EUROPEAN COMMISSION

SCIENCE RESEARCH DEVELOPMENT

Environment and climate programme

AGUAS PROJECT

Palaeoclimatic reconstruction and the dynamics of human settlement and land-use in the area of the middle Aguas (Almería), in the south-east of the Iberian Peninsula

Contract No: EV5V-CT94-0487

Research results

EUR 18036 EN

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Edited by:
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Directorate-General
Science, Research and Development

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1. INTRODUCTION

The Aguas Project was designed in order to investigate the evolutionary dynamics of metastable systems and the role of human practices as a crucial factor in the desertification and degradation of the Mediterranean region. The specific project objectives were:

1. To establish the variation and magnitude of palaeoclimatic conditions manifest in cultural and contexts in the area of the middle Aguas between 4000 BC and 800 BC, and its relation to the present day situation.
2. To elucidate ecological changes which have occurred prior to human occupation.
3. To identify the phases of expansion and contraction of human occupation as manifest in archaeological and palaeoenvironmental data.
4. To employ these data to evaluate existing models of human-environmental interaction and their relationship to disturbance, stability and resilience in the evolution of socio/natural systems.
5. To construct a Geographical Information System (GIS) for the middle Aguas (Vera basin, Almería), so as to provide a framework within which environmental data (geology, soils, vegetation) and archaeological/historical data (settlement patterns, exploited resources, trends in economic production) can be combined in order to generate an understanding of long term dynamics and to use as the basis for modelling human settlement and associated land-use changes.
6. To propose a new interpretative model of the long-term metastability of the human-modified environments of the middle Aguas between 4000 BC and 800 BC.

These objectives were maintained throughout the project, but the temporal and spatial limits were extended. Instead of considering the year 800 BC as the upper temporal limit, the analysis was extended up to the present day. Geomorphological investigations were carried out in order to understand the palaeo-climatic changes before 4000 BC. Spatially, not only the middle Aguas but also the lower Aguas were included in the analysis. The expansion of the project dimensions allowed us to consider a whole variety of ecological situations, ranging from intermontane basins and slopes to badlands and river and marine terraces located in the lowlands. This has been of prime importance in order to gain a better insight into the relationships between the human and natural variables.

The reports of all the participants add up to around 350 pages and more than 40 maps, while the database of the project is 250 additional pages. The coordination team of the Aguas Project was asked by the DGXII to present a synthesis of the main results of these two years of research in a final report, which is the text here presented. It is also intended to publish all the scientific contributions of the Aguas Project in their full length in a separate monograph.

The scope and complexity of the factors and relationships addressed, implies the transformation of conventional research strategies bound to disciplinary discussions into an integrated approach directed towards interdisciplinary collaboration. Therefore, one of the main targets of the Aguas Project consisted of the development of an integrated and coherent epistemology for this type of socio-natural investigations, that can be transferred to other periods and places. This implies the development of a general theory which gives sense to and structures the socio-ecological research in relation to the proposed objectives (chapter 2).

The complexity of the social and environmental questions we try to understand implies that the inferential framework which allows us to gain knowledge through empirical data can not be structured any longer around a monocausal axiomatic. Many of the questions we ask about the process of climatic change and/or degradation concern a whole set of environmental and social factors, which can appear to be related in apparently contradictory ways. Therefore, the methodological framework has been designed in relation to the multidimensional questions asked in the Aguas Project and in accordance with the theoretical structure of the project. The characteristics and the epistemological possibilities of each of the applied techniques are briefly described in chapter 3.

Chapter 4 defines the general environmental features of the area under study: the lower and middle Aguas valley located in the most arid part of Southeast Spain. A twofold modelling-testing approach allows us to build up important empirical knowledge of different types of scenarios (chapter 5). In this sense, the Aguas valley is used as a test case for the evaluation of successive alternative trajectories in the same spatial unit, which will contribute to the definition of the factors implying irreversible degradation and loss of natural resources for future economic cycles. Finally, the policy implications of the results presented here are discussed, including the proposal of an analytical method to define the spatial and temporal units of most ecological importance and those which can be economically developed most successfully and with less impact (chapter 6).

The temporal definition of the conclusions is provisional, due to the fact that C14 and Optical Luminescence samples are being processed at this moment. These absolute dates will contribute to a much more precise chronological resolution of the natural and social trajectories observed. This information has to be considered in the final publication of this report.

Institutions and researches which have participated in the Aguas project

Main institutions:

Universitat Autònoma de Barcelona (UAB): V. Lull - coordination; Regionaal Archeologisch Archiverings Project-Universiteit van Amsterdam (RAAP): R.Brandt; University of Reading (UR): R.Chapman; International Ecotechnology Research Centre-Cranfield University (IERC): J.McGlade.

Collaborating institutions:

Instituto de Conservación y Restauración de Bienes Culturales-Ministerio de Cultura, Madrid (ICRBC), Unisfère (US), University of Chicago (UCh), Universität Bremen (UBr), Universidad de Almería (UA), University of Cambridge (UC), Universidad de Granada (UG), University of Newcastle (UN), Universität Paderborn (UPD), Université de Paris-Sud (UP), Universitat de Barcelona (UB), Universidad de Valladolid (UV).

Researchers:

E. Aramburu (UA)	Archaeological survey
J. Buikstra (UCh)	Anthropology & Palaeo-nutrition
R. Brandt (RAAP)	Remote Sensing & GIS
P. V. Castro (UAB)	Palaeo-economy
R.W. Chapman (UR)	Eco-Archaeological survey & Palaeo-demography
G. Delibes (UV)	Archaeological Survey
L. Dever (UP)	Palaeoclimatology & Geohydrology
T. Escoriza (UA)	Archaeology Survey
Mª D. Fernández-Posse (ICRBC)	Archaeology survey & Digital Elevation Modelling
Ch. French (UC)	Soil Micromorphology
C. Gil (UA)	Soil science
S. Gili (UAB)	Economic Asessment of Natural Resources
Ch. Hagedorn (UBr)	Isotopic analysis
W. Herget (UPD)	Hydrology & Water Resource Management
J. L. López Castro (UA)	Archaeological Survey & Classical Archaeology
V. Lull (UAB)	Coordination
C. Martín Morales (ICRBC)	Archaeological Survey
J. McGlade (IERC)	Modelling
M. Menasanch de Tobaruela	Medieval Archaeology
R. Micó (UAB)	Agricultural Studies
D. Passmore (UN)	Holocene Geomorphology
J. Pätzold (UBr)	Isotopic analysis
R. Risch (UAB)	Palaeo-economy
C. Rihuete (UAB)	Anthropology

Mª O. Rodríguez Ariza (UG)	Palaeo-botany & Anthracology
Mª E. Sanahuja Yll (UAB)	Coordination
L. Schulte (UB)	Quaternary Geomorphology
A. C. Stevenson (UN)	Palaeo-botany & Palynology
P. Verhagen (RAAP)	Remote Sensing and GIS
G. Wefer (UBr)	Isotopic analysis

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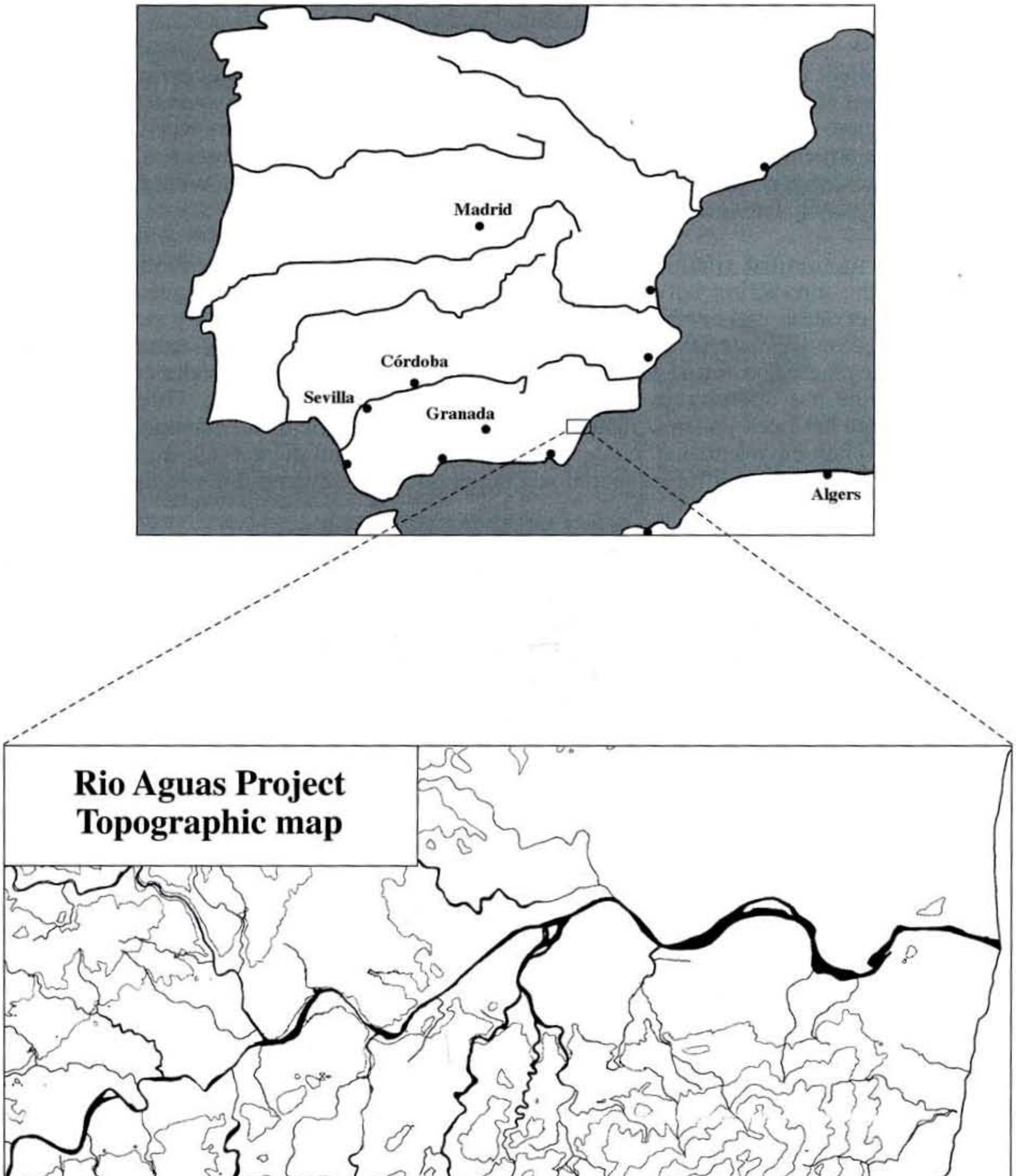
TEMPORAL SCALE		
Chronol. cal BC/AD	PERIOD	**Chronol. bp**
4000-3000	NEOLITHIC	**5200-4350**
	COPPER AGE	
2000	EARLY BRONZE AGE	**3600**
	MIDDLE BRONZE AGE	
1000	LATE BRONZE AGE	**2800**
	COLONISATIONS (Phoenician, Punic)	
0	ROMAN	**2000**
	EARLY MIDDLE AGE	
1000	AL-ANDALUS	**1000**
	MODERN AGE	
2000	PRESENT DAY	**0**

Table 1: Temporal scale of the Aguas Project.



Map 1: Spatial scale of the Aguas Project.

2. THE THEORETICAL STRUCTURE AND THE ECOLOGICAL MODEL

The editors.

The Aguas Project attempts not only to impliment different palaeo-ecological investigations and to produce a set of particular results, but also to further the discussion between disciplines and to integrate socio-ecological research into a multicausal explanatory framework. The present day academic structure, with its departmental organisation and the separation of social from natural sciences, is generally unsuited for the type of research necessary in order to address the complex relationship between societies and environment.

The general theoretical framework in which palaeoecological investigations take place emphasises the interaction between natural and social factors and distinguishes between empirical observation and conceptual abstraction (fig. 1). For the Quaternary period climatic conditions, geological material and relief provide the framework in which all natural and social dynamics take place. The aim of paleo-climatic research is, in our view, to understand the effect climatic change has upon environmental and socioeconomic conditions. Often, Holocene climatic change has been underestimated, in favour of technological and demographic factors, in order to explain environmental change. Yet today there is sufficient evidence which shows that climate is variable at different spatial and temporal scales, even if this variability over the last millennia is still ill-defined.

Through the combination of the natural elements of climate and geology, the hydric regime and the drainage system are defined. At the same time the formation of sediments, due to erosion, and of soils, takes place. This gives the necessary conditions for the development of vegetation. At the same time, but not on the same level as the climatic and geological conditions, vegetation, soils and water systems form a mutually related organisation, which allows the development of the biosphere and the specific environments. On the other side, drainage systems, sediment deposits, soils and flora have effects on climate and relief at different temporal and spatial scales. Therefore these natural elements can only be considered as indirect evidence of past climatic conditions.

At the moment of the appearance of human societies, three objective conditions have to be fulfilled so that social life can exist: men, women and the material objects which are used by them. The reproduction of society supposes a specific form of relation between these elements, that expresses itself in three types of production: *basic production,* the *production of material objects* and *maintenance production.* To place all three productions on the same level of social necessity allows us to acknowledge their interdependency (Castro *et al.* 1996b).

Basic production refers to the generation of new subjects, which provide the labour force that acts upon the environment, transforming it into social spaces. Taking this production into account means to consider the biological reproduction as a specific and socially necessary labour process.

The *production of material objects* refers to the generation of food supplies and all other types of products designed to be used or consumed.

Finally, *maintenance production* is responsible for the conservation and maintenance of social objects and subjects (male and female). This production allows the increase of the social value of things without changing its use value, either artificially or through labour invested in the improvement of the physical, chemical, affective and aesthetic characteristics of subjects and objects.

Each of the three productions contains specific material factors, whose causal links can be expressed in the following *basic economic scheme* (Risch 1995; Castro *et al.* 1996b):

$$NR + LF + MP => P$$

where:
NR = natural resources exploited and used by human society,
LF = labour force needed for the economic activities,
MP = means of production, which are implemented in these activities, and
P = the final product and the aim of every economic practice.

In each of the three productions, any of these factors is liable to be appropriated by agents which do not participate in the production process. If this leads to an unequal distribution of material and energetic costs and benefits in a society, a surplus production and, consequently, social exploitation is developing.

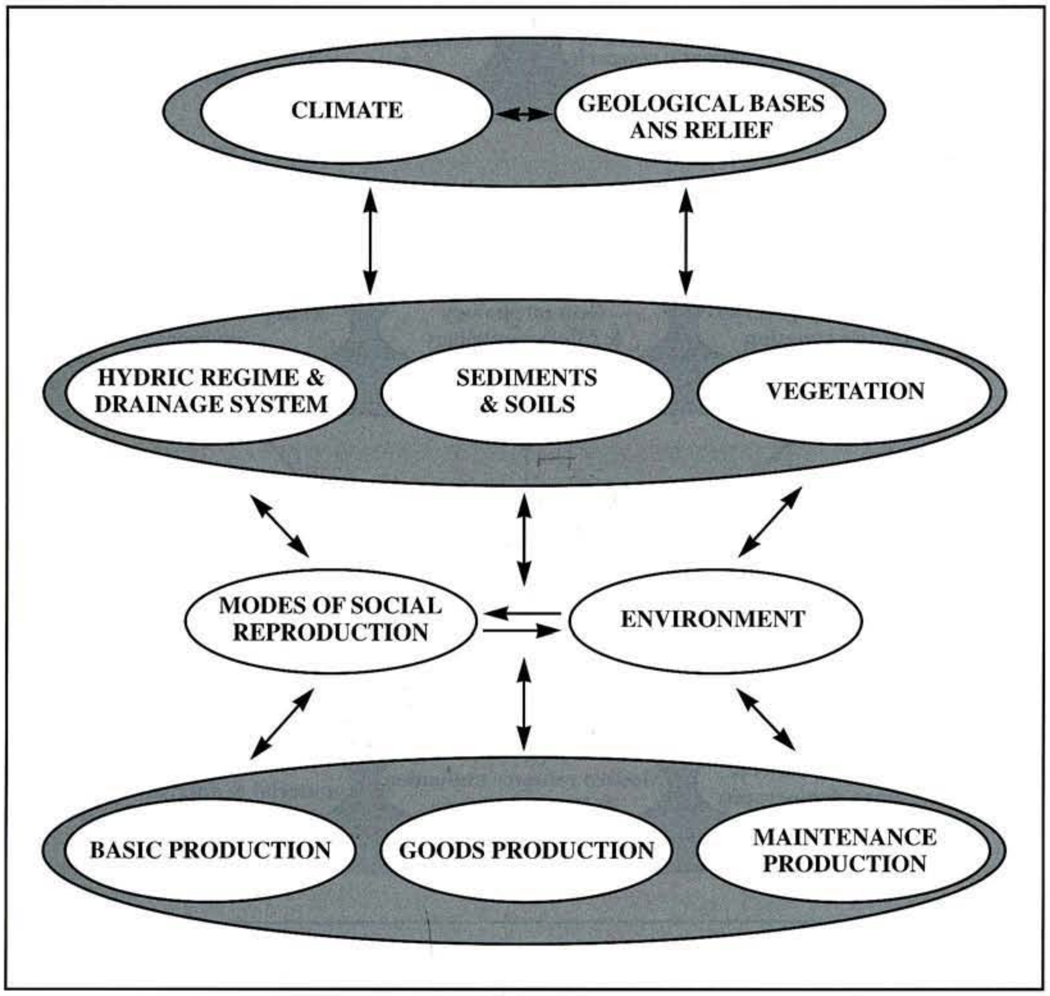


Fig.1: Theoretical structure of the social spaces.

The position occupied by the different individuals or groups in relation to the production and consumption processes of the different economic factors in the three productions is of prime importance in order to define the social relations of production. The combination of the social relations of production results in the *modes of social reproduction*. Here the different types of social organisations can be characterised in terms of: 1. the organisation of the production of subjects, objects and of their maintenance; 2. the individual or social benefits of the consumption of the generated products, and 3. the ecological costs of this social production and distribution of natural resources, products and labour force.

The natural conditions and the social production interact in two spheres, the first, which is socially conditioned, formed by the *mode of social reproduction*, the second, which is naturally conditioned, formed by the *environment*.. Both are physically expressed in to *social spaces*. The mode of reproduction describes and explains the relationships between men, women, their products and natural resources through *social productions* and specific *social practices* (Castro *et al* 1996b). The *social space* represents the integration of the *environment* into *territories* and *landscapes*. While in the territories the appropriation of natural resources and production takes place, the symbolic universe through which society perceives the environment and the territories configures the social landscapes. Both spheres, the mode of social reproduction and the environment, represent notions about the material world and they have empirically observable correlates.

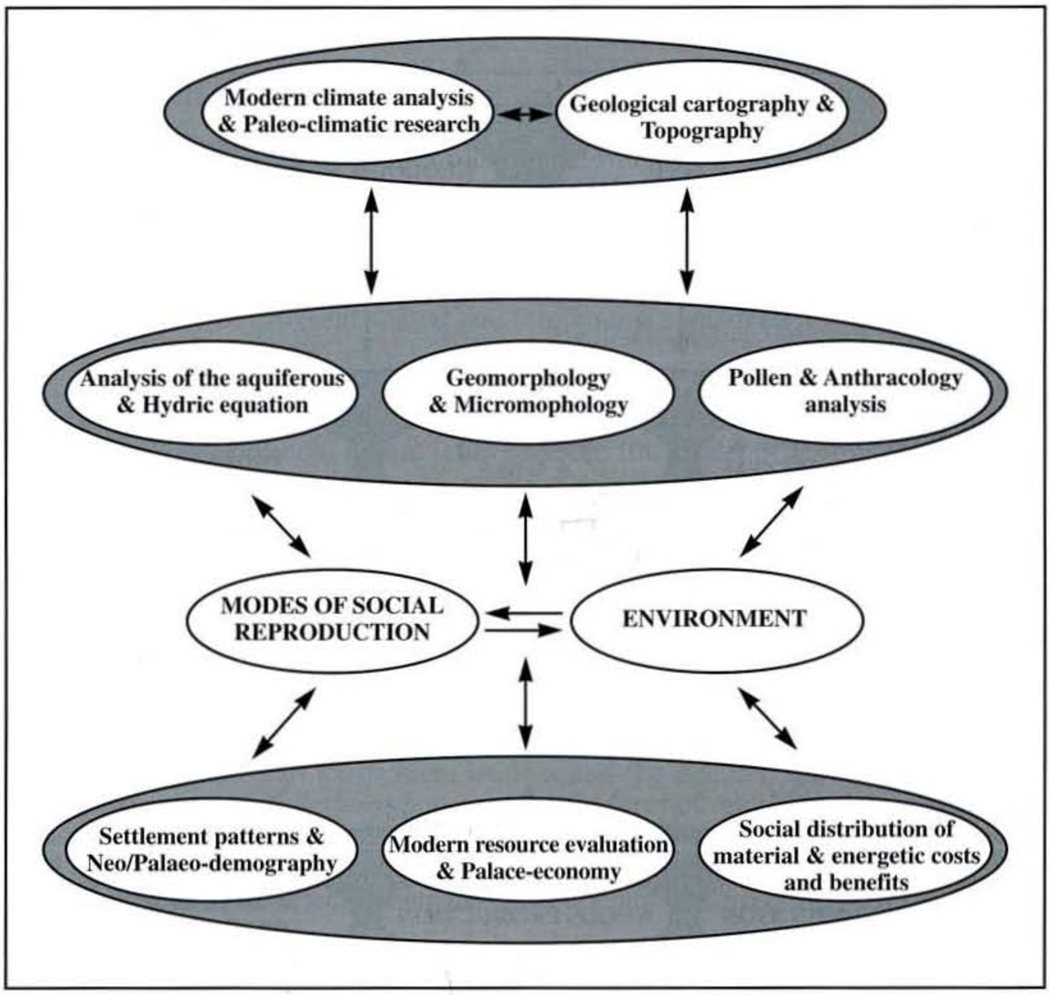


Fig.1: Theoretical structure of the social spaces.

Finally, this theoretical framework also implies the conceptualisation of the social and natural materiality. The archaeological and paleo-ecological objects can have three forms of appearance (Lull 1988):

1. *circundata*: naturally determined part of each object. They represent the environment and inform us about the natural conditions.
2. *arteusos*: Natural resources which have been socially appropriated and which have social benefit. They refer to the social exploitation of resources and inform us about the social spaces.
3. *artifacts*. Artificial products which constitute the physical means of society. They will inform us about the modes of social reproduction.

The articulation between environment and social territories, and between circundata, arteusos and artifacts forms the spatial and material expression of the interaction between human societies and nature. In an historical sense it defines and reflects the ecological situation under each mode of social reproduction. Nature and the social organisation are separate and at the same time mutually conditioned entities of our reality, so that the state and dynamic of one part reflects and effects the situation of the other. The proposed categories attempt to address and to represent this duality in the material objects and spaces, through which we perceive reality.

In this way, the paleo-ecological and archaeological objects provide all the possible information on the environmental conditions, the social management of their resources and the material means of exploitation. In order to obtain this information a complex structure of interdisciplinary research is necessary, where different methodologies proceed in independent analytical ways, but are mutually related in the explanation of the reality. One of the main outcomes of the Aguas Project is the development of this theoretical and methodological structure, which can be applied for eco-historical understanding and the climatic, ecological and socioeconomic assessment of the development possibilities of other regions[1].

[1] The full development and specific examples of the application of this theoretical framework can be seen in Castro et al. 1996a, 1996b, Lull 1988, Ruiz et al., 1992, Risch 1977.

3. THE METHODOLOGIES AND THE EVIDENCE

3.1. CLIMATIC ANALYSIS

3.1.1. Actual climatic conditions[2]

In order to understand past climatic trajectories and their changes, it is necessary to gain a better understanding of the present day situation. In southeast Spain the network of pluviometric stations is limited and most of the totalisers are placed in the larger towns and villages, located in the lowlands. The climate of the mountain or *sierra* areas, which constitute an important element of this environment and represent an important reservoir for different natural resources, is still insufficiently known.

In order to understand the actual climatic conditions of the middle and lower Aguas; two totalisers were installed in the catchment of the Rambla Añoflí (also called Rambla Ancha), which is a tributary of the Aguas coming down from the highest part of Sierra Cabrera. This catchment, which is also the subject of hydrological analysis (see below), represents a transect through the Sierra Cabrera and allows us to gain important information on the micro climatic conditions existing in the *sierra* environments of southeast Spain. The first totaliser was installed close to the hydrological gauging station (150m). The second one functioned in the neighbourhood of the Cortijo del Charco, which is still fairly accessible (250m). Measurements were collected either after rainfall, or at weekly intervals. Finally, the analysis of climatic data from neighbouring stations with long-term observations allows us to recognise periodicities in the rainfall of the region beyond the short-term observations of our totalisers.

3.1.2. Palaeo-climatic conditions

To talk about socio-natural interaction or co-evolution implies that we are able to differentiate climatic from anthropogenic variables that act upon the environment. The definition and understanding of both types of variables needs to be based upon a rigorous methodology, i.e. one that presents an explicit axiomatic and well defined strategies of interpretation and verification. In general, palaeo-climatic research involves three problems:

1. The epistemology of climatic research. It is of prime importance to establish the relationship between the evidence and its climatic implications. In many cases it is impossible to establish a mechanical link between the material evidence and the climatic or environmental situation, and the verification of a certain hypothesis (e.g. desertification, increase in pluviosity, etc.) will depend on the ways in which we are able to establish causal links between different types of evidence (pollen, erosion, hydrology, etc.). A linear reading of one type of empirical research will only give in very few cases a final answer to our questions.

2. Temporal resolution. In the first place, we need to use an absolute and calendric temporal scale. For many years it has been known that dates provided by, e.g., dendrochronology, C14, thermoluminescence, varves, etc. are not comparable; not only because of their different degrees of precision, but also because the temporal scales are different, and imply different calibrations. In the second place, it is of prime importance to define what it is we are dating, and, what is the relationship between the date and the palaeo-ecological context. In the third place, the relation between the date and the temporality of the event should be specified. The response of a certain natural element to a given climatic change might be slow, while other parts might react much faster.

3. Spatial resolution. In a similar way to the temporal aspects, the spatial resolution of the palaeo-climatic evidence has also to be defined. When comparing the results on Holocene climatology from different European or North African regions, one is surprised about the important differences between one region and another. The question remains in many cases if we are looking at climatic differences on a regional scale, which would be very interesting to understand, or if the patterns are only the result of dating problems or induced by an insufficient epistemology.

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[2] W. Herget, Universität Paderborn (DE).

In general, it would be important to define for each type of palaeo-climatic evidence the following points:

1. The suitability of the empirical data as climatic evidence.
2. The method used for dating the empirical data.
3. The accuracy of the dating method, its temporal scale and calibration.
4. Relation between the date of the sample and the date of the climatic evidence.
5. Spatial scale of the climatic evidence.

The palaeo-climatic research in the Lower Aguas was based on a twofold strategy, one consisting in the analysis of more or less direct climatic indicators, and another one based on indirect evidence. In the first case, isotopic and trace element analysis on organic and inorganic materials are of prime importance as they constitute, when distorting effects on the compositions can be ruled out, tracers of environmental and climatic conditions. In the second case, palaeo-botanical analysis, micromorphological study of palaeo-soils and geomorphological analysis of sedimentary deposits were undertaken. Here the climatic information can be obliterated by other factors, mainly anthropic action. This differentiation between anthropic and climatic factors depends on the methodological development reached by each type of research applied.

3.1.2.1. Isotopic studies of secondary carbonates[3]

The chemical and isotopic composition of continental carbonates can be a good indicator of the environmental conditions existing in the soils at the moment of their precipitation. When we are dealing with palaeo-soils the past climatic conditions can be established. The contents in O^{18} allows us to approach the variation of temperatures. On the other side, the content in C^{13} signals the types of soil occupation and the intensity of photosynthetic activity. The understanding of the isotopic variations (ε) at the moment when the liquid phase (b) and the solid phase (cal) changes is a necessary step in order to determine on a temporal scale the C^{14} activities measured on the carbonates.

This analysis was carried out on two sections at the southern slope of Gatas (sections of the archaeological sondages 2 and 4). This provides an isotopic sequence for the third and second millennia cal BC.

3.1.2.2. Analysis of stable isotopes O^{18} and O^{16} in *Glycimeris* shells[4]

The isotopic analysis of marine shells can be of prime importance for the reconstruction of past temperature changes. This palaeo-climatic approach is based on the fact that the relationship O^{18}/O^{16} is temperature dependent, if the following conditions are provided:
1. That the $CaCO_3$-shells were formed under thermodynamic equilibrium with the surrounding water environment with stable salinity (Craig and Gordon 1965).
2. The isotopic composition of the shells are not altered after formation by diagenetic processes.
3. The shell-growth takes place during the whole yearly temperature cycle.
4. The evaluation of the isotopic composition of sea water, in which the shell was formed, should be possible (Rye and Sommer 1980).

All these conditions are fulfilled in the case of the *Glycimeris violascens* and *Glycimeris glycimeris* shell, common along the Mediterranean coast of the study area. The topography of the Aguas river mouth and its aquifer (Carulla 1977), allows us to consider that the salt content in the sea is constant in this area. The analyses undertaken do not suggest that diagenetic processes altered the isotopic composition of the shells. The values obtained from a present day shell, collected on the beach of Mojácar, confirm that it is possible to identify the annual water temperature variability, at least during the first years of shell growth. The calculated temperatures are slightly higher than the actual ones, which might be a consequence of the fact that the available water temperatures come from points far away from the coast.

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[3] L. Dever, Université Paris Sud (FR).
[4] J. Pätzold, Ch. Hagedorn and G. wefer, Universität Bremen (DE).

The fact that these shells were collected by past populations and incorporated into habitation debris, offers a unique possibility to date this diagnostic material with a high degree of accuracy. The result is a sequence of marine paleo-temperatures which can be related to past climatic situations.

In total, 13 *Glycimeris* shells were analysed. 12 come from different contexts of Gatas, and one, as mentioned before, is a recent example from the present day beach at Mojácar. The shells were cleaned, cut in halves and between 30 to 50 samples of 0.1 mg were extracted from each shell. 532 samples were analysed in total. The isotopic measurements were obtained with a mass spectrometer Finnigan Mat 251 with automatic C preparation of Kiel-type. The accuracy of the measurements is ±0.07‰ for the O isotopes and ±0.1‰ for the C isotopes. The obtained maximum and minimum ∂O^{18} values of each shell were calibrated with the palaeo-temperature equation from Epstein *et al.* (1953).

3.1.2.3. Trace element analysis on human bones[5]

Although trace element analyses form part of the anthropological studies undertaken on prehistoric skeletons in the context of the Gatas Project, their results are included in this report because of their relevance to the reconstruction of the paleo-climatic conditions.

Biochemical analysis of human skeletons can provide information relevant to ecological reconstructions. One technique that appears particularly promising for defining general ecosystem characteristics is based on levels of two trace elements, barium (Ba) and strontium (Sr) within the apatite fraction of bone. According to Burton and Price (1990a, 1990b), analysis of Ba/Sr ratios provides distinctions between individuals drawing sustenance from terrestrial, desert, and marine ecosystems. In this case we are specially interested in identifying if the Ba/Sr ratios of the human bones from the Aguas valley correspond to desertic conditions. At the moment this material is only available from the archaeological site of Gatas. Samples from three human skeletons, which can be dated in the first half of the second millennium cal BC, were analysed.

3.2. GEOLOGY AND RELIEF[6]

The only aspect of the Aguas valley which have been studied in the past in great detail are the pre-neogene and tertiary geological formations existing in the area (Rondeel 1965; Völk 1967a and b; Völk and Rondeel 1964). Yet, the results of series of geological projects undertaken have never been published in detail. Therefore the Aguas Project has not undertaken new geological fieldwork, but has concentrated on the recovery of the existing documentation and on the introduction of the relevant cartographic material into the Aguas G.I.S.

Apart from Rondeel's, Völk's and the Spanish geological maps (MGE-Sorbas 1975; MGE-Mojácar 1974), a 1:10.000 geological map was made in 1986 and 1987 by S. van der Schouw, from the Department of Structural Geology of the Vrije Universiteit of Amsterdam. It covers the area east of UTM 597 on the north side of the Sierra Cabrera. The study was focused on the Pre-Tertiary rocks of the *Alpujarride* complex and aimed at the establishment of a reliable stratigraphy. Nevertheless the tectonic complexity of the area made this task very difficult. In 1986 E.Sennema, from the same department, produced a map at 1:25.000 of the Tertiary deposits of the south edge of the Vera Basin, including the Aguas valley. It mainly confirms the observations made by Rondeel (1965) and Völk (1967a).

The relief of the Aguas valley was established on basis of the 1:10.000 topographic maps of the *Junta de Andalucía*, which were digitized and introduced into the Aguas G.I.S. The formations that form the present day relief were determined through the geomorphological study of the Aguas valley (see below).

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[5] J. Buikstra and L. Hoshower; University of Chicago (USA).

[6] L. Schulte, Universitat de Barcelona (ES) and Ph. Vergahen, R.A.A.P (NE).

3.3. GEOMORPHOLOGY, EROSION AND SOIL FORMATION PROCESSES

3.3.1. Geomorphology[7]

The objectives of the geomorphological fieldwork and research were as follows:

1. To document the successive phases of excavation and deposition of rocks and sediments which occurred during the Quaternary through a morphological, pedological and sedimentological classification of the successive generations of glacis, river terraces and soils. The structure of these deposits mirrors the different fluviodynamic regimes, which are linked to specific palaeo-climatic conditions (e.g. glacial/interglacial periods), as well as to anthropic impact on the environment (e.g. deforestation).
2. To investigate morphology, depositional environment and chronology of Holocene alluvial and colluvial valley fills within selected areas, and thereby assess the local environmental context of human occupation in the Lower Aguas.
3. To assess the potential of fine-grained alluvial and lacustrine sediments in the study areas for palynological analysis and micromorphological analysis.
4. To examine the linkages between patterns of catchment-wide sediment erosion, transfer and storage and Holocene land-use and climate change. Of particular importance here is the elucidation of linkages between human activity and the geomorphic stability of hill slope and gully systems.

The relief forms (pediments, alluvial fans, glacis, river and marine terraces) were mapped through air photographs, scale 1.18.000 (I.G.N. 1985), satellite images (SPOT) and systematic field work. At the key depositional outcrops a detailed morphostratigraphical description was carried out, which included sedimentological and edaphological analysis. The chronological classification of the visible Quaternary pelaeogeographical events was established on the basis of the relative height of the different deposits, of its stratigraphy, of the palaeo-soils, and their correlation with the morphostratigraphy of the central and northern part of the Vera Basin (Schulte 1994, 1995; Wenzens 1991). All of this was supported by U/Th dates for the early and middle Quaternary formations. Further C14 and OLS dates for younger formations are still being processed at this moment.

3.3.2. Micromorphology[8]

During the course of the project, the upper and middle reaches of the Rambla Ancha or Añoflí to the northeast of Gatas, the lower reaches of the Rambla Ancha northwards towards Turre, and the lower Aguas valley to the north of Las Pilas were thoroughly investigated by Dr D. Passmore, Lothar Schulte and Ch. French. A series of 14 sections were identified, described (map 2) and photographed from this geomorphological survey. 31 samples were taken from 11 of these profiles as well as three bedrock locations for micromorphological analysis. A further 21 sample blocks were also taken for micromorphological analysis from the cultural layers at Gatas. All sample blocks from the geomorphological survey and Gatas were made into 'mammoth' thin sections in the Geoarchaeology Laboratory, Department of Archaeology, Cambridge University. The methodology of Murphy (1986) and the descriptive terminology of Bullock *et al.* (1985) were used throughout. The detailed thin section descriptions are held in archive form at the Department of Archaeology, Cambridge.

In addition, representative samples of the marl bedrock and various colluvial sediments were taken for bulk density and shear strength tests. These analyses were undertaken in order to establish the susceptibility to and threshold at which a sediment will move downslope. An estimate of the natural ability and susceptibility of this material to move downslope may provide a crude 'index of erodability', and therefore give an idea of the propensity for environment modification in the area. Also, the marl-bedrock sediment was examined using a scanning electron microscope to establish its exact composition and to aid in the interpretation of the reworked marl sediments which commonly occur throughout the project area.

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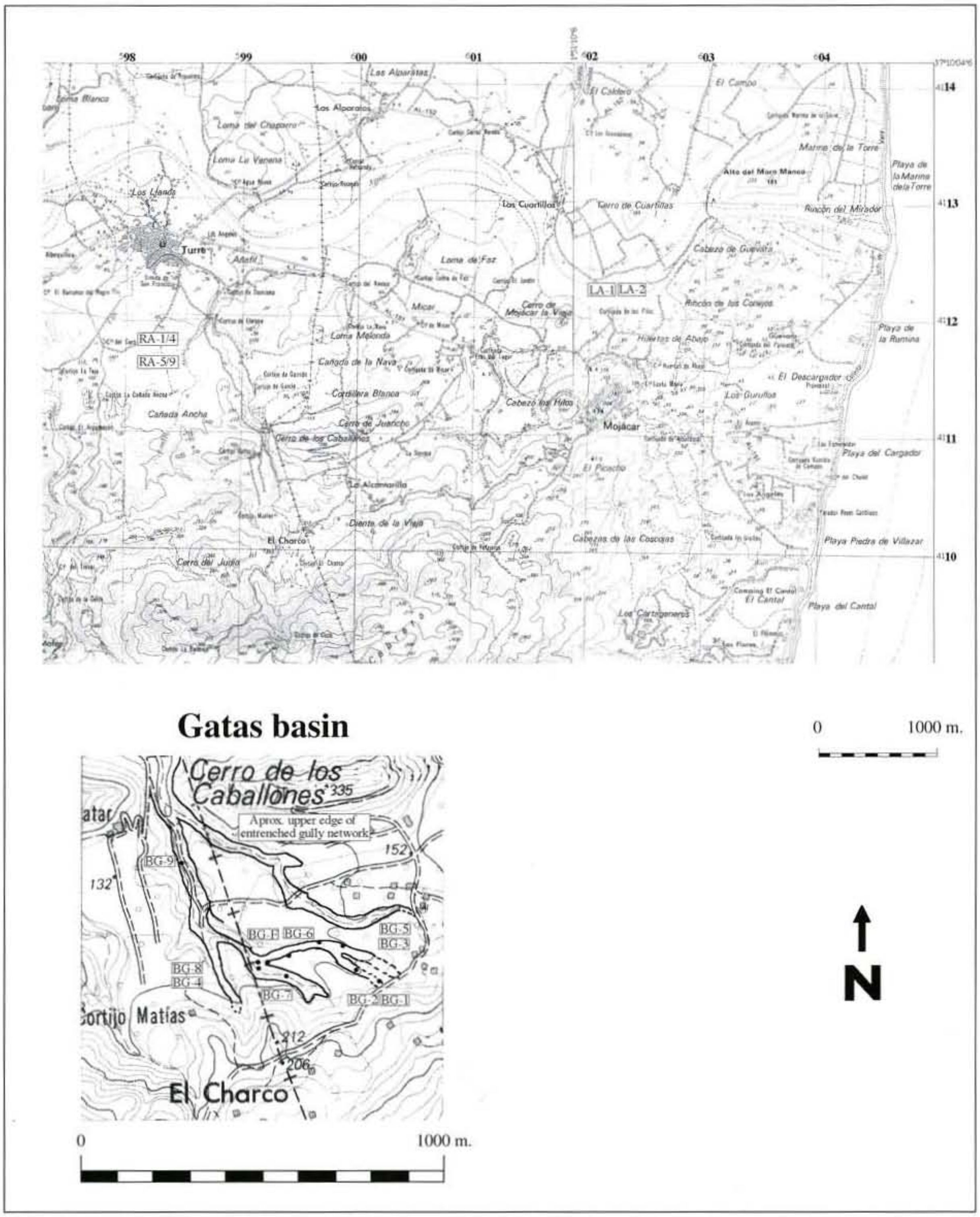
[7] L. Schulte, Universitat de Barcelona (ES); D. Passmore, University of Newcastle (UK).

