COMPUTER-AIDED INVESTIGATION OF ANCIENT CADASTRES

by

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Thesis Abstract

Computational methods can be applied to the study of ancient cadastral systems. This is demonstrated using known and suspected Roman cadastres. Computation reveals the high accuracy to which the Roman land surveyors could work and also leads to the hypothesis that cadastral grids were used to plan the location of other elements of the landscape. Studies of the relationship of cultural landscape features to hypothetical cadastral grids are described. These include the use of both conventional and simple Bayesian statistical methods, and geographic information system software.

An extended case study shows how computational methods, including the analysis of boundary patterning by Fourier analysis, need to be combined with other archaeological methods in order to build a case for the existence of a hypothetical Roman cadastre in South Norfolk. It is suggested that similar studies could be conducted in three other areas of Britain. It is argued that the existence of these systems is historically possible, scientifically well-founded and deserves further investigation along similar lines.

Frontispiece *View of the lower valley of the Cèze near Bagnols-sur-Cèze (France), showing agrarian structures probably influenced by the Orange B cadastre.*

Contents

Preface

Cadastres are among the most visually striking, historically significant, culturally influential and technically complex artifacts that have been left to us by antiquity. Their study now involves students from a growing number of disciplines, including Archaeology, History, Mathematics and Information Systems.

Much of the research described in this thesis is based on my own experience in the development and use of computer-based techniques, but other approaches could not be ignored. In some of these areas, with which I am relatively unfamiliar, I have sought and accepted help. For this assistance, including permission to access sites, I must thank the following people:

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To all these people I am most grateful, although naturally it should not be assumed that they all share my views; nor should they be held in any way responsible for my mistakes.

I would also have liked to have been able to thank Tony Gregory, former field officer for the Roman period of the Norfolk Archaeological Unit, who gave me some early encouragement. It is very sad that he is no longer with us.

Thanks must go also to those who have supported me during the course of this research, including colleagues at UEA not already mentioned, and above all my supervisor, Vic Rayward-Smith. However, the greatest gratitude is owing to those who have borne the heaviest burden. That is my family: Anne, Joanna, and Peter.

This study commenced in late 1986. Since then a number of results have been published. Sections of this thesis incorporate several of them in a revised form, including section 3.1.2 (Peterson 1992c), section 4.1.1 (Peterson 1992b) and section 5 (Peterson 1988b; Peterson 1992a).

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Phillips' Shilling Atlas (undated, prior to 1914) - Fig. 8.2;

Wells & Barrow (1931) - figure 1.1.

1 Introduction and Background

1.1 Introduction

This work aims to show how, in practice, computational approaches may be used to gain a better understanding of ancient, and particularly Roman, planned landscapes.

Two principal theories are proposed: one concerns the relationship between Roman *cadastres and other features of the cultural (man-made) landscape; the other postulates the existence of such systems in parts of the Roman empire where their presence has never previously been convincingly demonstrated.

Computational methods are appropriate in this context because we are dealing with formal information systems which could employ very accurate surveying technology. This allows the use of methods normally called "scientific", including hypothesis formation, prediction and testing. However, it will be suggested that this is not an approach which can be used in isolation.

Section 1 gives a brief appraisal of the state of knowledge of Roman cadastres among contemporary English-speaking scholars. It examines the possible origins of their views, which now appear over-simplified and over-materialistic. It then shows how, in the last ten years, new work by continental Europeans, chiefly French, has attempted to unite information obtained by archaeology and other scientific techniques with an interpretation of the *Corpus Agrimensorum*, the writings of the Roman land surveyors. This work has suggested many new avenues for research and will, one hopes, generate a new view of Roman cadastres, particularly in the English-speaking world.

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* Terms included in the glossary *(appendix 3)* will be marked with an asterisk at their first appearance.

Section 2 sets the context for the research described here. It suggests that we cannot limit the investigation, either by geography or method. Roman technology must be studied in the context of the whole Roman world. New methods are needed which will allow for the measurement and prediction of cadastral systems and which will also allow us to understand their relationship with other features of the landscape.

Such an approach faces the formidable difficulties presented by the ideological gap between English-speaking and continental European scholars. In theory, this gap might be easily bridged by the use of computational models which produce scientifically plausible and "objective" results. This is doubtful, and the section concludes with an examination of the possible reasons for this.

