Dingwall, L., S. Exon, V. Gaffney, S. Laflin and M. van Leusen (eds.) 1999. Archaeology in the Age of the Internet. CAA97. Computer Applications and Quantitative Methods in Archaeology. Proceedings of the 25th Anniversary Conference, University of Birmingham, April 1997 (BAR International Series 750, CD-ROM). Archaeopress, Oxford.

From The Ground Up: Visualising Ligurian Archaeological Sites

Michael McCullagh, Roberto Maggi, Mark Pearce, Jerry Ratcliffe

Abstract

Three archaeological sites in Liguria were surveyed by a University student party in April 1997, in cooperation with the Italian state archaeological Service, to provide the basis for building computer views to enhance interpretation of the sites, and to provide educational material for use in University and other student courses. The survey methods used were chosen to enable rapid and cheap generation of results and were combined with some pre-existing survey data. A major constraint on the whole project was that the process of data collection, modelling, visualisation, and final video presentation of the results had to be completed in a three week time frame: one week preparation, one week in the field, and a final week preparing and presenting the results and the digital video at the CAA97 meeting. An assessment of the results from this exploratory project indicates that the methods used, together with additional recently available approaches, can be employed successfully to generate useful model, visual, and animated interpretations of complex sites in a relatively short period of time.

1 Ligurian sites in northern Italy

The choice of the three sites (Fig. 1) involved in this project out of the many available in Liguria was related to their state of excavation, importance in terms of Stone and Copper / Bronze Age archaeology, research activity of the authors of this paper, and suitability of the terrain in offering different survey training possibilities for students.

The first site chosen was the Valle Lagorara jasper quarry, dating to the late fourth or early third millennium BC, which was excavated from 1989-95 (Maggi *et al* 1996). The Lagorara became a major part of the visualisation work owing to its importance as a significant stone age archaeological site in Liguria. The valley, about 3km long, is now an area of chestnut wooded slopes with many derelict terraces interspersed with a few working ones, lying at an altitude of around 750m with a relative relief of 150m. The excavations were supplemented by extensive air photograph and subsequent photogrammetric digital coverage for much of the area. Modelling and visualisation of the Lagorara valley and its sites could proceed immediately on receipt of the detailed survey contour and spot height data and its transformation to the standard Italian coordinate UTM system.

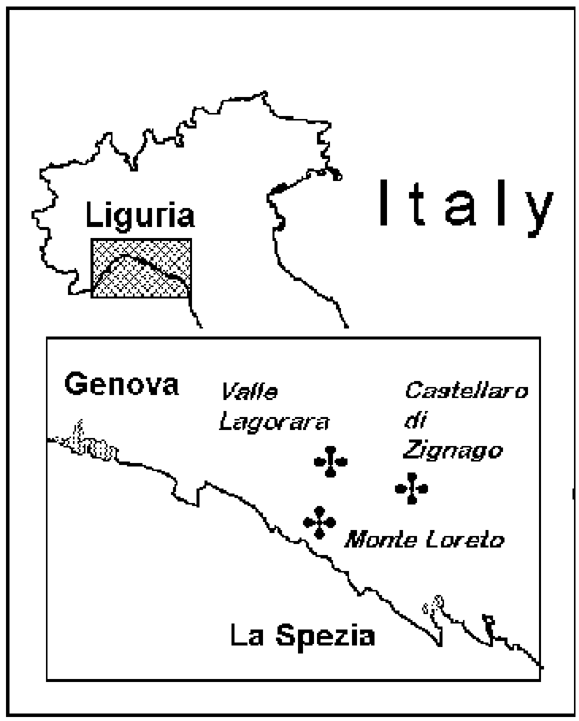

Figure 1. The location of the three survey sites in the region of Liguria.

In September 1996 two of the authors undertook a trial excavation at Monte Loreto - the second field site studied and modelled. No pre-existing data existed for this site, and much of the survey work during the week took place in this mountainous, heavily wooded area. The woods are mostly mixed pine, deciduous trees, and bushes at about 225m altitude and exhibit 100m relative relief. The surveys were carried out using total stations for detailed site survey, and GPS hand-held receivers for location of the multiple mining and beneficiation areas within the Monte Loreto region. The survey of the Monte Loreto sites was very much a preliminary study to see what could be achieved with perhaps three days in the field in adverse (visibility) surveying conditions. The total station and GPS data for the multiple sites were to be assembled into a terrain model with the various sites located and then passed to other software for visualisation and placement into the Italian grid system.