[8] Ch. French, University of Cambridge (UK).



Map 2: Areas where detailed geomorphological and micromorphological analysis were carried out.

The micromorphological samples were obtained from the following profiles (map 2):

1. Gatas basin

A series of seven profiles were recorded and sampled in the middle reaches of the Barranco de Gatas (BG). Profiles 2 and 3 examined possible palaeosols overlain by debris flow deposits at the head of the barranco, profiles 4 and 8 examined laminated deposits associated with terrace formation mid-way down the barranco and below the Gatas site, and two sets of spot samples were taken from the Quaternary marl and fine laminated deposits.

2. Rambla Ancha/Añoflí reaches
A further series of six profiles were recorded and sampled from the lower reaches of the Rambla Ancha (RA). These were taken from the upper colluvial/alluvial units infilling the terrace/river channel units 5, 8, 16, 21 and 22, and from the marl subsoil of an associated tributary valley.

3. The Lower Aguas basin
At the base of the slope immediately below the Las Pilas site (LA), there was an excellent exposure through the slope/terrace interface which was examined and recorded (also see Schulte, this volume). Abundant sherds of pottery were present throughout the profile, some of which were similar to the Copper Age undecorated plain wares from the Las Pilas excavation itself. The stratigraphy in section LA-1 revealed about 1.5m of colluvial silt overlying 65cm of calcitic silt which gradually merged with an immature soil of about 40cm in thickness. This soil was developed on further deposits of calcitic silt alternating with thin lenses of calcium carbonate. Towards the base of this material, there was a thinner and more poorly developed soil, resting on a marl subsoil. Eight sample blocks were taken for micromorphological analysis from the main horizons of this sequence, and both the upper and lower colluvial deposits were also sampled for bulk density and liquid/plastic limit determinations. To complement the examination of the marl subsoil material undertaken for the Barranco de Gatas and Rambla Ancha areas, a marl subsoil exposure about 1km upslope and to the southwest of the Las Pilas site was sampled for bulk density and liquid/plastic limit determinations.

3.4. HYDRIC REGIME AND DRAINAGE SYSTEM[9]

The hydrological investigations carried out in the context of the Aguas Project were based on the following considerations:
1. The study of the present day water circulation offers the basis for a modelling of present as well as past situations in relation to water resources.
2. The identification of the low stream flow and its seasonal fluctuations provides information on the amount of water available in the system. As a premise, one can say that the present day ecological situation of the environment is the driest stage since the early Holocene. Thus, the present day measurements represent an absolute limit, which does not seem to have been exceeded during the last millennia. This gives us a quantitative figure of the availability of resources during prehistoric and historic times. Furthermore this allows us to gain knowledge on the functioning of the local aquifers.
3. While climate, vegetation and sediments were submitted to major anthropogenic and non-anthropogenic changes during the last 6000 years, the behaviour of the aquifers seems to have been relatively stable.
4. During the summer of 1994 a forest fire destroyed the whole northern side of the Sierra Cabrera. From a hydrological point of view this means that the influence of vegetation and therefore of transpiration is largely minimised. Thus, the discharge measurements become a clearer indicator of the behaviour of the aquifer.

The hydrological situation of the area is evaluated be means of a hydric equation. Given the absence of previous data and the time and resources available, this research concentrated on a detailed analysis of the Añoflí catchment, a tributary of the Aguas (map 3). For this area the following equation is suggested:

$$I = O + S$$

where
I = inflow, O = outflow, S = storage

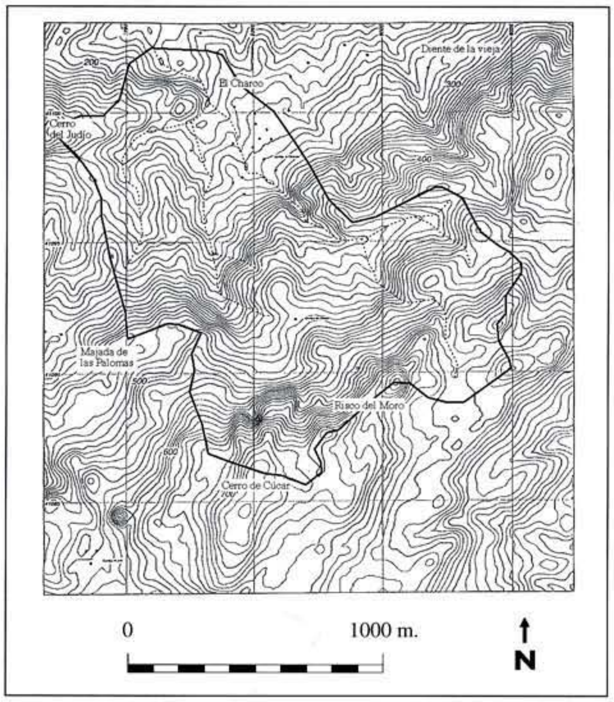
[9] W. Herget, UniversitÄt Paderborn (DE).

That equation can be adapted in the following way:

$$P = D(Sp_{Ch} + Sp_{Cu} + Sp_{Ga} + A) + ET_{pot} + U + \Delta S$$

where:
P = precipitation
D = discharge in the barranco
ETpot = potential evapotranspiration
Sp_{Ch} = spring affluent of Fuente del Charco
Sp_{Cu} = spring affluent of Fuente del Cucar
Sp_{Ga} = spring affluent of Fuente de Gatas
A = otherwise affluents
U = underground affluents
ΔS = charge in storage

As mentioned above, the official data base is very scant. Water maintenance institutions have not undertaken any measurements in the last years nor have they established a hydrological equation for the area. The information concerning present and past irrigation infrastructures is also very poor since, according to the Water Board in Almería, no written documents exist for the Añoflí territory. Some information should exist in the archives of the *Confederación Hidrográfica del Sur* in Málaga, but several written requests sent to this institution proved unsuccessful.



Map 3: Gatas and the upper rambla Ancha or Añoflí area used for the description of hydric cycle, hydric flows and traditional water use.

The interviews held with inhabitants of the area provided some general information about the hydrological situation in relation to the behaviour of a partial aquifer and with reference to the main events of the water management.

During the first trip we established the catchment area in which the gauging station was installed (map 3). It embraces Barranco del Cantón, Barranco del Charco and Barranco del Salto, which come together in the Añoflí or Ancha watercourses. At its deepest point a gauging station was set up. Emilio Aramburu Escolano, from Mojácar, has been measuring data from this station, as well as from the totalisers, every week since the end of January. The automatic water stage recorder presented several problems due to the extreme temperatures in the area during the first year. It had to be brought back to Paderborn, where the whole system could be checked over and reset.

3.5. VEGETATION DYNAMICS

The present day vegetation of the middle and lower Aguas could not be studied in the context of the project, as a dramatic wildfire occurred during the summer of 1994 and destroyed the whole northern side of Sierra Cabrera. Nevertheless, some detailed analyses of this area were carried out in the past (e.g. Ferres and Risch 1987). The botanical studies of the Aguas Project concentrated mainly on the Holocene vegetation dynamics, which are still insufficiently understood in the Southeast of the Iberian Peninsula.

3.5.1. Pollen studies[10]

Unlike other areas of Spain, the southeast has had very few studies conducted upon it since the very arid climatic conditions are not conducive to pollen preservation in sedimentary systems. The approach taken in the Aguas Project was twofold. One consisted in the extraction of three pollen columns in combination with the geomorphological survey. A 4.3 metre sediment core was obtained from Cortijo del Campo (20 m) (map 2), located in the floodplain of the lower Aguas valley. Samples at 8 cm intervals were submitted to conventional pollen preparation techniques (Moore *et al.* 1991). Two c. 2 metre cores have been recovered from two montane basins (650-700 m) at the highest area of the Sierra Cabrera, Balsa del Marchalico and Balsa de Alquirrico de los Peñones. This allows us to compare the vegetational dynamics of the two extreme ecological situations found in the Aguas valley. Together with the previous data from Gatas (253 m) this gives us a vegetational transect through from the top of Sierra Cabrera to the coastal areas of the Aguas valley. The second approach consisted of a thorough revision of the data obtained by other botanists that have worked in the area during the past, specially the pollen samples obtained by B.Mariscal in the context of the Archaeomedes project.

3.5.2. Anthracology[11]

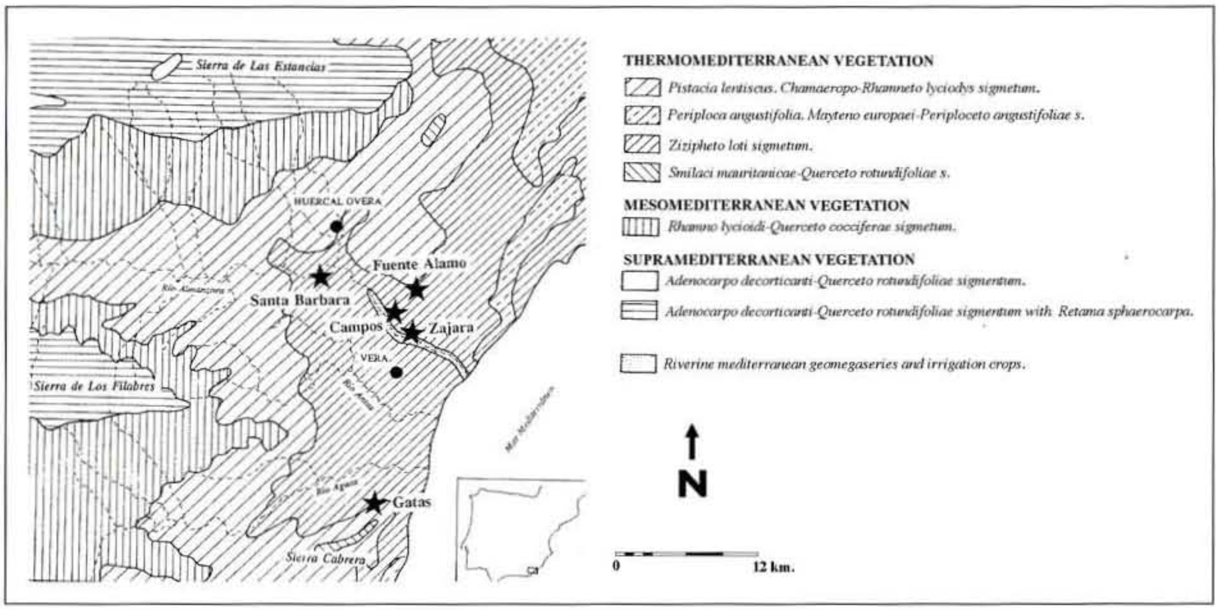
Anthracology is a relatively new discipline and its role in the reconstruction of vegetation in the first place and, indirectly, also of past climatic situations, has been underestimated for a long time. Only lately has it become clear that palynology and anthracology are complementary methods which can offer a detailed reconstruction of past vegetation and its social exploitation.

The process followed by trees or shrubs from their past habitat until the present day, when their remains are interpreted in palaeo-ecological terms, is long and consists of several stages which modify the simple correlation between identified flora and past vegetation. Each anthracological spectrum represents a strongly synthesised information source on the original situation. It does not give direct information about the total amount of burned wood, the precise area of exploitation, the degree of degradation or the structure of the vegetation. All this information has to be obtained by means of statistical techniques and palaeobotanical insight. Basically, one can distinguish four main stages:

1. The stage of the use of vegetation, related human exploitation practices, such as gathering of wood and transformation of wood in the settlements.
2. The stage of deformation of the anthracological spectrum, where different factors are implied: chemical factors which reduce the wood mass through carbonisation; environmental factors, where the charcoal deposited in the archaeological sediments is submitted to postdepositional processes which distort and/or filter the information.
3. The stage of collection of anthracological samples in the context of archaeological excavations. In the case of the Aguas Project charcoal remains were obtained through systematic recovery strategies during excavation as well as from the flotation of sediments.

[10] T. Stevenson, University of Newcastle (UK).
[11] Mº Oliva Rodríguez Ariza, Universidad de Granada (ES).

4. The stage of the strictly anthracological study, where the charcoal remains of each site are identified, measured and counted. Here we apply the specific methodologies of the anthracological discipline.



Map 4: Vegetation series of the Vera basin and the location of the sites with anthracological analysis.

Most of the anthracological samples studied and evaluated in the Aguas Project come from the Gatas site, and cover a temporal span between 2800-1000 cal BC and c. 950-1100 AD. All this material had been identified by R. Gale in the context of the Gatas Project. The ecological interpretation of this material was undertaken considering also the anthracological samples from different Copper and Bronze Age sites in the Almanzora valley, located at the northern side of the Vera basin (Zájara, Campos, Santa Bárbara, studied by Mª Oliva Rodríguez Ariza, and Fuente Alamo, studied by Schoch and Schweingruber, 1982). These sites (3000-1300 cal BC) cover approximately the same time span as Gatas in the Aguas valley. The comparative analysis allows us to gain better insights into the regional variability and to obtain wider empirical support for the vegetational dynamics in southeast Spain.

3.6. SETTLEMENT AND DEMOGRAPHY[12]

3.6.1. Intensive and extensive archaeological survey

Archaeological survey may take a number of different forms, but on the whole it aims to recover information about extant surface archaeological remains. Therefore, it does not purport to recover material representative of what was once in existence, but what is accessible now (Cherry 1984:118). However the results of such survey will enable us to make inferences about past settlement and demographic dynamics using more representative samples of the material traces of past human activities. Survey is also more than merely recording and collecting artifacts lying on the surface; it often makes observations about known sites, as well as identifying new ones. It can also gather information on current land use, geology, soil types, natural features within the territory, the location of natural resources (clay, water, building materials, minerals) and can highlight areas or sites which are being threatened by human and/or natural processes.

In the case of the Aguas valley survey, we began by examining the known archaeological record for the middle and lower Aguas valley. Archaeological sites from different periods of the

[12] The editors.

Holocene have been discovered here during the last hundred or so years, either as a result of intentional searching (e.g. by the Siret brothers in the 1880s, or by the Vera basin survey of the Almizaraque project in the 1980s), or by fortuitous processes, such as construction and destruction of buildings and roads, quarrying, erosion of terraces, etc). The EU-funded Archaeomedes project established a data base of 221 archaeological sites from the fifth millennium BC to the fifteenth century A.D, for which cultural and locational attributes were recorded (see Castro *et al.* 1994).

Building upon this existing knowledge, we decided to undertake two kinds of survey: selective survey and systematic survey.

1. Selective survey aimed to evaluate the known archaeological sites in the middle and lower Aguas valley, recording the distribution and density of surface materials, collecting diagnostic cultural materials for dating, preparing a photographic record, and recording such locational attributes as the UTM coordinates, the height above sea level, and the local topography; this work was undertaken by E. Aramburu, T. Escoriza and J. L. López Castro (University of Almería), G. Delibes (University of Valladolid), Ma. D. Fernández-Posse and C. Martín (I.C.R.B.C. del Ministerio de Cultura).

2. Systematic survey aimed to walk a transect of 8km length and 1km width along the rambla de Mófar, from the top of the sierra Cabrera (Cerro del Arráez at 918m) down to the Aguas river immediately to the west and north-west of Turre. The choice of this transect was based on an evaluation of existing site distributions and knowledge of where previous surveys had taken place within the middle and lower Aguas. It provided a means by which the locational and altitudinal distribution of known archaeological sites in the Aguas could be checked against the new data from a previously unsurveyed area. This survey was carried out by R. Chapman (University of Reading) with R. Micó (Universitat Autònoma of Barcelona).

The systematic survey transect was examined using a combination of the 1:25,000 sheet (1031-II) of the Mapa Topográfico Nacional for Turre, the 1:10,000 sheets (1031 4-1 and 4-2) of the Mapa Topográfico de Andalucía, and eight 1km square sheets taken from the 1:5000 scale airphotomosaic of the *Centro de Gestión Catastral y Gestión Tributaria del Ministerio de Hacienda* in Madrid (sheets 1031 10 01, 1031 10 02, 1031 10 03), taken during a flight in 1991. These photos were enlarged to a scale of 1:2,500 and used as 40 x 40 cm sheets for recording in the field. The use of this aerial cover made visible patterns of modern vegetation, land use and settlement, enabled us to plan our survey strategies for different parts of the transect before going into the field, and allowed direct mapping of areas of surface cultural materials/sites found during the walking. The eight photos were numbered from 1 (the southernmost, to the north-west of Turre, by the Aguas river) to 8 (the summit of the sierra Cabrera at Cerro del Arráez).

Within each unit walked by the survey team, only potentially diagnostic cultural materials (e.g. identifiable pottery forms, decorated pottery, stone tools) were picked up and collected for study, with areas of concentrated materials and site locations plotted on the aerial photographs, as well as more detailed georeferencing (with a 2-5m error) using the Geographical Positioning System Pathfinder Basic XL machine produced by Trimble Navigation. The cultural materials were washed and catalogued during the September field season, and then removed to Barcelona for more detailed study. With the aid of specialist colleagues (especially Dr. J.L.López Castro and Montserrat Menasanch) and published sources, we attributed the "sites" defined to one or more of eleven periods between the Neolithic and the Reconquest (roughly the fourth millennium BC to the end of the fifteenth century AD). These periods are as follows:

1. Neolithic (c. 4000 - 3000 cal BC)
2. Chalcolithic (c. 3000 - 2250 cal BC)
3. Argaric (c. 2250 - 1550 cal BC)
4. Post-Argaric (c. 1550 - 900 cal BC)
5. Phoenician I (c. 900 - 200 BC)
6. Phoenician II (c. 200 - 27 BC)
7. Imperial Roman (c. 27 BC - 400 AD)
8. Late Roman (c.400 - 550 AD)

9. Visigothic-Byzantine (c. 550 - 718/750 AD)
10. Omeya (c. 718/750 - 11th century AD)
11. Nazarine (c. 1232/1237 - 1492 AD)

This periodisation is based on that used in the Archaeomedes project, except for the renaming of period 5 ('Colonisation' in Archaeomedes) and the subdivision of 'Romanisation' (in Archaeomedes) into 'Phoenician II', 'Imperial Roman' and 'Late Roman', and the subdivision of 'Andalusian' (in Archaeomedes) into 'Omeya' and 'Nazarine'.

3.6.2. Palaeo-demographic calculations

Out of the three types of production which structure the socioeconomic research of the Aguas Project (see above), the *basic production* determines the demographic dynamic in the Aguas valley. Thanks to the definition of areas of human occupation through the intensive and extensive survey, it is now possible to estimate the number of inhabitants living in this area from c. 4000 BC to 1600 AD.

Two palaeo-demographic formulae were applied to every single archaeological period and site, in order to obtain maximum and minimum values. Both formulae start from the extension of the area covered with human remains:

1) $P = 200 A$ (after Renfrew 1972)
2) $P = 146 SqrtA$ (after Kramer 1978)

where:
P = estimated population of the settlement, and
A = size of the settlement, measured as the extension in hectares of the archaeological remains visible on surface.

Nevertheless, the results obtained from these formulae were corrected by means of archaeological information on past occupation practices. Thus we took into account that during the Neolithic and Copper Age periods, each one lasting around 700 years, not all known sites needed to be occupied at the same moment, as has been confirmed by excavations in other areas. A mobile settlement pattern implied that villages were not occupied uninterruptedly during several generations. Only sites with a considerable stratigraphic sequence (e.g. Las Pilas) were considered as stable settlements existing during several centuries.

Another problem results from the low chronological accuracy of the archaeological material (hand made and coarse pottery) found on many early mediaeval sites. In some cases, where no other diagnostic material was found, this means that a site could be occupied during Late Roman (400-550 AD) and/or Visigothic-Byzantine (550-700 AD) and/or Early Andalusian period (700-1200 AD). These settlements (Rambla del Estrecho - nº 225, Cortijo de la Irueña - nº 613, Cortijo de la Cueva Sucia - nº 614) have been included in all three periods. Yet, in all cases we are dealing with small settlements located in the lower part of the Rambla de Mofar. The over-estimation this could imply in the demographic calculations is minimal and restricted to one area.

Thanks to the excavations of Gatas it has been possible to correct the values calculated for the Argaric period (2300-1550 cal BC). This is of prime importance, as during these moments we are dealing with a state organised economy, where Gatas accumulates and processes the subsistence goods of a much larger and dispersed population, living in areas which only in some cases can be visualised through archaeological survey (see Lull and Risch 1996 for a wider discussion of this topic). Given that the nutritional habits of these populations are fairly well known, the identification of grinding rooms and instruments in Gatas, through which most of the yearly grain production is channelled, provides an excellent element for the evaluation of the total population living in a region (Risch 1995). This formula for demographic calculation can be written as:

3) $$P = \frac{Ha \,.\, (Mx=Mn) \,.\, Vu \,.\, PC}{Hx \,.\, T \,.\, Ial}$$

where:
P = Population maintained with a given flour production.
Ha = Settlement area.
Mx = Number of grinding instruments registered during the excavation.
Mn = Number of grinding stones which do not remain in the archaeological record, due to depositional and post-depositional processes.
Vu = Use life of the grinding stones.
PC = Relation between daily flour production, and daily flour consumption per person, i.e. number of person which are maintained with the flow produced by one grinding instrument.
Hx = Surface excavated in the settlement.
T = Occupation period of the settlement.
Ial = Number of grinding stones stored and not used regularly.

This formula has been applied to the prehistoric settlement of Gatas, which at the moment is the only one which offers this kind of information. Nevertheless, the surface counts of grinding stones undertaken at other settlements, suggest that Gatas is the only surplus cereal processing centre in the Lower Aguas valley during the second millennium BC. Barranco de la Ciudad, and all the other Argaric sites show much lower quantities of food processing instruments, which seems to correspond to a type of production restricted to the local population.

3.6.2. Demographic dynamics during the last 500 years

After 1500 AD the population of the lower Aguas can be established through historical documents, such as the *Libros de Repartimiento*, *Catastro de Ensenada* and the *Amirallamientos*. In these cases often only the head of the family or owner appears, so that a multiplication factor of 4,5 is applied, which is the mean known family size for these periods. For the last centuries the obtained values can be corrected with the data coming from population census.

The fact that between 1500-1600 AD archaeological as well as historical data are available, provides an interesting chance to compare and to evaluate both methodologies.

3.7. ECONOMIC ANALYSIS[13]

The *goods production* and the *maintenance production* of each period is defined in terms of the *basic economic scheme* (NR + LF + MP => P), presented in chapter 2.

The means of production (MP) are known from the archaeological record, and the potential labour force (LF) results from the palaeo-demographic analysis. Given the socio-ecological perspective of the Aguas Project, what is needed is the analysis of the amount and type of natural resources (NR) transformed into products (P) in a given period of time. The ecological evaluation of these exploitation and transformation processes has to be undertaken in relation to the natural resources potentially available in the area, and, in the case of organic resources, to their reproduction periodicities. This approach attempts to provide a quantitative and qualitative evaluation of the socio-natural interaction, in terms of matter and energy, during the different historical periods.

Main attention is given to agricultural production and land use, as well as to wood management, as the exploitation of land and vegetation represented the major causes of environmental impact during most periods. Furthermore the importance of husbandry and mineral resources is considered.

[13] The editors and Ph. Verhagen, RAAP (NL).

The material evidence for this kind of analysis has been obtained from five kinds of empirical research:
1. Archaeological excavations undertaken in the multistratified site of Gatas - Turre (2800-1000 cal BC; 950-1100 AD) and in a series of sites located further north, in the Almanzora valley, which supply information for periods lacking or less well documented at Gatas: Almizaraque (3000-2250 cal BC), Cabecico de Parra and Villaricos (800 BC-300 AD) and Cerro de Montroy (400-900 AD). These excavations have provided carbonised and mineralised seeds, and, in some cases, faunal and charcoal remains. In the context of the Aguas Project this material has been evaluated in terms of agricultural production, husbandry and wood exploitation.
2. Systematic/intensive and selective/extensive field survey (see 3.6.1) provided data on the geographic location and extension of a more representative sample of the settlements existing during each chronological period from c. 4000 BC to 1600 AD.
3. Written records from the 16th (*Libro de Repartimento*), 18th (*Catastro de Ensenada*), 19th (*Amirallamientos*) and 20th century (*Censo Agrario*) have mainly provided information on agricultural production.
4. Present day land use, according to existing land use maps, evaluation of air photographs, remote sensing and field work.
5. Traditional hydraulic infrastructure of the 18th to early 20th century has been mapped and described on the basis of air photographs and field walking, in relation to the hydrological investigations. This allows us to gain insight into both the amount of water available in the recent past, and the functioning of a technology that permitted an important increase in the agricultural production in this area and in Southeast Spain in general. The possibility that the visible and still partially functioning hydraulic infrastructure is based on a much older system, developed during the Andalusian period, can not be confirmed.

In order to carry out this type of research a specific methodology had to be developed and tested, which has not existed so far either in ecology or archaeology. This methodological proposal constitutes one of the main contributions of the Aguas Project to future palaeo-ecological research.

3.7.1. Evaluation of the agricultural potential of the Aguas valley

In order to understand past land uses and to propose future possibilities for economic growth and environmental recovery, it is of prime importance to understand the ecological variables that condition different agricultural practices in the middle and lower Aguas. The main agricultural strategies which were considered are 1. *regadío* or wet farming, 2. *secano intensivo*, i.e. dry-farming with one or two fallow years, and 3. *secano extensivo*, i.e. dry-farming with up to ten fallow years. Each of them was characterised in terms of five geo-ecological variables on a 1:50.000 scale basis: 1. height, 2. geology, 3. solar radiation, 4. distance to nearest river bed or *rambla*, and 5. slope. The raw data was obtained through the Aguas G.I.S. and analysed by means of conventional statistical procedures.

3.7.2. Investigation of the hydrological structures

Different historical and archaeological information shows that, at least during the later part of the Andalusian period (13th-15th centuries AD), a well developed water management technology existed in the Sierra Cabrera. Part of this knowledge seems to have been transmitted to the Christian population which settled in the area from the 16th century and gradually expelled the previous Andalusian communities. From the 18th century until the first half of the 20th century an extensive hydraulic system was constructed and maintained in the Aguas valley and on the slopes of the Sierra Cabrera. Understanding of the functioning and the still remembered knowledge of these channels, field systems, cisterns, water mines, etc. can be of great value in order to assess the potential water resources available in the area for past and future environmental and economic development based on sustainable methods.

Until today, practically no investigations have been carried out on the integrated function and the environmental implications of the traditional water management system. Next to field surveys and the evaluation of air photographs, interviews with the local inhabitants were of prime importance in this analysis. They are complementary sources of information and allow us to check preliminary hypotheses. Furthermore the water storage capacity of this ancient system is evaluated and confronted with the water resources measured today in the context of the hydrological analysis of the Aguas project. For this reason the mapping and evaluation of the hydraulic infrastructure concentrated on the same catchment where the gauging station and the two rain totalisers were installed, i.e. the Añoflí catchment.

3.7.3. Analysis of the agricultural production

The main analytical stages of this axis of the project are:

1. To propose an hypothesis on the population health from diet patterns.
2. To calculate the agricultural land needed to satisfy these subsistence needs in specific populations.
3. To infer the cultivation strategies of each period.
4. To evaluate the environmental effects of the land use as established in points 2 and 3.

The definition of the human diet from carbonised and mineralised plant remains is based on two assumptions. The weight percentages of the main species (cereals and legumes) are directly related to their respective role in the diet. Furthermore cereals and legumes provided most of the consumed carbohydrates, at least since the mid-late third millennium BC, given the present day evidence on plant exploitation in the Aguas and other regions of Southeast Spain. The human subsistence needs are variable, depending on age, sex, health and on the activities undertaken by the individuals (Pyke 1970: 106-107, table 6.3; Scrimshaw and Young 1978, McGready 1981). Values between 2200-3000 Kcal are normally assumed to be sufficient for a proper nutritition (W.H.O.-O.M.S. 1974). Due to this variability our calculation starts from the mean values of 2600 Kcal and 60-70 g of proteins per person and per day. Around 2200 Kcal would be provided by cereals and legumes, the main sources of carbohydrates in agricultural societies in Mediterranean regions. The rest is obtained through the consumption of other products, such as meat, milk and other secondary products.

The method used in order to establish the implications of these subsistence needs in terms of the agricultural production of each period, proceeds in the following way:

1. Definition of the importance different plant species have in the diet at different periods. This implies the carpological identification of seeds and the calibration of the numerical values into weight, taking into account that each grain type has a different weight.

-*Hordeum vulgare*. According to Molina Cano (1989: 159), the weight of full-grown grain can vary considerably, from 5 to 80 mg dry weight, although it is normal to see values around 35-40 mg. Using the lowest value of this range, 1000 seeds = 35 g. The same weight is assumed for *Triticum*.
-*Vicia faba* var. *minor* : 1000 seeds weight around 310-400 g (Langer and Hill 1987: 280). Using the lowest value, 1000 seeds = 310 g. We have applied the same figures to other varieties of Vicia consumed in the Aguas valley (*V. sativa* and *V. ervilia*).
- *Pisum sativum* : 1000 seeds weight between 150-200 g (Langer and Hill 1987: 275). Using the lowest value, 1000 seeds = 150 g.
-*Lens culinaris* : 1000 seeds represent 20 g (Langer and Hill 1987: 266).

2. Calibration of weight into nutritional values of each species, which vary according to their physical properties. For each period the relative weights of the different grain types produced were transformed into their actual calorific and protein contribution to the diet, according to the following reference values (per 100 g):

-*Hordeum vulgare* = 356 Kcal; proteins: 10,5 g; fat: 2,1 g; carbohydrates: 72,0 g (Kislev and Bar-Yosef 1988: 176).
-*Triticum sp.* = 342 kcal; proteins: 12,0 g; fat: 2,2 g; carbohydrates: 71,0 g (Kislev and Bar-Yosef 1988: 176).
Given that the nutritional components of barley and wheat refer to complete grains, which can not be directly consumed, we have chosen to work on the basis of the nutritional values provided by flour. With 70% of flour extracted from the grain, 341 kcal are obtained (Pyke 1970: 66-67). The figures for barley are similar, so that the same value is used for both cereals. The differences in terms of proteins and fat are also relatively small, and lay around 10-12 g and around 1,5 g in each case.
-*Vicia faba* = 326 kcal; proteins: 24,5 g; fat: 1,4 g; carbohydrates: 55,5 g (Kislev and Bar-Yosef 1988: 176).

- *Pisum sativum* = 340 kcal; proteins: 24,0 g; fat: 1,2 g; carbohydrates: 59,0 g (Kislev and Bar-Yosef 1988: 176).
- *Lens culinaris* = 335 kcal; proteins: 22,5 g; fat: 1,0 g; carbohydrates: 60,0 g (Kislev and Bar-Yosef 1988: 176).

3. Once the importance of the different plant species in the subsistence of each period has been defined, the agricultural land needed for the production of the yearly per capita food resources can be established, if the following factors are considered:

3.1. In the first place, one has to take into account that, in the case of cereals, traditional grinding techniques imply a 30% loss of the original seed weight.

3.2. Also, the stored seed volume assigned to the sowing of the next year has been considered in the calculations. The productivity indexes calculated for dry-farming are 1:6 for cereal, and 1:16 for legumes. In the case of wet-farming the indices are 1:20,8 for cereals, 1:25 for *Vicia* and around 1:33 for peas, values which have to be added to the annual subsistence needs of each person (Molina Cano 1989; Ferré 1979; García Romero 1941; Fornés 1983; Sánchez Gavito 1979).

3.3. The soil productivity indices for each considered plant species are obtained from the present day knowledge on the traditional agriculture of southeast Spain, before more intensive technologies, such as dripple irrigation or plastic protections, were introduced. Soil fertility was probably higher in the past, but grain quality, preservation of crops against diseases, grain storage facilities and agricultural technologies are higher in modern times. Therefore it is not probable that the obtained values over-estimate past agricultural territories.

The land yield indices for dry-faming are:

-*Hordeum vulgare* = 700 kg/ha (MCA prov. Almería 1982: 60; Ferré 1977: 142).
-*Triticum sp.* = 400 kg/ha (MCA prov. Almería 1982: 60; Ferré 1977: 142).
-*Vicia faba* = 2000 kg/ha (Sánchez Gavito 1979: 196).
- *Pisum sativum* = 2000 kg/ha (Sánchez Gavito 1979: 196).

The land yield indices for wet-faming are:

-*Hordeum vulgare* = 2500 kg/ha (MCA prov. Almería 1982: 52).
-*Triticum sp.* = 1500 kg/ha (MCA prov. Almería 1982: 52).
-*Vicia faba* = 3000 kg/ha (Sánchez Gavito 1979: 196).
- *Pisum sativum* = 4000 kg/ha (Sánchez Gavito 1979: 196).

3.4. Traditional dry farming in southeast Spain implies that each year of cultivation is followed by an average of two fallow years, which are needed to recover soil fertility. This implies that the amount of land needed for the dry-farming cereal production has to be multiplied by three: one third of land is cultivated, while two thirds are left fallow and can be used as grazing areas.

3.5. Finally, the location and extension of the agricultural territories depends on the cultivation strategies used in each period. These have been evaluated in view of the existing carpological data, isotopic analysis on seed material, archaeological evidence of agricultural infrastructure (hydraulic systems) and historical documents. Nevertheless, the agricultural territories of each period have been calculated considering two different types of scenarios. The first considers a situation where all crops are obtained through dry-farming, while the second considers that irrigation was applied to certain plant species, according to the above mentioned evidence.

These reconstructed agricultural strategies are the following:
a. From the Neolithic until the Phoenician II period the existing evidence suggests that legumes were cultivated on more humid soils due to natural flooding or with limited infrastructure for ocassional irrigation. On the other side, cereals seem to be cultivated under dry farming. This agricultural strategy is supported by isotopic analysis (Araus *et al.* 1996) and the morphology of the cereal grains (Stika 1988; Hopf 1991).

b. From the Imperial Roman period onwards it is suggested that legumes and wheat were cultivated be means of more or less developed irrigation systems, while barley remained typical dry farming crop. This is suggested by the importance of wheat during these periods, as shown in the carpological data of Villaricos and Cerro de Montroy, the archaeological evidence in the Iberian Peninsula and north Africa (Shaw 1982; Hitchner 1990) and early medieval historical documents of southeast Spain (Yelo *et al.* 1988).
c. From the Nazarine-Morisco period (c. 1250-1600 AD) until modern times no carpological information is available. Subsistence production and agricultural territories are established by means of historical data. The *Libro de Repartimento* of Turre gives a precise idea of the agricultural situation in the lowlands during the late medieval period, while the *Libro de Repartimento* of Teresa allows us to reconstruct the cultivation strategies of the terraced Cabrera slopes. The 18th, 19th and 20th centuries are documented by further written evidences, as mentioned above.

The relation between seed weight and each sedimentary unit of the stratified settlement of Gatas allows us to evaluate the changing importance of the cultivated species through the different chronological periods.

3.7.4. Analysis of meat production from faunal remains

Faunal data coming from archaeological sites represents an important source of information in order to determine the role of animal resources in the human diet and the importance and organisation of husbandry and hunting practices in past economies. Here the analysis is based on the weight of the recovered bones, rather than on the number of remains, which is the usual archaeological way of presenting the data, but which depends more on depositional and postdepositional factors, and does not correlate with the protein contribution of the different animal species to the human diet. The proportion between bone and meat weight is approximately 1:7 (Driesch 1972). The major consumed animal species contribute in the following way to the human diet (per 100 g) (Pyke 1970):

- *Bos* (cattle) = 331,6 Kcal; 16,7 g proteins; 28,8 g fat.
- *Ovis-Capra* (sheep and/or goat) = 310 Kcal; 15,4 g proteins; 27,1 g fat.
- *Sus* (pig) = 425 Kcal; 13,1 g proteins; 41,0 g fat.
- *Cervus* (red deer) = 310 Kcal; 15,4 g proteins; 27,1 g fat.

The relation between bone weight and each sedimentary unit of the stratified settlement of Gatas allows us to evaluate the changing importance of husbandry and hunting strategies through the different chronological periods.

3.7.4. Analysis of wood exploitation from the charcoal remains

The assessment of the human exploitation of trees and shrubs was undertaken by means of carbonised wood remains coming from the multiperiod settlement of Gatas and other sites located in the Vera basin. The main requirement is that the charcoal remains are collected systematically, using wet and dry sieving devices. As all wood species are affected by the same depositional and post-depositional processes, the assumption is made that there exists a correlation between the number of identified fragments per sedimentary unit and the degrees of wood exploitation.

The charcoal fragment density in each sedimentary unit of the stratified settlement of Gatas allows us to evaluate the changing importance of the species and of wood extraction strategies along the different chronological periods.

3.7.5. Analysis of wood exploitation from the charcoal remains

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The charcoal fragment density in each sedimentary unit of the stratified settlement of Gatas allows us to evaluate the changing importance of the species and of wood extraction strategies through the different chronological periods.

3.7.6. Socio-ecological evaluation of the relationship between economic production (mainly agriculture) and natural resources

One of the approaches developed in the Aguas Project in order to evaluate the social and economic impact on the environment is a calculation of the relationship between agricultural needs of given populations and the available resources in the regions chosen for human settlement. This relationship between the availability of natural resources and socio-economic needs can be approached through GIS-based modelling. For the purpose of the project, a modelling procedure has been developed that allows us to evaluate the possible environmental impact of agricultural production in the Aguas valley (fig. 3). The modelling is done in two steps: firstly, maps are calculated that specify the attractivity of the environment as a function of agricultural potential (obtained through 3.7.1.) and ease of access to the land. Secondly, the supposed zone of cultivation is mapped assuming that human groups will use the land that is as attractive as possible, i.e. the land with the highest production potential and at the shortest possible distance from the settlement.

The *Attractivity Index* that forms the basis of this modelling is a multiplicative index of land use potential probabilities and a normalised distance index, and can be written as:

$$A = p(L)\,(1 - (D/D_{max})^2)$$

where
A = attractivity index
p(L) = land use type probability, measured on a scale from 0 to 1
D = distance, measured in hours of walking, and
D_{max} = the maximum possible distance.

In this particular case, the distance decay is assumed to be a square function of the actual distance, an assumption that is commonly used for gravity models, as the travelling time will become increasingly constraining at larger distances from the settlement. For ease of calculation, Dmax is set to two hours, which means that areas that require more than four hours walking a day in order to be exploited will not be available for cultivation. The index will range from values near 1 on locations close to the site with optimum land use potential, to 0 on locations that are either wholly unsuited for agriculture, or are too far away from the settlement.