Sections 3 gives four examples showing how the parameters of the grids of possible centuriations may be determined, and what uses can be made of this information. We start with a study of a possible extension of the virtually certain Orange B cadastre. We then look at a system in South Limburg (Holland) whose existence is very much doubted. Next we study a third system, in the Saône plain, eastern France, which reveals a very accurate survey, and makes us wonder how it could have been achieved. Finally we use computation to test the plausibility of a supposed cadastre of south-west France.

We then describe a simple statistical test of association of distribution of archaeological features (appropriately defined) with hypothetical cadastral grids. This is then applied to the case of Roman sites in South Limburg, supporting the idea that the cadastre exists.

However, since conventional statistical tests are unsuitable for use with small amounts of data, and difficult to combine with existing evidence, we suggest an alternative Bayesian approach, exemplified by a study of medieval sites on Romney Marsh. The simplicity of this approach, which is developed from first principles, may make it attractive to those who generally mistrust statistical techniques.

Section 4 describes the theoretical basis for proposing that oblique features were planned in trigonometrical relationship to cadastral grids. Since this theory of oblique planning has such a vital role in the formulation of a hypothesis concerning the existence and extension of a particular grid, it is necessary to know how often such relationships could arise by chance. Computer-based Monte Carlo simulations indicate the likelihood of random generation of single segment trigonometrically related features. Hence an estimate can be made of the chance of a double-segment oblique relationship.

We then describe two studies using Geographic Information System (GIS) software. One, in the area of Romney Marsh, indicates that the variation of density of possible cadastral traces is associated with soil type in a way that can be considered as evidence for the cadastre's existence. However, another projected study, of the association of Romano-British settlement with a possible cadastre and with soil types in South Norfolk, was not feasible and it may be possible to suggest some reasons for this.

Section 5 is an extended study of the smallest of the cadastres which, according to these research results, may exist in Britain. The subject area requires that such detailed studies are conducted because evidence produced by computation may be viewed with scepticism, particularly when it is isolated and in contradiction to "self evident" facts. Such results may only be acceptable if they can be fitted with other types of evidence. Hence the need for a pluralistic approach.

This detailed study of the South Norfolk cadastre includes a computational study of field boundary distribution using Fourier analysis, the results of soil probing and excavation, the geometrical study of Roman roads, evidence from crop-marks, microtopography and toponymy, and a description of contemporary and foreseen development of roads and other features.

In section 6 we propose further studies in Essex, Kent, Lincolnshire and Leicestershire, where some initial work reveals evidence of many of the same phenomena.

Section 7 is a critique of the work from two viewpoints. Firstly the historical plausibility of these theories is considered. If Roman cadastral systems were established in Britain, how can this suggestion be reconciled with what is now known about the capabilities of the *agrimensores* and their activities in the latter half of the first century AD?

Secondly the scientific merits of the work are considered. Are its faults greater than those of other work which, as the example of South Norfolk shows, allows preconceptions to influence the way data are captured, processed and presented? Can we suggest that there are principles evident in this work which can be applied generally to the science of Archaeology?

Section 8 concludes, firstly, that we should consider drawing a new map of Roman Britain, one that includes those cadastres and indicates their degree of probability. Since these systems are (in one sense) the largest known Roman artifacts, the establishment of their likely reality would greatly effect our view of Roman Britain. The second conclusion is that quantification is a sound basis for the study of ancient cadastral systems.

The areas mentioned in the text are shown here *(figure 1.1)*. Summary information for Britain can be found in the conclusions *(figure 8.1)*.