The third site, chosen for contrast both in topography and archaeology, is a very windswept, high altitude (965m) fortified mountain-top site covering perhaps 4 hectares - Castellaro di Zignago. There is no tree cover, but the relative relief is still about 50m within the immediate vicinity, with a cliff on the northern side and small plateaux or terraces on the southern and western margins. Strategically situated close to the main Apennine watershed, it dominates a large area, and has long been used to control trade routes to the north of Italy. Model building involved generation of a basic topographic map for the area with at least a 1m contour interval that could be used to provide the basis for later detailed mapping of the excavated summit and potential terrace sites.

1.1 The Valle Lagorara jasper quarry

The first site, the Valle Lagorara jasper quarry, dating to the late fourth or early third millennium BC, was excavated from 1989-95 (Maggi *et al* 1996). The Valle Lagorara is a short narrow valley, running north-south between a jasper formation to the east (Monte Scogliera) and a clay-schist formation to the west. Jasper is a siliceous rock made up of thin layers of radiolaria and pelithic schists: red or brown in colour and easily chipped. Jasper is the most common lithic raw material used to make chipped stone tools in Eastern Liguria, comprising 98% of the Mousterian assemblage and 83% of the Copper/Early Bronze Age assemblage. Two areas of mining have been found, showing three methods of quarrying:

1. hard hammering of vertical or sub-vertical layers, leading to the formation of conical recesses in the near vertical valley sides;
2. hammering off of pieces from horizontal or sub-horizontal layers;
3. levering off of already partly exfoliated vertical layers.

The quarry tools used were dolerite and ferro-gabbro grooved stone hammers (mauls). A few metres to the north of the quarry were two rock shelters under a jasper boulder which fell from the cliff face in the early Holocene. Two stages of manufacture were detected on site:

1. the roughing out of preforms (which took place at the quarry face);
2. the final roughing out of preforms and the production of finished artefacts (which took place at the rock shelters).

Radiocarbon dates from the south rock shelter (Beta - 45751: 3930±190 bp = 2920-1890 cal BC (2s) and Beta 87979: 4510±70 bp = 3491-2923 cal BC (2s)) confirmed the typological dates indicating a Copper and Early Bronze Age chronology (Copper/Early Bronze Age pottery; disk-headed bronze pin).

1.2 The Monte Loreto copper mine

The late nineteenth century saw a minor copper rush in Italy, much of it with British capital. Arturo Issel, professor of geology at Genoa in the late nineteenth century, reported ancient mining activity at two mines opened at that time, Libiola and Monte Loreto. Although the prehistoric galleries at Libiola seem to have been lost as a result of modern mining activity, a wooden pick-handle was recently radiocarbon dated to the fourth millennium BC (GIF - 7213: 4490±90 bp = 3497 - 2920 cal BC; Bln 3367: 4610 ± 50 bp = 3510 - 3135 cal BC) (Maggi and Del Lucchese 1988, 336-338). No other early prehistoric copper mines are known in Italy, and since modern mining at Monte Loreto, near Masso, was less extensive, it was thought that this site was a more promising place to search for a surviving prehistoric mine site.

In September 1996 Nottingham University Department of Archaeology and the Soprintendenza Archeologica della Liguria undertook a trial excavation at Monte Loreto. Two trenches were opened: the first ran just below and adjacent to a fissure that seemed to correspond to the nineteenth-century reports; and the second at the foot of the scree below the fissure. At the same time, the fissure was dug out by a group of cavers from Genoa; all (100% sample) excavated material was dry-sieved.