The maps of attractivity indices per settlement have been used to find the most probable zones of cultivation for each archaeological period. For each settlement, a calculation has been made of the hectarage needed to feed the estimated population (see above). Consequently, these areas have been mapped in the GIS, taking the highest attractivity indices first and then finding less attractive areas until the total number of hectares needed is exceeded.

From a socio-ecological perspective, the use of land with low attractivity indices for cultivation implies a less balanced relationship between natural resources and subsistence needs, and a higher risk of environmental degradation and/or a greater input of labour in agricultural production.

3.7.7. Mapping of the agricultural territories during the last 6000 years

The mapping of modern traditional land use distribution is far from optimal, and is currently based on the 1:50,000 mapping performed by the Spanish Ministry of Agriculture in 1977-1978 (Ministerio de Agricultura, Pesca y Alimentación, 1982). At the beginning of the project, not only were we confronted with an inadequate mapping of current land use, but also the data on prehistoric land use was even less satisfactory. The remains of palaeosols and past land exploitation are few and scattered, and do not allow a detailed reconstruction of the agricultural territory that may have existed in the past. For this reason, it was decided to embark upon the development of a new modelling approach to the reconstruction of prehistoric land use patterns. The modelling of the agricultural potential of the area has been performed by analysing the ecological characteristics of the current (traditional) land use map (see 3.7.1.). The results of this statistical analysis have been used to perform a maximum likelihood classification of the ecological variables involved (see 5.6.1.), resulting in maps of the most probable land use at a certain location.

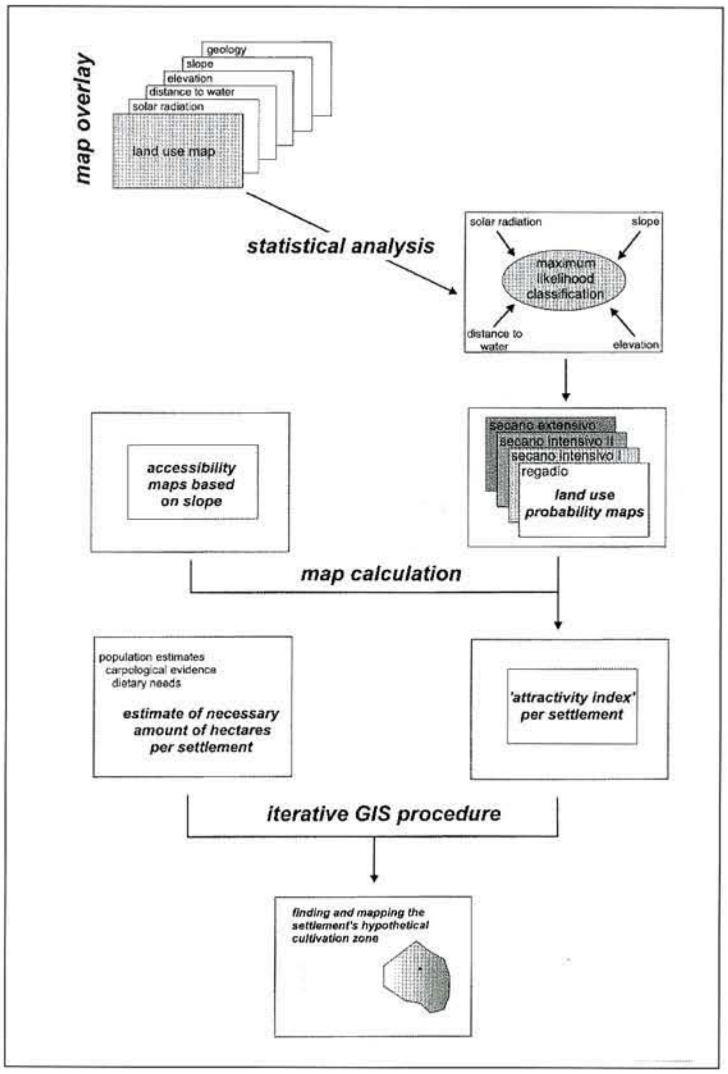


Fig. 3: Flow chart of the procedure followed for the prehistoric land use distribution modelling.

An issue not addressed so far, but which is necessary for this modelling is the mapping of the accessibility of the terrain: even though certain areas may have a high land use potential, they may not all be easily accessible from the settlement. Walking time distances in rugged terrain can be approximated in GIS by means of calculating cost surfaces (also known as friction surfaces), which take into account the difficulty of negotiating the terrain. A cost surface specifies the difficulty of traversing each grid cell, based on the friction factors that are deemed important for travelling speed. In the case of the Rio Aguas Valley, the main difficulty is formed by slope, as the rivers in the area are dry most of the year, and therefore will not become major obstacles for travel. According to Gorenflo and Gale (1990), the effect of slope on travelling speed by foot can be specified as:

$$v = 6\,e^{-3.5\,|s + 0.05|}$$

where:
v = walking speed in km/h
s = slope of terrain, calculated as vertical change divided by horizontal change, and
e = the base for natural logarithms.

This function is symmetric, but slightly offset from a slope of zero, so the estimated velocity will be greatest when walking down a slight decline. As we are interested in the estimation of time needed to go from a settlement to the fields and back, we can add the estimate for going down and the estimate for going up to find the actual amount of time spent. However, an exact estimate is not required in this particular case, as we will be comparing the relative accesibilities of areas, and not their absolute values. Using the equation above, a cost surface has been constructed for the study area that specifies that amount of time needed to traverse each grid cell and go back again. This cost surface is used to calculate a cumulative cost surface departing from each settlement in the Rio Aguas Valley, which can be used as a measure of the accessibility of the area as perceived from the settlement.

3.8. G.I.S. AND REMOTE SENSING[14]

Over the past fifteen years, geographical information systems (GIS) have profoundly changed the way in which archaeologists use and perceive geographical data. GIS has come a long way from being used as a tool for producing sophisticated cartographic representations to a more mature status as an instrument that can be used for representation, description as well as interpretation of archaeological and environmental data sets. For this reason, the construction and use of a GIS database for the Río Aguas Valley has been one the primary aims of the project. It was anticipated that this database should be used primarily for two objectives: in the first stage, a predictive model was made to assess the probability that new archaeological sites could be found in the area, and in the second stage, an attempt was made to use the GIS for the modelling of prehistoric land use patterns (see above). The building of the archaeological predictive model was discussed in detail in the first year report (Lull 1995), and will not be dealt with in this chapter. The current report will therefore focus mainly on the land use modelling that was done in cooperation with the UAB.

The SPOT images used for the study area have the following characteristics:
-SPOT 1 multispectral (XS) K 040 - J257/0 acquired on 09 May 1987 (HRV1 with a viewing angle of 25 degrees left).
-SPOT 1 panchromatic (P) K 040 - J257/0 acquired on 25 Oct. 1992 (HRV1 with a viewing angle of 29 degrees right).
These scenes had to be geometrically corrected in order to be strictly compatible with the cartography used for the area, which is in UTM coordinate system (zone 30). Subsequently, the SPOT-XS images were merged with the SPOT-P image in order to enhance the spatial resolution of the SPOT-XS images. Finally, this neo-image has been categorised following land-use thematics.

The GIS database for the Río Aguas Valley has improved considerably the present day cartographic documentation of the natural resources and features of this area. The introduction of new geological and geomorphological information, together with the construction of a 1:10,000 DEM implies a significant increase in the resolution of the dataset. The mapping of the present day soils and vegetation however is still far from the desired level of detail. In the case of vegetation the destruction produced by the already mentioned fire of summer 1994 in the Sierra Cabrera is an irrecoverable loss.

The DEM for the Rio Aguas study region was created using the 1:10,000 topographical maps of 1991, which contain contour lines at a 10 m vertical interval. The maps have been scanned and vectorized so they could be imported into the GIS. Apart from vectorizing, it was necessary

[14] Ph. Verhagen, R.A.A.P. (NL).

to label each contour line with its elevation value in order to create a digital contour map for the area. The labelling was mainly done by Dr. Nikolai Nenov and colleagues at PenPres (Sofia, BG). A DEM could then be creatred by using an interpolation algorithm that assigns elevation values to each pixel on the map. The algorith used is known as regularized spline with tunable smoothing and tension (Mitásová & Hofierka 1993) and is incorporated in GRASS 4.1 as the program s.surf.tps. The algorithm tries to fit a function through the existing data-points that most adequately describes the terrain. This type of interpolation is a flexible and powerful way to create DEMs and yields better results than most other methods. An added advantage of the regularized spline interpolation is its ability to calculate gradient, aspect and second derivatives or curvatures directly from the spline function, instead of using local neighbourhood filters. However, the interpolation will never be perfect as it is a generalization of the existing topography on the basis or already generalized maps. Especially in the case of shap terrain breaks or in areas where data-points are sparse, the interpolation will be pone to errors. The DEM has been interpolated to a vertical resolution of 1 m and a horizontal resolution of 10 x 10 m.

At the present moment the G.I.S. database is based on the following thematic cartography, which was relevant for different research lines of the project:

TOPOGRAPHY

- Servicio Geográfico del Ejército (1970), *Mapa Militar de España 1:50.000: Vera 1014,* Servicio Geográfico del Ejército, Madrid.
- Instituto Geográfico Nacional (1985), *Mapa Topográfico Nacional de España 1:25.000: Turre 1031-II, Mojácar 1032-I, Garrucha 1015-III,* Instituto Geográfico Nacional, Madrid.
- Junta de Andalucía (1991), *Mapa Topográfico de Andalucían escala 1:10.000: 1032 (1-1), 1032 (1-2), 1031 (2-1), 1031 (3-1), 1031 (2-2), 1031 (3-2), 1014 (3-4), 1014 (2-4), 1014 (4-4), 1015 (1-4),* Junta de Andalucía, Consejería de Obras Públicas y Transportes, Dirección General de Ordenación del Territorio, Almería.
- Verhagen, Ph. (1994-1995), *DEM elevation model at a 1:10.000 scale, based on maps provided by the Junta de Andalucía*, Aguas Project, DGXII.

GEOLOGY

- Espinosa Godoy, J. S., Marín Vivaldi, J.M., Martín Alafont, J.M. & Pereda, M. (1974), *Mapa Geológico de España E. 1: 50.000 Mojácar,* Instituto Geológico y Minero de España, Madrid.
- Espinosa Godoy, J. S., Marín Vivaldi, J.M., Martín Alafont, J.M. & Pereda, M. (1974), *Mapa Geológico de España E. 1: 50.000 Garrucha,* Instituto Geológico y Minero de España, Madrid.
- Kampschuur, W. & García Monzón, G. (1974), *Mapa Geológico de España E. 1:50.000 Sorbas,* Instituto Geológico y Minero de España, Madrid.
- Kampschuur, W. & García Monzón, G. (1974), *Mapa Geológico de España E. 1:50.000 Vera,* Instituto Geológico y Minero de España, Madrid.
- Van der Schouw, S. (1987), *Geologische kaart van de N.O. Sierra Cabrera 1:10.000*, Unpublished report, Faculteit Aardwetenschappen Vrije Universiteit, Amsterdam.

GEOMORPHOLOGY AND SOILS

- Aguilar, J., Fernández, J., De Haro, S. & Sánchez Garrido, J.A. (1988), *Proyecto Lucdeme: Mapa de Suelos escala 1:100.000, Garrucha-1015, Mojácar-1032*, Ministerio de Agricultura, Pesca y Alimentación, ICONA, Universidad de Granada.
- Pérez Pujalte, A. & Oyonarte Gutiérrez, C. (1989), *Proyecto Lucdeme: Mapa de Suelos escala 1:100.000, Sorbas-1031*, Ministerio de Agricultura, Pesca y Alimentación, ICONA, Consejo Superior de Investigaciones Científicas, Granada.
- Delgado Calvo-Flores, G., Delgado Calvo-Flores, D., Parraga Martínez, D. Gámiz Martín, E., Sánchez Marañón, M., Medina Fernández, J. & Martín García, J. M. (1991), *Proyecto Lucdeme: Mapa de Suelos escala 1:100.000, Vera-1014*, Ministerio de Agricultura, Pesca y Alimentación, ICONA, Universidad de Granada.
- Schulte, L. (1994-1996) *Geomorphological map of the Aguas valley*, Aguas Project, DGXII.

LAND USE

- Ministerio de Agricultura, Pesca y Alimentación (1982), *Evaluación de Recursos Agrarios: Mapa de cultivos y aprovechamientos 1:50.000 Garrucha 1015, Sorbas/Mojácar 1031/1032, Vera 1014,* Ministerio de Agricultura, Pesca y Alimentación, Subdirección General de Producción Vegetal, Madrid.
- Herget, W. (1994-1996), *Land use and hydraulic structures map of the Añoflí catchment*, Aguas Project, DGXII.

3.9. MODELLING[15]

The modelling framework and its epistemological basis is consistent with previous work (McGlade 1994, 1995) in that it argues for a hierarchical scalar approach to questions of social natural dynamics. All model characteristics of socio-cultural phenomena are necessarily both incomplete and contingent; we need a variety of model scenarios at different temporal and spatial scales, and the representation of the socio-natural system at different levels of aggregration. Only in this way can we deal adequately with the question of complexity. Thus we can investigate possible dynamical trajectories to which socio-natural systems may have been prone. More specifically, we are interested in examining the role of social, political and environmental factors in the structuring of prehistoric land-use dynamics. Since the observational scale at which these phenomena are investigated is a crucial aspect in their interpretation, a methodology has been devised so as to encompass a variety of scalar representations.

The integrated multiscalar modelling framework (MMF) is conceived as a knowledge base with a functional hierarchy of three semi-autonomous levels (micro, meso and macro), and accessed by means of a nested set of windows environments. These are initially constructed utilizing two object oriented modelling environments (STELLA and VenSim) which are linked by nonlinear differential equations. Results are exported to EXCEL for further statistical analysis. The model structure is designed to be 'semi-decomposable' so that specific sub-sets of the global model can be isolated for analytical purposes. The user can interact with the system at the level of text, global dynamics or parameter exploration. At an operational level, the proposed integrated modelling structure involves three procedures:

Level I: mapping - establishing the boundary domain of the model and the selection of the relevant state variables appropriate to the specific problem set;
Level II: construction of mathematical relationships - establishing the primary causal connections of the selected variables and converting them into formal mathematical logic. This involves their realisation as coupled sets of nonlinear differential equations;
Level III: simulation and sensitivity analysis - the exploration of dynamical regimes to which the total system is prone. In addition, this involves establishing viable parameter ranges for the variables, so as to determine which ones exhibit resilience to perturbation, and which ones are highly sensitive to such perturbation.

[15] J. McGlade, Granfies University (UK).

4. THE CASE STUDY: THE MIDDLE AND LOWER AGUAS

The editors, Ch. French & A.C. Stevenson.

The Aguas Project focuses on the area comprised of the Aguas river to the north, the Mediterranean sea to the east, the Rambla de Chozas to the west and the peaks of Sierra Cabrera to the south, in Almería province (southeast Spain). This spatial unit covers a surface of 100 sq. km that has to be organised into meaningful units, depending on the scientific goals defined by each of the disciplines involved in the project.

In this region the aim is to understand the functioning of the social and natural spaces of the middle and lower Aguas river from the northern watershed of Sierra Cabrera down to the coastline. This means a height difference from 918 (Cerro del Arráez) to 0 m above sea level in a distance of less than 10 km. This fact gives an idea of the geological, geomorphological, vegetational, hydrological, micro climatic and socioeconomic variability that we can expect to find in our study area. Contrary to the position held in many of the neo- and paleo-ecological studies on southeast Spain, where aridity is presented as a constant variable, the diversity of socio-natural conditions is a characteristic feature both in time and space. A clear definition of this diversity is still lacking, as the relationship between the natural and social variables is still poorly understood. Tackling this aspect and analysing the resilience of such a diversified socio-natural system are probably the most complex objectives of the project. However, this is a point that has to be faced in order to take into account why an apparently arid region was the stage of some of the most important demographic and socioeconomic developments of the western Mediterranean at different periods during the Holocene.

4.1. Climatic conditions

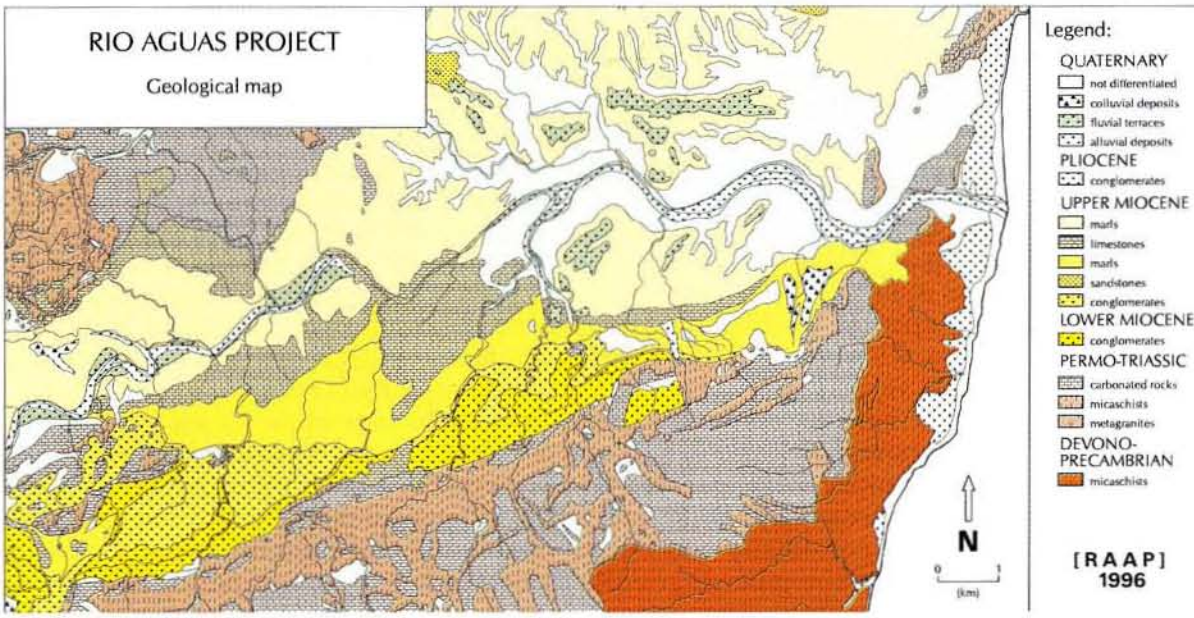
The lower and middle Aguas is situated at the heart of what today is called arid south-east Spain. It is characterised by a highly irregular and unpredictable rainfall and constant temperatures (Geiger 1970; Capel 1990). Often months and years with high levels of rainfall can be followed by others of extreme aridity. Los Gallardos, the meteorological station nearest to the Aguas river, suffered during the period from 1961 to 1991 its driest year in 1964, with 93 mm rainfall, and its wettest year in 1989 with 1212 mm. This shows that the mean rainfall over these 30 years, i.e. 254 mm, is of little value if we want to understand the socio-natural dynamics of the mid and late Holocene period. While torrential events are the most widely discussed, by far the most frequent rains are of low intensity and have little influence on soils, but might be important for the existence of the vegetation. Furthermore, given the scarcity of meteorological stations, little is known about the intra-regional variability of rainfall. In view of the strong topographic differences described above, this variability is one of the factors to be analysed by the Aguas Project. The resilience of many social and natural systems that developed during prehistoric and historic times might have been highly dependent on the differential rainfall in the lowlands and highlands, on the yearly periodicity and on the periodicities of rainfall during the main vegetation periods April-September (agricultural demand) and humid periods October-February (recharge of the aquifers). The temperatures are a more or less constant variable with a yearly periodicity under the present day climatic conditions of the coastal regions. Using again Los Gallardos as an example (120 m above the sea level), the annual means fluctuate on average between 16 and 23 °C. January tends to be the coldest month with an average temperature of 12.3 °C, while August, the hottest month, reaches a mean value of 29.6 °C.

One of the most debated aspects of environmental research in the western Mediterranean is the question of the climatic fluctuations during the Holocene period. While some evidence indicates that these fluctuations existed (e.g. Rohdenburg and Sabelberg 1972; Zazo *et al.* 1993), the dating and interpretation of this data is not yet clear. Especially with regard to the botanical information, a great part of the observed variability does not have to be explained in terms of climatic changes, as was considered until recently, but can rather be seen as the result of a specific socio-natural co-evolution affecting the micro-climatic conditions (May *et al.* 1992). Therefore, in the context of the Aguas Project, this question is to be addressed through an interdisciplinary approach, in which also minor temporal and spatial differences should be considered.

4.2. The geological background and the geomorphological dynamic

The Preneogene formations are represented today by the Sierra Cabrera, which is part of the inner zone of the Cordillera Bética. In general terms, this area is constituted by the tectonic superimposition of different sloping layers from alpine collisional tectonic processes, basically the convergence between the Eurasiatic and African plates. The structuring of these Betic layers seems to have concluded in the post-Serravalien phase, corresponding to the middle Miocene (Groupe de Recherche 1977). Geological studies (Simon 1963; Nijhuis 1964; Bicker 1966; Rondeel 1965; Helmers and Voet 1967) have differentiated four main tectonic complexes on the basis of the differential degree of metamorphisation of the materials and the nature and depth of their series (*Nevado-Filábride* complex, *Intermediate* or *Ballabona-Cucharón* complex, *Alpujárride* complex, *Maláguide* complex).

In the Middle and Lower Aguas, we are mainly interested in the *Alpujárride* complex, which constitutes the major part of the Sierra Cabrera. Its Palaeozoic base is formed by schists with a high composition of mica. Marble and quartzites are also present in small quantities. This base is covered by layers dated in the Permotriasic and Triasic, which are mainly formed of filites with intercalations of quartzites, over which carbonated materials (limestone, dolomite), filites and gypsum can be found. In the Triasic levels it appears as an important intrusive deposit of micro-gabros. Furthermore, some remains of the *Maláguide* complex are present at the margins of Sierra Cabrera, where they overlap with Alpujárride materials because of tectonic activities. These relics are formed of schist, limestone, dolomite, sandstone and argilite (map 5).



Map. 5: Geological base of the Aguas valley.

These Preneogene formations and their materials form the basis for the Tertiary and Quaternary erosive and sedimentological processes. The Neogene is characterised by intense tectonic movements that led to the emergence of the present day *sierras*, as well as to the appearance of trenches that allowed, together with oscillations in the sea level, the formation of the sedimentary basins, like those of the Aguas valley. This led to alternating layers of conglomerates, sandstones and pelites, due to marine and continental sedimentation (Völk 1967a & b). During the Messinian event, corresponding to the Younger Neogene, more shallow conditions have been documented in the basins. A combination of climatic, eustatic and tectonic movements resulted in a drastic lowering of the sea level and sporadic drying out of the Aguas valley (Kölling 1985), although this aspect is still debated. The clearest consequence of this episode of partial or total desiccation was the massive deposition of evaporites (gypsum), which formed large deposits in the higher Aguas and had a remarkable influence on the environmental conditions of the lower parts of the valley, specifically with respect to vegetation and hydrology.

During the Quaternary, successive periods of excavation and deposition resulted in different relief formations as pediments, glacis, river and beach terraces. Most of these deposits were cemented at the top by calcium carbonate, preventing their total erosion in many areas. The Quaternary morphostratigraphy has been studied in the Almanzora (Wenzens 1991, 1992a & b) and the Antas catchments, both located to the north of the Aguas (Schulte 1994, 1995). In this sense, it is of great interest to establish the morphological sequence of the middle and lower Aguas, in order to understand the Quaternary climatic, fluvial and tectonic dynamics, including differentiation of warm and cold periods.

4.3. Hydric regime

The aquifers seem to respond to these climatic changes, representing an important feature in holding back the water resources and distributing them over long periods of time. Up to date, hydrological studies based on long-term measurements are practically nonexistent in southeast Spain (there was only one hydrological measurement station in the Aguas valley working for a short time). Most of the data on the response of the fluvial system after torrential events is provided by concrete observations of the local populations, with the inaccuracies this type of data includes (Capel 1990). On the other hand, the rivers of the southeast are usually described as *ramblas* or intermittent water courses that remain dry over most of the year. While this is true of the lowlands, the water flow in the *sierras* seems to be higher, although no reliable data is yet available. Only through the setting up of a gauging station in the tributary of the Aguas called Rambla de Añoflí or Rambla Ancha, is it possible to understand the functioning of the aquifers and to define quantitatively the available water resources. 18O and tritium analysis undertaken have shown that the Triasic aquifer of the Sierra Cabrera is recharged by the rain falling in the high areas (Carulla 1977, 1979). The transition time between rainfall and outcrop of the water is relatively short, and has been estimated to be between several months and two years. Further isotopic analysis on the solid phase is expected to gain insight into the temporal dynamics of the climatic and fluvial system.

4.4. Soils

The Aguas valley of today is characterised by exposed soils, dry, deeply incised gullies or barrancos, and large, irrigated areas of fruit trees. The topography varies from steep slopes in the Sierra Cabrera to terraced valleys, dissected by deep gullies and leading across gentle slopes to the wide and meandering floodplain of the Aguas river.

In many cases, there is little or no soil surviving, especially on the middle and upper slopes of the Sierra Cabrera. Here, erosion of the bedrock marls and schists is predominant. Each storm event generates new rock and sediment debris, some of which accumulates on the terraces at the base of the steep slopes, and some of it which is carried downstream and downslope in the gullies and eventually into the Aguas system.

The soils on the cultivated and abandoned terraces are dominated by calcareous silt loams with varying amounts of rock rubble. These soils are highly susceptible to erosion and movement over short and long distances, especially if the fields are not maintained and used. Nonetheless, their very calcareous and friable nature makes them relatively fertile as long as they are irrigated and retained by terrace walls. Overgrazing, frequent burning off and neglect lead to vegetation loss, the formation of surface crusts and new gully formation after rain storms, all of which begin the process of deterioration and erosion.

The lowermost slopes adjacent to the Aguas river are probably the most stable part of the environment. Nevertheless, these areas are subject to some accumulation of fine soil material from upslope, recent gullying, modern drainage activities and the dumping of rubbish, as well as the urban spread of towns such as Turre. Because of these pressures, the land and soil in these areas tends to be seriously under-utilised for arable crops and fruit crops.

4.5 Vegetational dynamics

The extreme aridity of much of the Province of Almería has resulted in the area being described as a semi-desert with a mediterranean vegetation that is sufficiently distinctive for it to be classified as a special very arid variant within Iberia (Peinado et al. 1992).

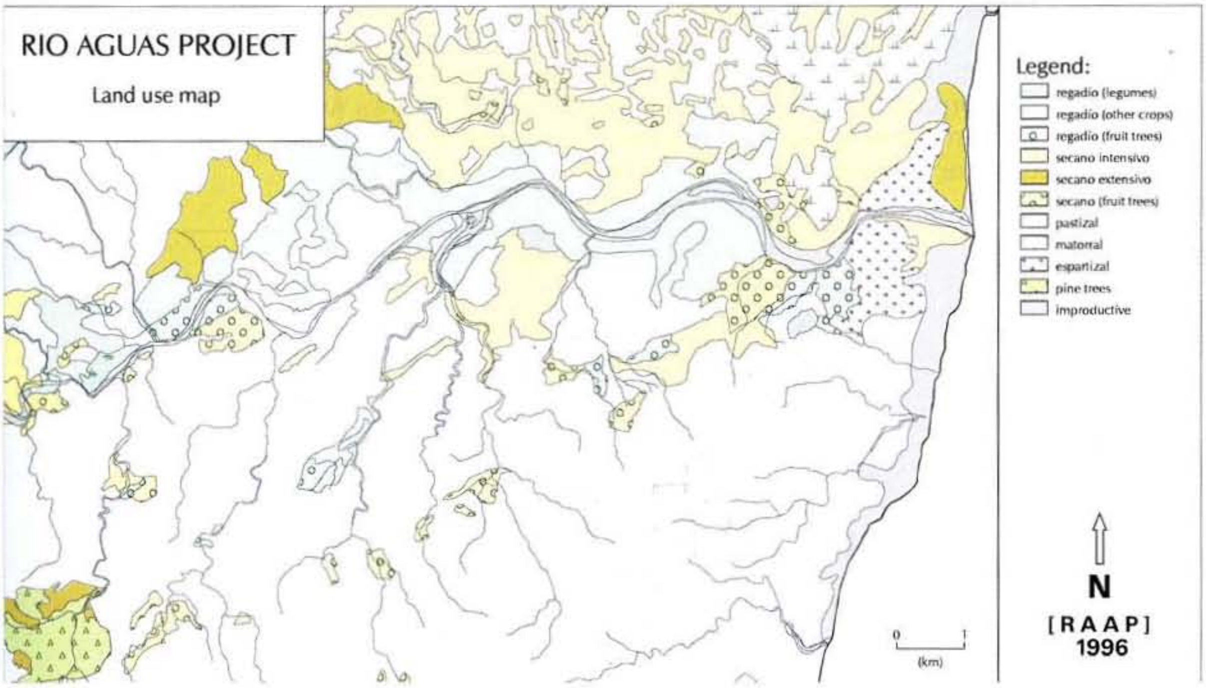
A broad classical vegetation classification provided by Rivas Martinez (1987) shows that for the lowland areas of the Vera Basin the vegetation can be classified as a Thermomediterranean *Zizypheto loti sigmetum* (32b), with the foothills of the surrounding mountains classified as a semiarid *Chamaeropo - Rhamneto lycioidis sigmetum* (31a). The only other variant is restricted to the highest parts of the Sierra Cabrera (> 700 m) where a community of *Smilaci mauretanicae - Querceto rotundifoliae sigmetum* (27b) dominated by *Quercus coccifera* occurs.

At the present day, there are about 2000 species in the Middle and Lower Aguas and the Sierra Cabrera, which represents approximately 40% of all the botanic species known in the Iberian Peninsula. This richness is due to the pedological and climatic variability of the area. The lowland alluvial plains of the three major rivers running through the Vera Basin have long been cultivated for cereal and other irrigated crops, e.g. legumes. Natural vegetation is restricted to field boundaries and other inaccessible areas and consists mainly of esparto grassland (*Lygeum spartum*) and dwarf aromatic shrub and herb communities (tomillares) with *Thymus*, *Cichorium intybus* and *Borago*. In the river valleys, most of which have an ephemeral water supply, grow *Phragmites australis*, *Tamarix gallica*, *Cytisus sp.*, *Holoschoenus*, *Polypogon* and *Artemisia*, with *Arundo donax* occasionally planted. The flatter, drier portions of the ephemeral stream beds are often dominated by *Thymelaea* and aromatic shrubs like *Thymus*, *Lavandula* and *Rosmarinus* together with esparto grass. Trees are generally absent from the alluvial plains apart from those that result from deliberate crop planting, e.g. *Ceratonia siliqua* and groves of *Ficus carica*.

The foothills of the Sierra Cabrera have been terraced extensively, although a significant number have been subsequently abandoned, for irrigated cultivation of Citrus, Pomegranate, Olive and Almond trees. Natural vegetation is restricted to the margins of fields and abandoned terraces and consists of esparto grass and aromatic shrubs like *Thymus*, *Lygeum spartum, Cistus*, *Tuberaria*, *Zizyphus*, *Rhamnus alaternus*, *Chamaerops humilis*, *Asphodelus*, *Gladiolus* and *Hypericum sp*. The deep barrancos that drain the middle portions of the Sierra Cabrera have a more benign environment and a number of pines chiefly *Pinus halepensis*, grow within the river valley together with a number of taller shrubs like *Pistacia lentiscus*, *Cytisus sp*. and grasses like *Phragmites australis*. The upland portions of the Sierra Cabrera (> 700m) are dominated by a fire-derived, low-lying *Quercus coccifera* woodland with species like *Cistus ladanifer*, Satureja. The two upland alluvial basins here are dominated by a seasonally flooded grassland. In isolated locations experiencing a more benign environmental regime there are isolated stands of *Quercus suber* and in some of the deep river gorges occasional *Quercus faginea* trees (Latorre and Latorre 1996).

The internal dynamics as well as the spatial variability of these associations are still poorly understood. One of the aims of the Aguas Project is to approach the botanical conditions of the region from a multi-temporal perspective, in order to define the historical circumstances that have determined the present day territory and to understand the resilience of such a system. Southeast Spain is still a *terra incognita* from a palaeo-botanical point of view, where the importance given to vegetation in most environmental and archaeological studies is not supported by a solid database.

It is clear, that the vegetation of the region has been heavily modified by human activity since prehistoric times. Indeed some controversy exists over whether the region ever had a substantial forest cover or not. Castro Nogueira (1982) favours the continuous absence of forest cover throughout much of the Holocene, whereas Latorre and Latorre (1996) from ethnohistorical and archival investigations suggest that woodland cover was once more extensive and has been significantly reduced as a result of the nineteenth century increase in mining activities in the basin. The evidence from Roquetas del Mar (Yll *et al.* 1994) does indeed suggest the presence of Holocene *Quercus rotundifolia /Q. coccifera* woodlands but these disappeared around 5000 BP and little indication of extensive woodland cover is found subsequently in the pollen profile. While the undated pollen core extracted from the floodplain of the Río Aguas within the context of the current project demonstrates a environment that has been without a significant woodland component during its deposition.



Map 6: Present day land-use in the Aguas valley.

5. SOCIO-NATURAL INTERACTION DURING THE LAST 6000 YEARS IN THE AGUAS VALLEY

5. 1 CLIMATIC CHANGE

J. Buikstra, L. Dever, Ch. Hagedorn, L. Hoshower, J. Pätzold, L. Schulte & G. Wefer.

5.1.1. Quaternary morphodynamic and climatic change in the middle and lower Aguas (results of 3.2., 3.3.1., 3.8.)[16]

In order to understand the climatic changes of the last 6000 years it is of prime importance to develop a general model of the climatic dynamics in the Southeast. In the last decades the importance of regional variations of global climatic conditions and the difficulty of extrapolating results from one region to another have become clear (Rohdenburg and Sabelberg 1972). The geomorphological study of the Aguas (map 7) allows us to determine the general climatic dynamic in combination with tectonics, river capture and eustatic fluctuations since the Pliocene/Pleistocene transition (c. 2400 kyr BP).

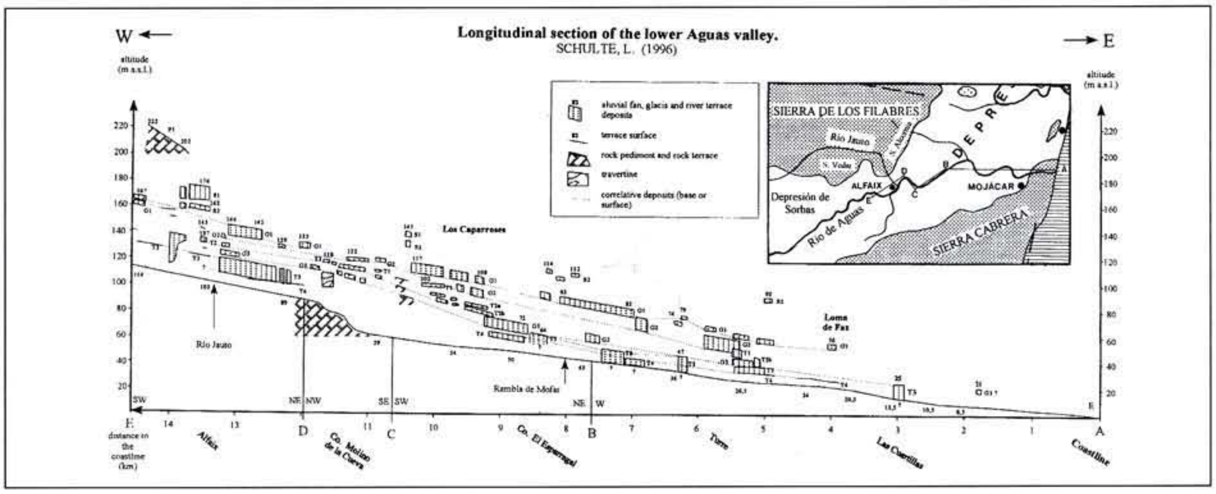


Fig. 4. Longitudinal section of the lower Aguas valley.

The depositional morphology of the Vera basin covers from the Villafranchien until the Holocene and is characterised by the installation of three river systems (Río Almanzora, Río Antas and Río Aguas) and its relation with climate changes, river capture and the Mediterranean base level. The chronology of the Río Aguas, based mainly on morphological, sedimentological, edaphological criteria and U/Th dates, has been classified as follows (fig. 4):

Villafranquien:	- pediments P1
	- alluvial fans S1 and S2
	- glacis G1 and G2
Middle Quaternary:	- fluvial terraces T1, T2a, T2b and T3
	- glacis G3
Late Quaternary:	- fluvial terrace T4 (Würm)
	- fluvial terraces H1, H2, H3 and H4 (Holocene)

On the ground of correlations between the deposits of the Río Aguas, Río Antas and Río Almanzora it is now possible to establish the morphostratigraphy for the whole of the Vera basin. This detailed morphodynamic analysis turns the Vera basin in one of the best studied regions of the Iberian Peninsula (fig. 5).

[16] L. Scgulte, Universidad de Barcelona (ES).

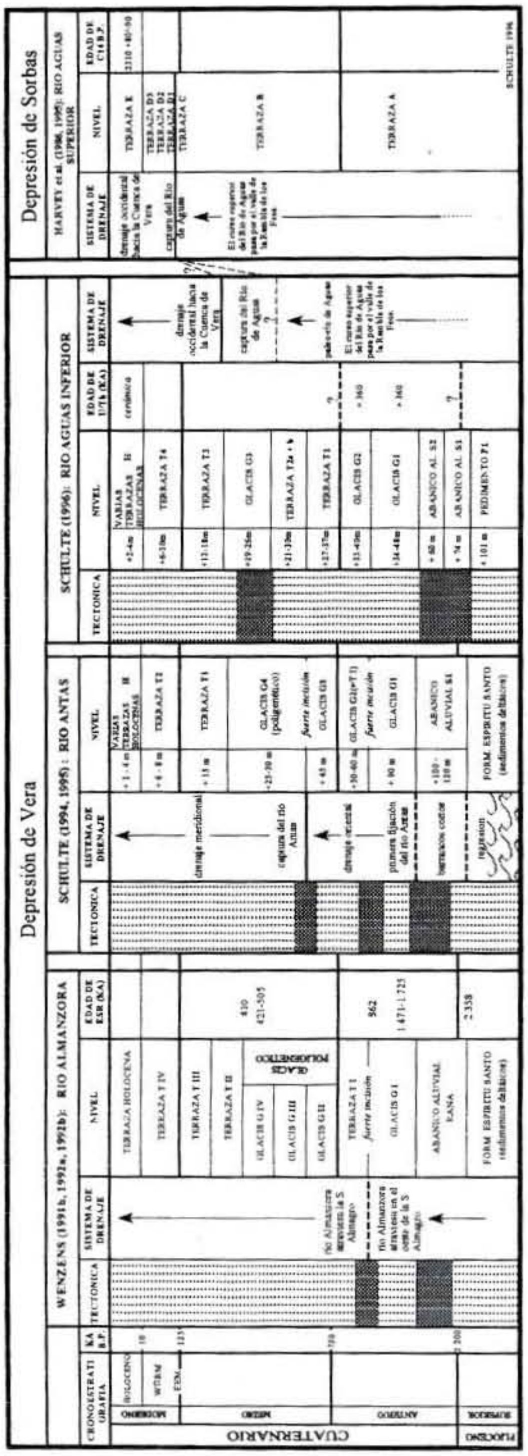


Fig. 5. Morphostratigraphy and chronology of the Vera and Sorbas basins.