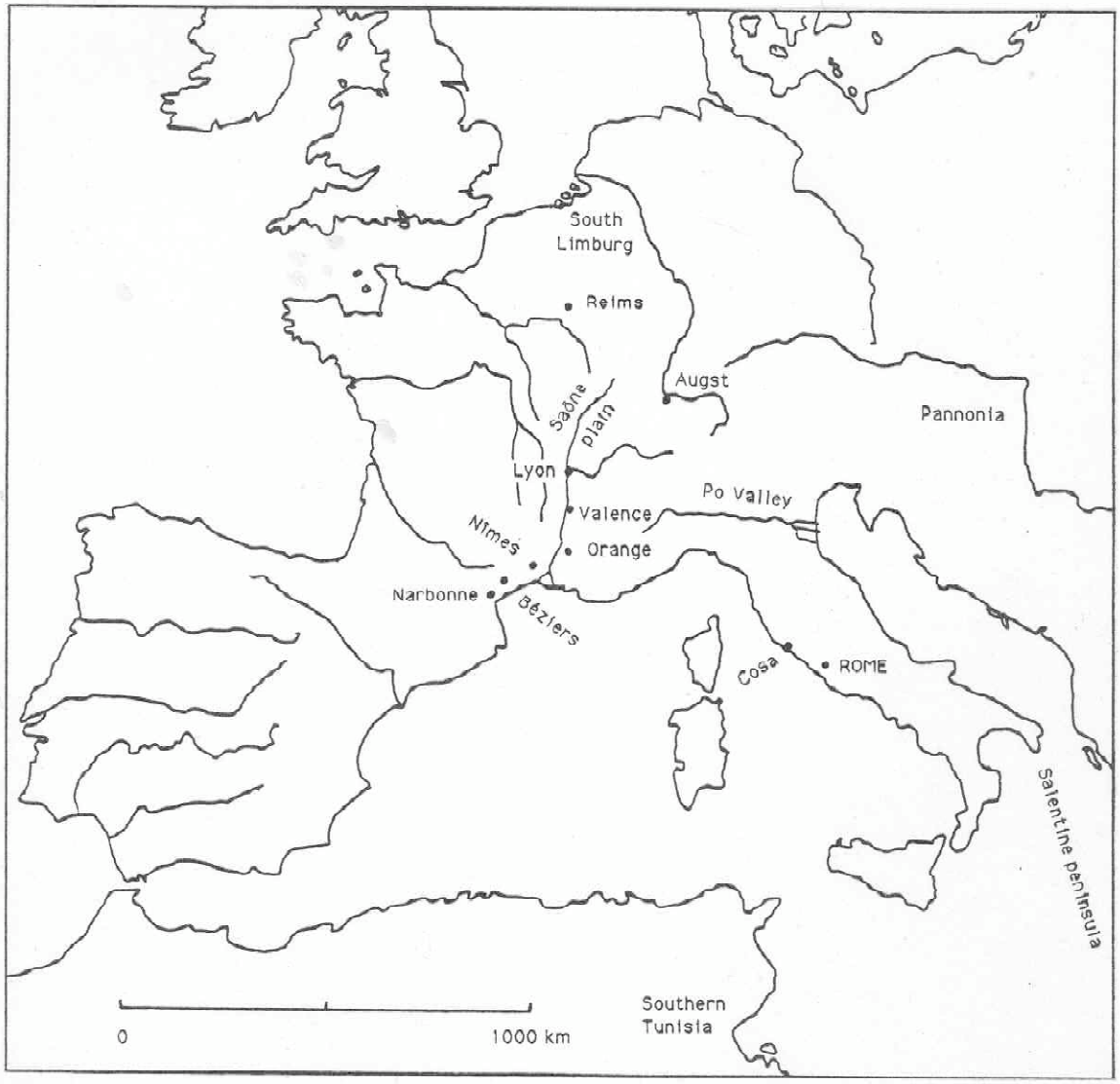

Figure 1.1 Areas mentioned in this study.

1.2 Conventional ideas about Roman cadastres in the English-speaking world

English-speaking archaeologists tend to think that the establishment of a formal and regularly planned Roman cadastre was limited to a particular administrative context - the allotment of land to members of a veteran **colonia*[1]. Furthermore they can present a view of *centuriation - a term which they misleadingly ascribe to all regular Roman land planning - that makes it bound to produce agrarian structures which are arbitrary and obvious[2]. Such beliefs, which lead to a misleadingly simplified view of Roman cadastres, are still a conceptual barrier to the progress of research.

John Bradford's (1957) aerial photographs may have served to strengthen this barrier, rather than break it down. His clearest examples make the strongest impression; and this may lead us to ignore what is less obvious, but perhaps more typical[3]; this is despite his text, which contradicts all these simplistic ideas[4]. Nevertheless, Bradford's book contributed greatly to the study of Roman planned landscape, and so, following the appearance of Dilke's *Roman Land Surveyors* (1971), the stage was set for a development of ideas and for further empirical study of Roman planned landscapes by English-speaking archaeologists.