The first trench showed evidence of nineteenth-century mine prospecting, prehistoric scree and mining spoil. The second trench uncovered a dry stone wall structure and a probable production facility as yet undated. The fissure was excavated to a depth of 3.81m and provided evidence for nineteenth-century prospecting. A date of Copper/Early Bronze Age can be suggested for the earliest mining at the fissure based on finding a grooved hammer-stone of the same type and lithology as those found at Valle Lagorara. A similar hammer-stone was found in the fill in a site 20-30m north, where a nineteenth-century mine shaft cuts a probable prehistoric working. Part of the hillside above the mines is remarkably barren, and completely free of the dense woodland (mixed pine and deciduous) that covers the rest of Monte Loreto. Fragments of copper ore, and 50 or so grooved hammer-stones and grinding-stones were found on the surface. The site can be interpreted as a beneficiation area where primary ore processing (enrichment) of the ore took place prior to removal for smelting. The Monte Loreto prehistoric copper mine area may be tentatively dated - on the grounds of its parallels with the Valle Lagorara jasper quarry - to the fourth millennium BC.

1.3 The Castellaro di Zignago

The Castellaro di Zignago site dates from the second millennium BC with natural and artificial terraces to the south and west.Three sites were excavated between 1969 and 1971 (Scarani and Mannoni 1974; Mannoni 1975; Mannoni and Tizzoni 1980). The first consists of medieval fortifications on the summit including early medieval layers: thirteenth/fourteenth-century pottery overlay evidence for a second millennium BC hut. There is also evidence of two phases of occupation levels to the east of the summit in the second millennium BC, and a flat area 20m lower and to the south of the summit, with evidence for two phases, the latter with a quadrangular hut. Dating was primarily by Later and Final Bronze Age pottery, suggesting prehistoric occupation in the later second millennium BC. During the present field campaign an additional find of an Early Copper Age soapstone ornament was made.

2 Surveying techniques and GPS

Many different survey techniques are available to the archaeologist designed to cope with a number of different situations, scales, and requirements [Bettess 1992; Uren and Price 1994]. The processes involve everything from methods used to survey the building of the Egyptian pyramids (levelling and chain survey) to the use of satellite navigation systems [Leick 1995]. The difficulty is choosing the correct tool for the task. The three Ligurian sites provided the possibility of using two modern instruments to build a database for later modelling and visualisation.

2.1 Total station limitations

Perhaps the most useful method for general surveying of topography and location of individual items is the total station, which determines position accurately to within a few millimetres over distances of up to several kilometres if necessary. The system employs an infrared distance measurement process allied to a virtually automatic theodolite at the recording station, in association with a prism to reflect the infrared beam located on top of the desired target measurement site. It suffers a major problem when being used in visually obstructed, or wooded, or mountainous areas in that speed of survey tends to be sacrificed because firstly the prism cannot be seen and hence no measurement made, and secondly the prism holder has to move but carefully and slowly on difficult terrain from one measuring site to another. Thus a survey which took a couple of hours on an unobstructed Castellaro di Zignago mountain top took several days on the wooded slopes of Monte Loreto.

2.2 Ground level photography

The mine sites on Monte Loreto became individual surveys covering areas of perhaps a hectare each. They were extremely costly in terms of time and it proved quite difficult to obtain accurate readings owing to the steep hillside, and considerations of safety for the prism holders. The locational information gained should have been accurate to within a centimetre, but owing to terrain difficulty was probably closer to ± 10cm much of the time. This was not a major problem for a general topographic map of the area as the ground was largely composed of exposed pillow lava giving a surface with about ± 50cm relative relief.

A faster survey method would undoubtedly have helped at Monte Loreto. One possibility investigated following return from the field was using pairs of photographs in stereo mode taken from ground positions. Given two photos that image the same area, with at least three points of known location and height in both, it is possible to determine the x,y,z of any other points common to both photographs. The accuracy of the final results depends on the quality of the photographs, knowledge of the camera optics, accuracy and good distribution of the three known points, and the ability of the surveyor to pinpoint exactly similar locations on the two photographs.

Recently interactive Windows based software (Wireframe Express v3.0 for example) has become available to perform this entire operation using normal 35mm (or digital camera) photos without the usual rather extreme requirements and cost demanded by more professional systems. The Synthonics web site, at http://www.synthonics.com, contains details and a demo version of the remarkably easy to use software. We shall be using this package when we return to Monte Loreto in 1998 as it enables us to take two or more photos in the field, survey in a few fixed points, and allows us to collect far more data, anywhere on the images, either on cliff surfaces, or in inaccessible areas. Many sites can be worked on simultaneously, limited only by the amount of computing machines available.