[his detailed morphological and edaphological stratigraphy allows us to make a further step in he long term palaeo-ecological reconstruction of the Quaternary climatic cycles in the Vera ›asin. The evidence complements the results obtained by recent pollen analysis (Zagwijn and 5uc 1984; Pons and Reille 1988; Burjachs and Juliá 1994; Pantaleón-Cano et al. 1996) and ›xygen isotopes studies on deep sea cores (Rossignol-Strick and Palanchais 1989; Bertholdi *et* ›*l.* 1989; Combourieu and Vergnaud 1991) in the western Mediterranean.

Lower Pleistocene
The upper Pliocene and the lower Pleistocene include periods of extreme aridity, as well as of humidity (fig. 6). Mainly the well developed red fersiallitic soils (redness rating up to 15; compare Hurst 1977) have to be ascribed in their genesis to a subtropic seasonal wet and warm type of climate. The same holds for the rubification of the loose sediments in the alluvial fan (S1) and glacis (G2) of the lower Pleistocene. On the contrary, the upper Pliocene pediments P1 might correspond to arid climatic conditions with reduced weathering and an extremely irregular rainfall. A few torrential events led to catastrophic floods, removing coarse material which eroded hard rock surfaces without fossilising them. The synsedimentary calcrete of the glacis G1, dated with an U/Th date older than 350.000 BP (sample AG-415)[17], also indicates an arid climate, where phases of high energy transport alternated with periods of low water flow and high evapotranspiration (Wenzens 1992b). In general, the lower Pleistocene climatic oscillations can be understood more as hydric than as thermal fluctuations. In agreement with the well developed red soils and isotopic variations of the western Mediterranean it can by seen that the mean annual temperatures of this period seem to have been higher than during the middle and upper Pleistocene (Bertoldi et al. 1989; Combourieu and Vergnaud 1991).

Middle Pleistocene
With the start of the middle Pleistocene the climatic contrast between cold and warm periods increases (fig. 6). With the Glacis G3 of the river Antas the first compact, cold period terraces appear, which correspond to a braided gravel river-system (the same is the case in terraces T1 and T2 of the Río Antas and terraces T3 and T4 of the Río Aguas). On the contrary, glacis G4 (Río Antas) and glacis G3 (Río Aguas) have to be ascribed to interglacial or transitional periods, due to their low discharge dynamic and, partially, to the included soil formation. In general, temperatures, but mainly rainfall during the middle and younger Pleistocene are not sufficient any more in order to allow the formation of well developed red mediterranean soils (Schulte 1994, 1996).

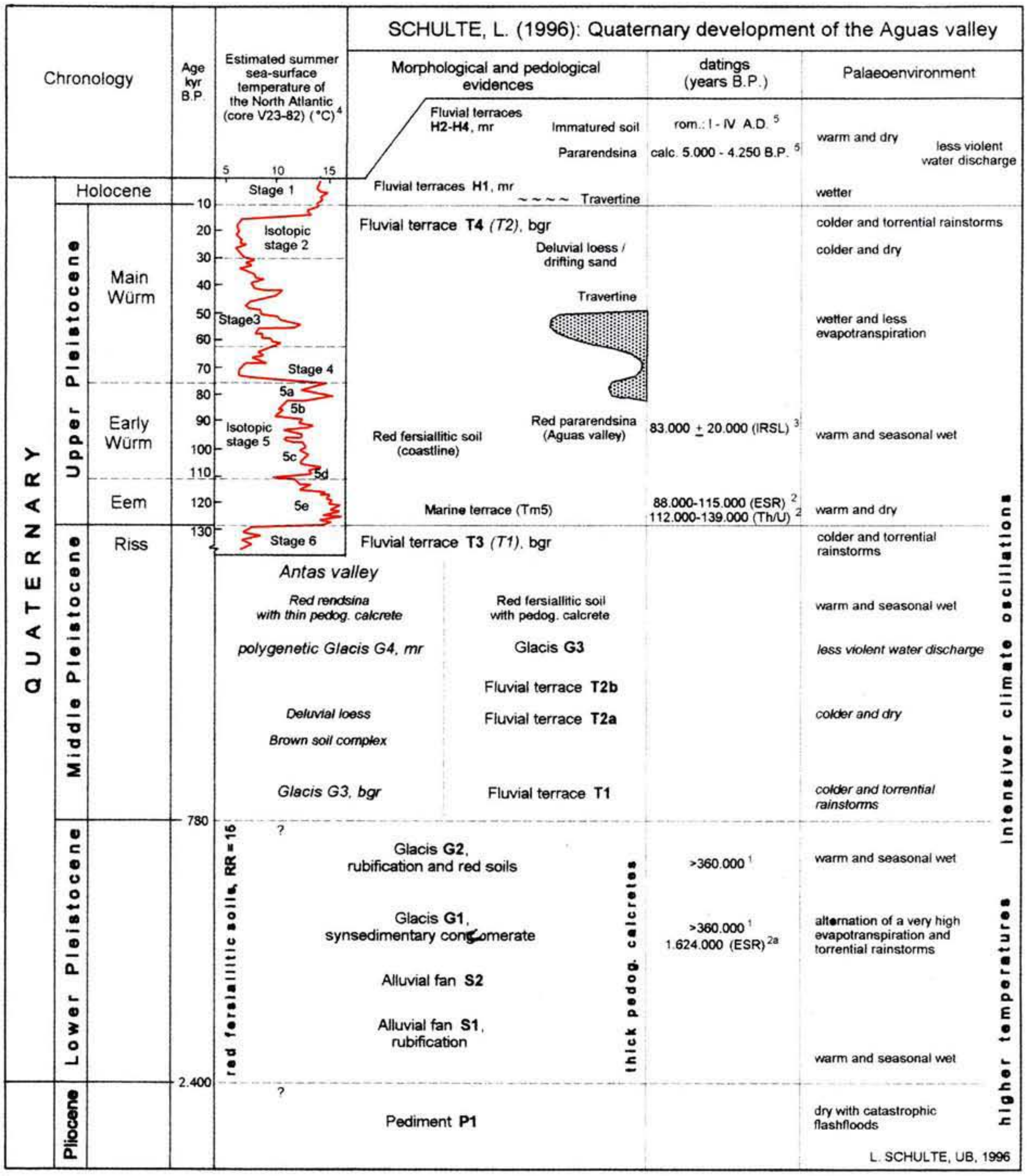
Upper Pleistocene and Holocene
Final chronological definition of the last climatic cycles is still dependent on the absolute dates being processed at the moment (fig. 6). The cold period terrace T3, predated 83.000±20.000 BP. by IERSL (Courty *et al.* 1994), of the Río Aguas can be ascribed to the penultimate glacial period, i.e. the isotopic stage 6. The last warm period is represented in the Vera basin by the 13 m-beach terrace formed during the last interglacial sea level maximum (stage 5e?). The red soil with pedogenic calcrete, which covers this marine terrace, must be younger. Pendant in the middle Aguas valley has been dated 83.000±20.000 BP by IERSL. Therefore, it is possible that during stage 5e in the Vera basin could have existed warm and dry conditions, similar to those of the present Holocene period, while the following transitional period, stage 5d to 5a, was characterised by seasonal wet climate, better suited for soil formation.

The travertine formation observed in the middle Aguas also corresponds to stage 5a, although its main formation process falls in stage 3. In principle, today the formation of travertine in the extreme semi-arid southeast Spain is understood as an indicator of humid phases with higher spring water flow. The development of travertine in the Río Aguas was probably limited or interrupted during the stadial, cold-torrential (?) isotopic stage 4.

After the wetter stage 3 climate seems to experience a temperature decrease and a reduction or rather an intensification of rainfall. Stage 2 is related to eolic sands and the formation of deluvial loess, which indicate a dry climate. According to the malacology of the loess profile from Velez-Rubio (Almería) temperatures must have been much lower (Brunnaker and Lozek 1969). This is also documented by the lowering of würmian snow limit in Sierra Nevada (> 1.000 m). During maximal glaciation temperatures must have been at least 6.1° C lower. To this period corresponds the fluvial terrace T4 of the Río Aguas. The braided gravel river had a high water discharge. Next to the influence of a periglacial dynamic, an intensification of sporadic rainfall

[17] These dates were obtained thaks to the collaboration of Dr. Juliá (Institut de Ciències de la Tierra "Jaume Almera"-CSIC).

under conditions of increasing aridity, as has been documented in the pollen profiles from Padul and Carihuela (Florschütz, Menéndez and Wijmstra 1971; Pons and Reille 1988; Carrión 1992), also seems to have played an important role.



[1] Th/U-datings (U-series decay) realized by Dr.R. Julià, CSIC, Barcelona.
[2] after WENZENS (1991); ESR = Electron spin resonance
[2a] ESR date of a interstratified travertine of the glacis GI near Sierra de Almagro (WENZENS 1991).
[3] after COURTY et al.(1994); IRSL = Infrared stimulated luminescence
[4] after SANCETTA et al. (1973)
[5] artefacts

bgr = braided gravel river
mr = meandring river
RR = redness rating
Glacis G4 etc. = Morphostratigraphy of the Río Antas after SCHULTE (1995)

Fig. 6: Quaternary geomorphological and palaeo-climatic dynamics of the Río Aguas (with additional data from the Río Antas).

The beginning of the Holocene is marked by wetter climatic conditions than at the present day, as indicated by a travertine formation at the Río Antas. Only later, probably after 6000 BP, aridity seems to increase. It is important that during Holocene no red soils have developed, which implies the lack of a marked seasonal humidity, apart from (anthropogenic) denudation and accumulation processes.

5.1.2. Isotopic studies of secondary carbonates (results of 3.1.2.1.)[18]

The isotopic contents of the carbonate signal fluctuation in the photosynthetic activity on the soils, which is a function depending on temperature and soil water contents. The dissolution and precipitation phases adjust to the dissolution of gypsum. The soluble product is higher than that of calcite and allows us to obtain an over-concentration in relation to calcite due to the contribution of calcium, which comes from the gypsum. Under certain conditions of evaporation and degasification of the solution the precipitation of secondary carbonate takes place. Depending on the relation of carbon in the liquid and gas phase an open or a closed system is defined for the CO2. A functioning in an open system corresponds to a precipitation of carbonate impoverished in ^{13}C, which indicates the contribution of carbonate of biological origin, i.e. higher photosynthetic activity. On the contrary, higher ^{13}C contents signal a tendency towards a more closed system under a reduced CO2, i.e. lower photosynthetic activity.

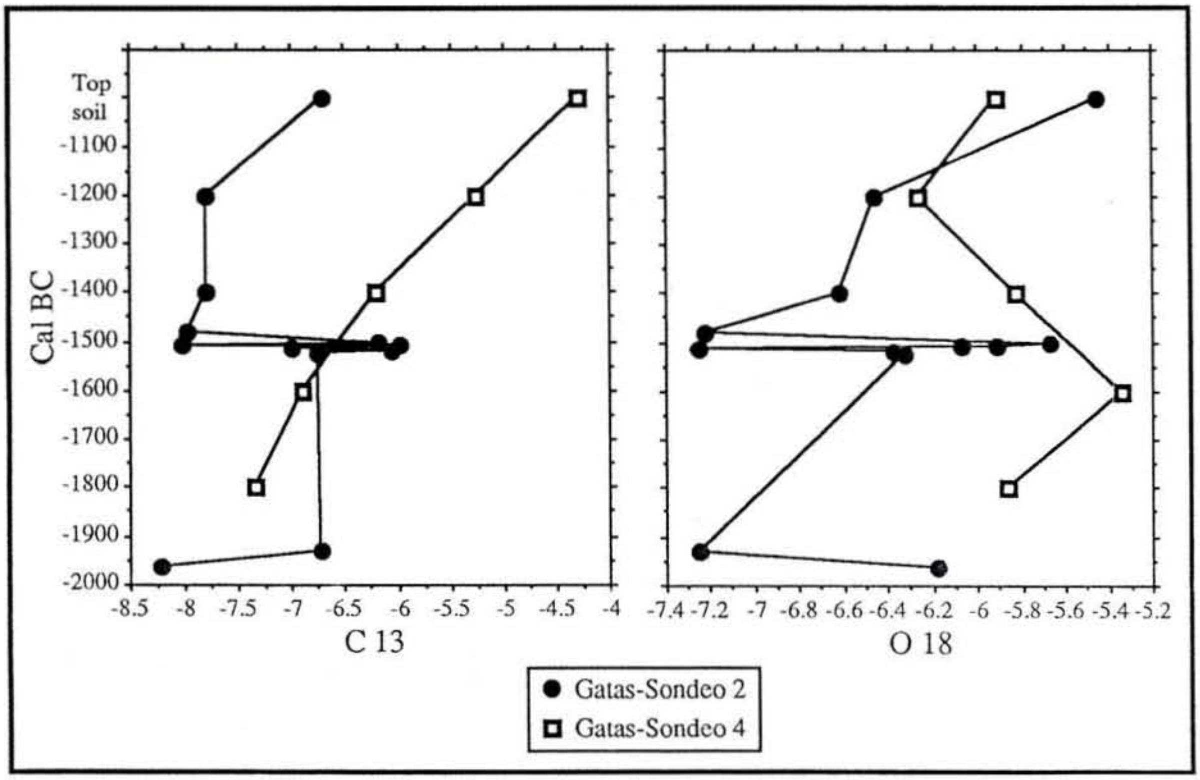


Fig. 7: Isotopic variations on carbonates.

Samples obtained from sondage 2 and 4 of Gatas show a general tendency towards more arid or less vegetated territories from 2000 cal BC until 1000 cal BC. The present day top soil is characterised by even less photosynthetic activity. The anomalies observed in sondage 2 around 1500 cal BC seems to correspond to anthropic alterations of the sediments, and can not be used for paleo-climatic reconstruction. This is supported by the archaeological evidence: while sondage 4 seems to represent natural sediments, the deposits of sondage 2 formed in closer relation to anthropogenic activity in Gatas.

[18] L. Dever; Université PAris Sed (FR).

The stability of the relative proportion of carbonates in the samples from both profiles suggests the functioning of relatively homogeneous hydric conditions, which regulate the flux of the quantity of material.

These results can be compared with the ^{18}O fluctuations in the profiles. In this case reduced ^{18}O contents correspond to colder and/or to more humid conditions. In this sense it can be observed (fig. 7), that during the first half of the second millennium cal BC dry and/or warm climatic conditions existed, something which correlates well with the results obtained form isotopic study of marine shells and trace element analysis on human bones (*see below*). Around 1600 cal BC maximum temperatures and/or aridity seem to have existed, which could be even higher than today. Samples from sondage 4 indicate a constant decrease in temperature and/or dryness until *c.* 1000 cal BC, which can not be detected clearly in sondage 2. The ^{18}O content in the top soils corresponds to the present day dry and warm conditions.

5.1.3.O18 and O16 isotopes in Glycimeris shells (results of 3.1.2.2.)[19]

The 532 isotopic analyses carried out on well dated *Glycimeris* shells show that the mean sea water temperature was 0.33-0.44° C higher during the first half of the second millennium cal BC than today. Furthermore, it is interesting that, while the maximum yearly temperatures were similar or even slightly lower (-0.03-0.11° C) than today, the minimum temperatures were higher (+0.76-0.91° C). This seems to suggest that the seasonal differences were less and that winter temperatures were even milder than today.

After 1550 cal BC a temperature decrease is observed. While yearly minimal temperatures still remain a little bit higher than today (+0.28° C), the maximum temperatures are 1.46° C lower. Seasonal differences seem to be even less marked than before. This cooling tendency continues, and by 1200-1100 cal BC the mean temperature has dropped around 2.5° C since the final Argaric period (1750-1550 cal BC). Maximum temperatures were 2.92° C and the minimum temperatures were 1.15° C lower than today.

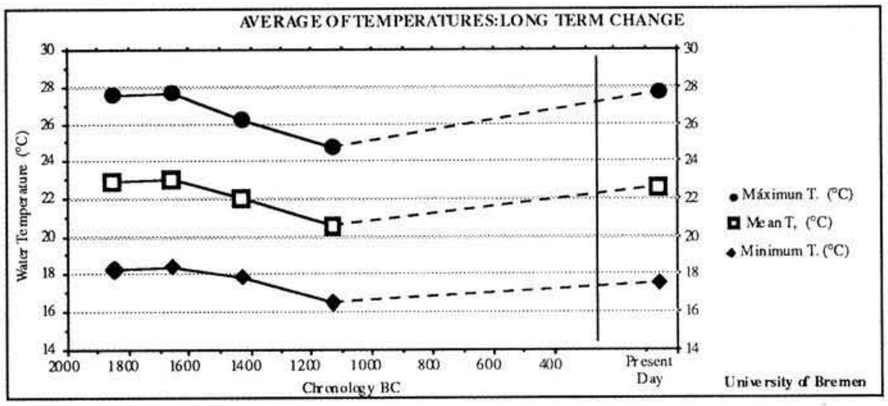


Fig. 8: Maximum, minimum and mean water temperature changes at the coast of Almería, based on isotopic analysis of *Glycimeris* shells.

5.1.4. Trace elements on human bones (results of 3.1.2.3.)[20]

As noted in chapter 3, ratios of the trace elements barium and strontium vary across the world. In a worldwide sample Burton and Price (1990a, 1990b) have demonstrated systematic differences between human remains recovered from coastal marine, inland terrestrial (non-desertic), and inland desertic environments. Preliminary results from analyses of values for log ratios from tombs 23a (Ba: 88 ppm, Sr: 3397 ppm); 33S (Ba: 99 ppm; Sr 2600 ppm); and 33N (BaL 123 ppm; Sr 1659 ppm) are presented in figure 9. The Gatas ratios obviously group with

[19] J. Pätzold, Ch. Hagedorn and G. Wefer; Universität Bremen (GE).
[20] J. Buikstra and L. Hoshower, University of Chicago (USA).

other values for inland desertic sites, suggesting that the environment of the Gatas region has not changed significantly over time.

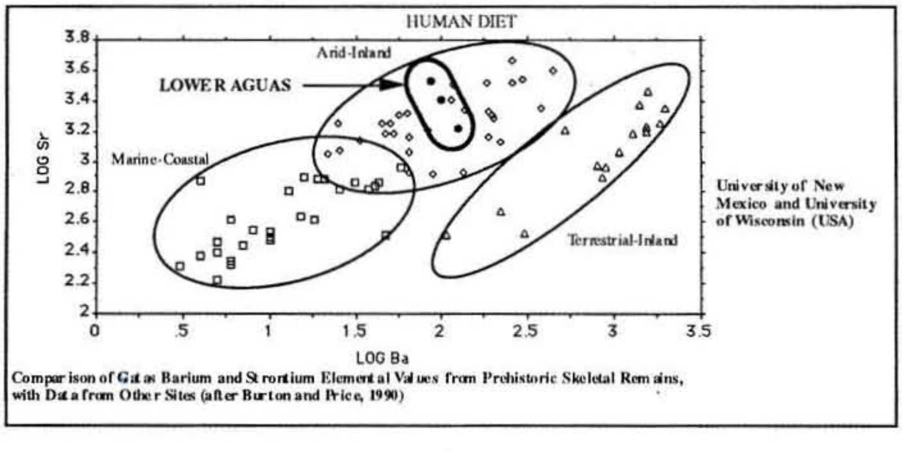


Fig. 9: Trace element values Ba/Sr of Gatas in relation to reference samples (data from Burton and Price 1990)

5.1.5. Conclusions[21]

Since the upper Pliocene-lower Pleistocene a long sequence of climatic phases has been documented for the Aguas valley, which have wider implications for the palaeo-climatic conditions of the Southeast of the Iberian peninsula. In general it can be seen that colder or warmer periods do not correlate with an increase or decrease in rainfall, but rather that different scenarios seem to be possible during glacial and interglacial periods. Nevertheless, since the middle Pleistocene, more concentrated rainfall, producing torrential events, tends to appear at moments of temperature decrease.

The Holocene climatic conditions are defined, in comparison with previous moments, by reduced fluvial dynamic and scarce edaphogenesis. The research undertaken confirms the existence of climatic fluctuations during recent millennia. According to the different types of isotopic and trace element analysis the first half of the second millennium cal BC was characterised by high temperatures and arid climatic conditions, which seem to be similar to the ones existing today. Winter sea temperatures even seem to have been warmer than today. But in the second half of the second millennium they decreased by around 2-3° C. This shows that the Southeast of the Iberian Peninsula reflects the same climatic dynamic as observed in other areas.

Yet the question remains as to how this temperature decrease is correlated with pluviosity. Muzzolini (1985) claimed an increase in humidity around 1000 BC (1200 cal BC) for North Africa, and Lamb (1981) estimated that the British Isles also saw a temperature decrease around 2° C after 3000 BP (1200 cal BC). The question about the implications of this change on the rainfall of southeast Spain is important to answer, as there does not have to be direct correlation between temperature and pluviosity. Wigley, Jones and Kelly (1980) have stated that while in Eastern Mediterranean an increase in temperature is also linked to an increase in pluviosity, in the Central and Western Mediterranean it implies less rainfall. The 13C increase in the sections of Gatas rather appears to indicate more arid and drier conditions, which can not be explained only in terms of human degradation of the vegetation cover (see below). A similar situation has been documented in southeast Spain during the the little ice age. According to the analysis of the glacier at La Veleta (Sierra Nevada), temperatures during the 16th-19th centuries AD have been lower than at the end of the 19th century and during the 20th century (Gómez, Schulte Salvador 1996). Nevertheless this did not necessarily correlate with higher rainfall, but rather

[21] Buikstra, J., Dever, L., Hagedorn, C., Hoshower, L., Pätzold, J., Schulte, L., Wefer, G. & the editors.

with a more concentrated rainfall producing an increase in torrential events during this period. In this way it seems probable that a similar general dynamic as observed in the middle and upper Pleistocene, still effects southeast Spain today and implies that a decrease in temperature is correlated with an intensification of rainfall.

5.2. GEOMORPHOLOGICAL, EROSION AND EDAPHIC PROCESSES

Ch. French, D. Passmore & L. Schulte.

5.2.1. Holocene fluvial dynamic of the Río Aguas (results of 3.3.1.)[22]

The geomorphological investigations carried out on the Holocene deposits of the Río Aguas provide a preliminary stratigraphy of the juxtaposed fluvial terraces (map 7). The oldest observed terrace (H1) could be dated to pre-Chalcolithic times and relates to the fluvial dynamic before 5000 cal. BC, possibly in the early Holocene. This represents a morphodynamic active period, and thus a period with higher discharge (torrential events). H2 could not be dated so far, but appears to be of pre-modern date (1500 AD), as is suggested by the presence of 18th or later pottery found in sediments covering this terrace. H3 contains Copper age and Andalusian pottery. Radiocarbon dating of charcoal, extracted 1.5m below the terrace surface next to Cortijo el Navajo, provided an age of 430±50 BP or 1514±97 cal AD (Beta-100599). The accumulation of the H3 terrace can be interpreted as the response of Aguas river dynamics to increasing erosion processes during the transition between the Andalusian and Modern period. H4, the last Holocene terrace, is definitely post-Andalusian. During the 1970s terrace H4 belonged partially to the active riverbed of the Río Aguas, as aerial photographs show. All these terraces present a less violent water discharge than, for example, observed in the Würm terrace (T4). The fact that H3, H4 and, maybe also, H2 could have accumulated during the last 500/600 years, implies higher sedimentation/erosion rates during this period. This correlates well with the evidence obtained from coring of the sediments in the river mouth of the Antas and the Almanzora (Hoffmann 1988), as well as from the Holocene stratigraphy of the Río Antas (Schulte 1995). Both terraces documented in this river system seem post-Andalusian (16th century AD), as is shown by the presence of modern pottery in H2 and in the upper part of H1.[23]

5.2.2. Detailed geomorphological and micromorphological analysis of the Barranco de Gatas, the Rambla Ancha and the Gatas settlement (results of 3.3.1., 3.3.2.)[24]

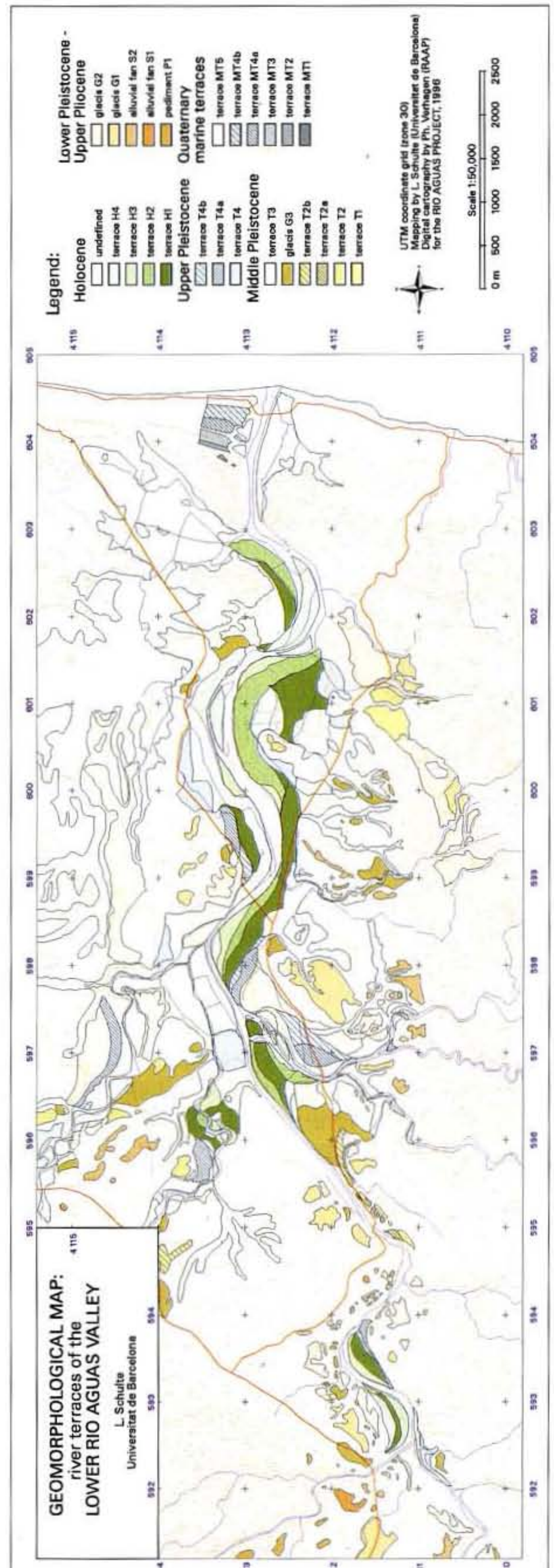
1.The Gatas basin ('Barranco de Gatas')

This is a small (c. 0.5 km^2) intramontane basin situated between the Cerro del Judio and Cerro de los Caballones (map 2), lying below the archaeological site of Gatas and has been termed the Gatas basin or the barranco de Gatas. Here the middle reaches of the rambla de Ancha (also called rambla de Añoflí) and a tributary, the Barranco de Gatas, are deeply entrenched (up to 14m) into interbedded Quaternary gravels and loams, Miocene marls and a thin overburden of alluvial fan gravels and fine sediments. Previous work (Courty, Fedoroff, Jones and McGlade 1994) dated these latter sediments by luminescence (ISRL) techniques to c. 6800 BP and has suggested that large-scale entrenchment of the basin occurred sometime after this date. The geomorphological survey undertaken by Schulte shows that the entrenchment occurred much earlier than the first human occupation of the area. The alluvial fans can be correlated tentatively, due to the importance of tectonic activity, with G1 and G2 of the Río Aguas. U/Th dates of travertines from -1.5 m of the glacis G1 pendant and from -3 m of the glacis G2 correlative in the basin have provided an age older than 350.000 B.P. A further sample from the upper part of the sedimentary sequence (Section BG-F) is being processed at the moment by OSL dating methods.

[22] L. Schulte, U.B. (ES).

[23] At the moment, a total of for luminescence samples have been submitted for analysis, and will provide further information on the age of the fluvial terraces and on the morphodynamic active phases.

[24] Ch. French, University of Cambridge; D. Passmore, University of Newcastle (UK).



Map 7: Geomorphological map of the Aguas Valley.

Field survey of the entrenched gully floors throughout the basin has also revealed considerable variability in the extent and nature of valley floor deposits. Upper reaches of the gully network are less-incised and frequently infilled with thick (at least 1.3 m) deposits of poorly sorted colluvium, alluvium and debris flow material; these sediments are well-exposed in incipient headcuts developed through cultivation terrace scarps, for example at sections BG-1 and BG-2 (see map 2). At present it is unclear whether this material precedes, or post-dates, major agricultural terracing of the gully floors. At BG-2 a palaeosol identified at a depth of 1 m has been interpreted on the bases of micromorphological analysis, as comprising stabilised, redeposited marl subsoil, perhaps developed on an already truncated subsoil surface. This soil had received organic and carbonised material as a result of human activities, and been exposed and saturated during warm and damp periods, all prior to burial by subsequent erosion of material from upslope which now comprises the present day terrace system. Although there is no directly associated dating evidence for this profile, its description falls into Courty *et al* (1994) stage 3c-d or the Neolithic-Bronze Age periods. The only profile that exhibited a definite buried soil was BG-3. Here, a calcitic 'loam' with an excremental fabric organised into a weakly developed blocky ped structure and some incorporation of organic material was developed on the Neogene marl subsoil. It was buried by subsequent debris flow. It was dominated by micro-sparitic calcium carbonate, with only minor lenticular gypsum present. This palaeosol, although it may be developed on an already truncated subsoil surface, would seem to equate with Courty et al. (1994) stage 1 of calcareous loam development on the upper edge of the Barranco in the early post-glacial period.

The middle and lower reaches of the intramontane basin are frequently narrow and locally incised through bedrock, although wider reaches do exhibit low terraces, c. 1-2.5 m high, that are inset within the entrenched gullies and are of Holocene age. Preliminary examination of terrace exposures suggest many of these deposits represent slumped and reworked gully-side material (e.g. BG-9); in some localities, however, these deposits are partly or wholly comprised of alluvium (e.g. BG-8) and occasionally contain pottery sherds (BG-7) or charcoal fragments (BG-4).

	Profile 2	Profile 3	Profiles 4 & 8
Suggested interpretation:	secondary soil formation on eroded schist /marl bedrock; some anthropogenic activity; buried by debris flow	*in situ* soil formation on Neogene marl bedrock	terrace edge in barranco, with alternate wetting/ drying & alternate stabilisation/burial & erosion; all buried by later calcitic colluvium
Suggested chronology:	Neolithic to Bronze Age	early post-glacial to Neolithic	early post-glacial

Table 2: Summary of suggested interpretation and chronology for the Barranco de Gatas profiles.

2. Rambla Ancha
Holocene incision (locally up to 8 m in depth) in this 0.5 km reach, between Cortijo de García and the confluence with the Barranco de Gatas, has exposed a well developed sequence of terraced alluvial and colluvial valley fills (map 2). Geomorphological mapping, survey and logging of exposed sedimentary sequences has identified some 26 discrete valley fills; these have been correlated on the basis of height above the modern channel bed and lithostratigraphy and collectively comprise a sequence of at least 5 Quaternary and Holocene depositional terraces between 2-5 m in thickness. These terraces exhibit a sandy gravel basal member (representing channel bed and bar deposits) overlain by variable thickness of fine-grained, calcitic alluvium deposited in a low-energy overbank, floodbasin and channel fill environments and locally augmented by colluviation. Fine sediment profiles through five terrace units

spanning the depositional sequence in the Rambla Ancha have been sampled for micromorphological analyses (Profiles RA1-5, described below). In addition, a profile has been sampled through calcitic colluvium exposed in a gully on the west side of the valley (Profile RA-6). In order to establish the chronology of this sequence a total of three sediment samples, representative of the three oldest alluvial terraces, have been submitted for luminescence dating. Due to delays at the luminescence laboratory we are still awaiting these results and a full description and interpretation of the fluvial sequences at the Rambla Ancha will be forthcomming. However, a west bank terrace unit (Profile RA-5) lying 3.5m above the current river bed has been dated by ^{14}C (on charcoal fragments recovered from the base of the fine member) to 1340±50 BP or c. 714 cal AD (Beta-100600). This would suggest that the lowermost two or possibly three fluvial terraces within the study reach were deposited during the post-medieval period.

Profiles RA-1/2/3 are all calcitic 'loams' exhibiting an excremental fabric, dominated by micro-sparite calcium carbonate, with minor lenticular gypsum. These sediments are acting as alluvial infilling deposits of inactive and partially infilled former channels, and formed in slow to ponded, fine sediment-rich, water flow. Most probably, these sediments represent reworked Neogene marl subsoil material derived from the tributary valley to the west by water erosion events (as observed in profile RA-6). Recent gullying through this material in this tributary valley to the west indicates how easily and quickly this may have occurred in the past, in this case through a lack of maintenance of the terrace system and large areas of bare soil.

Profile RA-4 is similar to profiles RA-1/2/3 except that it contains aggregates of the same organic soil fabric as observed upslope in the Barranco de Gatas in profile BG-2, as well as fragments of the gypsic crusts observed in profiles BG-4/8. In this case, the alluvial infill of the former channel is comprised of eroded soil material probably carried a considerable distance downstream, as well as eroded marl subsoil material from the adjacent and immediately upslope tributary valley.

	Profile 1	Profile 2	Profile 3
Suggested interpretation:	calcitic alluvium	calcitic alluvium	calcitic alluvium
	Profile 4	Profile 5	Profile 6
	calcitic alluvium with reworked eroded material derived from Barranco de Gatas soils	calcitic alluvium	calcitic marl derived from Neogene marl bedrock
	Profile 1	Profile 2	Profile 3
Suggested chronology:	pre-late Neolithic	pre-late Neolithic	pre-late Neolithic
	Profile 4	Profile 5	Profile 6
	post-Medieval	post-Medieval	late Quaternary

Table 3: Summary of suggested interpretation and chronology of the Rambla Ancha profiles.

Profile RA-5 appears to contain a combination of material similar to all the other Rambla Ancha channel alluvial sediments. It contains eroded gypsum-rich marl subsoil, as well as minor amounts of eroded organic soil material and gypsic crusts similar to those observed upstream in the Barranco de Gatas.

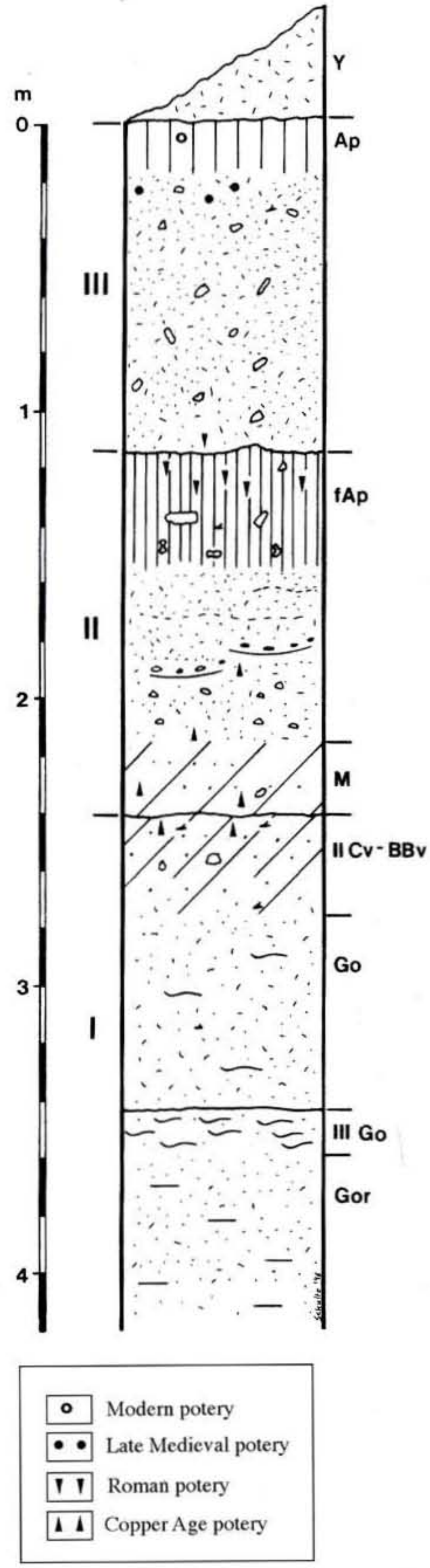
The major problem with these interpretations is that the amount of reworking of earlier channel infills and alluvial terrace deposits is unknown. Consequently, some or all of the material could already have been in the system for a long period of time, and therefore be relatively meaningless in land-use terms and implications. Absolute and relative dating of the channel units is therefore crucial if further interpretation is to be made of these analyses.

3. The Lower Aguas Basin (El Campo site).
Sediments infilling the El Campo alluvial basin were investigated by continuous sediment coring using a percussion corer. The 4.3 m core recovered for pollen analysis is largely formed by fine grained silt and clay alluvium, with a prominent fine gravelly colluvial horizon between 3.9-4.3 m. Colluvial sediments are most likely derived from an upstanding bedrock knoll located some 20m north of the core site (map 2).

4. The montane basins of the Sierra Cabrera.
Continuous sediment coring of Balsa de Marchalico and Balsa Alquirrico has recovered 0.8 and 1.8 m of fine, unstructured clays respectively. A new technique is currently being applied that may facilitate palaeoevironmental reconstruction and C14 dating.

5.2.3. The Las Pilas section (results of 3.3.1., 3.3.2.)[25]
During the geomorphological and edaphological fieldwork a section was discovered at the margins of the Aguas near the Copper age site of Las Pilas, which provided a sedimentary sequence from the early Holocene until modern times. While the river terraces are indicators of the general morphodymanic of the Aguas catchment, this section allows us to gain insight into small scale edaphological and erosion processes. Sedimentary (stage; fig. 10) and micromorphological (units) analyses have allowed us to establish the following stratigraphic sequence (fig. 10):
- Stage I-Unit I (+355 cm): Pre-Holocene compacted powdery gypsum.
- Stage I-Unit II (355-335 cm): Redeposited marl from erosion upslope, with some influence of river erosion. Low gypsum contents, introduction of coarse and very coarse gypsum crystals and gleyfication of the sediments indicates prolonged periods of higher water table position and ground water fluctuations. The suggested date is early Holocene.
- Stage I-Unit III (335-255 cm): Rapid deposition of Unit II type marl from upslope, with gypsum formation suggestive of alternating damp/hot conditions. The presence of prehistoric pottery at the top of this unit suggests this erosional episode occurred before the Copper age.
- Stage I-Unit IV (255-245 cm): Unit IV was exposed as a surface for a long period of time ('standstill horizon'). This allowed the formation of an immature soil. It is a poorly formed A horizon with a minor organic component developed on a calcareous substrate. It probably reflects more humid palaeo-environmental conditions. The presence of Copper Age pottery dates this unit between 3000 and 2300 cal BC.
- Stage II-Unit V (245-215 cm): This unit is markedly different than unit IV and obviously represents a different erosional episode, probably of material from unit II and subsequently from the marl subsoil of unit I. Deposition was initially rapid but then slowed considerably allowing the formation of frequent minute gypsum crystal infills. Also the increase of coarse material and the presence of pottery fragments and organic matter reflects important processes of instability at the end or after the Copper Age.
- Stage II-Unit VI (215-150 cm): Slow erosional episode similar to unit IV, due to a lessening of erosion further upstream or construction of terraces, which prevented much of this erosional material from reaching the Las Pilas profile. The pottery found and its stratigraphic position implies that this unit formed after the Copper Age (2300 cal BC) and before the Roman period (I-IV century AD).
- Stage II-Unit VII (150-90 cm): Seems to represent a less morphodynamic active period, with some type of soil development and anthropogenic use (Ap), as shown by the large number of pottery sherds found. These fragments allow us to date this unit into the Roman period, when the near by settlement of Las Pilas was occupied again.

