a DTM from a densely vegetated area, as there could be much less data than in the case of a flat open area. The fourth example is located in uplands near the village of Millà. It is a stark area with very little vegetation and a rugged surface. This is an example of where the DTM is almost a DSM, so the classification and the filtering of the points have little influence on the result. The fifth test is over the medieval village of Montlleó, which is located on a hill near the Port d'Àger. We want to try to visualize the topography of the abandoned settlement, in which only the church remains in a good condition.

4. Work Methodology

The methodology used in this study is based on a series of steps that involve data processing and analysis. The ICGC, provider of the data, performed the pre-processing of the point cloud, classifying, filtering and interpolating the points to obtain the DTM. The DTM is the main product with which the archaeologist works. In recent decades, dozens of publications have explained how to obtain the best ways of processing the DTM to enhance the visibility of features on its surface.[7] For

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[7] For a general comprehension see: Rachel Opitz and David Cowley, *Interpreting archaeological topography: 3D data, visualisation and observation* (Oxford: Oxbow Books, 2013).

archaeologists the main target is to make the DTM as 'readable' as possible to facilitate the detection of every detail that could reveal some feature of interest. In order to achieve this objective, archaeologists work with basic and advanced algorithms applied to a raster surface. Some of these applications are used in this study to test the potential of the ICGC's DTM and are described below.

All the operations performed for this work were executed with GRASS-GIS software, release 7.0.3. It is free, open source software that disposes of all the modules to obtain the raster manipulations described below.[8]

5. Analytical Hill Shading

This is the most basic technique to enhance the visibility of a DEM. In fact, a raster DEM is a surface that is normally displayed with a palette of colours based on the value of each pixel. The value of the pixel represents its altitude. Normally this kind of visualization does not have a good level of realism and makes it difficult to distinguish the objects represented. The Hill Shading or Shaded Relief is an algorithm that simulates the presence of a light source that illuminates the surface directly, creating brighter and darker areas. The result is a more plastic surface due to the shadows created around the objects, which depend on the incident angle of the light. The GIS used to perform this algorithm has a pre-implemented script that, by selecting various parameters, generates the raster's hill shading. In particular, it is important to modify the angles of incidence and the direction of the light source to create different illuminated scenarios. Indeed, the visibility feature depends on the direction of the light: if the light is parallel to the object, then it will not create a shadow and it will not be visible; conversely, a transversal light will enhance the plasticity of a feature and create a shadow. Thanks to the software, it is also possible to create some unrealistic scenarios, such as making the sunlight come from the north and creating a reversed surface with depression perceived as relief. This technique is useful for plane surfaces with oblique light, which permits the enhancement of the micro relief. It becomes clear, though, that the global visualization of the terrain is a disadvantage. Indeed, to have a

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[8] Geographic Resources Analysis Support System (GRASS) is released under a GNU GPL (General Public License). The modules used for the image processing of DTM in this work are: r.relief, r.slope.aspect, r.shaded.pca, r.local.relief, r.skyview. Some of these are installed on the official release and others can be downloaded through the official page of add-ons for GRASS GIS.

general idea of what could be visible on the surface, it is necessary to continuously change the light angle, generating multiple shaded relief images. This could be a time consuming process and cause confusion. The Principal Component Analysis has been proposed to avoid this problem.

6. Principal Component Analysis

The principal component analysis (PCA) applied to a DEM surface is a reaction to the problems that occurs when working with the analytical hill shading. Its aim is to obtain a unique raster image composed of three images, in which the maximum quantities of features, which are otherwise only visible through several hill-shading images, can be seen. The proposal made by Devereux in 2008 starts with16 hill shaded images from 16 different positions of the light source.[9] The information contained in the 16 images is rearranged in 16 new images in such a way that the maximum amount of information is stored in the minimum number of images. In this way, the three first images usually contain 95% of the information and the remaining 5% is in the other 13 images. Thanks to this, when combining the first three images, it is possible to visualize the majority of features illuminated by 16 different angles.

As stated in the official online manual of GRASS GIS, the *r.shaded.pca* creates relief shades from various directions and combines them into RGB composition. The combined shades highlight terrain features which wouldn't be visible using standard shading technique.[10]

7. Slope

The Slope is another basic analysis that can be made on a DTM surface and that could be useful for visualization. It represents the incline percentage or degree of the surface. Mathematically it can be expressed as the derivative of elevation because it represents the rate of change between a cell and its neighbours. High values of slope represent a steep surface and usually, in greyscale visualizations, are shown as darker. Low values of slope represent a flat surface that is shown as brighter.