2.3 Air photography and photogrammetry

Air photography could be used employing modern digital photogrammetric techniques but often either the photographs are not available, or are rendered useless, as at the Monte Loreto site, by dense woodland obscuring vital ground information. Castellaro di Zignago would have been an ideal photogrammetric survey example, had suitable photography existed! The Valle Lagorara photography formed the only coverage sufficiently good to provide detailed topographic information.

2.4 Hand Held GPS

GPS survey has always been a very low accuracy approach to topographic surveying, particularly when using hand held receivers, not because the process of calculation is intrinsically inaccurate but because the military satellites that provide the position signals to the receiver deliberately incorporate an element of error that is not easily removed without employing the necessary military decoding equipment. Full details of the process of GPS satellite surveying can be found in Leick (1995), or a more readable introduction to GPS, co-ordinate systems and projections in the excellent web pages of the Geographer's Craft Project at http://wwwhost.cc.utexas.edu/ftp/pub/grg/gcraft/. The major GPS trade journal at http://www.gpsworld.com/ has many links to other useful GPS interested sites, and the http:/www.geoplace.com/books/WebCatalog/ contains a complete bookstore covering the surveying, cartography, and geography areas.

In this study two hand held Garmin 45 receivers were used which, in common with all other single GPS receivers, can determine location in latitude and longitude to rather worse than 50m. When two receivers are relatively close to each other the errors can be reduced considerably by comparing the differences between the two rather than the absolute locations. If one of the receivers is considered to be a "base" station and is located at a known point on a map then this differential survey can be made an order of magnitude more accurate than the unassisted single receiver. Another alternative is to use a commercial "differential" correction signal available from a commercial base station which is radio transmitted to the single local receiver which can then perform the correction calculations. This latter approach provides metre accuracy, but is expensive compared with the cost of two hand held receivers. The hand held GPS can be operated in off-line differential mode by downloading all the GPS data from them as they generate it in the field into a computer (we used Psion Siena organisers for cheapness and portability). The files generated can then be compared later, the position differences calculated, and the position information for the field survey plotted. Although the results are not known in real time in the field, they can be made available within minutes of collection.

The question of accuracy of this approach remained to be settled before using the simple two receiver differential method to determine both accuracy and the most sensible employment of the technique in the field. The authors performed a test using the Garmin GPS receivers – any brand would perform similarly - which resulted in the graph shown in Figure 2. The two instruments were set up 16m apart in a fairly open position, but with numerous trees and buildings within 20m in any direction – a normal somewhat obstructed survey location. Remote antennae ("mushrooms") placed directly on the ground were used at these locations instead of the receivers' internal aerials to minimise people effects on the received satellite signals. The receivers were then switched on and data collected using two Psions for 25 minutes. The data from the Psions was then extracted, reformatted, time correlated, and converted to geographic co-ordinates in metres on the ground surface using our own software.

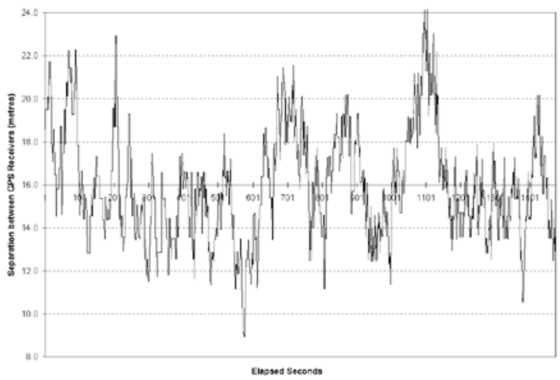

Figure 2: Errors in hand held GPS location measurement used in simple differential mode.

Figure2 shows the differences in position in metres recorded between the two machines. The mean difference is almost exactly 16m, and the standard deviation is 2.5m. 95% of the distribution should lie within 5m of the mean, and all observed differences do lie within 8m of the mean value. The conclusions from this simple differential test indicate that any location can be recorded with a single reading – any given second – to an accuracy of ± 8m maximum error, or by pausing for perhaps one minute at any given location, to an accuracy of ± 5m at worst.