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[1] Thus Simon Esmonde Cleary (1987: 195-6) is prepared to consider proposed "centuriations" at Colchester (Camulodunum) and Gloucester (Gleuum), but he is generally unsympathetic to any proposed centuriation in Britain, and appears relieved that Lincoln (Lindum colonia) has been "spared" such an attempt to identify a formal cadastre.

[2] Oliver Rackham (1986: 159-60) talks of centuriation "marching mindlessly across mountain and gorge" and states that "real centuriation is unmistakable".

[3] Consider Bradford's (1957: 207-210) description of one of the cadastres of Valence.

[4] In (Bradford 1957). Centuriation round *oppida, fora and municipia* in Italy (page 214), centuriations at various angles (passim), walls and ditches as *limites* (page 210).

The stage may have been set, but the actors have shown little interest. Now, 20 years later, the conceptions of Roman cadastres held by most English-speaking archaeologists and landscape historians still seem to be over-simplified, over-materialistic and out of touch with the results of foreign research. This shows itself in three beliefs which have, for many, achieved the status of fact, but which nevertheless should be doubted. They are firstly that centuriations are associated only with *coloniae*, secondly that their orientations are always determined either astronomically or by main roads and thirdly that the **limites* themselves are pre-ordained to be roads or paths.

Why should this be so? What evidence has contributed to these views? Could this evidence have been used to support different conclusions?

Topographical and archaeological evidence is available which presents a different picture, but it is recent and chiefly the work of scholars from other cultures. It seems to have had little influence on the beliefs of English-speaking archaeologists. For them, apart from Bradford's photographs, the chief source seems to have been the writings of the Roman land surveyors, the *corpus agrimensorum*. We can consider how a selective reading of these texts could have been used to support the conventional view of Roman cadastres.

With regard to the relationship between *coloniae* and centuriated cadastres we find, on the first page of Julius Frontinus' *De agrorum qualitate* (Thulin 1971: 1, 6), the following: "*ager ergo diuisus adsignatus est coloniarum*". This looks clear: if the land is 'divided and assigned' (i.e. centuriated) it is the land of a *colonia*. But we would be wise to read on, because Hyginus, in his *Liber gromaticus de divisionibus agrorum.* (roughly speaking "Surveyor's manual of land division"), tells us, in speaking of provincial land, that "*multis huius modi agrum more colonico decimanis et kardinibus diuiserunt, hoc est per centurias, sicut in Pannonia:*". (Thulin 1971: 168, 1-3). As François Favory (1983: 126, note 263)) says, "Ce passage me semble constituer la meilleure réponse à ceux qui

refusent d'admettre la possibilité d'une centuriation hors d'un territoire colonial". We see how Hyginus confirms the existence of provincial land divided "in the manner of a *colonia* by **decumani* and **kardines*" with the phrase "that is, in *centuries" to make it abundantly clear to his readers, who may not be expecting such a cadastral structure in such a context, that it exists.

But how can the writings of the Roman land surveyors contain apparent contradictions? Whose opinion is to be believed? The answer lies in a consideration of the function of the majority of these documents. It seems very likely, as Hinrichs suggests (1988: 172-173), that they were training manuals for civilian *mensores*, surveyors who also had a quasi-judicial role. This would lead to simplification in the more elementary and theoretical texts, supplemented by detail drawn from real life at a later stage of the surveyor's education, thus introducing apparent contradictions. Accordingly we would be wise to rely more upon the detailed and circumstantial writings, rather than upon those which seem to generalise. For this reason Hyginus' report of centuriated, but non-colonial, land in Pannonia is preferable because it is followed by a detailed list of types of land in the province. This seems to indicate that he had direct knowledge, or was very close to the source of the information[5].

The possible orientation of Roman cadastres has also been subject to over-simplification. Oliver Rackham (1986: 159) claims that centuriation is "oriented exactly north and south (occasionally at 45°)". Such an impression could hardly have been gained from a study of real cadastres on the ground, and may derive ultimately from illustrations in the *corpus agrimensorum*, which do indeed show centuriations with **kardo maximus* running vertically and

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[5] Furthermore this faith in Hyginus need not be shaken by lack of knowledge of centuriated cadastres in the area, since it is only to be expected that the areas of the empire most vulnerable to barbarian conquest and disorder would be those in which Roman cadastral structures would be less immediately apparent today. As Bradford says (1957: 214), "The discovery of the *limitatio* in Pannonia remains one of the outstanding tasks".