[25] Ch. French, University of Cambridge (UK), and L. Schulte, UB (ES).



Perfil: Las Pilas (14m s.n.m.)

SCHULTE, L. (1996)

>37 cm	Y	Material antropogénico (bancal).
19 cm	Ap	gris - marrón claro; poca materia orgánica; viva efervescencia al HCL; piedras poco abundantes; textura arenosa limosa; ceniza; cerámica de los s. XVII-XVIII.
98 cm	C	gris muy claro - marrón claro; aparentemente no orgánico; viva efervescencia al HCL; piedras poco abundantes; matriz arenosa limosa; cerámica de los s. XIII-XV (época árabe) y posterior al s. XV; depósito de vertiente.
37 cm	fAp	gris - marrón (2,5Y 5/4); materia orgánica; viva y en la base muy viva efervescencia al HCL, concreciones calcáreas de 5 mm en la base; piedras poco abundantes; textura arenosa - francosa ; ceniza; cerámica de los s. I-IV (época romana).
64 cm	C	amarillo/marrón claro (2,5Y 6/4); aparentemente no orgánico; viva efervescencia al HCL; piedras y gravas poco abundantes; textura limosa, algunas bandas limosas; cerámica calcolítica 5.000 - 4.250 cal. B.P.; depósito de vertiente.
25 cm	M	amarillo - marrón claro (2,5Y 7/4); aparentemente no orgánico; viva efervescencia al HCL; textura arenosa; cerámica calcolítica 5.000 - 4.250 cal. B.P.; coluvión (?).
40 cm	II Cv - BBv	amarillo marrón (2,5Y 6/6), hacia abajo disminuye la intensidad; aparentemente no orgánico; viva efervescencia al HCL; piedras y gravas poco abundantes; textura arenosa francosa; cerámica calcolítica 5.000 - 4.250 cal. B.P.; rendsina - suelo pardo mediterráneo poco elaborado.
67 cm	Go	amarillo gris claro con manchas ferruginosas; aparentemente no orgánico; viva efervescencia al HCL; textura arenosa - francosa.
16 cm	III Go	amarillo gris con abundantes manchas ferruginosas; aparentemente no orgánico; viva efervescencia al HCL; textura arenosa - francosa; horizonte de oxidación.
>54 cm	Gor	amarillo gris claro con manchas ferruginosas y de reducción; aparentemente no orgánico; viva efervescencia al HCL; textura arenosa - francosa.

Fig. 10: Section through the slope deposits north of Las Pilas.

- Stage III-Unit VIII (90-0 cm): Erosional episode with important sedimentation in the Las Pilas profile. The presence of Nazari period and modern pottery at the top of the sequence implies that this accumulation took place after the Roman period and before the 15th century AD. The Nazari settlement of Mojacar la Vieja, from where some of this material could have come from, is located only some one hundred metres southwest from the Las Pilas section. The lack of accumulation during modern times seems to be a result of the presence of agricultural terraces.

5.2.4. Conclusions[26]

Despite extensive searching during the survey for buried soils within the barrancos and ramblas associated with the lower reaches of the Aguas valley, almost none were identified. It appears that almost every available land surface has been truncated and eroded to some degree, as well as being subject in many cases to later burial by eroded subsoil material derived from further upslope. Nonetheless, it is suspected that the present day terrace system does bury and preserve parts of relict territories with intact palaeosols which remain to be discovered. This type of future sampling investigative work, combined with a full dating programme is essential if greater sense is to be made of this territory in human land-use terms.

The combined geological, geomorphological and micromorphological work of this project have suggested that the tributary valley systems of the Barranco de Gatas and the Rambla Ancha were already deeply incised and gullied by the early Holocene. The subsequent landform history was dominated by further erosion and limited deposition of slope and valley deposits, with much of these sediments effectively being flushed right through the valley system into the Aguas river system. What is left is small zones or remnants of former terraces associated with channel units, particularly in the middle-lower reaches of the Rambla Ancha where there is a broadening out of the valley and a gentler slope.

These conclusions generally complement the extensive work of Courty *et al.* (1994) from the Archaeomedes Project, but in some instances no new evidence was found to corroborate their findings. By the early Holocene there was a general lack of well developed soil cover in the Barranco de Gatas to Rambla Ancha area. Those soils that survived were fine textured calcareous loams which had eroded from pre-formed calcitic soils in a slow aggradational dynamic. These soils were characterised by an absence of horizonation, much reworking through biological activity, no coarse component, abundant calcitic silty clay intercalations and large lenticular gypsum crystals in the pores. At the same time, the Las Pilas area was characterised by gypsum accumulation as a result of water trapped in small depressions with low energy alluvial sedimentation in a seasonally warm and wet climate with a fluctuating and high water table. In addition to this, the present work would suggest a much stronger colluvial aspect to the Las Pilas area as a result of the erosion of the gypsiferous marl subsoil derived from upslope, followed by much reworking and localised re-erosion of the same material, but nonetheless accumulating on the fringe of a seasonally active river floodplain. The Las Pilas section (Unit-III), as well as the BG-2 section present evidence of damp and hot environmental conditions possibly until the Copper Age, i.e. 3000 cal BC. According to the Las Pilas profile, soil development at the bottom of the Aguas valley seems to have been poor during the third millennium, and was even worse during the first millennium AD.

Courty *et al.* (1994) also suggest that the entrenchment of the Rambla Ancha occurred much later in the Holocene, in the early Argaric period (c 2300-1960 cal BC). This was associated with wind and water erosion at the Gatas site. Thereafter, there was never a return to the aggradational dynamic in the Sierra Cabrera uplands. Yet the new U/Th dates, and the marked absence of Bronze Age artifacts in the Rambla Ancha channel systems suggest that the entrenchment and infilling of the meandering channel systems occurred much earlier. Moreover, in the middle reaches of the Rambla, these systems, once out of use and infilled, appear to have remained relatively stable and accumulated relatively small amounts of subsequent alluvial deposition, with their upper surfaces ostensibly being mirrored by the present terrace construction levels. In contrast, it is therefore suggested that the Rambla Ancha,

[26] French, Ch., Passmore, D., Schulte, L. & the editors.

once entrenched and infilled with its present course established, remained relatively stable throughout at least the later prehistoric and historic periods. Indeed, in the new contexts examined from the site of Gatas, there was much deliberate deposition with occupation debris in structures and building collapse, with the only indication of water erosion observed in the laminated infillings of the cist burials. The latter need imply no more than post-burial groundwater percolation into the cavity created by the cist, rather than wider scale erosive events.

The fact that two of the four Holocene terraces of the Río Aguas could be dated into the very late Andalusian and modern period, seems to imply an intensification of erosion/sedimentation processes during the last 500 or 600 years. These higher sedimentation rates seem to be induced by anthropogenic factors, such as possible changes in the Nazari agricultural strategies, the depopulation of the area during and after the 16th century AD and the abandonment of the Andalusian terrace and irrigation system. Nevertheless, the importance of the so called "Little Ice Age" in this respect can not be underestimated. The existence of colder climatic conditions during the 16th-late 19th century has recently been confirmed also in the Southeast of the Iberian Península through the investigation carried out on the glacial remnant of the *Corral del Veleta* in the Sierra Nevada (Gómez, Schulte y Salvador 1996).

5.3. HYDROLOGICAL REGIME AND WATER EXPLOITATION

W. Herget

As mentioned in chapter 3 detailed hydrological analysis was carried out in the catchment of the Rambla Ancha or Añoflí, an area of 1,607 km2. *The main questions concern the quantity of water available in this area, the distribution of the water flow along the year and the human management of these water resources in sub-modern times.*

5.3.1. The natural hydric conditions (results of 3.1.1., 3.4., 3.8.)

In summer 1994 a wild fire destroyed the vegetation of Sierra Cabrera. This event will effect the local micro-climatic conditions, as well as the run-off during many years. Nevertheless, these negative circumstances offer an advantage for the hydrological investigations. The present day values represent an exceptional situation on which other situations can be modelled. Also, it is interesting to analyse in the following years how the system recovers from this dramatic degradation of the environment.

	P1 (250 m) in mm	P2 (150) in mm
Measuring period 1.21995-3.31996	296	284
Main vegetation period 1.4.1995-30.9.1995	80	80
max	54	54
Humid period 1.2.1995-31.3.1995 and 1.10.1995-31.1.1996	151	143
max	55	52

Table 4: Pluviosity measurements in Sierra Cabrera.

The Spanish hydrological year starts on the 1st of October, the transition between the dry and the humid period. The main vegetation period, in which sufficient water should be available for the filling of the soil storage in order to allow the growth of the principal cereals and vegetables, lasts from the beginning of April to the end of September (see Achtnich 1980; Israelsen and Hansen 1962; Schendel 1967; Doorenbos and Pruitt 1975). The humid period in which the aquifers are recharged begins on 1st October and ends on 31st March. It is therefore convenient to differentiate between the period of high agricultural water demands, which has been of prime importance in historical as well as in pre-historic times, and the humid period. The measuring period carried out in the context of the Aguas Project allows to analyse one complete dry season, while the wet season is combined of two humid periods.

Of 18 rainfall events in the measured period 7 fall into the main vegetation period, and 11 into the wet period. Of the 7 events which occurred during summer time only one was sufficient to infiltrate and to moisten the soil. The maximum rainfall was similar in both periods with little more than 50 mm. The fact that 4 out of 18 rainfalls provided higher values in the upper totaliser (P-1) suggests that inhomogenities, which have been detected and analysed insufficiently in southeast Spain so far, even exist in this small catchment. Nevertheless the overall differences between the upper and the lower totaliser are small (12 mm), and do not corroborate the values given by Perez Pujalte and Oyonarte Gutiérrez (1989) in the context of the main soil analysis and mapping project undertaken so far in southeast Spain. For a height difference between 160m to 260m a rainfall variation of 74 mm is calculated.

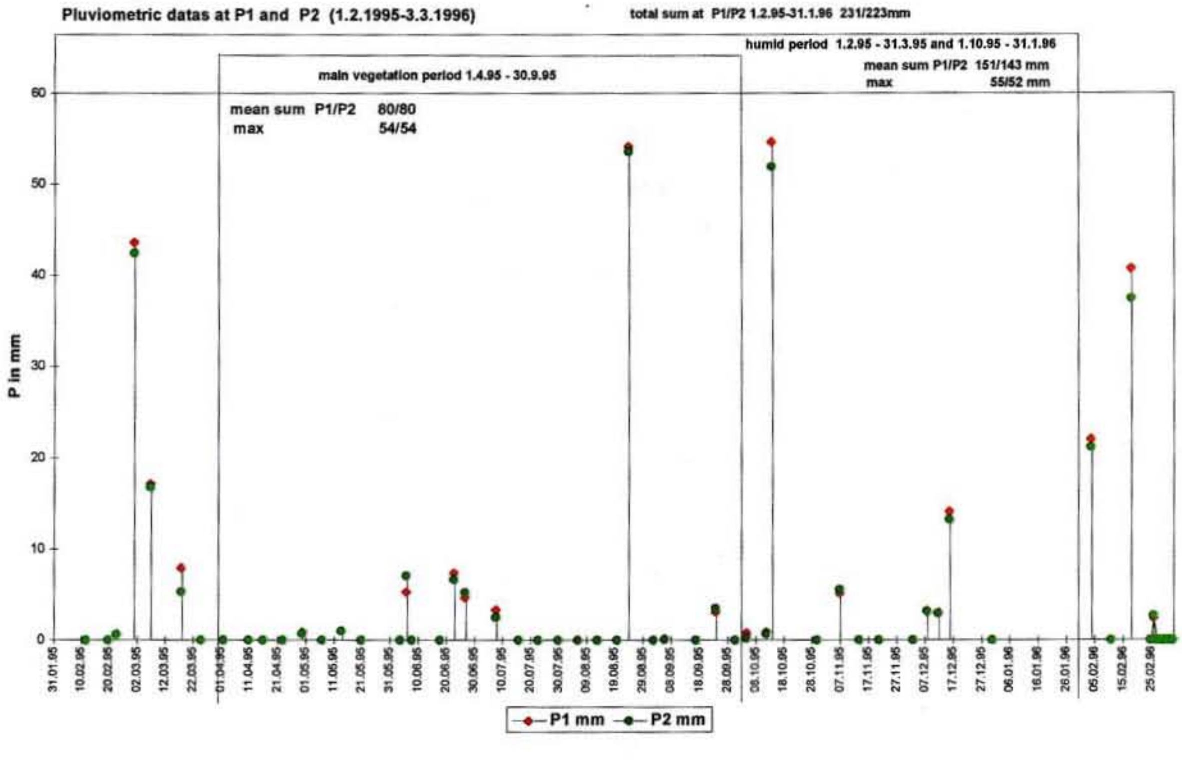


Fig. 11: Rainfall measured in the totalisers P1 and P2.

The rainfall data recorded in Gatas can be compared with the information from the surrounding stations for the period between February 1995 and February 1996. Only the station Garrucha Faro offers uninterrupted daily values for this time span. Table 5 shows the most representative values for the corresponding periods of rainfall measurements.

In the first place it can be observed that between February 1995 and August 1995 the lowest values, in terms of rainfall sum, variability and maximum are found in the inland station of Vera, located in the center of the Tertiary basin. The highest values were registered at the coastal station of Garrucha. The other inland stations situated close to or in a sierra environment present an intermediate situation.

	Gatas (mm)	Garrucha Faro (mm)	Cuavas de Alm. (mm)	Los Gallardos (mm)	Vera I.L. (mm)
Height above sea (m)	200	12	90	120	100
Location	mountain slope	coast	lowland, mountain margins	lowland, mountain margins	lowland, centre of the basin
Period 2.95-2.96 (13 months)					
sum	290.2	189.6			
mean	12.6	9			
standard deviation	17.4	16.9			
maximum	53.9	67.5			
Period 2.95-8.95 (7 months)					
sum	144.0	157.1	112.5	112.8	81.4
mean	13.1	14.3	8	11.3	8.1
standard deviation	18.2	22	13.3	20.3	9.8
maximum	53.9	67.5	48.5	67.0	32.0
Main veget. period 4-0.95 (6 months)					
sum	80.1	95.9	111.4		61.9
mean	8.9	13.7	9.3		6.9
standard deviation	17	24.3	15.1		6.4
maximum	53.9	67.5	48.5		18
Wet period 2.- 3.95, 10.95-1.96 (6 months)					
sum	146.9	93.7		168.5	
mean	13.4	6.7		11.2	
standard deviation	18.1	12.2		16.3	
maximum	53.9	35		67	
Sum 2.95-1.96 (12 months)	226.9	189.6		281.3+X	

Table 5: Precipitation values at Gatas (Sierra Cabrera) and neighbouring stations.

During the main vegetation period between April and September the coastal area presents the highest rainfall variability and maximum values. Yet, the highest precipitation values occur in inland locations at the margins of the sierras. In the wet period, February/March 1995 and October 1995-January 1996, the highest values in rainfall sum, variability and maximum are observed in the stations which lie closest to the mountains. Most of the precipitations between February 1995 and January 1996 took place at the station of Los Gallardos, which due to the lack of measurements during September 1995 must have been slightly higher (table 5). All this comparative data shows that there is no specificity in the results obtained from the area arround Gatas in comparison to the other stations of the Vera basin. The influence of the wild fire, which affected large parts of Sierra Cabrera in 1994, can not be identified with the available measurements. It is possible that the relatively high rainfall events occurring during the humid period are a consequence of this event.

In order to interpret these results in relation to the availability of water for human needs some factors have to be taken into account: At the beginning of the 1960s, after a period of scarce rainfall the gallery of the so called Fuente de Gatas was enlarged to the karst aquifer. The obtained discharge was so important, that it was limited by the water authorities. Approximately in the same period the karst aquifer was perforated in the area of the Diente de la Vieja, in order to supply the town of Garrucha (c. 10km north of Sierra Cabrera). This produced a sudden emptying of the affected aquifer with an effluent of c. 800 l/second. After approximately 1.5 hours the spring of La Alcantarilla, which used to provide 11 l/s, dried out. This is equivalent to 800 l/s * 5400 sec = 4320m3, or to the water obtained previously from the La Alcantarilla spring during 4.5 days. Although the well was closed again, the delay in taking measures led to a wide scale lowering of the ground water level. As the spring of La Alcantarilla dried out a new mina, which provided 11 l/s, had to be constructed further downhill. According to the owner as well as to the administrator of the Cortijo de Gatar the affluent of the Fuente de Gatas, which originally produced maximal 14l/s, decreased, so much that in 1982/83 a well was cored next to the spring. The extracted water amount was limited to 20 l/s, although only 15 l/s are used in order to fill the new cistern with a storage capacity of 250 m3. The total water extracted during the main vegetation period is approximately 13 times 250 m3 = 3250 m3. This volume is approximately twice as much as the total discharge measured at the gauging station in the same period of time. According to the administrator of the Cortijo de Gatar an extraction of 15 l/s produces a lowering of the water table of 17-18 m. He considers that this value can be tolerated every 14 days during 5-6 hours. After the pumping of 15 l/s stops, the water table needs around 12 days to reach a level 20 cm below the previous period. In this way the present day situation shows a balanced functioning. Moreover it is observed that the water flow is bigger during the Summer than during the Winter: "notable" which corresponds to c. 2 l/s. This suggests a temporal delay of half a year between infilling through rainfall during the humid period and the slightly higher effluent during the main vegetation period. At the beginning of 1993 some water was detected again at the spring of La Alcantarilla, which suggests a recovering of the karst aquifer. This can also be an effect of the recharging precipitation situation since the last decade.

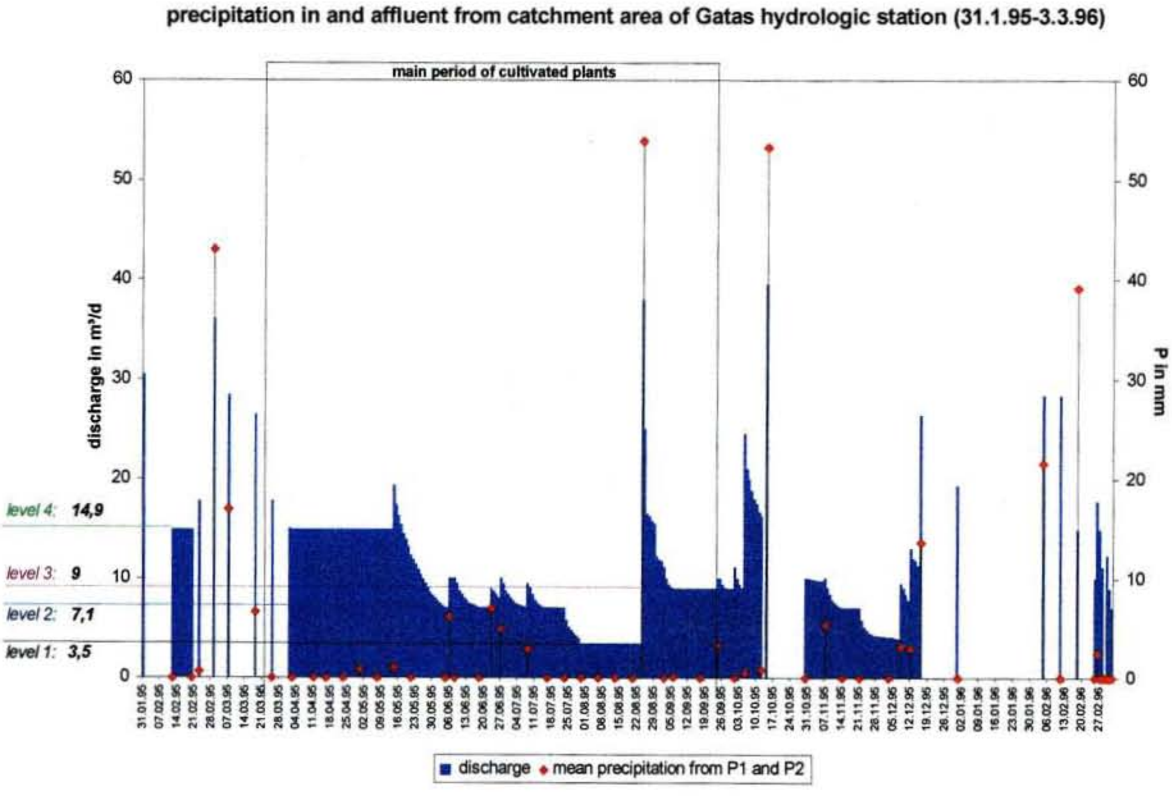
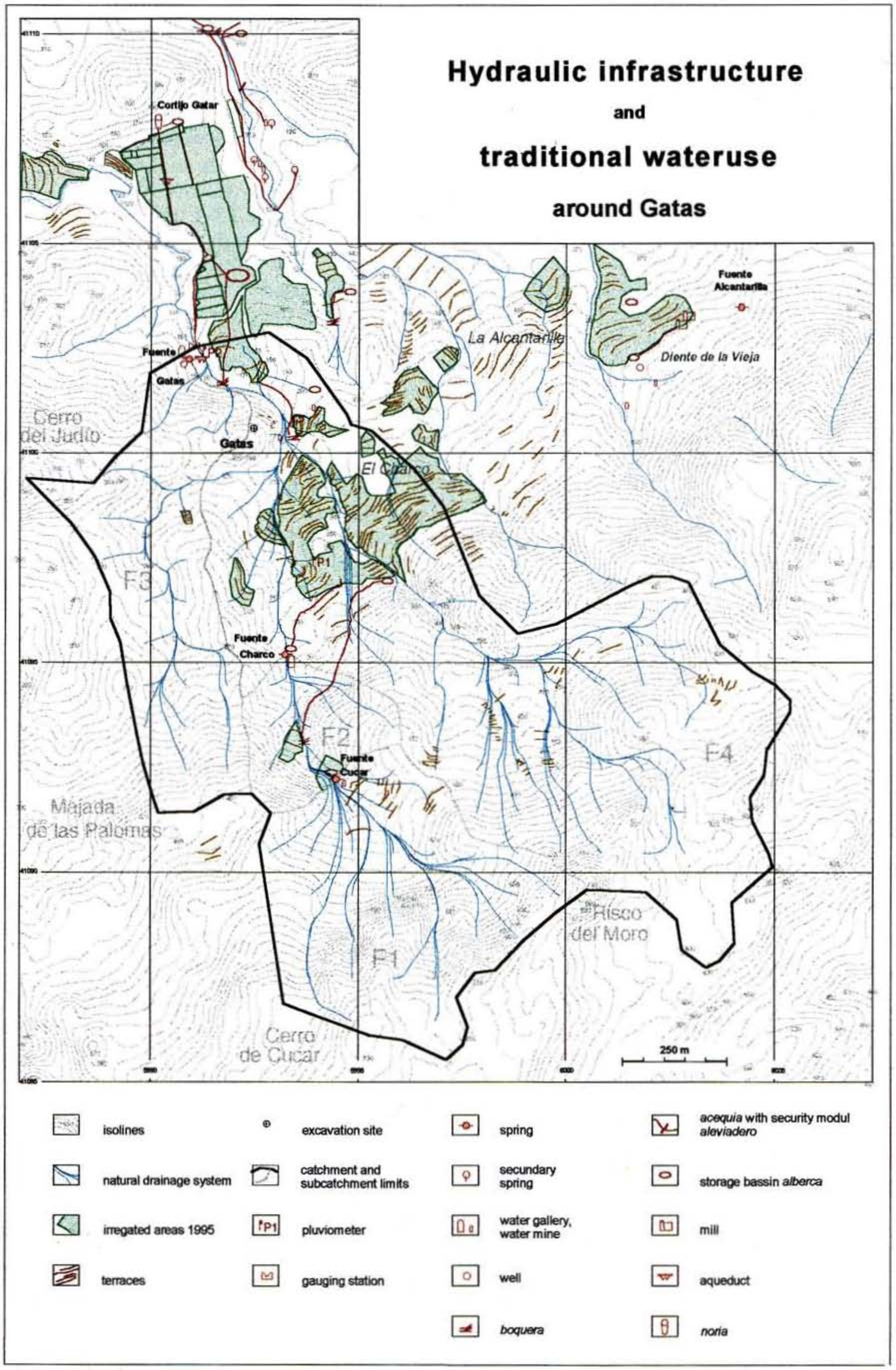


Fig. 12: Mean rainfall of P1 and P2 and affluent measured at the gauging station.



Map. 8: Hydraulic infrastructure and traditional water management.

Given that the gauging station was designed in order to register up to 100 l/s and that measurements could be taken only some hours after rainfall, fig. 12 does not represent the runoff values occurring during or immediately after extreme torrential event. The lack of vegetation and the abandonment of large parts of the traditional system implies that the mean basic discharge measured in the gauging station corresponds to the lowest values ever reached by the system. Clearly four levels between 3.5 and 14.9 m3/d become visible. The calculated sum of 1822,75 m3 for the main vegetation period represents a bottom value for the upper Añoflí catchment.

	Effluent in m3/day	Effluent in L/s	Nº od days with higher values
Level 1	3,5	0,04	54
Level 2	7,1	0,08	113
Level 3	9,0	0,1	148
Level 4	14,9	0,17	183
Maximum effluents	38	0,44	0
Summ of main vegetation period	1822,75 m3		

Table 6: Affluents of the Rambla Ancha.

5.3.2. The water balance and the hydric equation (results of 3.4., 3.7.2.)

The natural water flow depends on: 1. rainfall, and its inter and intra-annual fluctuation; 2. evapotranspiration; 3. surface and subsurface conditions; 4. storage capacity of the studied area. The catchment of the gauging station in the Añoflí/Ancha study area can be subdivided into four sub-catchments (F1-F4). At their lowest point the gauging station was installed. The general water-balance equation can be defined in the following way:

$$N = Ao\ (R1+Q1+S1+R2+Q2+S2+R3+Q3+S3+\ G(R4+F4))+Au+ETB+Eb+Ew+H+F5+F6$$

where

N = precipitation.

ETP = evapotranspiration, dependent on climatic, edaphological and botanical factors.

Eb = evaporation from bare soil, which depends on climatic and edaphological factors.

Ew = evaporation from water surface (*barranco*, open channels and *albercas*).

Q1 = affluent from the Cucar spring (area F1) (f(ETP1, Eb1, Ks, Sc, Ss)), dependent on the storage behaviour in the vegetation cover, the soil, the carbonate rocks, the schist, the alluvial and colluvial sediments as well as on its surface and situation in the sub-catchment F1.

Q2 = affluent from the Charco spring (area F2) (f(ETP2, Eb2, Ks, Sc, Ss)), dependent on the storage behaviour in the vegetation cover, the soil, the carbonate rocks, the schist, the alluvial and colluvial sediments as well as on its surface and situation in this sub-catchment.

Q3 = affluent from the Gatas spring (area F3) (f(ETP3, Eb3, Ks, Sc)), dependent on the storage behaviour in the vegetation cover, the soil, the carbonate rocks, the schist as well as on its surface and situation in this sub-catchment.

G = affluent from the remaining area F4 (f(ETP4, Eb4, Ks, Sc, Ts, Ms, Ss)), dependent on the storage behaviour in the vegetation cover, the soil, the carbonate rocks, the schist, the alluvial and colluvial sediments, the travertine formation, the Miocene pelits, the conglomerates as well as on its surface and situation in this sub-catchment.

Au = groundwaterflow of the three main storages, which exits the catchment without being measured at the gauging station.

H = water extracted though hydrological infrastructure and which exits the catchment without being measured at the gauging station.

Ao = discharge measured at the gauging station.

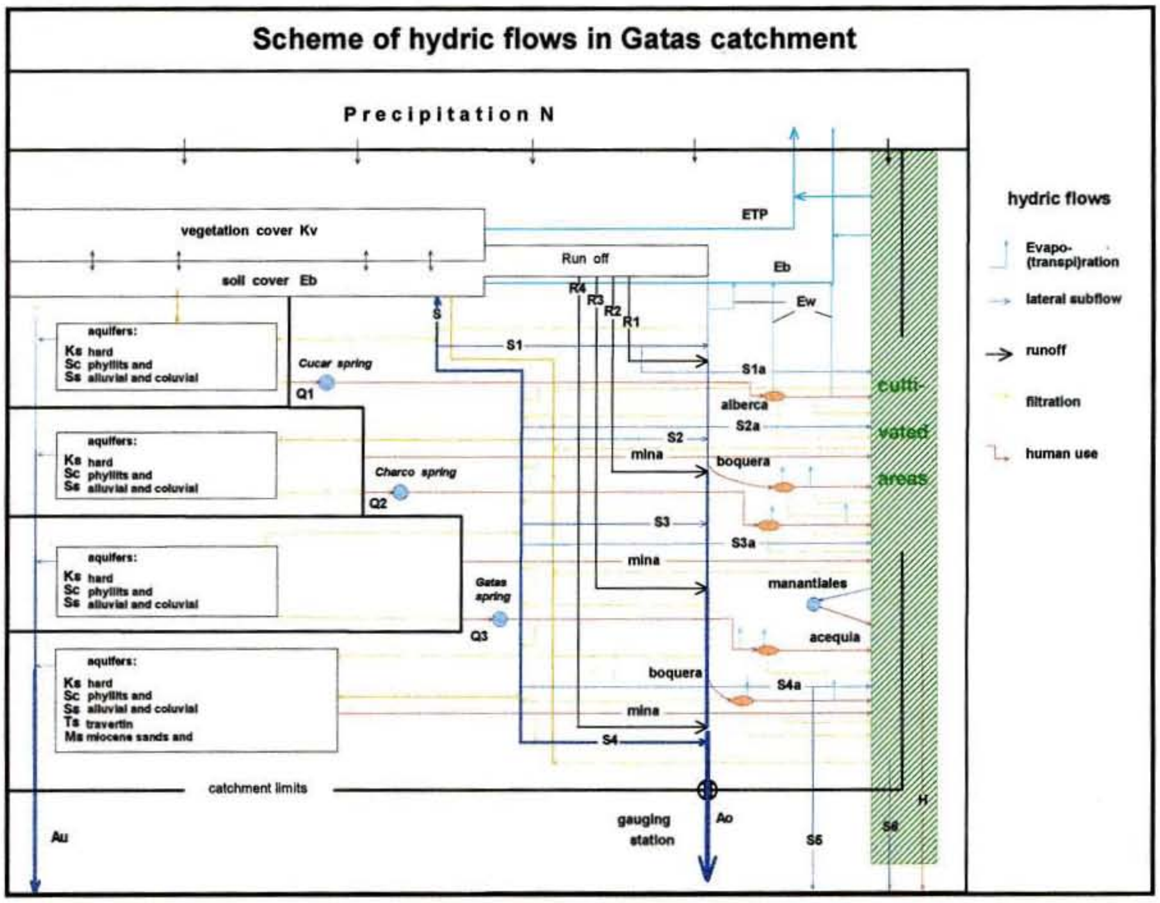


Fig. 13: Scheme of the water flow in the upper Añoflí catchment.

The whole system is determined by internal hydric flows and their interactions (see fig. 13), where:

R1 = run-off from sub-catchment F1 to creek.
R2 = run-off from sub-catchment F2 to creek.
R3 = run-off from sub-catchment F3 to creek.
R4 = run-off from sub-catchment F4 to creek.
S1 = subflow from sub-catchment F1 to creek.
S1a = subflow from sub-catchment F1 to cultivated areas.
S2 = subflow from sub-catchment F2 to creek.
S2a = subflow from sub-catchment F2 to cultivated areas.
S3 = subflow from sub-catchment F3 to creek.
S3a = subflow from sub-catchment F3 to cultivated areas.
S4 = subflow from sub-catchment F4 to creek.
S4a = subflow from sub-catchment F4 to cultivated areas.
S5 = subflow from non-cultivated areas, which exit the catchment without being measured.
S6 = subflow from cultivated areas, which exit the catchment without being measured.
Ks = storage characteristic of the carbonate aquifere.

Sc = storage characteristic of the phyllits and schists.
Ss = storage characteristic of the alluvial and colluvial sediments.
Ts = storage characteristic of the travertine.
Ms = storage characteristic of the Miocene pellits and conglomerates
Kb = storage characteristic of the soil.
Kv = storage characteristic of the vegetation cover.

The scheme of the hydric flows (fig. 13) represents a model of the waterflow in the catchment of the gauging station. It clearly shows the involvement of the different processes in this area. How this natural system has been used traditionally is indicated on the right side. The number and direction of the arrows signals how tightly both systems are linked together. Here the vegetation and soil water storage plays an important role. The consequence of a denser vegetation is that more water is transferred to the atmosphere through interception and evapo(transpi)ration. On the other side two other factors, which are also relevant for the evaporation, such as wind and temperature, become less important. Moreover the speed of rainfall on the surface is slowed down, reducing erosion processes. Less puddling of the surface soils and a more developed root network allows higher infiltration rates. This is then related to two processes. If in the past vegetation cover was more important, as the botanical analysis have shown (*see below*), it can be assumed, in the first place, that water infiltration was higher and, in the second place, that the aquifers received more water. This probably led to an increased storage capacity in the catchment, so that the springs produced more water and during longer periods of time. If the same holds true for the whole of the Río Aguas, even under similar climatic conditions as at the present day a more balanced water regime seems to have existed. In this sense it seems interesting to mention, that according to the agronomist Mr. Egea, from the town hall of Mojacar, the Río Aguas contained water during longer periods in the 1970s, i.e. when the traditional land use was still functioning, than today.

Therefore the characteristics of Ao, R1-R4, Eb, ETP, Au, Kb, Kv and S1-S4 were different in the past. This has no influence on the storage capacity of the aquifers, but implied a more moderate system input and output, i.e. the duration of the discharge. Only the storage capacity of the erosive deposits of alluvial sediments Ss would be less developed.

An increasing importance of the anthropic impact would have two consequences on the water circulation. In the first place a reduction in the vegetation cover would be followed by the opposite process to that described above. In the second place, part of the water flow and its suspended material would be spatially displaced, through the introduction of *Boquera* systems. This means that the spring affluents do not flow to the Ramblas but are channelled to the cultivation areas, and that the transported material is depositing on the cultivated surfaces. The *boquera* below the Cucar spring catches around 15 l/s when rainfall is higher than 5-10 mm (5-10 times a year). The second *boquera*, located further down in the *El Charco* sub-catchment (map 8), is highly destroyed. Yet it seems to have been able to deviate between 10 and 20 l/s during important rainfall events (3-5 times a year). The third *boquera* below the Cerro del Judio and Gatas, allowed to gain 100-150 l/s, but only during torrential events (0-5 times a year). This technological device changes the temporal and spatial distribution of ETP, Eb, Ew, H, F5 and F6. In this way the traditional hydraulic system counteracts degradation processes which otherwise would have resulted from a reduction of the vegetation cover. If the traditional system is abandoned the surface run-off R1-R4 and, thus, Ao increases, while the storage capacity of the catchment decreases. This shows the importance of the traditional land use in order to constrain erosion. Successive phases of abandonment of such intensive water exploitation systems, suppose an overall loss of the storage capacities of the area and worst hydric conditions for new phases of agricultural production. The development of the hydrological infrastructure in the area since the Andalusian period seems to indicate, that increasing aridification was faced through the successive development of new technical devices designed to maximise the available water. The same seems to take place at the present moment with the introduction of dripple irrigation, plastic pipes and plastic covers. These reduce water loss, while the karst aquifer is exploited up to the limits of its regeneration possibilities. Filtrations S5 and S6 are eliminated, as well as evaporation Ew. Water coming from filtrations S1-S4 and from run-off R1-R4, which can only partially be stored in the system and increases erosion processes, remains unused. In this way the water retaining effect of the traditional infrastructure is lost.

5.3.3. The artificial components of the traditional water use system (results of 3.7.2., 3.8.)

The recent agricultural production in the Añoflí catchment is characterised by intensive irrigation, dry farming and transhumant husbandry. Its spatial distribution follows a vertical organisation, as documented in an even more pronounced way in the Sierra Nevada (Roeder 1990). The spatial organisation of the cultivated areas is conditioned by three main factors: 1. slope, 2. solar radiation, 3. flow density. The areas with high annual insolation, moderate slopes and superficial humidity correspond greatly with intensive agriculture. Surfaces with relatively low yearly solar radiation, more pronounced slopes and dry soils coincide with dry agriculture.

In the studied Añoflí catchment, of 1,607 km^2, and bordering parts of the nearby area of *La Alcantarilla* the following elements of the historical hydraulic system could still be documented (map 8):
- 2 galleries
- 10 smaller water-shafts or minas
- 5 superficial water deviation devices *(boqueras)*
- 4 primary springs (*fuentes*
- 6 secondary springs (*manantiales*)
- 12 channels (*acequias*)
- 10 cisterns (*albercas*)
- 1 waterwheel (*noria*), non-existent anymore, but documented through personal interviews.
- 2 aqueducts.
- 2 waterdriven mills.
- 1 well.
- 1 barranco crossing channel (*aliviadero*).

This system of water management at the northern side of Sierra Cabrera is an integrated part of the mountain agricultural ecosystem, which is also typical in other regions of southeast Spain (Herget 1993). Similar networks are known in other parts of Europe, such as in the large Alpine transversal valleys (Annales Valaisannes 1994; Menara 1988). The Sierra Cabrera system can be defined as an open cascade system. Loss of agriculturally useful water occurs through filtration and evaporation along the channels and in the areas of the cisterns. Wild vegetation absorbs another part of the water from the soils. In any case, the greatest water loss is caused by the infiltration after surface irrigation of the agricultural plots. Yet, as will be seen in the hydric equation, one can only use the term "loss" in a limited way: the infiltration improves the slope water contents, forming a network of small waterlines which partially appear again in the secondary springs and can be used in this way on cultivated fields further down in the system. Moreover, the humidity existing at the channels and cisterns supposes the development of trees, bushes, and useful grasses (Herget 1993).

The principles of this traditional water management system can be summarised as follows:
- durable use of the natural factors and excellent knowledge of the local conditions.
- high adaptation to the morphological conditions.
- high degree of flexibility towards climatic fluctuations, linked with low flexibility towards marked present day socioeconomic changes.
- rational use of the water resources.
- use of local materials.
- implementation of simple and user-friendly technology.
- low but continuous labour investment needed in order to maintain the system.
- acceptance of water-loss.
- high autonomy of the individual peasants under tight control through the community.
- periodic and aperiodic collective work in order to maintain the totality of the system.

The functioning of this system is characterised by its high durability and persistency in the face of the different natural conditions, but it is barely capable of surviving under drastic socioeconomic changes.