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[9] Bernard Devereux, Gabriel Amable and Peter Crow, "Visualisation of LiDAR terrain models for archaeological feature detection", *Antiquity*, 82/316 (2008), pp. 470-479.

[10] <https://grass.osgeo.org/grass70/manuals/addons/r.shaded.pca.html>. 15th March 2015.

All GIS software can perform this basic but very useful analysis. In our aims of improving visualization of features, it can be useful to apply this kind of algorithm. The important thing to keep in mind is that the visualized surface is not the real surface but a representation of the slope rate of change, so it has to be interpreted to avoid misunderstanding.

8. Openness and Sky View Factor

The openness is based on the concept of diffuse light, an illumination from every point in the scene. This technique was presented in 2002 for the visualization of digital terrain models.[11] To understand how this algorithm works it is necessary to deal with some trigonometric calculus. There are a few main steps that have to be made to obtain an image of this kind. It starts with the computation of all the elevation angles between point A and point B over direction D at distance L. Using Pythagoras' theorem it is possible to obtain the projected horizontal distance between points A and B. Then the elevation angle is the arctangent of the ratio between the elevation difference and the horizontal distance. For every direction at distance L from the point, there exists a maximum and minimum elevation angle (zenith and nadir). The surface is created by dividing the arc length (360º) in 8 parts and calculating and computing, the zenith and nadir angles for every direction from the selected point and then computing the medium value. In the author's words "the resulting maps of openness superficially resemble digital images of shaded relief or slope angle, but emphasize dominant surface concavities and convexities".[12] The results are determined by the parameters selected during computation, in particular the radius of application of the semi sphere and the number of directions.

The Sky View Factor is a similar technique that was proposed for archaeological purposes in 2011 by a Slovenian research group.[13] The illumination of the surface comes from a semi sphere that creates a diffuse illumination and represents the sky over the surface. The semi sphere is centred on the illuminated point. Assuming that a) the light intensity in the

[11] Ryuzo Yokoyama, Michio Shirasawa and Richard J. Pike, "Visualizing topography by openness: a new application of image processing to digital elevation models", *Photogrammetric engineering and remote sensing*, 68/3 (2002), pp. 257-266.

[12] Yokoyama, Shirasawa and Pike, "Visualizing topography by openness", p. 257.

[13] Klemen Zakšek, Kristof Oštir and Žiga Kokalj, "Sky-view factor as a relief visualization technique", *Remote Sensing*, 3/2 (2011), pp. 398-415.

semi sphere is constant and b) excluding the effect of the earth curvature for small surfaces, it is possible to compute the quantity of visible sky from a point as follows:

$$s = 1 - \frac{\sum_{i=1}^{n} \sin \gamma_i}{n}$$

In this formula, n denotes the number of directions and γ the elevation angle of the horizon. The values of s, the visible sky, are in the interval [0, 1]. Value 1 means that the entire sky is visible from that point. Then, this value is used to determine the intensity of the greyscale of the pixel in order to enhance the morphology of the surface. As with the openness, this algorithm enhances the micro relief and the concavities, but the visualization is more realistic than the openness. The important parameters are again the number of directions (between 8 and 32) and the dimension of the radius, which depends on data resolution.

Because these two techniques are similar and the second is derived from the first, we applied only the Sky View Factor using the module developed for GRASS GIS *r.skyview*.

9. Local Relief Model

The Local Relief Model (LRM) "represents local, small-scale elevation differences after removing the large-scale landscape forms from the data".[14] This method, as described by its creator Ralf Hesse, is based on applying the technique of Trend Removal to enhance variations over the earth's surface. Trend Removal is a statistical principle in which the data trend is removed and the residual data are retained. The larger objects in the landscape represent the trend while the residual objects are the little differences in elevation. The algorithms consist of several steps that can be summarised as follows:

- The application of a smoothing filter to obtain a more homogeneous surface.
- A process of map algebra subtracting the new smoothed image from the original one.
- The improvement of the raw LRM by enhancing contours.

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[14] Ralf Hesse, "LiDAR-derived Local Relief Models–a new tool for archaeological prospection", *Archaeological Prospection*, 17/2 (2010), pp. 67-72.