**decumanus maximus* horizontally on the page. In one case another centuriated area is shown at 45° to this. Also, in the text, Frontinus might appear to support the idea : "*Optima ergo ac rationalis agrorum constitutio est, cuius decimani ab oriente in occidentem diriguntur, kardines a meridiano in septentrionem.*" (Thulin 1971: 14, 10-12)[6].

It is natural for us to assume that vertical on the page is equivalent to north-south, and there may be nothing new in this assumption. It is likely that, whatever the orientation of the cadastre on the ground, the **formae* were stored with the inscriptions horizontal. The cadastral map fragments of Orange (Piganiol 1962), which are tablets (*tabulae*) having some similarity to the *formae* of three cadastres, are now displayed in this way in the Orange museum, so that they can be read easily. In the cases of cadastres A and B the direction nearest to north on the ground is, on the cadastral inscriptions, towards the floor and to the right respectively[7]. In other words cadastre A is portrayed as if the observer were looking south, and cadastre B as if he were looking west.

Without knowing the true orientation of the cadastre on the ground, it would be easy to assume from a *forma* that the axes had a north-south and east-west orientation. This mistake may have been made on two occasions by no less an authority than Ptolemy [8,9], so there

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6 But note that this set-up, with *decumani* east-west and *kardines* north-south, is regarded as reasonable and the best. This implies that Frontinus recognised the existence of cadastres with other orientations, which he did not consider so good or reasonable.

7 See Chouquer's (1983b) reconstruction of cadastres A and B.

8 (Dilke 1987: 195 & fig 11.12). The shift in orientation from Ptolemaic to modern coordinates of towns on the Via Aemilia may be due to the orientation of the cadastres, whose axes are generally perpendicular and parallel to the main trend of the road.

9 (Trousset 1978: 160, note 3). Part of the coast of Tunisia is shown incorrectly oriented in Ptolemy's world map, probably because it was assumed that the *decumanus maximus* of the South Tunisian cadastre ran east-west, an error of about 45°.

is some excuse for Rackham's error; but it is most regrettable that such a misleading statement should have found its way into a text-book with the definitive title *The History of the Countryside*.

Another determinant of orientation is supposed to be a main Roman road. This 'rule' has a long history in England. It was Henry Charles Coote who insisted (1878: 58) "that the *limites maximi* and the *viae militares* are all confounded under the one latter term". In other words, according to him, the principal axes of the cadastre came to be regarded as main roads, thus leading to the belief that the cadastre had been based on them. Furthermore it has long been believed that much of the vast area of centuriated land to be found in the Po valley, northern Italy, is aligned upon the Via Aemilia (Potter 1987: 121). This gives some apparently factual backing to claims based on the textual sources.[10,11]

However, despite the probability that some cadastres were based on main roads, it is clear that not all were. One can find in the *corpus agrimensorum* nine possible factors determining orientation,

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[10] But even this claim is weakened by Chouquer's (1981) study of ten cadastres between Rimini and Bologna. Three are aligned on the main road; one is partially aligned (the road changes direction); six adopt another orientation.

[11] An anecdote based on the author's experience may be appropriate here to illustrate this point. Locally, in Norfolk, England, both amateur and professional archaeologists seem to prefer the road-based to the astronomical theory of orientation. The South Norfolk A cadastre was proposed to a professional archaeologist employed by an archaeological unit as a specialist in the Roman period. He initially objected to the idea because the cadastre is nowhere parallel to the principal Roman road running south from Venta Icenorum. When it was pointed out to him that a feature catalogued in the Sites and Monuments Records (SMR) as "possible Roman road" formed part of the grid, his theoretical objection vanished (although other objections remained). He had found the "Roman road" upon which the cadastre had to be based, whereas in the author's opinion this feature, a possible *limes quintarius*, was just one trace among many. See below *(4.1.1, 5)* for further discussion.

which have been listed by Joël Le Gall *(figure 1.2)*. We observe that he is at pains to counteract undue stress on astronomical influences by emphasising the influence of the natural and cultural environment[12].