5.3.4. Conclusions

The traditional water management system is characterised by the maximisation of scarce water resources. The natural conditions are exploited up to the possibilities of regeneration of the deposits. Drastic alterations of the system, such as the search for water resources for Garrucha at the beginning of the 1960s, are beyond the flexibility of the traditional agrarian ecosystem and produced a type of degradation, the consequences of which have never been studied in detail. Probably the degradation of the aquifers, which only seem to recover slowly after several decades, contributed to the abandonment of the traditional land use strategies and the developed hydraulic infrastructure.

Large amounts of water, which due to technical problems can only be exploited in recent times, were not as important for the traditional water management as the low average effluents. The decentralised structure of the system was designed to optimise those devices which could easily be extracted from the natural water circulation with the available technology (*minas*, *galerias*). Here the slope water infiltration plays an important part in the water balance of the area, which is the basis of the traditional land use.

In order to answer the question of the potentially available water resources only the data registered by the gauging station and the information gained through interviews with the local population can by used. This allows us to consider that under sub-modern normal circumstances three times more water was available than measured by the gauging station, during the main vegetation period. In total around 5072 m^3 of this affluent could have been used for agricultural practices from this point downwards. Furthermore 3.5 m^3 can be considered as an absolute basis or minimal discharge at the gauging station.

The pluviometric analysis shows that rainfall on the northern slopes of Sierra Cabrera (250-220 mm from 1.2.1995 to 31.1.1996) does not seem to be significantly higher than in other areas of the Vera basin. The lower rainfall sums at the Vera station in summer 1995 seem to point to a difference between the inner basin and the mountanous and coastal surroundings but should be cleared up by a special time series analysis of all regional stations. This is surprising in view of the more developed vegetation (before the wild fire) and the apparently more humid conditions of Sierra Cabrera. This shows the importance of the water circulation and storage through the karstic aquifer, which formed the key of the traditional hydraulic system and land use. The alteration of the system from outside, without a clear understanding of its functioning and capacities, supposed a rapid decrease in the water resources available in the Aguas valley, which had important socioeconomic consequences for the region. The infrastructural measurements taken by traditional agriculture, in order to mitigate the erosive processes furthered by deforestation, disappeared. Therefore a recovery of the ancient water management system combined with modern technical possibilities could allow a regeneration of the damaged system, in order to obtain large water resources for the future. At the present day the highest water discharges occurring after intense rainfall and which where recovered in the past through the boquera technique, remain unused. Only in the studied 1,6 km^2 catchment of the Añoflí this supposes a loss of 130-180 l/s for each important rainfall event, whose immediate effect is the lowering of the water table. These resources represent an important source for present and future socioeconomic development.

5.4. VEGETATION AND ITS EXPLOITATION

Mª O. Rodríguez Ariza, A.C. Stevenson & the editors.

5.4.1. Pollen analysis in southeast Spain (results of 3.5.1.)[27]

Although a number of pollen sites are available from which rigorous reconstruction of past vegetation and climate change in the Iberian peninsula can be obtained, a number of problems continue to hamper efforts to provide a clear Holocene vegetation and climatic history for the southern part of the peninsula. These restrictions include many sites suffering from: poor chronological control; restricted pollen/time sequences; being caves (with all their associated taphonomic complexities), or have yet to be fully published. Only five sites have the necessary dating control to provide a long term record of Holocene vegetation change in the southern part of the Iberian peninsula - Lagoa Travessa, Portugal (Mateus 1989, 1992); Laguna de las Madres, Huelva (Stevenson 1985, Stevenson and Harrison 1992), Laguna Medina, Cadiz (Stevenson unpublished); Padul, Granada (Florschütz *et al.* 1971; Pons and Reille 1988); and Las Salinas, Alicante (Juliá *et al.* 1994). Within the next three years a number of other additional long Holocene sequences from southern Iberia will be available that will enrich our present knowledge viz: Laguna Tollos and Zarracatin (Sevilla), Las Salinas (Alicante) and Fuente de Piedra (Malaga). For the Southeast of Spain the following information is provided:

Padul, Granada

The pollen record from Padul (c. 785m altitude) in the foothills of the Sierra Nevada (Florschütz *et al.* 1971; Pons and Reille 1988) represents one of the longest continental pollen records in Europe, although the Holocene is only represented until ca. 4450 BP (3150 cal BC), i.e. the end of the Neolithic period. The Holocene vegetation sequence show that after the end of the last glaciation when the area was dominated by pine/*Artemisia*/*Chenopodiceae* forest steppe the site was rapidly invaded by oaks (both evergreen and deciduous). This period of forest establishment was halted by ice re-advance during the younger Dryas and steppic elements like *Artemisia* and *Chenopodiceae* returned. Pons and Reille (1988) interpret this change back to steppic conditions, but with only minor fluctuations in the regional forest elements, as caused by moisture deficit rather than decrease in temperature. The final melting of the European ice sheets sees the reestablishment of an evergreen oak/*Pistacia* forest around the site with deciduous oak woodland elements elsewhere in the mountain range. Minor fluctuations in the amount and composition of the oak forest occur until c. 8200 BP (c. 7100 cal BC) when pine begins to play a more prominent role in the forest communities while values of evergreen oak decline, *Olea* makes a continued presence and deciduous oak pollen increases. Pons and Reille (1988) attribute this to the clearance of *Q. ilex* from around the site allowing a proportional increase in regional forest taxa. This pattern is reversed from c. 6300 BP (c. 5200 cal BC) when evergreen oak pollen values increase and deciduous values decline.

Roquetas del Mar, Almería

This site is one of the three pollen sequences available from the Almería region. The other two sites, San Rafael and a 20 m core from the Antas estuary have not yet been fully published. A3.6 m core was obtained from Roquetas del Mar and containing a sediment record dating to c. 6000 BP (4900 cal BC). The early part of the sequence is dominated by Olea and deciduous oak pollen together with significant amounts of *Chenopodiaceae* pollen. Subsequently, around 260 cm deciduous oak pollen declines and evergreen oak pollen increases reflecting an aridification and *Chenopodiaceae* is replaced by *Artemisia*. From 150 cm, which is later than a C14 date of 2380 cal BC, obvious impacts of anthropogenic activity are seen as tree taxa decline, especially evergreen oak and ruderal taxa like *Artemisia* and *Astraceae* increase
(Aguirre *et al.* 1994).

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[27] Stevenson, A.C., University of Newcastle (GB).

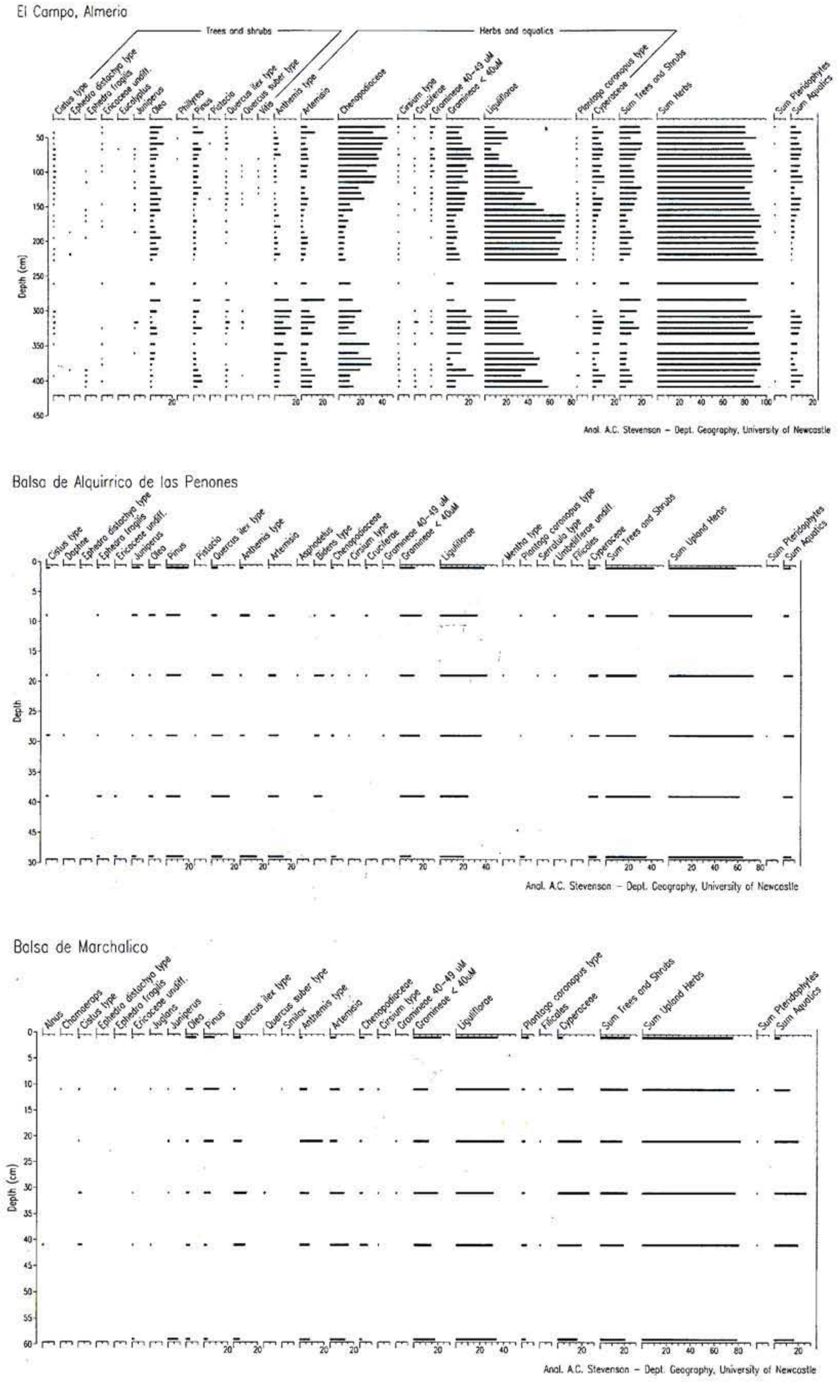


Figure 14: Pollen diagrams from the Aguas Valley and Sierra Cabrera.

The Aguas and Almanzora valleys, Almería

The previous data existing for the Almanzora and Aguas basin is of low quality and should be tested with a large amount of circumspection. The interpretations drawn from the data suffer from possible misidentifications and misunderstanding about the nature of seasonal stream systems in semiarid areas and their pollen rain. Only some tentative interpretations can be made.

For the Neolithic (c. 4000-2300 cal BC) samples from the Aguas valley the pollen counts are quite low and variations between samples are unlikely to be statistically reliable, however, it is clear that there is little arboreal and shrub pollen from these samples. The samples from the Neolithic period of the Almanzora are dominated by Salicaceae pollen (unfortunately, it is not clear as to whether it is *Salix* or *Populus* pollen) and indicates that the samples derive from a very different sedimentary context, possibly close to a river channel. The dominance of the samples by Salicaceae pollen effectively prevents any further conclusions being drawn about the nature of the regional vegetation.

For the samples from the Chalcolithic (3000-2300 cal BC) at Gatas the pollen sums are very low but one sample contains striking amounts of *Juglans* pollen, although arboreal pollen values in general are very low. *Juglans* is known from the southeast during the last glacial period (Carrión and Sanchez 1992) and there is some debate as to whether these populations survived into the Holocene. The samples from the Almanzora contain very low pollen counts and are unlikely to be very reliable indicators of regional vegetation, but arboreal pollen values are low.

For the Argaric periods (2300-1550 cal BC) at Gatas very little pollen is recorded, and what is recorded appears to be dominated by *Q. ilex*. The first five samples should be disregarded because of the low counts (c. 30 pollen grains). The last sample has large amounts of Juglans pollen. In the samples from the Almanzora, pollen counts are very low but *Ficus* pollen features prominently in the Fuente Alamo samples.

For the post-Argaric (1550-1000 cal BC) samples from Gatas, the counts are very low but with similar spectra to the Argaric. The differences between periods may well be the result of different taphonomic processes acting on the deposited sediment at different times.

For the Roman period from the Almanzora the pollen spectra indicate little arboreal cover while the Andalusian period at Gatas sees a large increase in the shrub and tree pollen sum but these are mainly accounted for by the large increase in *Cistus* pollen, indicative of widespread firing of the hillsides. It is in these samples that significant numbers of Morus pollen are found.

The modern pollen sequences from Gatas and the Almanzora in general are very similar to those of the Andalusian and Roman periods.

A new pollen core was obtained from "Cortijo del Campo", located close to the Aguas mouth. It represents an alluvial sediment sequence (4.3 m) that bottomed out in Tertiary clays and silt. The sediment has been systematically examined for samples for radiocarbon dating and charcoal fragments at 100-101 cm and 300-301 cm have been submitted for AMS dating with Beta Analytic. Unfortunately, the sample from 100-101 cm failed to provide enough material, while the sample from 330-331 cm returned a date of 3300±50 BP or 1550±50 cal BC (Beta-100602). This date clearly places the commencement of sediment accumulation in the core to the Chalcolithic period.

The early part of the sequence is dominated by Liguliflorae, Gramineae and Chenopodiaceae pollen with a small amount of arboreal pollen in the form of *Olea* and *Pinus*, confirming the charcoal evidence recovered from Gatas. During the Chalcolithic (3000-2300 cal BC) it appears the *Olea* was less frequent in the subsequent Bronze age while pine appears to have been more prevalent in the Chalcolithic in comparison to the Bronze. It is difficult to ascribe a causal mechanism in the absence of a more complete record of vegetation from the area. However it is clear that woodland fires were occuring, as evidenced by charcoal fragments in the core, which appear to be associated with raised levels of *Cistus* pollen, a well known pyrophyte. The lack of arboreal pollen values is confirmed by comparison to the pollen sequence from Roquetas del Mar where arboreal pollen values, chiefly*Quercus ilex* type decline post 6000 BP and never recover. It is unfortunate that many of the trees, especially food source ones, are insect pollinated and do not show up in the palinological record.

Locally, Liguliflorae values increase mid-way through the core before declining to low levels as Chenopodiaceae pollen replaces it and suggests that the immediate site represented a marshy area in a frequently inundated portion of the valley floor.

Two short sediment cores were obtained from the very arid endoreic basins in the Sierra Cabrera (650-700 m) of "Balsa de Marchalico" and "Balsa de Alquirrico de los Peñones", overlooking the important archaeological site of Gatas. Unfortunately, pollen preservation was generally poor because of the aerobic nature of the sediments. Figure 14 present skeleton pollen diagrams for the top 50-60 cm of each core. Few trends can be seen in the sediment record and the lack of any chronostratigraphic markers -i.e. *Eucalyptus* makes the sediment sequences difficult to date. However, the pollen spectra reflect the present dominance of the valley sides by *Quercus coccifera* and other mediterranean matorral elements while the ruderal taxa mainly derive from the basin floor which is periodically inundated, preventing tree and shrub invasion.

5.4.2. The Holocene climatic sequence from an anthracological perspective (results of 3.5.2.)[28]

For the early Holocene period no anthracological records have been obtained so far in the Aguas valley, nor in the Southeast of Spain in general, given the relative scarcity of Mesolithic and Neolithic settlements in the area and the lack of interdisciplinary excavations. Nevertheless, important anthracological research has been carried out on materials coming from excavations in the Spanish Levante, further northeast, and in central and southern Andalucía, further west of the Southeast.

12000-6300 cal BC:
Málaga: The increasing importance of *Olea* and the presence of deciduous *Quercus*, *Quercus ilex-coccifera*, *Pistacia lentiscus*, *Rosmarinus officinalis*, *Arbutus unedo*, *Buxus* and *Lavandula* suggest an increase of temperatures, rather than of pluviosity (Badal 1990).

6900-5300 cal BC (beginning of agricultural exploitation):
Levant: The presence of woodland vegetation formed by *Quercus ilex*, *Quercus faginea*, *Fraxinus* and some *Olea*, suggests a subhumid and fresh mediterranean climate. Between 5800-5300 cal BC the evergreen oaks dominate the vegetation, while the presence of *Olea* becomes more important (Vernet, Badal and Grau 1983, 1987).
Malaga: The decrease around 6000 cal BC of the Leguminosae in favour of the *Olea* and the increase of *Rosmarinus*, *Cistus* and *Pistacia lentiscus* would correspond to a thermomediterranean formation, under higher temperatures but similar pluviosity conditions (Badal 1990).

5300-4900 cal BC:
Levant: This period is characterised by the development of a *Pinus halepensis* and a certain opening up of vegetation, as shown by the presence of species such as *Juniperus*, *Erica arborea*, *Erica multiflora* and *Olea*. This situation can be the consequence of the pressure of Neolithic population on the environment, in combination with a temperature increase (Vernet, Badal and Grau 1983, 1987).
Málaga: The increase in low matorral species such as *Rosmarinus*, *Pistacia lentiscus* and *Cistus sp.* together with a decrease of *Olea* and the constant although low presence of *Pinus halepensis*, seems to indicate the anthropic pressure on the vegetation around 5200 cal BC in this area (Badal 1990).

[28] Rodríguez Ariza, Mº O., Universidad de Granada (ES).

4900-3000 cal BC: While *Pinus* and *Quercus* species practically disappear, the expansion of *Olea* becomes important. The presence of small bushes such as *Erica* and *Rhamnus* provides further evidence for the Neolithic degradation of the environment (Vernet, Badal and Grau 1983, 1987).

From 3000 cal BC onwards, i.e. the beginning of the Copper Age, the Vera basin presents probably the best anthracologcal sequence of the Iberian Peninsula.

3000-2300 cal BC (the beginning of metal production):
The predominance of *Olea* (35-65%) in all sites (Zájara, Campos, Santa Bárbara) together with *Pistacia lentiscus* (10-20%) may express a local theromediterranean formation of lentiscar, which corresponds to semiarid-lower dry ombroclimatic values (c. 250-400 mm) and to mean annual temperatures around 17° C, practically frost free. Frost could only have occurred between December and February. The presence of *Salix* and *Populus* indicates the presence of a ripisilva formations along the river channels.

2300-1550 cal BC (El Argar State):
The anthracological remains from Fuente Alamo (Schoch and Schweingruber 1982) reflect a vegetation dominated by maquia and matorral, with *Pistacia*, *Pinus halepensis* and *Olea* being the most important wood providing species. The ripisilva is only represented by *Tamarix*, a shrub still dominant today in the ramblas of the area.
In Gatas the situation appears to have been slightly different, although maquia and matorral are again the dominant formations. They are dominated by *Olea* (41%), *Pinus halepensis* (20%) and *Quercus ilex-coccifera* (15%). *Populus* and *Salix*, common in the previous period, still seem to have existed in the Aguas valley. In general this sees to imply more humid environmental conditions. It can be suggested that the thermo-mesomediterranean evergreen *Quercus* formations, which today can only be found in the highest areas of Sierra Cabrera extended much further downwards.

1550-1000 cal BC (Late and Final Bronze Age crises):
After 1550 cal BC the presence of *Pinus halepensis* and Quercus ilex-coccifera represent less than 4% of the total anthracological record in Gatas. On the other side, Pistacia sp. which only represented 4% in the previous moment, is now the main species (21%) associated with Olea (61%). Also Salix and/or Populus decrease, while the more resistant Tamarix increases. If this is not linked to a change in the management of wood resources, an idea which is not supported by the contextual evidence, the Late Bronze Age seems to be characterised by a more open lentiscar vegetation and drier hydric conditions.
During the final part of the second millennium cal BC vegetation seems to recover to the stage described during the El Argar period. Olea (40%), Pinus (18%) and Quercus ilex-coccifera (15%) are again the dominant maquia type vegetation, while Pistacea (2%) decreases significantly. Nevertheless the absence of Salix and Populus would imply that the ripisilva did not recover along the river channels, and may be caused by agricultural exploitation of these areas.

5.4.3. Conclusions
After the post-glacial temperature and humidity optimum, around 6000-5000 cal BC an important vegetation change appears to have occurred throughout the Mediterranean coast and implied an increase in temperature and aridity, together with the development of a more open woodland in which the presence of deciduous Quercus gets less important, in favour of evergreen oak and Olea.

By 3000 cal BC this maquia and matorral vegetation of the Vera basin is dominated by the presence of Olea, or at least this is the most socially exploited wood species. The represented species indicate high temperatures, with practically frost free winters. The riverine areas see the development of deciduous trees like Salix or Populus. More humid climatic and better hydric

[29] The editors.

conditions seem to have existed. The degradation of this ripisilva seems to be a process occurring between the end of the Copper Age (c. 2400-2250 cal BC), as observed in Los Millares (Rodríguez Ariza and Vernet 1991) and Fuente Alamo (where it is already absent when this site is occupied around 2250 cal BC), and the end of El Argar (1550 cal BC).

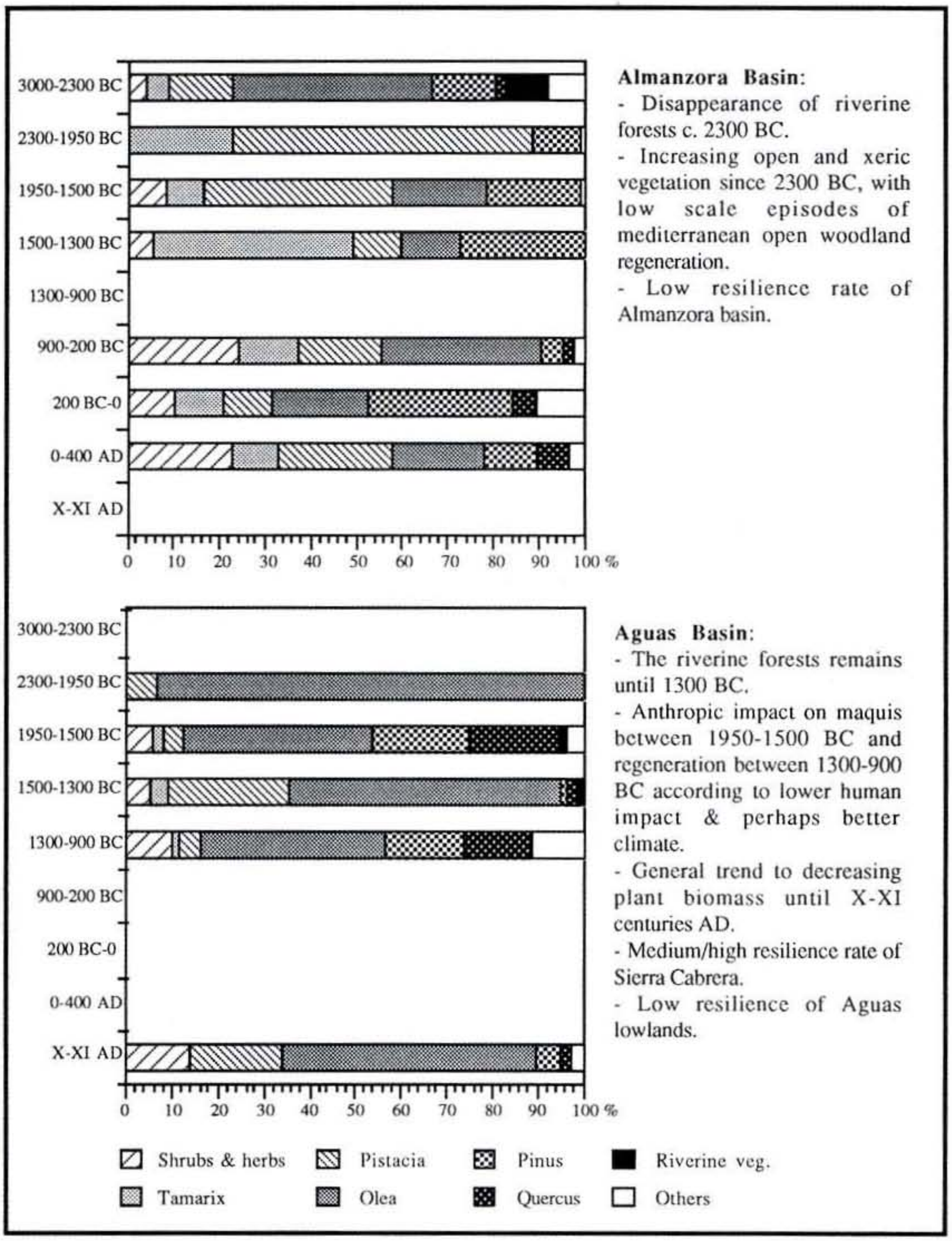


Fig. 15: Exploitation of wood resources in the Vera Basin.

The El Argar period (2250-1550 cal BC) also sees, as will be shown below, a massive exploitation of the maquia. The degradation caused by these strategies seems to become visible in the exploitation of less quality and less variable wood species during the post-Argaric period.

The presence of Tetraclinis articulata in Fuente Alamo and Cerro de las Viñas in Murcia (Grau 1990) implies that pluviosity must have been low and temperatures high during the first half of the second millennium BC. The identification of halophitic plants, such as Salsola (Stika 1988) or Atriplex (Schoch and Schweingruber 1982), suggests than some soils are already suffering the problems of aridity induced salinisation.

Yet while the maquia seems to recover around the slopes of Sierra Cabrera, more arid conditions seem to prevent the formation of the previous ripisilva, despite the possible increase in pluviosity which occurred around 1200 cal BC (see above). Salix and Populus are still absent in the first millennium BC from the charcoal and pollen record of the lower Almanzora, and do not appear to have recovered, but rather were replaced by the more arid and salinity resistant Tamarix. The same is the case with the maquia formations which existed on the Tertiary plains until the El Argar period. The Imperial Roman wood exploitation centred on Olea, cultivated at that time, and Pistacia, representing an open matorral formation. The use of shrubs and herbs for fuel signals the degree of deforestation reached in the lowlands, since the second millennium BC.

A different dynamic can be observed in the Sierra Cabrera. Here, in the X-XIth century AD, vegetation still presents a similar structure to the one observed during prehistoric times, although it resembles more the degraded situation of the post-Argaric period, than that of the first half of the second millennium cal BC.Olea (56%) and Pistacea (19%) are now the most dominant wood providing species, while Pinus (5%) and specially Quercus (3%) only have a minor importance. The identification of Zizyphus lotus, which today only exists in the driest part of Almería and Murcia, and the frequent use of Leguminosae implies dry climatic conditions and a more open vegetation. Despite of widespread firing of the hillsides, vegetation of Sierra Cabrera seem have recovered in successive phases, as already observed in at the end of the second millennium BC. The pollen cores from the endoreic basins at 700 m height show rather stable Quercus coccifera vegetation even in recent times.

5.5. DEMOGRAPHY AND SETTLEMENT

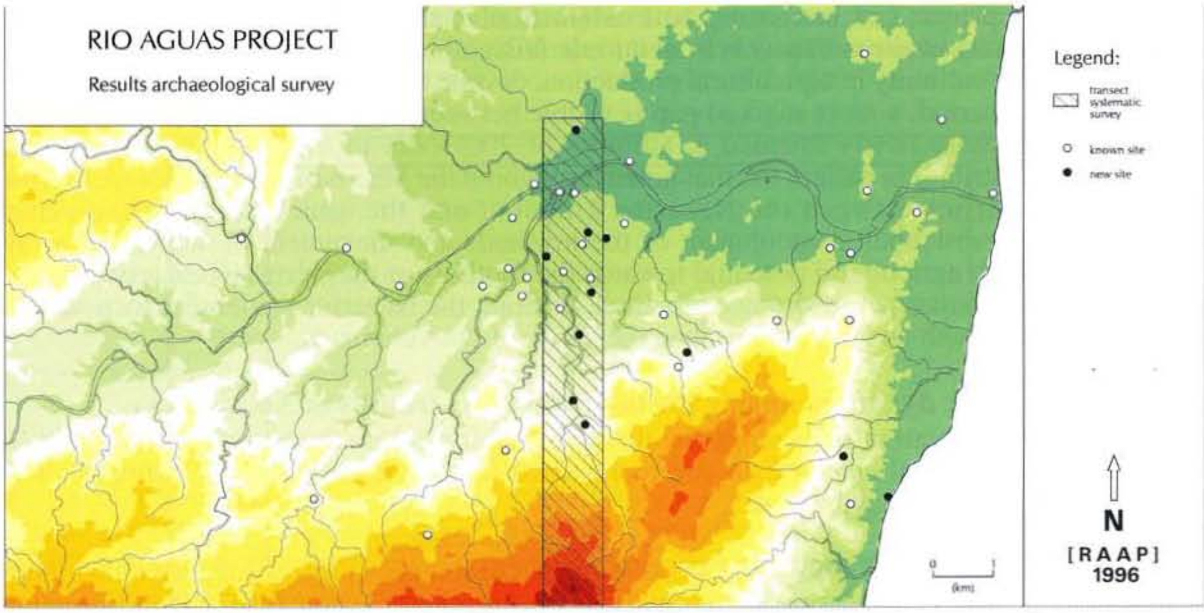
R.W. Chapman, G. Delibes, T. Escoriza, MªD. Fernández-Posse, J.L. López Castro, C. Martín Morales & M. Menasanch.

5.5.1. Settlement in the Aguas valley (results of 3.6.1.)

Figure 16 shows the frequency of sites known, by period, before the 1995 survey, and those new sites which were found during the survey. The frequencies of sites of some periods (e.g. Chalcolithic, Omeya) are unchanged, but note the significant increase in Neolithic sites, the appearance of Phoenician occupation (previously unknown), the increase in Roman sites by some 25-33%, and the major increase in post-Roman sites of the Byzantine and Nazari periods. When the site distributions are examined by period, the following major changes in focal areas of settlement expansion and contraction (social spaces) are visible:

(1) The data on Neolithic and Chalcolithic sites confirm what had already been observed in the Archaeomedes project, namely that almost all sites in the latter period were newly occupied, with larger surface areas, and that they represented an intensification of the agricultural colonisation. Interestingly, as we see will see below, the largest known Chalcolithic settlement in the Vera basin is located at Las Pilas in the lower Aguas valley.

(2) There is a major dislocation in settlement between the Chalcolithic and the Argaric c.2250 cal BC, with only one site, Gatas, showing continuity of occupation. Not only do the numbers of known sites decrease by over 50%, but the focal area of settlement changes, with abandonment of sites in the middle Aguas area of Turre. Population nucleation led to the occupation of only four settlements in the lower Aguas. Site locations conform to the pattern noticed in the Archaeomedes project, namely one determined more by factors of political control than in previous periods. There is some evidence for renewed activity in the middle Aguas in the Postargaric, but no great change from the Argaric pattern.



Map 9: Settlements for 4.000 BC to 1.500 AD.

(3) A third, major dislocation occurs between the Postargaric and Phoenician-Punic periods, when sites to the south of the Aguas are completely abandoned, and the only evidence for occupation consists of one site, Cortijo de Riquelme, located immediately to the north-west of Turre. When placed in the context of the Vera basin as a whole, this is an exception to the distribution revealed by the Archaeomedes project, which showed Phoenician-Punic settlement to be concentrated overwhelmingly in the lower Almanzora in the north of the basin.

(4) A fourth dislocation occurs between the Republican and Imperial Roman periods, when a more evenly dispersed settlement pattern characterises the middle and lower Aguas, and areas which had been abandoned since either the Chalcolithic, some 2000 years earlier, or the Postargaric, over a millennium earlier, now became focal areas for settlement and agricultural exploitation again.

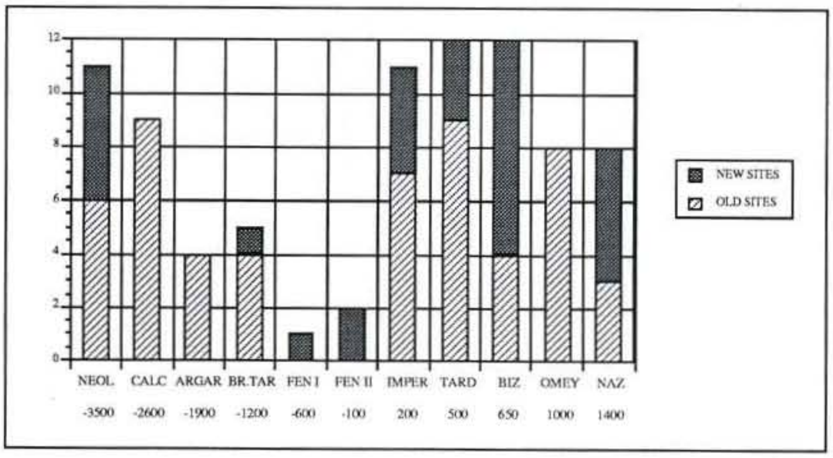


Fig. 16: Frequency of sites per historical period known before and after the Aguas Project.

(5) The focal settlement areas continued from the Imperial Roman to the Later Roman, Visigothic/Byzantine periods and Omeya periods, although settlement was less evenly dispersed after the Imperial Roman period. Surprisingly, given the hypothesis (advanced in the

Archaeomedes project) of increasing soil exhaustion in the Late Roman period, there is complete continuity in site occupation from it to the Visigothic/Byzantine period. This supports the inference of continuity in agricultural production, despite the fall of the Empire. By the time of the Nazarine period, a more marked gap is visible between sites located along the banks of the Aguas, and those newly founded at altitudes of 200-300m in the foothills of the sierra Cabrera. This distribution pattern fits that noted throughout the Vera basin, as politico-defensive factors (i.e. conflict between the Nazarine kingdom and the attacking Christian state) determined the substantial abandonment of the lowlands and movement of settlement away from areas of high agricultural potential towards the foothills of the sierras. Here terracing for irrigation became vital for subsistence practices. Overall, the Nazarine settlement focussed on the sierras in the south and east, rather than the north, of the Vera basin.

5.5.2. Demographic dynamics during the last 6000 years (results of 3.6.2, 3.6.3.)

Calculations of population sizes using the three archaeological methods outline in chapter 3, along with the historical census data, are represented for the Aguas valley in figure 17. The following observations may be made.

(1) For the Vera basin as a whole, the work of the Archaeomedes project suggested that there were four peaks in the population size, namely in the Argaric (c. 1900 cal BC), the Phoenician period (c.600 BC), the Later Roman period (AD 500) and the nineteenth century (a consequence of the mining 'boom'). While these data suggest an overall population of c.3500-3700 for the first two 'peaks' (although the populations themselves were distributed differently through the basin), the later 'peaks' were significantly larger, reaching c.15,000 in the Later Roman period and just over twice that amount in the nineteenth century. Each of these 'peaks' is followed by a drop in population numbers, in fact the higher the peak, the more marked the subsequent decline.

(2) There are notable similarities and differences between the demographic development of the Aguas valley as compared with the Vera basin as a whole. These are discussed under points (3)-(6) below.

(3) The Argaric population 'peak' is made even more marked by the use of the archaeological data based on surplus cereal production, which imply a higher population density within sites than calculated using site area alone. This higher intra-site density contrasts with the decline in site numbers mentioned above. Added to this observation is that of the extensive barley cultivation reconstructed for this period, and the deleterious consequences of this productive system for both the human populations and the land.

(4) The Postargaric population 'decline' is not followed by a 'peak' in the Phoenician period in the Aguas valley. In fact, the archaeological data suggest that local population size decreased further from the Postargaric to the Phoenician periods, by a figure of c.50%, in the first half of the first millennium BC, while the population of the Vera basin more than doubled. While there was clearly population increase at the regional level, the population centres changed as the Aguas valley became marginal to the Phoenician system, which focussed on the northern part of the Vera basin (see above).

(5) While there was a Later Roman 'peak' in the Aguas valley, as in the Vera basin as a whole, the population curve is steeper in the Aguas, as local population levels recovered after the Phoenician depopulation, and, as we have seen already, sites were evenly distributed across the study area.

(6) Within the Aguas valley there is an extra 'peak' of population in the Nazarine period, when the local population increased by some 33% before declining after the Reconquest. As was noted above, this period is marked by an expansion of population into the sierra Cabrera, where regadío was practised in areas which had not been previously cultivated. This contrasts with a decline of some 60% in the overall population for the Vera basin. Clearly, like the Phoenician

period some two millennia earlier, the focal area of settlement and population distribution within the Vera basin changed, but this time the movement was from north to south, in response to political factors (see above).

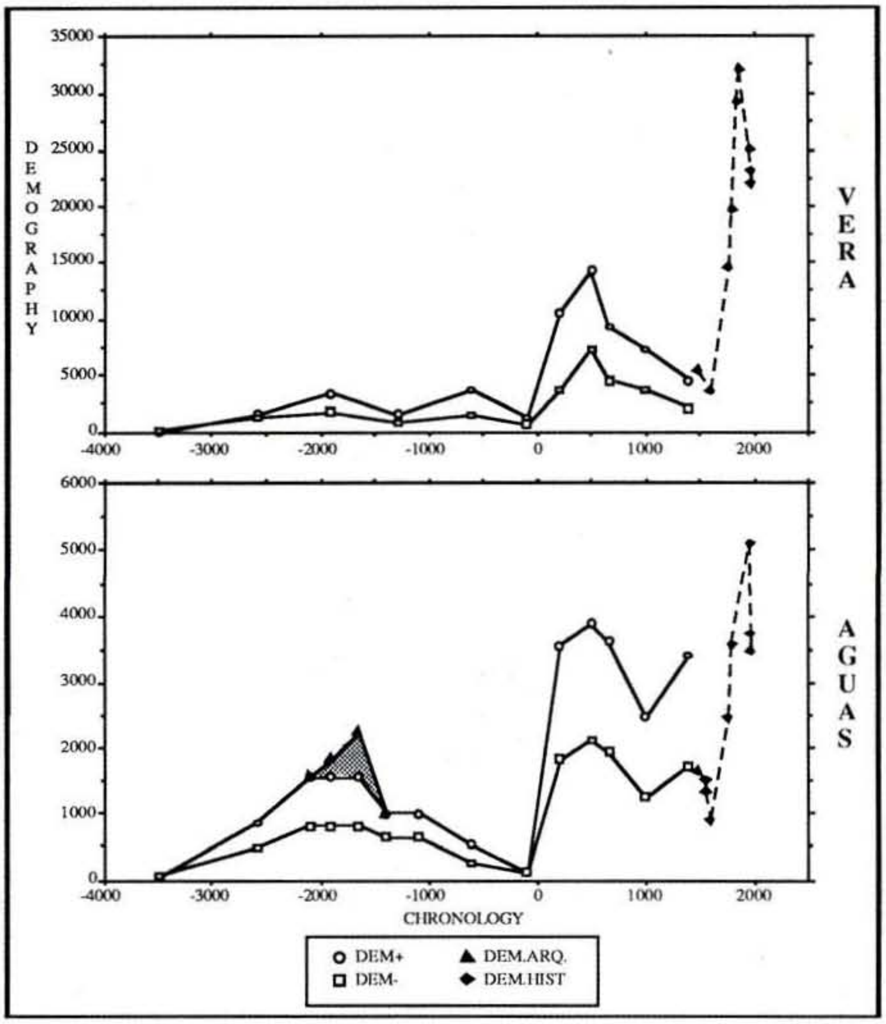


Fig. 17: Demographic development in the Vera basin and the Aguas valley

(7) Taken overall, the data supports the inference that, from the Neolithic to the Postargaric period, that is the late fourth millennium to the middle of the first millennium BC, consistently over 50% of the Vera basin population was concentrated in the middle and lower Aguas. It is relevant here to note (see above) that the largest known Chalcolithic settlement in the Vera basin is located in the lower Aguas at Las Pilas. There was a marked decline to only 5-8% of the regional population in the Aguas in the Phoenician, Republican and Imperial Roman periods. In fact, with the exception of the Nazarine period, when 75% of the Vera basin population was located in the Aguas, there was never again such a high percentage of the regional population located in the southernmost part of the basin. The percentage figures were more in the region of 30% and less, declining since the eighteenth century to less than 20%. At the present day the Aguas valley population comprises some 15% of the regional population.