This algorithm is implemented in Ralph Hesse's LiVT open source software for lidar data manipulation and also in GRASS GIS with the add-on *r.local.relief*. The image that is obtained is not easy to read but can enhance the shapes of the features on the surface very well.

10. Results

10.1. Area 1. *Torre dels Moros*

Thanks to the aerial photograph it was possible to perceive some concentric circles as crop marks in the field named *lo Bosc of Joanet*. The place name indicates a wooden area that has since disappeared. Thanks to the historical aerial photograph of 1946 it was possible to visualize the wood and some circular terraces. By observing the photographs we could interpret the topography and the geomorphology, thinking that the central part of the wood was at the higher height and the concentric terraces gradually descended to lower heights. Obviously we are in front of anthropic features but the actual topography cannot justify the morphology of these features. Indeed, from a lidar-derived DTM, we can see a different scene. As expected the medieval tower is placed at the highest point, dominating its surroundings. At the same time, just by calculating a profile from the DTM, it is easy to see that from the tower there is a constant descending altitude. So what we supposed to be a central high location is actually at an intermediate quota. In addition the concentric circular features are not positioned at the same level. At this point it is not possible to justify the field pattern as an adaptation to the topography. In addition the survey showed that the micro relief is only perceivable from the DTM and revealed the presence of a consistent amount of stones. In any case, no pottery or other micro-evidences of human activities were found during the survey because of the scarce ground visibility. This example showed that lidar gave an effective contribution to understanding the place's topography and opened new questions that are necessary to answer in order to understand the choice of this arrangement.

The dimensions, the shape and the location, with the available natural resources, bring to mind a typology of protohistoric settlement such as the Iberian settlement at Vilars d'Arbeca. Obviously at this time it is not possible to support this conjecture at all, even if it is clear that this area is a strategic place for a settlement. Only more intensive surveys will clarify the nature of these shapes.
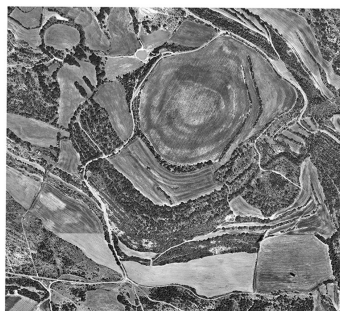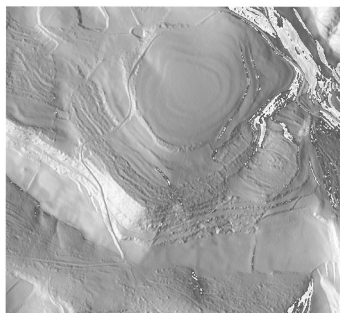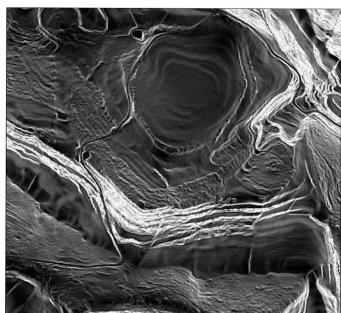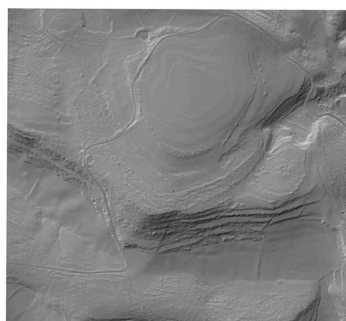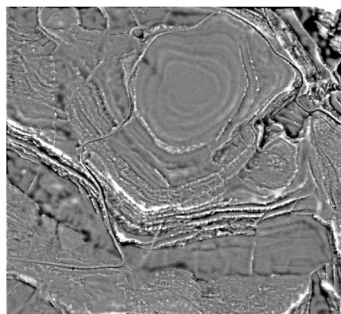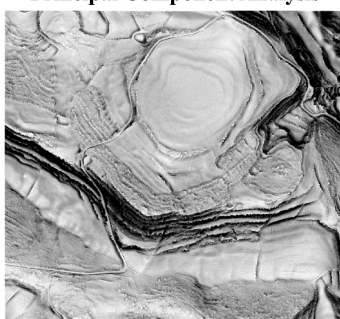
Aerial Photograph

Hill Shade

Slope

Principal Component Analysis

Local Relief Model

Sky View Factor

Figure 2. Area 1. Tower of Masos (by the Author)

10.2. Area 2. The Plain of Àger

This area was chosen to test the potential of the DEM on a plain. It is very important to enhance the micro relief of plains in order to obtain the maximum level of detail from the resolution of the raster. Using the image

processing techniques described above, we could enhance some details of the ICGC lidar DTM to observe the shape of agrarian divisions, the system of roads, some features of micro relief and some fossil parcels.