Environmental Factors	
1	The sea, parallel and perpendicular to the coast
2	Relief, the general direction of drainage
3	The maximum extent of the territory
4	A *via consularis*, i.e. main road
5	An orientation different to that of the cadastre of a neighbouring territory, to avoid confusion
Astronomical factors	
6	Orientation towards the rising sun
7	Orientation of *kardines* due north-south
8, 9	As 6 and 7, but with the *decumani* and *kardines* inverted

Figure 1.2 Factors theoretically affecting the orientation of Roman cadastres, after Le Gall (1975), with modifications.

Le Gall's championing of environmental causes is appealing, but of course there is no reason for orientation to be determined by only one factor. It would not be surprising if the surveyors chose orientations which would simultaneously satisfy natural environmental, cultural environmental and purely theoretical constraints. The relative importance of any cause would vary from case to case, and

[12] For example he suggests that the orientation of the cadastre of Augst is determined by environmental factor number 3, even though it is due north (Le Gall 1975: 319). He adds in a footnote that this east-west extension of the *pertica* is caused by the course of the Rhine and the regional relief. Thus factors 1 and 2 are also involved, if a major river is regarded as a sort of coast.

it is wrong to think that a single cause could necessarily explain the orientation of any particular cadastre, or indeed the wide variety of orientations observed in reality.

The concept of *limites* has also been oversimplified, and not just by English-speaking archaeologists. Coote (1878: 55) was, as ever, dogmatic:

> "I have spoken of the *decumanus maximus* and the *cardo [= kardo] maximus* as lines only, but in reality they took the practical form of public roads. ..... the *agrimensor* next proceeded to cut up the four regions .... by means of a repetition of lesser *limites*, or roads, parallel to the *limites maximi*, ...".

Raymond Chevallier (1976: 16) gives us this definition:

> "*limes*, a road of bare soil (cf *limus*, mud?), often acting as a boundary, a byroad, a subdivision for centuriation, then a road outside the ramparts, finally in the special military sense of a fortified frontier-work".

Potter (1987: 119) refers to the modern Italian placename Limiti "from *limites*, 'paths' ". All three authors define *limes* as if it were equivalent in meaning to "road" or "path"[13].

However, Benjamin Isaac finds just two meanings for *limes* in the early empire: 'Military Road' or 'Boundary'. He observes (Isaac 1988: 128) that in the second meaning it "is not a military technical term, but derives from surveyors' vocabulary". This suggests that, as a surveyor's technical term, it could be used of a purely notional line, just as it is in some of the examples that Isaac gives. This interpretation is supported by several passages in the *corpus agrimensorum*.

First we have the *agrimensores*' etymological discussions. Clearly, indulging in etymology was as dangerous then as now; the discussion surrounding "*limes*" seems particularly confused. Frontinus[14]

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[13] Even Dilke (1971: 150) thought that a proposed cadastre of Cologne was unlikely because a roman building was intersected by a theoretical *limes*.

[14] "*limites autem appellati transuersi sunt a limo, id est antiquo uerbo transgressa; a quo dicunt poetae 'limis oculis'; item limum cinctum, quod purpuram transuersam habeat, et limina osteorum. alii et prorsus et*

explores the idea that it is related to several words: *limus* (sideways), *limus* (a girdle or apron trimmed with purple worn about the abdomen), and finally *limen* (a threshold)[15]. Siculus Flaccus supports this latter derivation: "as thresholds show the entrances and exits to places, so similarly do *limites* to fields"[16]. A threshold is, of course, both a means of access and a boundary, so this derivation makes excellent sense.

We also have textual evidence that *limites* were not necessarily roads. Siculus Flaccus talks of cases in which villas may be placed on the *limites*, "*si villae in limitibus positae sint*", and in order to make this quite clear he adds "*id est limites in quibus incidunt*"[17]. In such cases, where the public right of way associated with the *limes* had to suffer a deviation, the *limes* was clearly a conceptual boundary.

Further evidence comes from the detailed and circumstantial report of Faustus and Valerius, describing how they established *limites* in Tunisia *(appendix 1)*. Some were roads, some were walls, and on others they "put nothing but caused deep ditches to be dug". This use of the word "nothing" reveals the attitudes of these *mensores*. To them the things of interest were the symbols of the cadastre. A physical structure, such as a ditch, was truly nothing unless it was made symbolic. Only very scanty physical structures were needed to symbolise the cadastre: such as stones, trees, or small mounds of earth concealing broken pottery. If these were lacking then the

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transuersos dicunt limites a liminibus, quod per eos in agro intro et foras eatur" (Thulin 1971: 13, 2-7)

15 He makes no reference to *limus* (mud), contrary to Chevallier.

16 "*Limites autem ab liminibus uocabula acceperunt, quoniam limina introitus exitusque locus praestant, limites agris similiter introitus exitusque*". (Blume, Lachmann and Rudorff 1848: 153, 7).