(8) The data presented above highlight differences of scale in the population dynamics of the Vera basin during the last six thousand years. While change within the middle and lower Aguas broadly followed regional trends, there were important exceptions which resulted in either a decrease (Phoenician) or an increase (Nazarine) in local human exploitation. In both cases the changes can be understood in the context of regional level political and economic changes, namely the

Phoenician colonisation centred on the town of Baria, at Villaricos, at the mouth of the Almanzora in the north of the basin, and the Christian armies' pressure on the Nazari kingdom. At the same time, we should be careful about thinking that settlement frequency and distribution automatically equate with environmentally significant exploitation. To take one example, although the nineteenth century population in the middle and lower Aguas valley was concentrated in the mining centres of the lower Almanzora river, there was a major extension of terracing in the sierra Cabrera (visible today almost as far up as the summit) as part of the infrastructure needed to support the workers and families associated with the centres in the north of the basin.

5.5.3. Conclusions

The systematic and selective surveys have enabled us to define more representative changes in the archaeological and historical record of local settlement in the Aguas valley, showing some major change in settlement representation for specific periods in the past, as well as confirming the known patterns for other periods. There is no simple continuity in either settlement or the population frequencies inferred on the basis of the archaeological evidence. Instead we can observe patterns of settlement and demographic continuity and discontinuity, as well as aggregation and dispersion. Four major peaks of population in the Vera basin, in the Argaric, Phoenician, and Later Roman periods and in the nineteenth century are not all reproduced for the Aguas valley, where population size decreased in the Phoenician period and there was an extra peak in the Nazarine period. This shows the effects of spatial scale and historical context, specifically the attraction of population in the Phoenician period towards the north of the Vera basin, and the politico-defensive factors which drove the Nazarine population into the Aguas, in the south of the Vera basin. This long-term and scale-dependant perspective is a unique contribution of archaeology (in combination with historical studies for the last half a millennium) and one which isolates potentially critical periods for the environment of the Aguas valley, within the broader context of the Vera basin.

5.6. POTENTIAL RESOURCES AND ECONOMIC DEVELOPMENT

The editors & Ph. Verhagen.

5.6.1. Ecological assessment of the agricultural potential of the middle and lower Aguas valley (results of 3.7.1., 3.8.)

The ecological evaluation of past demographic and agricultural trajectories, as well as the design of less aggressive policies for a future development of the area, require a precise understanding of the natural factors that condition the agricultural potential of the area. Therefore, a strategy has been developed (see 3.7.1.) which allows us to define the potential land types suited for different forms of agricultural exploitation and their extension. The combination of these data with the hydrological analysis is of prime importance in order to establish the actual limits of the agricultural production and development of the middle and lower Aguas.

Under middle and late Holocene climatic conditions the highest agricultural productivity depended on the natural flooding or socially induced conduction of water to the land, a strategy which today is known as *regadío* (irrigated agriculture). Surfaces depending exclusivly on rainfall present marked diferences in soil fertility. Areas where in modern times *secano intensivo* is practised offer the highest productivity in dry farming, while the yields of land used for *secano extensivo* are low, and can only be obtained once every four to ten years. The currently practised extensive agriculture is a consequence of the 19th century demographic pressure and economic development (industrial mining), which forced farmers to use marginal areas for this type of agriculture. This is illustrated by the fact that this land use type is also found on Pliocene deposits near the coast: this area seems to be more characteristic for secano intensivo, but the high salinity level of the soil impedes intensive exploitation.

The analysis of the ecological variables that determine the agricultural production reveals a clear ecological distinction between secano extensivo on the one hand, and *secano intensivo* and *regadío* on the other. Extensive dry farming is mainly confined to intermediate altitudes (100-

200 m) and a Miocene substrate, and is found on steeper and sunnier slopes (up to 20%) than the other two. Intensive dry farming and irrigated agriculture can be found on a Quaternary or Miocene substrate and prefer lower altitudes (0-100 m), where slopes are generally less than five percent. They are distinguished from each other by the proximity to ramblas: irrigated farming is only found in the vicinity of water, whereas intensive dry farming is located irrespective of the distance to water. Both land use types can be subdivided into a 'Quaternary' and a 'Miocene' group, with the latter being located on somewhat higher elevations. While the first group can profit from natural floods and subsoil humidity and, in general, provides a higher productivity, the agricultural exploitation of the second can only be improved through artificial irrigation, and is therefore dependent on the construction of hydraulic infrastructure and additional water resources.

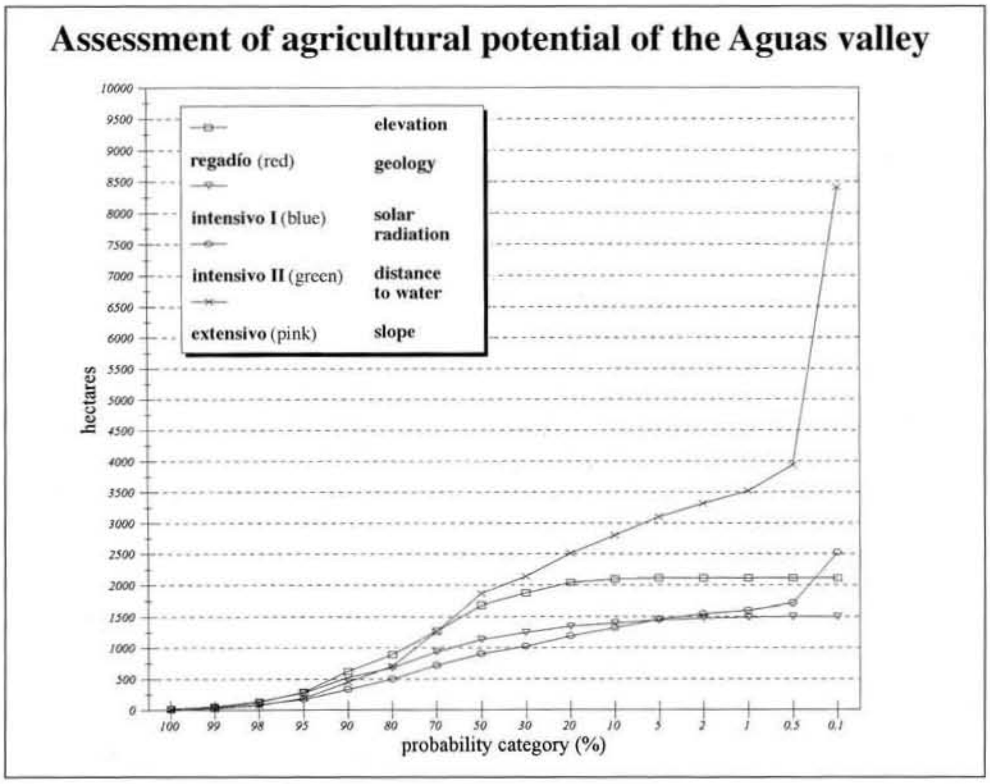


Fig. 18: Line chart of the cumulative frequencies of occurrence of land use probability.

The results of this analysis have been used to perform a maximum likelihood classification on the four continuous variables used (elevation, slope, solar radiation and distance to ramblas). In order to arrive at a classification that makes sense in an eco-agrarian context the geological conditions were also considered and four land use types were defined:

1 - *regadío* by means of inundation in the Río Aguas floodplain. This type of irrigated agriculture seems to have been available to prehistoric cultures that did not have access to technologies like terracing and the building of water conduits. The land which allows this type of agriculture is therefore characterised by the highest productivity and the lowest need for technological investment. This land use type is equivalent to the current areas of regadío on recent Quaternary deposits (alluvial and colluvial loam, silt, clay and gravel).

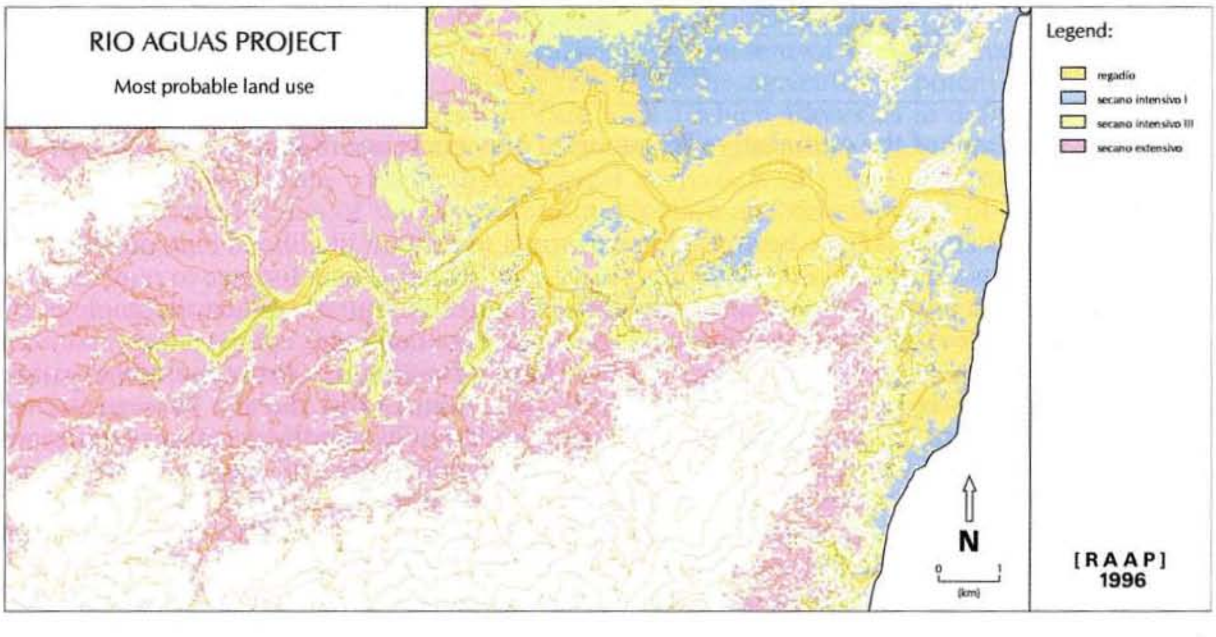
2 - *secano intensivo I* in the Río Aguas floodplain, found at larger distances from the river on the same type of deposits. The productivity of this land can increase naturally and reach the *regadío* yields, if the ground water level of the alluvial aquifers was higher, or if water was brought artificially to it. This land use type is equivalent to the current areas of secano intensivo on recent Quaternary deposits (alluvial and colluvial loam, silt, clay and gravel).

3 - *secano intensivo II* on the river terraces and Tertiary plains of the Río Aguas and in the foothills of the Sierra Cabrera. The agricultural productivity of this land basically depends on

the annual rainfall, and can only be increased through the development of hydraulic infrastructure. This land use type is equivalent to the current areas of *secano intensivo* and *regadío* on older Quaternary deposits and Miocene marls. Currently, some of these areas are irrigated by means of canals or water pipes.
4 - *secano extensivo* on intermediate altitudes in the foothills of the Sierra de Bedar and Sierra Cabrera. It represents the land with the lowest productivity. This land use type is equivalent to the current areas of *secano extensivo*, with the exception of the Pliocene coastal area, which cannot be distinguished from land use type 3 on the basis of the four variables.

The hectares of land available for each type of agricultural strategy have been calculated for different probabilities, i.e. the degree in which a given space fulfils the defined ecological conditions. In the line chart (fig. 18) the frequencies for each land use type probability are presented. The frequency of low-probability *secano extensivo* is very high, due to the fact that this land use category is not 'bounded' by an even less productive land use type, like matorral.

At an 80% probability limit, which can be considered an acceptable degree of adjustment of land to the necessary ecological conditions and which represents a turning point in the trajectories of most land use types (fig. 18), around 3000 hectares of land are available (900 ha *regadío*; 750 ha *secano intensivo I*; 500 ha *secano intensivo II*; 750 ha of *secano extensivo*). Expanding the situation to a 50% probability, where the next turning point of the trajectories can be observed, around 5600 ha could be cultivated (1700 ha *regadío*; 1200 ha *secano intensivo* I; 900 ha *secano intensivo* II; 1800 ha of *secano extensivo*). From this point onwards the possibilities of agricultural expansion get limited and are mainly found in terms of *secano extensivo*, i.e. the less favourable alternative. If the low quality *secano extensivo* soils are excluded, it can be followed that the middle and lower Aguas presents around 3800 ha of reasonably well suited *regadío* and *secano intensivo* land, in terms of geological bases, height, distance from the water courses, slope and solar radiation. This seems to represent the upper limit of the potential land available for agricultural practices in the area.



Map 10: Land use potentiality map, showing the most probable land use type (red: *regadío;* blue: *secano intensivo I*; green: *secano intensivo II*; purple: *secano extensivo*).

The map resulting from the maximum likelihood classification indicates the potential for the different land use types and confirms the general outline sketched above. Although the map is obviously a tentative approximation of the actual land use potential, it may serve as a basic model to define the relation between potential land use and exploitation in different past and future periods. Comparing this land use model at a 50% probability level with today's agricultural production, another 900 hectares should be potentially available for cultivation, mainly in the valleys of different rivers and ramblas. In fact, the overlay of the current land use map on top of the land use probability map shows that the real situation is not very different with 1164 ha not being cultivated in the area defined by the 50% limit. The development of these agricultural potentials mainly depends on the available hydric resources and on the design of a more effective water management strategy.

5.6.2. The agricultural strategies during the last 6000 years (results of 3.7.1., 3.7.3., 3.7.6., 3.7.7., 3.8.)

The paleo-agrarian analysis has allowed us to define the land use strategies developed in the Aguas valley during the last 6000 years and to model, in combination with the demographic calculations (*see above*), their spatial implications.

Figure 19 shows the relationship between the agricultural territories and the different agricultural land resources of the Aguas valley at an 80% probability limit (see 5.6.1) since the Neolithic period.

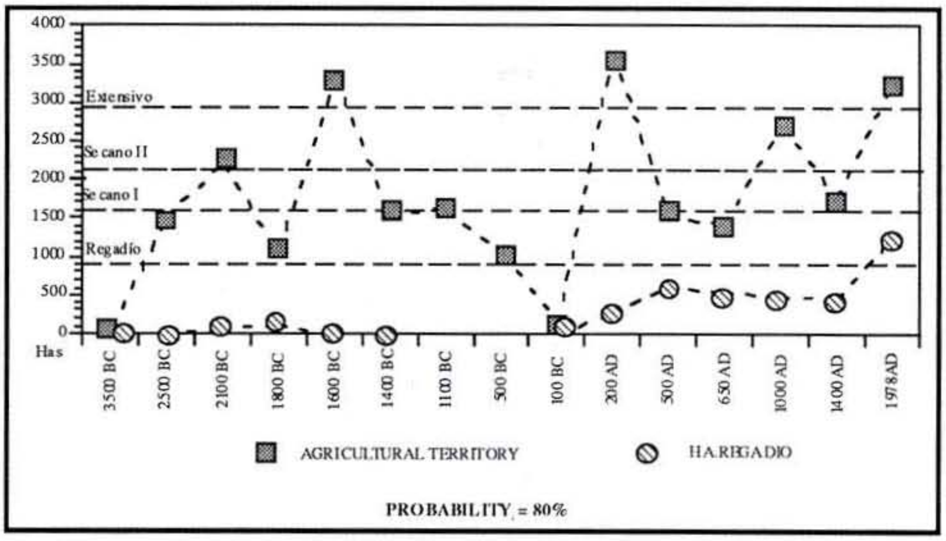
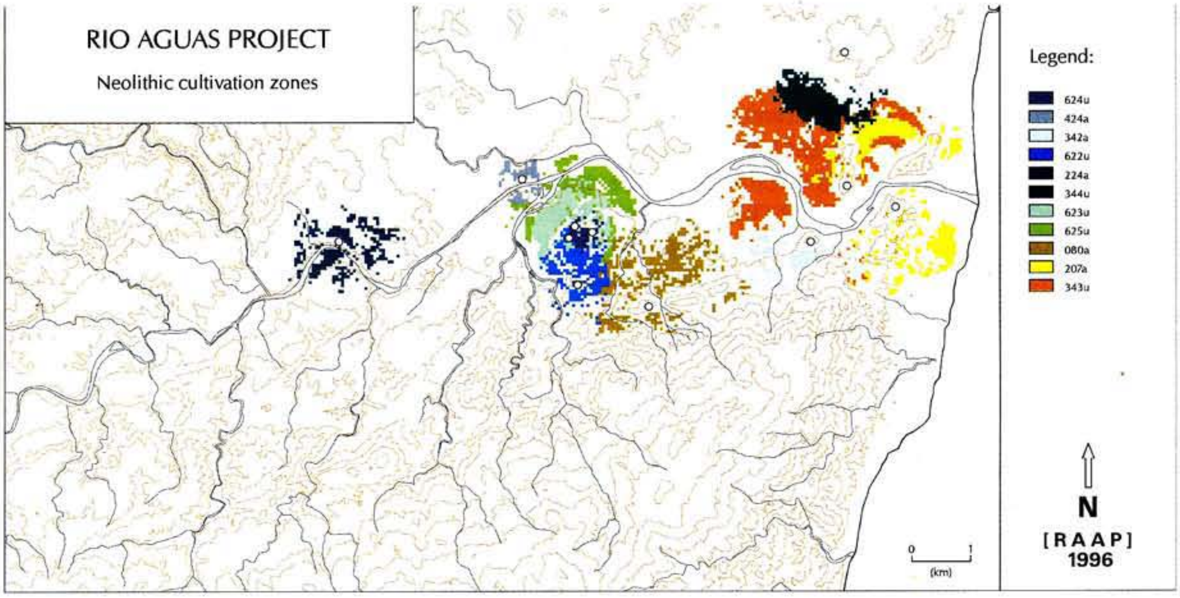


Fig. 19: Agricultural territories during the last 6.000 years.

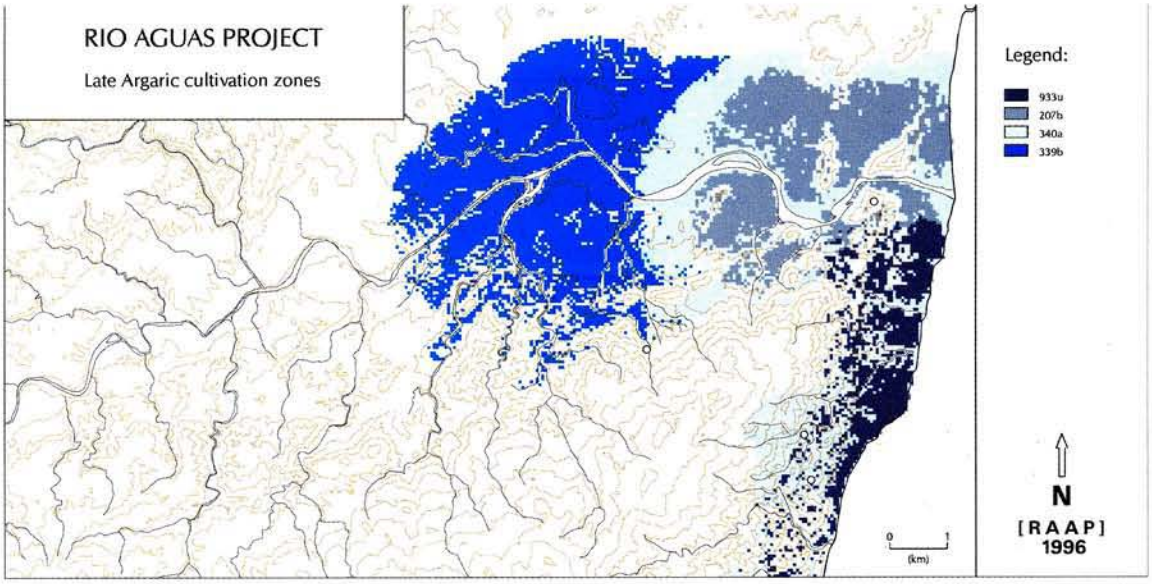
The first human populations (4000-3000 cal BC) of the Aguas valley settled in different types of ecological situations, taking advantage of the natural diversity existing in the Aguas valley. The agricultural strategies and spaces seem to concern dry farming as well as the cultivation of the more humid river margins. The proximity to water resources or more humid areas does not seem to have been a significant factor, which agrees well with the paleo-climatic evidence indicating more humid conditions during the early Holocene.

Higher population, more intensive agricultural practices and, probably, the tendency towards more arid conditions implied that after 3000 cal BC (Chalcolithic period) subsistence production mainly concentrated on the exploitation of the Quaternary valleys. The distance to water resources has become a relevant factor in the selection of settlements and agrarian spaces. This strategy allowed these populations to obtain the highest productivity with the lowest labour investment in semi-arid environments.



Map 11: Chalcolithic settlements and their agricultural territories.

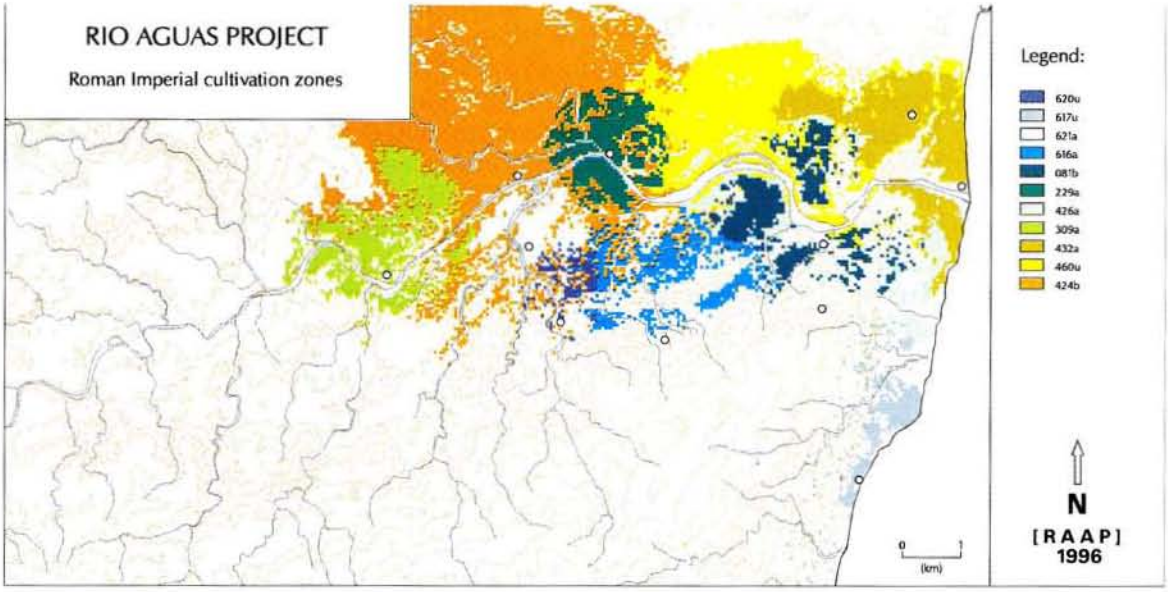
After 2300 cal BC (Argaric period I) agricultural territories exceed the limits of reasonably well suited land existing in the valley bottoms, due to demographic increase and the introduction of extensive dry farming strategies on the plains. From this moment on the beginning of an extensive barley monoculture takes place. That this strategy was economically and/or environmentally problematic becomes clear by the attempt made around 1900-1750 cal BC (Argar II) towards an increase in the production of legumes (*Vicia sp.*), which could only take place in the areas of higher humidity, i.e. in the valleys.



Map 12: Late Argaric settlements and their agricultural territories.

With the full development of the first prehistoric State formation (Argar III: 1750-1550 cal BC) the settlement of Gatas seems to become the main centre of accumulation, transformation and redistribution of the Aguas barley. Its production and an important demographic increase implied a drastic extension of the agricultural territories through the deforestation and exploitation of the Tertiary plains suited for *secano intensivo* II and *secano extensivo*. The advantages of barley cultivation are its resistance to low rainfall and its adaptability to poor soils. Nevertheless, from an economical point of view, the productivity obtained with this strategy is very low, specially if marginal *secano extensivo* soils are used (fig. 19). Its social consequences caused nutritional problems, as is indicated by the palaeo-pathologies observed on human skeletons of this period (Buikstra and Hoshower 1994). Its environmental consequences affected the history of the area even a long time after the collapse of the Argaric State around 1550 cal BC. Although the dry and hot climatic conditions detected during this period (see 5.1) favour such an extensive agricultural strategy, other social and economic trajectories could have been possible (e.g. migration to other wetter regions, demographic stability, development of irrigation farming).

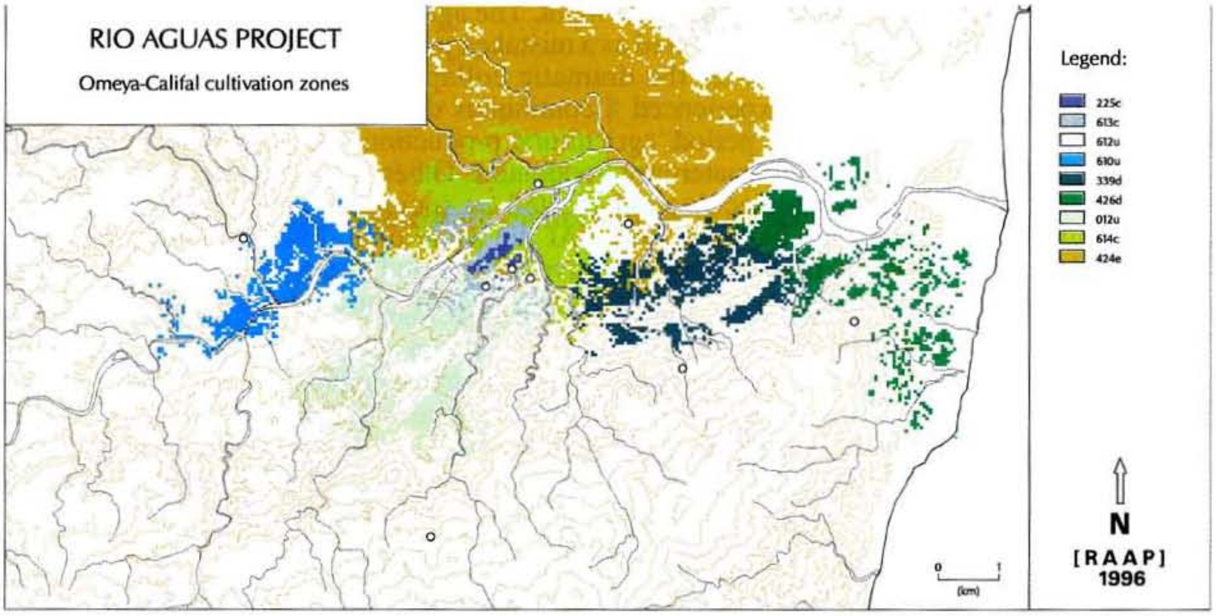
The trajectory from 4000 cal BC to 1550 cal BC shows the maximum economic exploitation of the Aguas valley with little or no technological input. The agricultural strategy imposed during the late Argaric period can only be considered as a mistaken policy in view of the environmental and social consequences it had. After the dramatic collapse of this State system, human occupation of the Aguas valley experienced a continuous decrease until the Roman period, around 1500 years later. Untill this period, agricultural production is limited again to the most productive surfaces existing in the Quaternary floodplains. Other areas of southern Spain seem to have been more attractive for ecological as well as socio-economical reasons, as the archaeological record shows (Chapman 1991). At the same time, low population numbers hindered the development of more labour intensive agricultural strategies, which apparently represented the only possibility to obtain better yields under the already degraded environmental conditions of the lowlands.



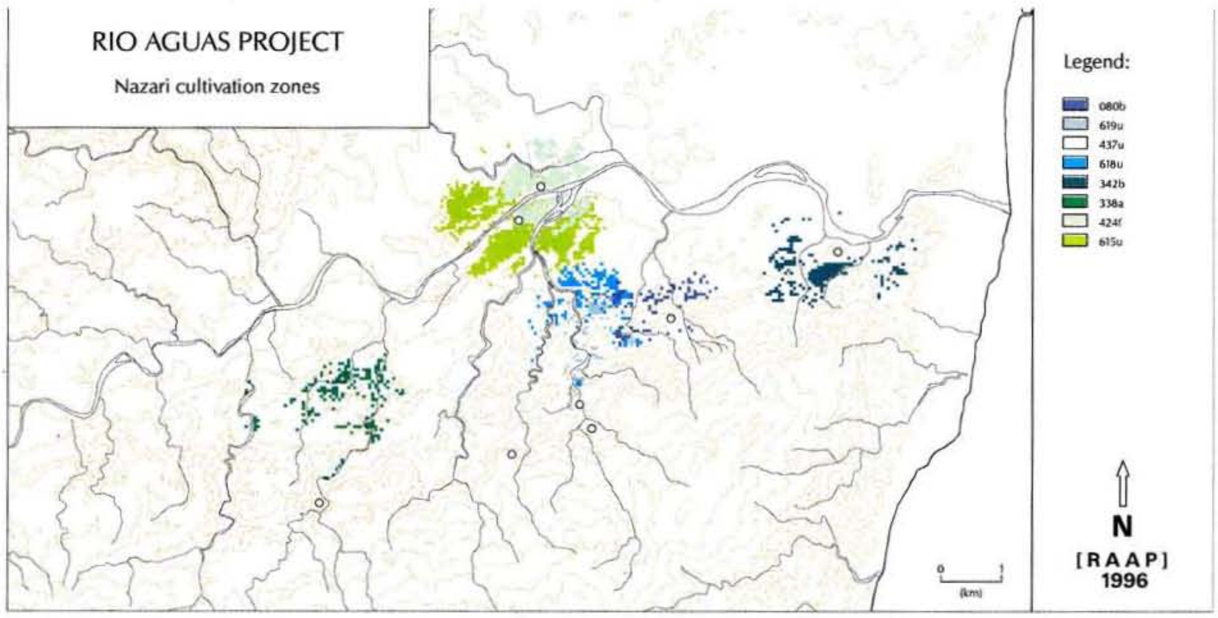
Map 13: Roman Imperial settlements and their agricultural territories.

During the period of the Roman empire (0-400 AD) new agricultural strategies and high population numbers led to a new period of agricultural expansion. While dry farming of barley was practised extensively on the plains, the growing importance of wheat can only be explained through the development of the first irrigation system on the Quaternary soils along the Aguas river, where the main *Villae* are located. As observed during the Argaric period, the need for surplus production furthered by the Roman State implied an exploitation of the agricultural resources above the ecologically defined limits and on less productive land.

The disappearance of this large scale political organisation was not followed by a depopulation phase of the Aguas valley, as occurred after the collapse of the Argaric state. Rather a less concentrated settlement pattern seemed to emerge during the Late-Roman/Byzantine period (400-700 AD), which aimed at a better exploitation of the most productive agricultural land, as the high *attractivity indices* of this period suggest. This decentralised occupation pattern corresponds to the development of the hydraulic infrastructure and irrigation farming in the valleys, as is also suggested by the dominance of wheat in the subsistence production. Probably this agricultural intensification through technological innovation and low but constant labour investment, has to be seen in relation to the links existing at this time between southeast Spain and North Africa, where irrigation systems played an important part of the agricultural territories. This strategy allowed these populations to reduce land use to the floodplains, but still to maintain a similar or even slightly larger population as existed during the Roman empire. Apparently, the lack of external demand for agricultural goods implied the abandonment of the low productivity dry-farming strategy on the plains.



Map 14: Omeya-Califal settlements and their agricultural territories.



Map 15: Nazari settlements and their agricultural territories

After a period of demographic crisis, probably caused by political instability, the IX-X century saw the emergence of a new settlement pattern and socioeconomic organisation, linked to the formation of the Andalusian state. The construction of a *hisn* or Andalusian castle high up the Sierra Cabrera (539 m) appears to be related to this development, as a military centre of the Aguas valley and the Vera basin in general. While the larger lowland villages of the previous period remain occupied, new settlements appear at the foot of the sierras in similar settings as to those documented for the Argaric period (e.g. Gatas). This two-fold occupation pattern corresponds to a new attempt to increase agricultural production, furthered by external demands. The lowlands probably saw the maintenance or the renewal of the previous irrigation system existing along the Aguas river, as well as a reintroduction of the dry-farming practices on the Tertiary plains. At the same time, the complex terrace and hydraulic system, whose main functioning characteristics can still be observed in the present day system (see 5.3), began to be developed on the slopes of the Sierra Cabrera, which explains the new type of site location. The introduction of this new technological device, despite being more labour intensive, allowed these populations to maximise the existing water resources and to reach the highest productivity levels. All these strategies take place in the Vera basin in combination with extensive husbandry, mining of iron ores and a specialised metal production, which exceeds the local necessities. The resources needed for these energy intensive activities must have implied an important deforestation in the mountains, as, according to botanical evidence, the plains already presented a similar level of degradation and aridity as today. It can be stated, that the introduction of terrace and irrigation systems on the slopes of the *sierras* represented, consciously or not, an agricultural strategy which counteracted the environmental degradation of the highlands.

In the 13th-15th century AD, when the Vera basin became a border region of the Nazari state, agricultural territories were reduced again. Although population density was nearly as high as during the Roman and Late-Roman periods exploitation of the Tertiary plains played a minor role and agriculture seems to have concentrated on the most productive surfaces, i.e. the Quaternary valleys and the mountain slopes with the highly developed hydraulic infrastructure. Still, this strategy allowed surplus production, not so much in terms of cereal crops as in previous periods, but of mulberry trees related to silk production and of olives. The historical documents of the 16th century (*Libro de Repartimiento*) report that in the area around Turre existed 1100 mulberry and 1500 olive trees. The inhabitants of the mountain village of Teresa grew around 1200 olive, almond, fig and mulberry trees. For the other sites no records exist, but the situation seems to have been similar. The achievement of these high levels of agricultural production with a low impact on the environment was only possible through a combination of economic and social factors. Undoubtedly, an adequate management of the water resources and the development of a complex hydraulic infrastructure laid the technological basis. Equally important was the dispersed settlement pattern and the distribution of enough land among the population to guarantee self sufficient production. Only cereal *secano* land and some tree plantations show an unequal property structure and allowed a certain surplus production.

The importance of the social structure in the agricultural strategies becomes clear after the expulsion of the Andalusian population from the Aguas valley and the distribution of the agricultural territories among the new Christian population. Despite the fact that much larger agricultural plots were given to these farmers, the irrigation system of the Sierra Cabrera was given up, claiming its "insufficient productivity". The consequence was the abandonment of the mountain settlements, a drastic population decrease and the activation of important erosive processes, as shown in the sequence of Holocene terraces documented in the Aguas valley (see 5.2), and which contributed further to the degradation of the area. Not before the end of the 18th century AD did the Aguas recover from its politically induced demographic crisis. At this point the socio-agrarian situation had changed considerably. Although many poor land owners still ran a small scale intensive *huerta* production, the dominant tendency is towards a concentration of property and large scale *regadío* as well as *secano* cash crop production. For example, in 18th century Turre 2% of the population owned more than 40% of all the irrigated land. This situation became even more pronounced in the 19th century, when the region experiences a sharp demographic increase caused by the important mining activities taking place mainly in the northern part of the Vera basin. Property of irrigation land is further concentrated and most of the poorest farmers now only own land suited for dry-farming. High food demands, caused by the high population density, implied the exploitation of all available resources. While the river valleys were cultivated with different types of irrigation systems, dry-farming is extended even to the worst quality land (*secano extensivo*). At the same time the remains of the Andalusian hydraulic technology were repaired and enlarged in the Sierra Cabrera. In this sense we can conclude that the 19th century applied all the possible agricultural strategies developed so far by different surplus economies: 1. the Argaric extensive dry farming on the plains, 2. the intensive irrigation of the valleys introduced in Roman and Late Roman times, 3. the high productivity-labour intensive mountain farming developed by the Andalusian populations. It is clear that this situation led to an overexploitation of all areas of the Aguas valley and contributed further to the present day degradation.

Despite an important demographic decrease during the 20th century, land use in the 1970s still exceeded the ecologically reasonable limits of the Aguas valley (fig. 19). For modern agriculture we can evaluate the agricultural strategies according to the four types of land use distinguished in chapter 5.6.1. According to the available land use map (see 3.8.), around 2900 ha are used for *regadío* and *secano intensivo*. It is interesting that the amount of floodplain *regadío* and floodplain *secano*, or *secano intensivo I,* adjusts to the 80% probability threshold, while the *secano intensivo II* type on the Tertiary plains, which today occupies 1200 hectares, is only available if the ecological conditioning factors are fulfilled at a 20% probability. Today another 380 ha are cultivated in the extremely poor *secano extensivo* conditions, which is available at a 95% probability. This implies that the present day agriculture is characterised by an underexploitation of the floodplains, and an overexploitation of the Tertiary plains. As we have mentioned above, the natural productivity of the plains is conditioned by rainfall, while that of the floodplains also depends on the groundwater level. Thus the underexploitation of the floodplains is a reflection of the degree of structural aridity reached in the area. With similar drought the Tertiary plains are preferred for either irrigation agriculture, dependent on hydraulic infrastructure, e.g. wells, and external water supply, or for a low productivity cultivation. The extraction of the ground water supposes a reduction of the alluvial aquifers, which again results in a further aridisation of the floodplains. In general, one can say that, in principle, under the present day conditions another 900 hectares are potentially available for cultivation (50% probability limit for *regadío* and *secano intensivo type I*), mainly in the valleys of different rivers and ramblas. The development of these potentials mainly depends on the hydric potentials and on the design of a more rational water management strategy.

5.6.3. Consequences of the combined exploitation of land, animals and wood resources in different demographic and socioeconomic situations (results of 3.6.2., 3.7.3., 3.7.4., 3.7.5.)

The empirical evidence obtained from the multistratified site of Gatas and the use of homogeneous quantitative indices (see 3.7.2, 3 and 4) allows us to compare agricultural production, meat production and wood exploitation. This information can than be evaluated in relation to demography (5.5) and the extension of the agricultural territories (5.6.2).

The first observation which can be made is that there is no direct correlation between demographic increase and expansion of the agricultural territories. The highest population indices occur around 1600 cal BC, the full development of the Argaric State, and around 1000 AD, the functioning of the Califal State, but the territories exploited in both periods are very different. Here the disadvantages of extensive crop monocultures and the high productivity reached by the Andalusian agricultural strategies become clear.

In the late Argaric phase, i.e. around 1600 cal BC, not only are the agricultural territories expanded, but also the meat production, obtained through sheep and goat husbandry, and the forest exploitation increase significantly. That this situation implied a clear over exploitation becomes clear in view of the social as well as the environmental processes occurring after 1550 cal BC. The collapse of the Argaric system is followed by a rapid drop in the population and a drastic reduction in crop production. The decreasing of soil fertility and the environmental degradation of the region is also shown in the palaeo-botanical evidence (see 5.4.). In this sense, it can be concluded that the demography, at least up to certain levels, is more the consequence than the cause of environmental degradation, something which is of prime importance for the development of future policies in Mediterranean environments.