These results indicate that although individual measurements on one small site would not be reliably located, it is certainly possible to determine the locations of multiple sites covering a large area and the position of any track ways between them, with a very adequate ± 5m margin. In the case of Monte Loreto this meant that inaccessible small mine locations, and the beneficiation site, could be located in the context of the whole mountain side, and accurately plotted on the map. This would not have been possible using any other cheap surveying process.

3 Modelling terrain

A wide range of modelling systems is available on many different computer platforms. Some of the options available are given in McCullagh (1996). General summaries are available in Petrie and Kennie (1990), Moore, Grayson, and Ladson (1991) and McCullagh (1988). The software archive at http://www.micros.hensa.ac.uk/ contains several shareware packages. The range of systems is considerable from market leaders such as ESRI’s Arc-Info GIS (www.esri.com) and DTM/W/G from Intergraph (www.intergraph.com) on workstation systems to shareware like Panacea (michael.mccullagh @nottingham.ac.uk) written by one of the present authors. All the systems have different capabilities and costs, but are quite suitable for modelling terrain from site survey based on scattered data point and break lines. These systems generate accurate terrain models based on the input data, but do not provide "realism" in terms of any views they may generate of the resulting models. This must be done using other software.

As the demand for more photo realistic views has increased, methods of enhancing terrain have become important, particularly through the use of fractal theory (Crilly *et al* 1993) to add surface roughness as in the excellent Vista-Pro package. Such fractally enhanced landscapes do not create a more accurate model. The roughness may be visually effective but will not be locationally accurate.

4 Visualisation of terrain and archaeological sites

Software for visualisation (Mccullagh 1996) tends to come in two flavours: that suited to real time animated visualisation, for instance VRML1/2 systems, and that leaning towards "photorealistic" view creation - usually ray tracing systems. The VRML type tend to allow high animation speeds of up to 15fps on standard PC based machines, but compromise by using low resolution, unsophisticated views of limited object content. These systems generate impressive views of simple models, often without a true relief model, and allow "walk throughs" of buildings and similar constructs to be generated in real time. The photorealistic systems – PoVRay for Windows v3 is a good example (www.povray.org or a mirror site such as micros.hensa.ac.uk) – allow extremely complex image generation with a full terrain height field, complete illumination specification, and as many complex objects (buildings, vegetation, clouds, etc.) as desired. The results are extremely realistic, but not in any way real time. A typical single frame view generated on a Pentium PC might take 20 minutes to calculate, but the quality can be superb! The algorithms used can be found in the general computer graphics literature (Earnshaw and Wiseman 1992), and for photo-realism see Watt and Watt (1992). The impact of viewing landscape, correctly proportioned, complete with any vegetative and human culture, and analytical results, allows one not only to present in an easily assimilable fashion (Hearnshaw and Unwin 1994), but also provides the key to using the analytic power of the human brain.

4.1 Animation Processes

Real time animation relies on simplicity of image, sophistication of display algorithms, and speed of machine to generate a display. But for quality animation off-line generation of the movie is still required, followed by play back in real time. The reason for the plethora of digital video formats for recording digital animations is due to the difficulty of generating efficient compression. 30 seconds of animation at low (US-TV) resolution occupies at least 150MB of disk space in uncompressed form. An hour might require a ridiculous 20GB.

Individual images can be compressed either without loss using GIF, TIF, BMP and other formats, or with an "acceptable" loss using the more complex encoding provided by JPG (Joint Picture Expert Group) and similar formats. This typically leads to compression factors of 75% or more for full colour images. Video compression can go one stage further by compressing not just within each frame but by looking at the differences between successive frames, and only encoding areas that change. This can give compression of well over 95% for many video sequences. A number of systems exist, but they tend to be dominated now by the older AutoDesk Animator formats (FLI and FLC), the Microsoft / Intel AVI formats, and the newer MPEG (Motion Picture Expert Group – v1/2/3/4) formats that handle both sound and vision and achieves compression levels 3 times or more greater than FLI/FLC.

Freeware and shareware software exists to generate many of these formats from image sets created by - for example – a PoVRay animation sequence. Most of the software is available from mirrors either at micros.hensa.ac.uk or linkable from there.