Research in *archéogéographie* and ancient topography needs to visualize these kinds of features as clearly as possible. Hill Shade, with a correct sun elevation and azimuth, and Slope were useful to understand the micro relief and to detect some fossil parcels, while PCA image results were more difficult to interpret. The Local Relief Model was without any doubt the technique that worked best to enhance linear features.
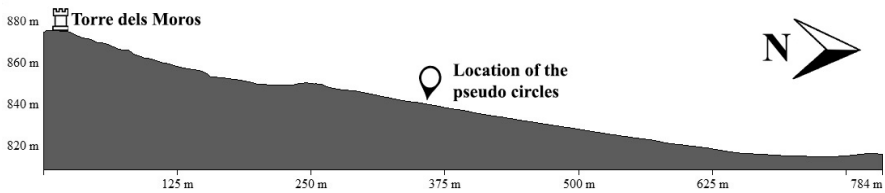

Figure 3. Area 1. Altitude section. The circles area are not the highest part and they are not followed at the same altitude (by the Autrhor)
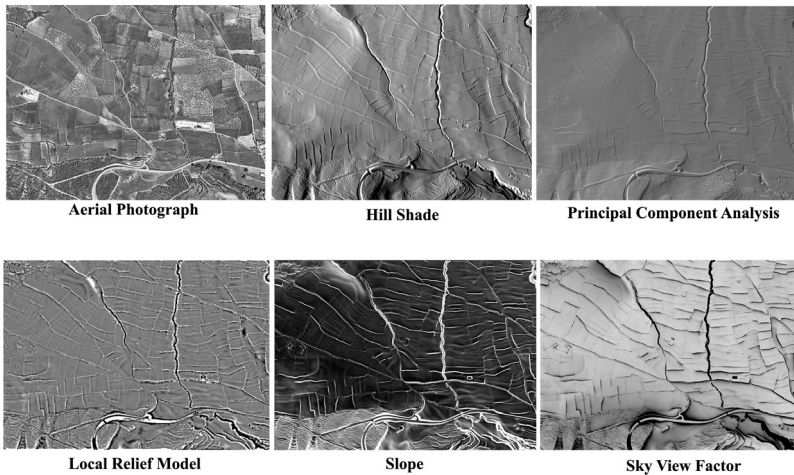

Figure 4. Area 2. Plain of Àger (by the Author)

10.3. Area 3. The Wood

The third area is a test over a heavy wooded area. First of all we have to consider two things. When the vegetation canopy is dense, fewer laser points hit the ground than in other terrains, so the classification and the consequent filtering reduce the level of detail of the terrain. We can still obtain a DTM but the interpolation process approximates a larger quantity of the surface. The 2-meter DTM will decrease in resolution even if every raster cell is still 2m^2. The opportunity to detect small archaeological features in this case is very low.

For this example we applied the Hill Shade, the Slope, the Principal Component Analysis, the Sky View Factor and the Local Relief Model techniques. The Hill Shade revealed a series of abandoned agrarian terraces. The visibility was sensibly improved with the PCA and the Slope while the LRM and the SVF only partially shaped these terraces.

Indeed, an important achievement was finding a new area of ancient exploitation. So far as we understand, with this surface it is possible to map all the terraces and other features hidden under the vegetation canopy. Small archaeological features are impossible to detect, however, and we would require a more dense point cloud from lidar.
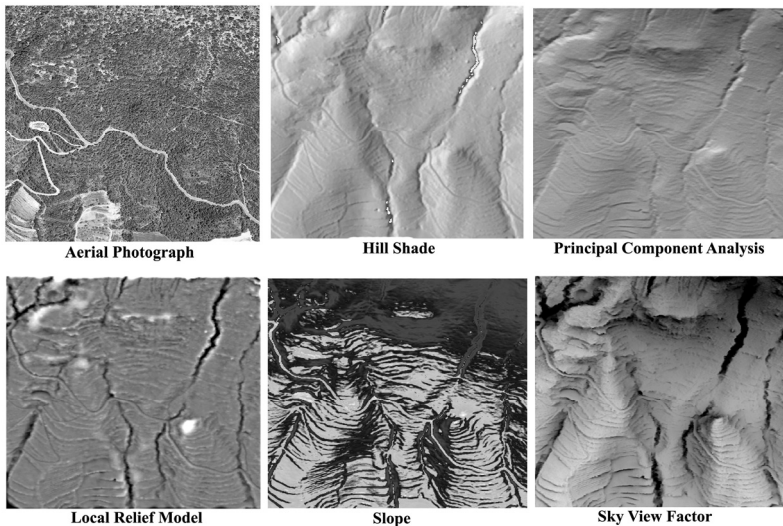