17 (Blume, Lachmann and Rudorff 1848: 158, 20 et seq). This caused problems because of necessary deviations of the right of way, and most land holders lived within their holdings.

cadastre ceased to exist; if they were present then the cadastre and its *limites* could be an invisible but genuine reality.

When seen this way, these systems are true land information systems; and illuminating parallels can be drawn with modern computer-based information systems, in which the reality resides in the procedures, as expressed in software, rather than in any particular hardware platform[18]. The hardware can change, and the software can be rewritten, with no effect on the reality of the system itself, conceptual though it is.

Thus Roman cadastres may present a challenge to archaeological study comparable to that experienced by 16th century astronomers. As Blumenberg says (1987: 642), "Copernicanism tore asunder the fit ... between the world and man's organs: the congruence between reality and visibility." Similarly in the study of these cadastral systems we are forced to consider the existence of real but essentially invisible artifacts. Many archaeologists, concentrating primarily on material and visible objects, would probably share the author's initial feelings of unease in this situation[19]; and this perhaps explains the refusal, by some of them, to accept a conception of Roman cadastres which is not tied to a single administrative context, which is not constrained by a simple set of rules and which does not insist upon immediate visibility as the criterion for existence.

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[18] See also Peterson (1990b: 586).

[19] This feeling was quite genuine, particularly when the theoretical line of a *limes* in the South Norfolk 'A' cadastre was found to pass, not (as expected) near a rural romano-celtic temple, but through it. See below *(5.3.1.2)*.

1.3 Some recent research on Roman cadastres in continental Europe

Meanwhile, in the rest of Europe, research has made considerable advances, both in the development of ideas about known cadastres and in the discovery of new ones. Some of these ideas, which contrast with prevalent British interpretations, have already been referred to. This section will further describe them, but, since the aim is only to set the scene for the application of computer-based methods, this description will be selective.

The continental European research has been conducted chiefly in France and Italy, generating a large French and Italian literature. This brief review will concentrate mainly on that in French. There are two reasons for this. Firstly, the French literature, particularly that which describes cadastral research in the Gauls, appeared more likely to be relevant to the author's interest, which was first stimulated by the observation of a possible system in Britain (Peterson 1988b). Secondly, this literature is the more easily accessible to an Englishman, both physically and in terms of language.[20]

The most prominent recent French work has been the output of the "Besançon team", which had the leading role in the production of *Cadastres et Espace Rural* (Clavel-Lévêque 1983a), the proceedings of a *table ronde* held in 1980. Naturally this drew upon a variety of earlier work, and it attempted to integrate readings of the *corpus agrimensorum* with information obtained from archaeology and topography.

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[20] Virtually all French language books and journals can be obtained by Inter Library Loan in Britain, which is not the case with those in Italian; for example, an important recent text in the series *Misurare la terra* edited by Settis and Pasquinucci (1989) is only available to be consulted in London. French is also almost always studied in school, whereas Italian is much less well-known.

In the archaeological sphere, interpretation of aerial photography was one of the chief tools described, since at that time very few excavations had been conducted which revealed traces of physical structures associated with the proposed cadastres. A most important technique was optical filtering of aerial photographs using coherent light. An English-language account is available (Chevallier, et al. 1970), but nevertheless a very brief description will be given here.

Optical filtering is a way of treating a spectral image generated by laser light passing through a semi-transparent photograph, often a negative. Features in the spectrum will reflect the organisation of features in the original photograph. If there were parallel features, the spectrum will show this by a line at right angles to the orientation of the original features. This line will be more or less clear, depending on how clearly the parallel features appear. If the features are well defined and at a constant frequency, bright patches will appear in the spectrum along the line, and from their spacing it is possible to calculate what was the interval between the features in the original photograph.

However, direct interpretation of the spectrum can only be used if the parallel features are well defined, which is frequently not the case. It is therefore more common to allow the laser light to continue past the spectral plane and be focussed as a further image, a reconstitution of the original, which may then be examined. If an opaque filter, which has an opening shaped like a maltese cross, is placed in the spectral plane, it will allow only certain features to appear in the final image. These have a limited range of angles depending on the orientation of the cross.