FLIs and FLCs can be generated by a number of packages. The DTA software (micros.hensa.ac.uk) is very effective at providing all forms of Animator output with excellent colour. MPEG creation packages are less common. The CMPEG program (stefan@lis.e-technik.tu-muenchen.de) is rather less effective in terms of colour, but generates good – but silent - MPG sequences. MPEG decoding can be performed by software (stefan again, for Vmpeg v1.6 or later) or preferably by hardware boards which are fast, reasonably cheap, and widely advertised in the PC magazines. The Microsoft / Intel AVI format is quite useful as it is flexible, contains many different codecs for sound and vision, is reasonably compact, and can be played on almost all Windows 95 and better machines. Software to generate AVIs can either be proprietary, such as Adobe Premiere, or shareware. An example of the latter is AVI Constructor (caracena@henge.com).

5 Views and Animations of Ligurian Sites

The aim of visualising the sites in Liguria was to allow interpretations to be displayed in relation to the relief of the areas, and to provide an interpretative movie record of the sites for use in a number of local museums. The six minute movie (Liguria.avi – 35MB including sound track), incorporating views, data and animations of the various sites, mixed with interpretative interviews and scene setting video of the Liguria sites is included in the CD accompanying this publication.

Figure 3 is a frame clipped from the movie showing part of the Lagorara valley and the relationship between the relief, the jasper quarries, associated working areas, streams, and the modern cart track. Figure 3a shows the plan view, and 3b the interpretative overlay draped over the terrain that forms part of the animation sequence.

Figure 4 gives a preliminary view of the Monte Loreto sites, also taken from the movie. The altitude model is shown centred in the 1:25,000 scale Italian topographic survey map in Figure 4a. Both GPS and total stations were needed to derive the correct relationship between the mines and their position in the Italian survey map. In Figure 4b the two main mining sites discovered so far have been represented as clefts and holes in the surface. The draped overlay is a contour map created from the terrain model. The beneficiation site lies to the north-east of this area.

The first stage in developing the model for the Zignago site has been to convert the basic survey data into a terrain model. This has now been achieved. The air photograph available for Zignago is at too small a scale to be useful for direct measurement of altitude, but will serve as a useful visualisation overlay in the future.

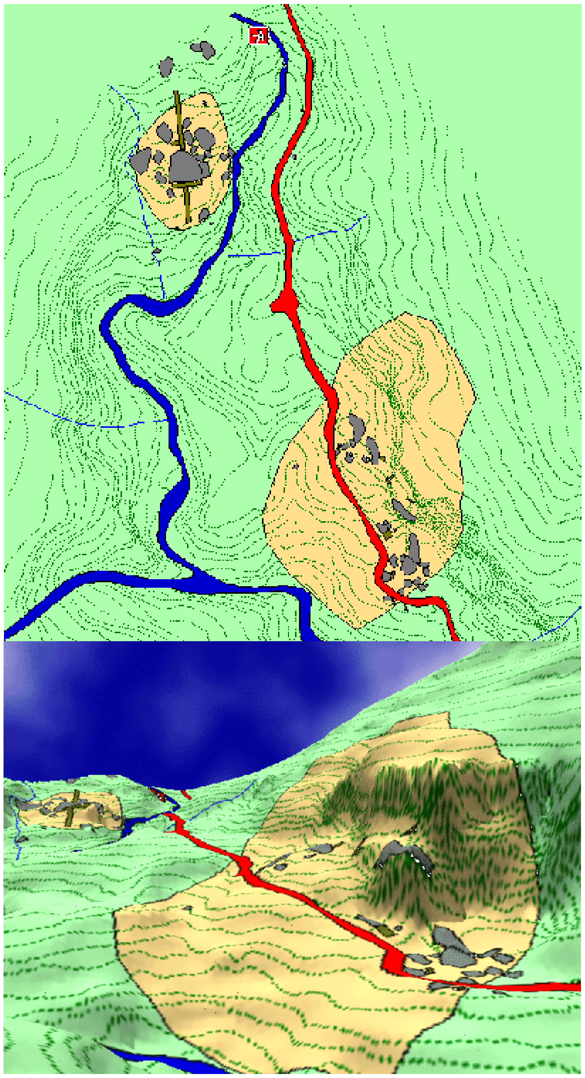

Figure 3: Both 3a [left] and 3b [right] show the same area, 3a as a plan view, and 3b as the plan view draped over the terrain model. Contours are shown as pecked lines, the local stream and cart-track as dark filled wide lines. The jasper exposures are just visible as two rough ellipses at bottom right and top centre. The grey areas within the ellipses mark the quarry and working sites. The grey long rectangles in the top ellipse mark the position of trenches.