Aerial Photograph	**Hill Shade**	**Principal Component Analysis**
Local Relief Model	**Slope**	**Sky View Factor**

Figure 5. Area 3 (by the Author)

10.4. Area 4. The Arid Uplands of Montclús

This area was chosen in order to have an inverse situation from area 3. Indeed, here the vegetation is very scarce and the classification and filtering of the point cloud generates a surface without many differences when comparing the DSM and DTM.

From the archaeological point of view, this is an area of transhumance itinerary with no other economic exploitation. The application of the image processing brought a smooth surface with no particular details. Only the Local Relief Model and the Slope gave some results, in particular the presence of two paleo channels with some terraces and the enhancement of transhumance paths. No other details can be detected from this DTM. In addition the interpolation created some artefacts that do not correspond to any feature in the terrain but are the result of the application of the algorithms. It is useful to remember that a lot of artefacts can be created during every phase of data processing and that sometimes these are difficult to distinguish from real features. The only solution to this problem is to constantly compare the digital elevation model with an aerial photograph or a ground survey.

10.5. Area 5. The Castle and Village of Montlleó

The village of Montlleó was located in the south face of the Àger valley near the Port d'Àger, and it is known from documentary sources to be a medieval village that developed around a former castle before 1173. The houses were abandoned before the 14th century, and then the church became just a hermitage dependent on the Àger church of Sant Vincent.[15]

The aim of our test is to detect the topography of the village or, at least, to determine the area where the village was settled. Indeed, the resolution of the DTM is not high enough to determine the topography of specific village features like remains of walls. However, it is possible to use an alternative interpretation to determine a possible extension of the village around the known features. In particular, with the PCA, it is possible to see some artificially flattened areas on the south face of the hill and away from the east side of the church. It is possible to distinguish these zones from the normal shape of the hill side.
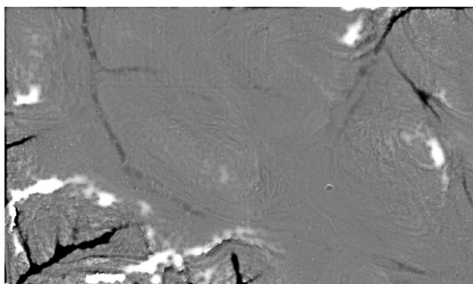
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[15] Jordi Bolòs and Francesc Fité, "Castell i Vilatge de Montlleó", *Catalunya Romànica. La Noguera*, ed. by Antoni Pladevall (Barcelona: Enciclopèdia Catalana, 1994), XVII, pp. 157-158.
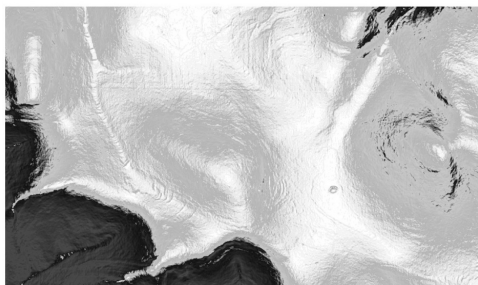
Aerial Photograph
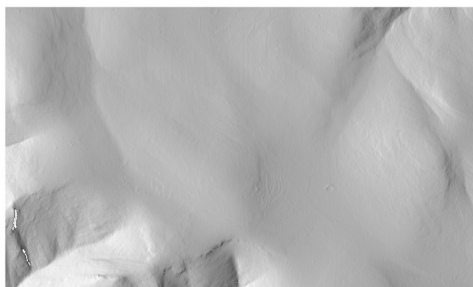
Hill Shade

Local Relief Model

Slope

Figure 6. Area 4 (by the Author)