Directional filtering can be applied at several angles, in order to identify those directions in which the greatest number of similarly oriented traces appear, and this procedure has been automated (Favory 1980: 373-382). There are several descriptions of its application to Roman and medieval cadastres (Chouquer and Favory 1980), (Clavel-Lévêque 1983b), (Chouquer 1985). When employed in this way the technique, when compared to unaided inspection of

aerial photographs and maps, is beneficial. It saves time; it also introduces a greater degree of objectivity, since no particular orientation is favoured for theoretical, cultural or personal reasons.[21]

In a discussion of aerial photographic interpretation, two other pieces of work must be mentioned. The first is a complete issue of the review *Photo-interpretation*[22], with text in English and Spanish, as well as French. This includes a very clear introduction to the subject of Roman rural cadastres (Chouquer and Favory 1983), and several excellent articles on specific areas, including the totally convincing proposed location of cadastre A of Orange (Chouquer 1983c).

The second, which deserves to be better known, describes just one photograph of an area immediately west of Reims (Legros 1970). Some existing boundaries are parallel and orthogonal, corresponding to a standard 710m grid with several intermediate divisions at 355m. And, more significantly, part of this pattern appears in the form of a crop mark which is locally discordant to the existing field system.[23] There can thus be little doubt that this cadastre exists, and the importance of the finding is that, according to traditional thinking, the cadastre lies extraordinarily far north.

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[21] Although Béziers has three known large-scale cadastres, the first (and for several years the only) cadastre to be detected was cadastre A (Clavel-Lévêque 1970). Admittedly this cadastre, being the latest, is the most obvious, particularly to the immediate east and to the south of the city, but the other cadastres are almost as obvious elsewhere. Could the early detection of cadastre A be due to its orientation, almost due north, which conforms to agrimensorial astronomical theory and also to our personal experience with modern maps?

[22] Volume 15, part 5.

[23] Legros regards this cadastre as clearly visible, but he finds its existence difficult to explain, because of the status of Reims as the *civitas* capital of a tribe especially friendly to Rome. Clearly Legros had difficulty because he had to make an effort to imagine a centuriation in this context; he may have been influenced by the traditional thinking described above.

Cadastres et Espace Rural also includes an article (Chouquer 1983a) which attempts to establish a theory of the dynamic morphology of Roman cadastral systems as a class. In other words, Chouquer tries to show how such systems may degrade into the forms that we now see. One of his areas of study, the Po valley, provides many examples of cadastres in which we may suppose that different parts are at different stages of degradation. Chouquer was thus able to formulate a number of model sequences of degradation, into which these examples fit.

Finally, *Cadastres et Espace Rural* contained new studies of cadastres which hinted at, but did not fully reveal, a most curious and almost totally unexpected relationship between cadastres and oblique features. Monique Clavel-Lévêque (1983b: 242) observed a relationship between Béziers A and a section of the (Roman) "voie domitienne" west of Béziers, southern France. She described it as follows: "A partir de Ponserme et jusqu'à Béziers tous les *decumani* coupent la voie à un coin de centurie avec la plus totale régularité". Similar relationships can also be seen in Chouquer's article on the location of the Orange cadastres. In the central part of Orange A there are three Roman roads, all passing through the corners of centuries, and one of them has the same angle as seen at Béziers, i.e. 1:2. However, these particular curious coincidences were not reported by Chouquer, although another example brought to light by the Besançon team at the same time was a 3:4 relationship east of Béziers (Chouquer, et al. 1983: 88) [24].

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[24] These results had been partially anticipated by two Italian workers, (Morra and Nelva 1977). They put forward a theory concerning oblique relationships between neighbouring cadastres, with particular reference to the north Italian plain. The first step in their theoretical procedure, which would explain why the angle between a number of neighbouring grids is Tan^{-1} 1/5, involves constructing a line at 1:5 through nodes in an existing cadastre which would form the basis of a new one. They preferred to concentrate on examples which are at this angle, because of the supposed ritual significance of the number five, but they also conceived of the possibility of other angles such as 1:2, 1:3, etc. Thus their theory went some way towards the more general theory described below *(4.1.1)*.