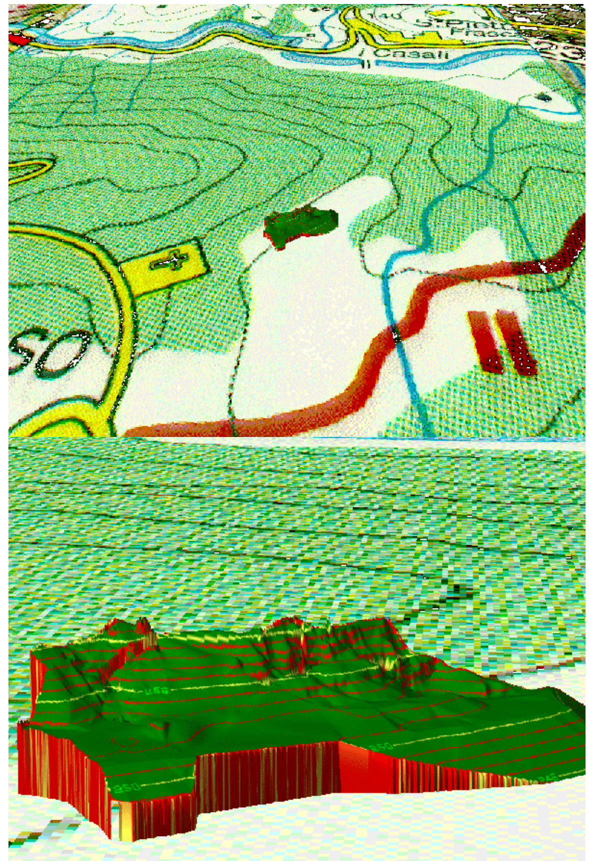

Figure 4: The position of the Monte Loreto site is shown 4a in the top diagram, which also includes the 1:25,000 map coverage of the area. 4b, at the bottom, gives a relief view of the area, and marks the approximate location of the main mine entrances.

6 The next stage

The authors developed the full movie in the three weeks from departure to Liguria to undertake the surveying operations to the first presentation of the movie at CAA97. The work, although meeting the original objectives, is still in an early stage. We hope to extend our surveying, visualisations, and animation procedures to develop the present sites and move on to new important sites in Liguria, such as the Libiola area. The aim is to generate a full visual interpretation of each of the major sites of the region, convert this into a digital movie sequence, add video expert interviews, and to make the sequences available both on the web and at museum visitor sites throughout Liguria.

There are many aspects that need developing, and features that need to be added before we realise this aim:

1. The surveying process in the field must be speeded up and improved, following field trials this summer, probably through the use of Wireframe Express or similar packages.
2. Full CSG models need to be added to the visualisation so that reconstruction animations of the sites in use can be made.
3. Aerial photography of the sites would be very useful in developing realistic overlays for some areas. At the moment only the Zignago site has any suitable coverage.
4. Investigation into using VRML/2 with genuine height models may lead to real time – although low density – animations that can be run from web sites. Similarly the possibility of using gaming software scene editors (Doom, Shadow Warrior etc) to generate erroneous but fast walk throughs needs exploration.

Visualisation is a field which is changing very quickly. Present techniques are unlikely to be in use in five years time, or perhaps even tomorrow, but the survey and archaeological information base will still be valid. It is important to ensure that the collection and storage of information gathered today can still be used with new systems as they appear. The only way to achieve this goal is through the continuous update of methods and applications in a research environment. This epitomises the international co-operation of archaeologists, geographers, students, and local authorities to generate, preserve, and display findings from a rich archaeological region for the benefit of both researchers and visitors.

Acknowledgements

The authors would like to thank: Dr R.E. Dugdale for his invaluable expertise in the field, the students taking the surveying module in the Department of Geography for their vital field assistance, and the University of Nottingham Vacation Study Fund for the necessary student field work support. M. Pearce would like to gratefully acknowledge support from the Dr M. Aylwin Cotton Foundation and the University of Nottingham New Lecturers' Research Grant Fund.

Bibliography

Bettess, F., 1992 *Surveying for Archaeologists*, University of Durham

Crilly, A J, Earnshaw, R A, and Jones, H, (eds), 1993 *Applications of fractals and chaos*, Springer-Verlag, Berlin

Earnshaw, R A, and Wiseman, N, 1992 *An Introductory Guide to Scientific Visualisation*, Springer-Verlag, Berlin

Hearnshaw, H M, and Unwin, D J (eds), 1994 *Visualisation in Geographical Information Systems*, Wiley, Chichester

Leick, A, 1995 *GPS Satellite Surveying*, second edition, Wiley Interscience, John Wiley & Sons, Inc, New York

McCullagh, M J, 1988 Terrain and Surface Modelling Systems: Theory and Practice, *Photogrammetric Record*, 12, 747-779

McCullagh, M J, 1996 Visualisation and Use of Terrain Models in Physical Systems Modelling, Third International Conference/Workshop on Integrated Geographic Information Systems and Environmental Modelling, Jan 1996, Santa Fe, US National Center for Geographical Information and Analysis (University of California at Santa Barbara), CD-ROM publication

McLaren, R A, and Kennie, T J M, 1989 Visualisation of Digital Terrain Models: Techniques and Applications, in *Three Dimensional Applications in Geographic Information Systems* (ed J Raper), 79-98, Taylor and Francis

Maggi, R, and Del Lucchese, A, 1988 Aspects of the Copper Age in Liguria, *Rassegna di Archeologia* 7, 331-338, Proceedings Congresso Internazionale, L'età del Rame in Europa, Viareggio 15/18 ottobre 1987

Maggi, R, Campana, N, Negrino, F, and Ottomano, C, 1996 The quarrying and workshop site of Valle Lagorara (Liguria - Italy), *Accordia Research Papers* 5 (1994), 73-96

Mannoni, T, 1975 Zignago, in *Archeologia in Liguria. Scavi e scoperte 1967-75*, 79-86, Genova: Soprintendenza Archeologica della Liguria

Mannoni, T, and Tizzoni, M, 1980 Lo scavo del Castellaro di Zignago (La Spezia), *Rivista di scienze preistoriche* 35 (1-2), 249-279

Moore, I D, Grayson, R B, and Ladson, A R, 1991 Digital Terrain Modelling: A Review of Hydrological, Geomorphological, and Biological Applications, in *Terrain Analysis and Distributed Modelling in Hydrology* (eds K J Beven and I D Moore), 7-34, Wiley

Petrie, G, and Kennie, T J M (eds), 1990 *Terrain Modelling in Surveying and Civil Engineering*, Whittles Publishing

Scarani, R, and Mannoni, T, 1974 Lo scavo del Castellaro di Zignago, in *Atti della XVI Riunione Scientifica in Liguria, 3-5 novembre 1973,* 159-176, Firenze: Istituto Italiano di Preistoria e Protostoria

Uren, J, and Price, W F, 1994 *Surveying for Engineers*, 3rd Ed, MacMillan

Watt, A, and Watt, M, 1992, *Advanced Animation and Rendering Techniques: Theory and Practice,* Addison-Wesley, London

Contact details

Michael McCullagh[1], Mark Pearce[2], Jerry Ratcliffe[3]
Department of Geography
University of Nottingham
University Park, Nottingham NG7 2RD
UK
[1]e-mail: michael.mccullagh@nottingham.ac.uk
[2]e-mail: mark.pearce@nottingham.ac.uk
[3]e-mail: jerry.ratcliffe@nottingham.ac.uk

Roberto Maggi
Soprintendenza Archeologica della Liguria
Museo Archeologico di Chiavari
via Costaguta 4, 16043 Chiavari GE
ITALY