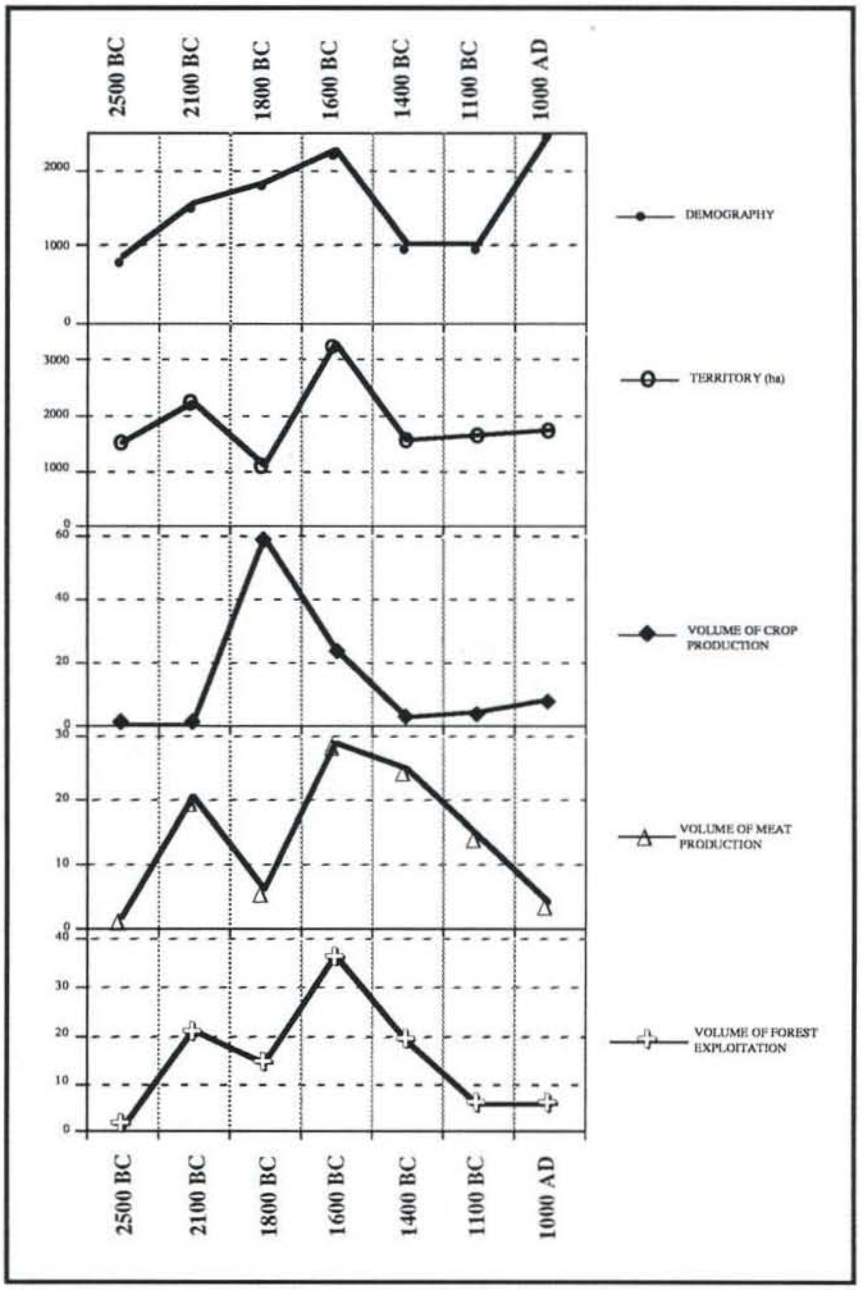


Fig. 20: Comparison between demographic trajectory, agricultural territories and goods production in the Aguas valley during the occupation phases of Gatas.

There is also no clear correlation between the economic impact on the environment and the productivity levels reached by food production. On the contrary, the moments of highest agricultural productivity (Kcal) take place around 1800 cal BC, while husbandry becomes the most relevant sector around 1400 cal BC. Therefore quality and quantity of the food resources do not depend on the extensive strategies developed around 1600 cal BC. It can be concluded, that the most environmentally aggressive strategies are independent of demographic pressure and the volume of production. The importance of political variables and specific decision making aimed towards an increase in surplus production, as occurred during the development of the Argaric State, are the prime causes of the environmental degradation of the Aguas valley.

In the case of the Argaric period anthropic impact caused an irreversible degradation that has conditioned the environmental and social dynamics until the present day. The wood exploitation indices were never again as high as during the Argaric period, while natural vegetation regenerated at a much slower pace from then onwards. The Tertiary plains where these trees and shrubs were deforested in order to gain further agricultural land seemed to be unable to recover and developed a more steppe like vegetation, which appears in the anthracological record of Phoenician and Roman times. Soil fertility, at least in the lowlands also decreased considerably, as the Las Pilas section shows. In general we see here the consequences of a mistaken environmental and economic policy, which can hardly by reversed, but which is relevant for other regions, where degradation still has not reached the levels observed in the Aguas.

5.6.4. Conclusions

Thanks to the palaeo-economic analysis developed in the context of this project, the Aguas valley probably represents today the region with the most detailed long-term agrarian history in the Mediterranean. This information is of prime importance in order to evaluate the potentialities of the area, the consequences of anthropic impact and the possibilities for future development.

The first result is that most societies and in different historical moments exploited around 1500 ha. It is interesting that this surface is equivalent to the land available in the Quaternary valleys (*vega*) at the 80% probability threshold. These soils allow us to obtain an optimal relation between necessary labour input and crop output. Through the introduction of hydraulic infrastructure productivity can be increased further. The maximum production volume with such an irrigation system seems to have been reached in Late Roman times, when the subsistence demands of up to 3900 persons could be satisfied. The Nazari period might have been the last time when this intensive agricultural strategy functioned in its full extension in the valleys, and allowed the growth of thousands of cultivated trees, in combination with a diversified crop production. Clearly the lowlands presented then a very different aspect to the dry and deforested picture visible today, thanks to this wide scale management of the water resources.

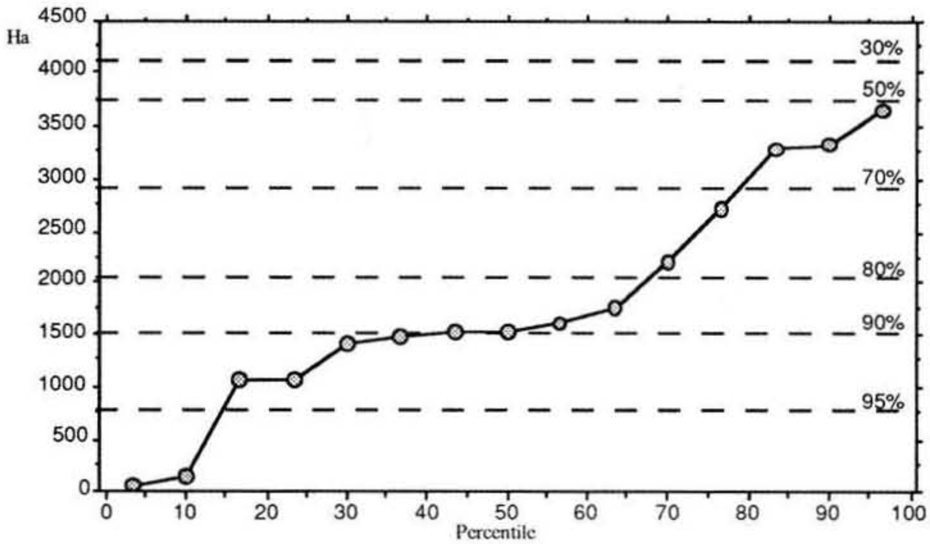
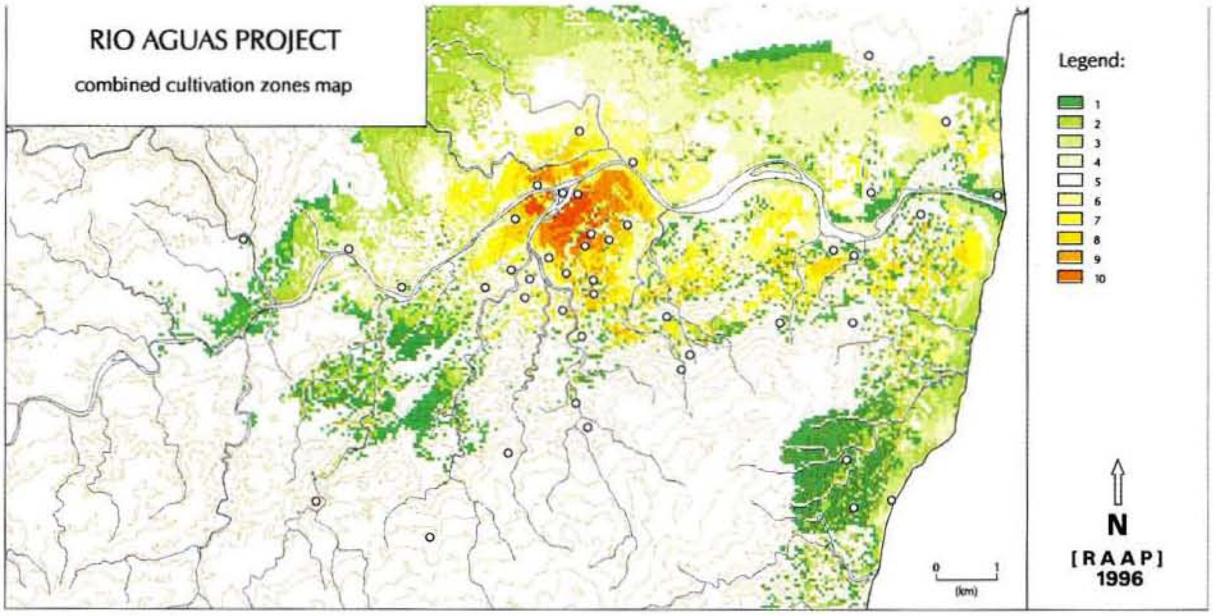


Fig. 21: Percentile distribution of the agricultural territories, which developed in the Aguas valley during the last 6000 years (same data as fig.19), in relation to the potential land (*regadío, secano* type I and II) at different ecological probability levels (see 5.6.1).

Approximately the same population as during Late Roman and Nazari times exists today in the area, but the main limiting factor now is the availability of water. The fact that today these potentials are less exploited than the Tertiary plains (see 5.6.2.) is a clear indication of the aridisation of the valley bottoms. In this sense, it has to be underlined that the lowlands presented during the Roman period an already degraded vegetation, due to the deforestation which occurred mainly during the second millennium BC. Therefore the availability of sufficient amounts of water must be linked to the high resilience and water storage capacity of the Sierra Cabrera, which has been documented at successive periods. This leads to the conclusion that any water infiltration furthering mechanisms in the high lands, such as the development of a denser vegetation and/or the extension of hydraulic infrastructure (see 5.3), have direct consequences for the recovery of the lowland aquifers and of the vegetation existing in the valley bottoms. In general the total water availability of the Aguas valley becomes larger.

Only in three historical moments were the agricultural territories extended beyond 3000 ha, forcing ecologically conditioning factors nearly up to a 50% probability threshold (fig. 19 and 21): 1. the Argaric state; 2. the Roman Empire; 3. the 19th and 20th century Capitalism, with a clear overexploitation of the local resources caused by the mining boom. The fourth state organisation which existed so far in the area, i.e. the Omeyan caliphate, and the early stage of the Argaric state present the next two highest values. In all these periods the best suited soils existing in the valleys were insufficient and extensive dry-farming was practised in areas where the agriculturally favourable factors are negative, i.e. productivity is low. Apparently, only in periods when the labour force had a low economic value did this agricultural strategy become feasible. Apart from its economic implications, the exploitation of the Tertiary plains during the Argaric period probably had the most important environmental consequences, when the maquia vegetation was deforested for the first time and never seemed to recover again, giving way to more open steppe like vegetation. The degradation caused by this state organisation could socially and economically only be overcome through an important investment in technology and labour force in the Roman empire, 1500 years later.



Map 16: Settlements and agricultural territories in the Aguas valley.

Map 16 shows the number of periods a given space had the highest probability of being used during the last 6000 years. It represents the sum of the modelled agricultural territories of all periods, and allows us to distinguish those areas which were most attractive for agricultural exploitation (red), from other with low productivity and/or high labour investment requirements (green).

The conclusion is that the Quaternary valleys (*vega*) could be cultivated successfully in all periods. On the contrary, exploitation of the Tertiary plains seems to result in a rapid fertility loss, *which prevented their repeated use.* Hill slopes where also used in few periods, but in this case because of the high labour input needed in order to construct the necessary terrace and irrigation systems.

This type of spatial modelling is crucial for the future development of the Aguas or similar valleys of southeast Spain. It indicates which areas present the highest resilience in relation to land use, and where anthropic impact is critical, either because of its social or of its environmental implications. Any management or development strategy of these areas should be submitted first to a detailed evaluation of its consequences on the socio-ecological variables described and analysed in this project.

5.7. MODELLING SOCIO-NATURAL SYSTEMS (results of 3.9.)

J. McGlade

One of the most interesting results of the modelling concerns the demographic dynamics. The population model which has been developed is able to characterise a hypothetical population at a site such as Gatas in the middle Aguas. A simulation model was constructed for two interacting populations (elite and commoner) based on an age-structured population divided into cohorts (0-9 yrs; 10-19 yrs; 20-29 yrs; 30-39 yrs; 40-49 yrs; 50-59 yrs and 60+). The model relates fertility levels to a generalised health level obtained from calculations of long-term nutritional health. Studies indicate that when nutritional deficit is severe, the birth rate drops rapidly and chronic malnutrition and increased levels of food intake above the subsistence point have much less of an effect. This is reflected in the fact that 80% of the variability in fertility is produced by a food per capita quotient of c.2300 Kcal/day.

Total fertility is calculated on the average number of children an Argaric woman at Gatas will have had in her lifetime (=6.4) multiplied by a stochastic coefficient. This estimate is reasonable for preindustrial populations and accords with studies done on archaeological populations such as the Maya and the Greek Bronze Age populations studied by Angel.

Our model assumes that the core of the elite class was an hereditary aristocracy. Archaeological evidence indicates that unless strong pressure of downward mobility exists, there is a strong tendency for such an aristocracy to grow at a faster rate than the rest of the population via a higher birth rate and lower death rate, due to superior access to critical resources. We might reasonably speculate, however, that if conditions become difficult, the elite will lose control of subsistence activities and may decline very rapidly.

Simulation of population cohort growth for a set of base parameter values demonstrates that equilibrium conditions are reached after 25 years, or about one generation. From a number of experiments to simulate population growth for a settlement such as Gatas, we can show that, from an initial population set at 230 individuals, steady state behaviour is reached after about 50 years. The difference between this result and the reference behaviour described above is due to the inclusion of a stochastic birth rate coefficient. If we perturb the population more violently by the addition of a disease vector visiting the population with a given periodicity, it is still able to retain a high degree of resilience, i.e. it does not collapse. However a threshold is reached at which the population is unable to sustain growth and, after c. 15 years, begins to decline. The most vulnerable age cohort is age class 0-9 years (fig 22).

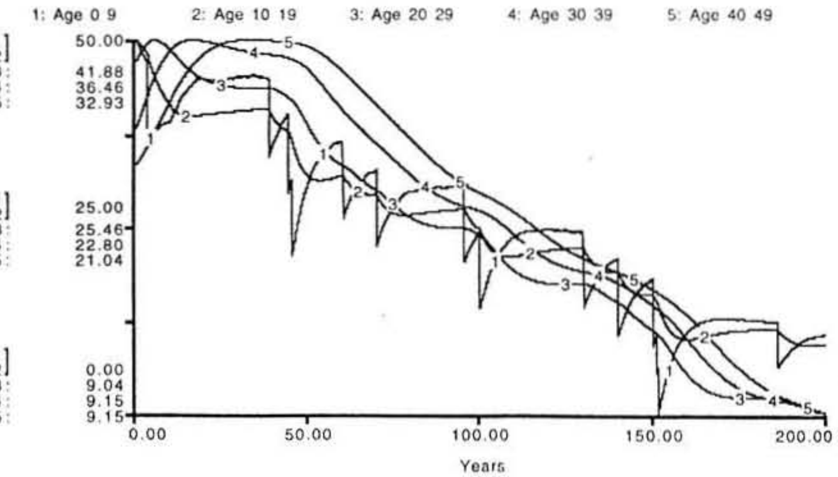


Fig. 22: Comparison of the effect of disease in age cohort 0-9yrs on the other age classes.

Perhaps the most important message from a wide variety of simulations is that this demonstrates that the effect population dynamics exert on social structure is considerable: the acute sensitivity of birth and death rate coefficients is seen in their response to even minimal parameter changes in fertility, as well as stochastic visitation of disease vectors. Such effects cause severe disruption in population structure, generally because the effects are most marked in the infant cohort.

As a consequence, the relationship between division of labour and the maintenance of social control is subject to periodic disruption. Thus the fragility of demographic structures (observed by many demographers, but largely ignored in archaeological models) demonstrates the essential instability of societal relations of production.

Functionalist and materialist models have frequently portrayed population structure as an external cause or independent variable acting upon the system. Such prime-mover models are inadequate precisely because they misrepresent the true dynamics of the social natural system. Population dynamics are frequently reduced to an aggregate variable; thus average growth values dominate discussion. Our results show that, to the contrary, it is the micro-scale age-structure of the population which is the critical issue for study. In addition, we have shown, in relation to the Bronze Age, that the birth rate is highly sensitive and can be considered to represent an endemic instability within demographic structure, partly as a function of the unpredictability of fertility rates - affected as they are by biology, age, nutritional stress, kinship rules, tradition, ideology, etc.

Our simulations demonstrate that the onset of aridification coupled with barley monocropping in the Argaric exerted a cumulative deficit effect on long-term nutritional health. Indeed, there is substantial evidence that monocropping regimes generate severe diarrhoetic conditions in populations, increasing the mortality rate in the primary age cohorts (F. Hassan, pers. com.). Thus it may be that the combination of subsistence practice and climatic changes over the long-term, acted to severely destabilize the demographic age-structure at Argaric settlements such as Gatas (see Buikstra and Hoshower 1994 on infant mortality at this, and other contemporary sites), leading to abrupt changes in the social division of labour. What we are underlining in these preliminary results is the problematic nature of societal reproduction in elite dominated communities and ultimately the limits of social control in stratified societies characterised by unequal distribution of wealth and power.

These simulation studies lay bare the fragility, uncertainty and sensitivity to abrupt transition lying at the heart of the social stratification in the Aguas and indeed, throughout the Vera basin.

Under these circumstances collapse is not a surprise, but represents a highly probable - and probably frequently encountered - evolutionary trajectory.

In addition, our simulations of soil/vegetation/crop complexes demonstrate the critical importance of soil-moisture in generating a nested set of structures from the micro-local level of soil structuration to the scale of the Aguas catchment. It is thus that we can say that the relationship between social-natural phenomena and hydrology forms a tightly knit coevolutionary dynamic (as shown in 5.3.).

Increasing aridification is not - as has often been suggested - a linear function related to decreasing soil structure and low yields. The crucial point about increasing aridity is that it leads to an increase in the probability of short-term climatic fluctuations and hence severely compromises any attempt at predicting crop yields and thus the creation of surplus.

6.CONCLUSIONS:
PROJECT RESULTS AND POLICY RECOMMENDATIONS

The editors.

6.1. Project results

As the previous chapter shows, the theoretical structure and the methodological framework developed and used in the Aguas project has allowed a better and much more detailed insight into the functioning of socio-natural systems. The main results can be summarised as follows:

1.) Temperature changes observed in other European regions do also occur in Southeast Iberia, something which has often been questioned (i.e. the Iberian specificity). Probably the same does not apply to pluviosity, but this issue needs to be confirmed on a more solid base. A correlation between lower temperatures and an increase in torrential rainfall events can be observed.

2.) Even though there are indication of rainfall differences existing between the centre of the Vera basin and its margins, totalisers placed in the Sierra Cabrera show that in the present day conditions pluviosity does not seem to be significantly different in the highlands than in other parts of the region, as has been considered on certain occasions. It was also shown that pluviosity increase according to height is not as pronounced as previously thought (12mm each 100 m instead of 74mm). This implies that the more favourable ecological conditions existing in the Sierra Cabrera or other mountain formations of southeast Spain are not so much caused by higher rainfall, as by a better water regulation and storage capacity. The geological characteristics of these areas, the vegetation and/or the development of large scale hydraulic and terrace systems are determinant factors in the availability of water.

3.) Most morphological features and the present day dissected environment belong to pre-Holocene formations (contrary to Courty *et al.* 1994).

4.) Erosional phases already existed before 3000 BC (as the Las Pilas-Unit III shows), when anthropic impact was absent or irrelevant. An intensification of the erosive and sedimentary processes has occurred during the last 500 years, leading to the formation of at least two out of four Holocene river terraces and of considerable sedimentary deposits in the rivermouths. This is related (i) to the agricultural and demographic crises taking place after the expulsion of the local Andalusian population in the 16th century AD and (ii) to the possible increase in torrential events during the European "small ice age".

5.) Soil formation during all Holocene periods is limited, as the Las Pilas and other sections show. Nevertheless, it is clear that soils have become successively poorer and less developed since the Neolithic period, mainly because of the inherent susceptibility of the local subsoils and soils to erosion. This process is aggravated by continuing human exploitation, but is also controlled by humans in specific circumstances and periods (e.g. development of terrace systems).

6.) Despite temperatures and pluviosity similar to today's, an important maquia vegetation existed until the second millennium BC. Ripisilva along the riverbeds and maquia/matorral vegetation were extensively deforested during the Argaric State (2300-1550 cal BC). Yet while the Sierra Cabrera biotopes show a high resilience capacity, and have recovered their general structure in spite of human intervention, the Tertiary plains have suffered irreversible degradation and the formerly extensive ripisilva has disappeared.

7.) Demography is not the direct cause of the environmental degradation. Population increase has normally been linked in the area with specific economic-political situations operating on a supra-regional scale and which interrupted the self sufficient resource organisation of the region and its inhabitants (e.g. the Roman Empire or the 19th century mining boom). On the other side, population decrease always followed after phases of environmental degradation through overexploitation (e.g. Post-Argaric period) or mismanagement (e.g. 17th century after the reorganisation of the Andalusian agrarian territories and property structure).

8.) There exists no direct correlation between food production and the extension of agrarian territories. The land use strategies are not determined by ecological conditions, but the consequence of specific political decisions related to general or individual, internal or external interests. Therefore it has to be concluded that despite minor climatic fluctuations and generally speaking dry conditions, it is policy making which plays the prime role in the conservation or degradation of these environments.

9.) The more aggressive strategies are:

- -High degree of exploitation of labour force.
- -Extensive dry-farming on Miocene plains.
- -Extensive sheep and goat grazing.
- -Overexploitation of wood resources.
- -Intensive pumping of Sierra Cabrera aquifers.

10.) The less aggressive strategies are:

- -Low degree of exploitation of labour force.
- -Intensive irrigation on floodplains.
- -Moderate cattle herding complemented by hunting.
- -Diverse and moderate wood exploitation.
- -Reduced exploitation of Sierra Cabrera.

11.) The rational management and/or natural stage of the highland vegetation has always been of prime importance for the state of the aquifers in the lowlands, for the socially usable water resources and for the general economic development of the area. The abandonment of the traditional *sierra* irrigation system in the 1970s, which until then counteracted erosion and water loss, contributed to the lowering of the ground water table and a further aridisation of the lowlands. Hydrological investigations have shown that today in the upper Añoflí/Ancha catchment (1.6 km2) between 130-180 l/s during rainfall remain unused. This shows that considerable water resources are still potentially available in the system and could be exploited in an ecological and economically positive way.

6.2. Policy recommendations

A set of fundamental recommendations result from this analysis, which are of prime importance for the ecological regeneration of the area, and which at the same time allow a better socioeconomic development of this and other similar areas. From the theoretical framework of this project it follows that ecological protection can not be undertaken at any cost nor consume resources that are necessary for social reproduction. In order to combine dialectically both sides of the same socio-natural reality it is important 1. to distinguish the relevant criteria for an environmentally and socially acceptable policy and 2. to develop an analytical articulation of these criteria in a formulation that allows us to determine the spatial and temporal entities which can or have to be submitted to the chosen policy.

With respect to the first point, it is clear that in arid environments, rather than for example ecological diversity, the relevant criteria must be 1. water storage and water discharge capacity and 2. biomass production capacity. In principle natural factors furthering these capacities are more adequate, as they allow populations to reduce labour input, and therefore the cost of the environmental policy. Yet, depending on the stage of degradation and on the economic benefits of the applied policy, human induced aid can be advisable.

In order to transform these criteria into specific environmental policies through an analytical procedure, the concept of a *Natural Resource Productivity* is proposed. It implies, that the possibilities of a socio-economic development in arid and semi-arid areas as well as the maintainance or improvement of the environmental conditions are directly related to areas which present a naturally high generation of resources. These spaces need to be understood, defined and managed in the most effective way. The general structure of the notion of Natural Resource Productivity can be expressed as:

$$NRP = (Ws + Bp)\ ST$$

where
Ws = water storage capacity
Bp = natural biomass production
ST = the spatial and temporal dimension in which a given ecological system shall be evaluated.

While Ws results from the hydrological investigation and, indirectly, the research on hydraulic infrastructure (3.4. and 3.7.2.), Bp is defined through a historical understanding of vegetation dynamics after successive periods of social exploitation and regeneration/degradation (3.5. and 3.7.5.). Those areas where the NRP index is highest should be protected or managed through specific policies, while areas with low NRP indices can be submitted to economic development with the resources generated in excess by the ecologically more favourable/productive spaces. It becomes clear that there has to be a co-responsibility between social needs and environment. The economic development and profits obtained in one area can not be considered as something independent from the spaces, where the consumed resources are generated. This might represent a possibility to limit environmental degradation and to set the conditions for future social development. Furthermore, in many regions and situations such a strategy supposes much lower costs, in terms of labour or technology investment, and less social conflict than current proposals (e.g. long distance channeling of water resources).

The practical application of a NRP index, in terms of visualisation and spatial definition, can be approached through G.I.S. procedures, on the basis of the information and results of the Aguas project. In the Aguas valley this could mean that the degraded Tertiary plains, which do not seem to be able to recover from the environmental degradation suffered since the second millennium BC and where the NPR indices are the lowest of the region, can be used for different industrial purposes or for modern dripple irrigation agriculture, as long as the mountain water storage and vegetation system is regenerated. If water is one of the main factors for future development, its social and individual consumption has to imply a responsibility with its natural production.

In the present situation a reactivation of the traditional irrigation systems could be the first step towards an increase in the NRP of the area and probably represents a better solution than reforestation programmes, as undertaken in the past with little success. Apparently the high resilience capacity of the *sierra* allows the natural growth of the most adapted vegetation, as it has done repeatedly over several thousands of years. The resulting increase of the water table in the lowlands could help to regenerate the valley bottoms, which today are underexploited and are not well suited for modern agriculture or industries. The fact that pluviosity and soils were not significantly different 500 years ago implies that it must be possible to introduce again tree plantations similar to the ones existing in the Nazari period, something which would contribute considerable to ameliorate the aridity and degradation of the territory and which represents a general social benefit. Better hydrological data and, therefore, a continuation of the discharge and pluviosity measurements in the area, are of prime importance in order to determine which volume of water would be available for this or similar development policies and which possibilities exist in order to increase these resources on a local scale.

The growing importance of tourism at the coast is another development possibility, but here again, water resources are the critical factor and demand a coresponsibility of the economical areas with the ecological spaces. Such a policy also favours the development of a conscience of the population towards the available natural resources and the need for their rational management. In this sense, it is obviously more convenient that the application of the notion of economic-ecologic coresponsibility corresponds to local democratic institutions. The introduction of democratic regional water management institutions is probably the best help for this area. The socio-natural investigation carried out provides the empirical knowledge and defines the critical factors on which a locally decided policy can be based. External interference and political impositions would neither contribute to the formation of a regional ecological consciousness, nor to an appropriate development of the area, as has occurred repeatedly in the history of the Aguas valley.

7. BIBLIOGRAPHY

Achtnich, W. (1980), *Bewesserungslandbau, agrotechnische Grundlagen der Bewässerungswirtschaft*, Ulmer, Stuttgart.

Annales Valaisannes (1995), "Les Bisses", *Bulletin annuel de la Societé d'çhistoire du Valais Romand*, Actes du colloque international Sion, 15-18.Sept. 1994.

Araus, J.L., Buxó, R., Febrero, A., Camalich, M.A., Martín, D., Molina, F., Rodríguez-Ariza, M.O. and Voltas, J. (1996), "Identification of ancient irrigation practices based on the Carbo isotope discrimination of plant seeds: a case study from the Southeast Iberian Peninsula", *Journal of Archaeological Science* (in press).

Badal García, E. (1990), Aportaciones *de la Antracología al estudio del paisaje vegetal y su evolución en el cuaternario reciente, en la costa mediterránea del Pais valenciano y Andalucía (18.000 - 3.000 B.P.)*, Tesis doctoral microfilmada, Universidad de Valencia.

Bertholdi, R., Rio, D. and Thunell, R. (1989), "Pliocene-Pleistocene vegetational and climatic evolution of the south central Mediterranean", *Palaeogeography, Palaeoclimatology, Palaeoecology*, 72: 263-275.

Bicker, R.E. (1966), *Geological investigations in the region west of Antas and Cuevas del Almanzora, south-eastern Spain*, Doctoral Dissertation, University of Amsterdam, Amsterdam.

Brunnacker, K. and Lozek, V. (1969), "Löss-Vorkommen in Südostspanien", *Z. Geomorph.* N.F., 13: 297-316.

Buikstra, J. and Hoshower, L. (1994), "Análisis de los restos humanos de la necrópolis de Gatas", en Castro, P., Chapman, R., Colomer, E., Gili, S., González Marcén, P., Lull, V., Micó, R., Montón, S., Rihuete, C. Risch, R., Ruiz Parra, M., Sanahuja Yll, M.E. and Tenas M. (eds) (1994b), *Proyecto Gatas: Sociedad y economía en el sudeste de España c.2500-900 cal ANE*, Memoria de la Junta de Andalucía, Sevilla.

Bullock, P., Fedoroff, N., Jongerius, A., Stoops, G. and Tursina, T. (1985), *Handbook for Soil Thin Section Description*, Waine Research, Wolverhampton.

Burjachs, F. and Julià, R. (1994), "Abrupt climatic changes during the last glaciation based on pollen analysis of the Abric Romani, Catalonia, Spain", *Quaternary Research*, 42: 308-315.

Burton, J.H. and Price, T.D. (1990a), "The ration of barium to strontium as a paleaodietary indicator of consumption of marine resources", *Journal of Archaeological Science*, 17: 547-557.

Burton, J.H. and Price, T.D. (1990b), "Palaeodietary applications of barium values in bone", in Pernicka, E. and Wagner, G.A. (eds), *Archaeometry '90*, Birkhäuser, Basel: 787-795.

Capel, J. J. (1990), *Climatología de Almería*. Cuadernos Monográficos, 7. Instituto de Estudios Almerienses. Diputación de Almería. Almería.

Carrión, J.S. (1992), "Late Quaternary pollen sequence from Carihuela Cave, southeastern Spain", *Rev. Paleobot. Palynol.*, 71: 37-77.

Carrión, J.S. and Sánchez-Gómez, P. (1992), "Palinological data in support of the survival of walnut (Juglans regia L.) in the western Mediterranean area during las glacial times", *Journal of Biogeography*, 19: 623-630.

Carulla, N. (1977), *Contribución al conocimiento de la dinamica hidrogeológica en clima semiárido (Depresión de Vera, Almería)*, Ediciones de la Universidad Autónoma de Barcelona, Bellaterra.

Carulla, N.(1979), "Utilización de los isótopos tritio y oxígeno-18 para el estudio de la hidrodinámica de aguas superficiales y subterráneas: Depresión de Vera (Almería)", *Simp.Nac.de Hidrogeología*, Pamplona: 481-502.

Castro, P., Colomer, E., Courty, M. A., Federoff, N., Gili, S., González Marcén, P., Jones, M.K., Lull, V., McGlade, J., Micó, R., Montón, S., Rihuete, C. Risch, R., Ruiz Parra, M., Sanahuja Yll, Mª E. and Tenas, M. (eds) (1994), *Temporalities and desertification in the Vera Basin, south east Spain*, Archaeomedes Project, Vol. 2, Brussels.

Castro, P.V., Chapman, R. W., Gili, S., Lull, V., Micó, R., Rihuete, C., Risch, R. y Sanahuja Yll, Mª E. (1996a), "Teoría de las prácticas sociales", *Complutum. Homenaje a M. Fernández-Miranda*: 35-48.

Castro, P. V., Gili, S., Lull, V., Micó, R., Rihuete, C., Risch, R. and Sanahuja Yll, M. E. (1996b), "Teoría de la producción de la vida social. Un análisis de los mecanismos de explotación en el sudeste peninsular (3000-1550 cal ANE)". *I Congreso de Arqueología social.* La Rábida, Huelva (in press).

Castro Nogueira, H. (1982), "Bibliografía botánica sobre el sector corológico almeriense", Boletín del Instituto de Estudios Almerienses. Homenaje al botánico Rufino Sagrado. Almería: 171-187.

Chapman, R. W. (1991), *La formación de las sociedades complejas. El sureste de la península ibérica en el marco del Mediterráneo occidental.* Crítica, Barcelona.

Cherry, J.F. (1984), "Common sense in Mediterranean survey", *Journal of Field Archaeology* 11: 117-120.

Combouieu, N. and Vergnaud, C. (1991), "Late Pliocene northern hemisphere glaciations: The continental and marine reponses in the central Mediterranean", *Quaternary Science Reviews*, 10: 319-334.

Courty, M.-A, Fedoroff, N., Jones, M.K. and McGlade,J. (1994), "Environmental dynamics", in Castro et al. (eds.) (1994), *Temporalities and desertification in the Vera Basin, south east Spain*, Archaeomedes Project, Vol. 2, Bruselas: 19-84.

Craig, H. and Gordon, L.I. (1965), "Deuterium and oxygen-18 variations in the ocean and the marine atmosphere", in Tongiorgi, E. (ed.), *Stable isotopes in oceanographic studies and paleotemperatures*, Consiglio Nazionale delle Ricerche, Pisa.

Doorenbos, J. and Pruitt, W.O. (1975), *Guidelines for predicting crop water requirements*, Irrigation and Drainage Paper 24, FAO, Rom.

Driesch, A. von den (1972), *Osteoarchäologische Untersuchungen auf der Iberschen Halbinsel*, Studien über frühe Tierknochenfunde von der Iberischen Halbinsel 3, Munich.

Epstein, S., Buchsbaum, R., Lowenstam, H.A. and Ureey, h.c. (1953), "Revised carbonate-water isotopic temperature scale", *Bull.Geol.Soc.Amer.* 62: 417-438.

Ferré, E. (1979), *El valle del Almanzora. Estudio geográfico*. Almería.

Ferres, L. and Risch, R. (1987), "La vegetación del territorio de Gatas", in Chapman, R. W., Lull, V., Picazo, M. y Sanahuja Yll, M.E. (1987), *Proyecto Gatas: Sociedad y economía en el sudeste de España c.2500-900 cal ANE*, B.A.R., Int. Ser. 348, Oxford: 125-131.

Florschütz, F., Menendez Amor, F. and Wijmstra, T.A. (1971), "Palynology of a thick Quaternary succession in southern Spain". *Palaeogeography, Palaeoeclimatology, Palaeoecology*, 10: 233-264.

Fornés, J. (1983), *Cultivo de habas y guisantes*, Sintes, Biblioteca Agrícola, Barcelona.

García Romero, A. (1941), *Agricultura y ganadería e industrias agrícolas*. Ramón Sopena, Barcelona.

Geiger, F. (1970), *Die Ariditát in Südostspanien: Ursachen und Auswirkungen im Landschftsbild*. Stuttgarter Geographische Studien, 77, Stuttgart.

Gómez Ortiz, A., Schulte, L. and Salvador Franch, F. (1996). "Contribución al conocimiento de la deglaciación reciente y gomorfología asociada del Corral del Veleta (Sierra Nevada)", in *IV Reunión Nacional de Geomorfología*. 18. a 20. sept. 1996. La Coruña: 543-558.

Gorenflo, L.J. and Gale, N. (1990), "Mapping regional settlement in information space". *Journal of Anthropological Archaeology*, 9: 240-274.

Grau Almero, E. (1990), *El uso de la madera en yacimientos valencianos de la Edad del Bronce a la época visigoda. Datos etnobotánicos y reconstrucción ecológica según la antracología*, Tesis doctoral microfilmada, Universidad de Valencia.

Groupe de Recherche (1977), "L'histoire tectonique récente (Tortonien à Quaternaire) de l'Arc de Gibraltar et des bordures de la mer d'Alboran", *Bull.Soc.géol. France*, XIX, 3: 575-614.

Helmers, J.J. and Voet, H.W. (1967), "Geological extensions of the Nevado-Filabride nappes in the eastern and central Sierra de los Filabres, SE Spain", *Geologie en Mijnbouw*, 47: 105-135.

Herget, W. (1993), "Zur traditionellen Bewässerungswirtschaft in der westlichen Alpujarra", in Popp, H. and Rother, K. (eds), *Die Bewässerungsgebiete im Mittelmeerraum*, Passauer Schriften zur Geographie, 13: 33-41.

Hitchner, R.B. 1990. "The Kasserine archaeological survey - 1987", *Antiquités africaines*, 26: 231-260.

Hoffman, G. (1988), *Holozänstratigraphie an der Andalusischen Mittelmeerküste*, Berichte aus dem Fachbereich Geowissenschaften der Universität Bremen 2, Bremen.

Hopf, M. (1991), Kulturpflanzenreste aus der Sammlung Siret in Brüssel, en H. Schubart and H. Ulreich, *Die Funde der Südostspanischen Bronzezeit aus der Sammlung Siret*, Madrider Beiträge 17, Zabern, Mainz: 397-413.

Hurst, V.J. (1977), "Visual estimates of iron in saprolite", *Geological Society of America, Bulletin*, 88: 174-176.

Israelsen, O.W. and Hansen, V.E. (1962), *Irrigation principles and practices*, John Wiley & Sons, New York.

Juliá, R., Negendank, J.F.W., Seret, G., Brauer, A., Burjachs, F., Endres, Ch, Giralt, S., Pares, J.M. and Roca, J. (1994), "Holocene climatic change and desertification in the western Mediterranean", in *Alfred-Wegener-Conference - Climate dynamics recorded in long continental high resolution time series since the last interglacial*, Terra Nostra, Bonn.

Kislev, M. E. y Bar-Yosef, O. (1988), "The legumes: The earliest Domesticated Plants in the Near east?", *Current Anthropology*, 29, 1: 175-179 (K&BY).

Roeder, S. (1990), *Das Poqueiratal: ein peripherer Raum zwischen Fremd- und Eigenbestimmung*, Diplomarbeit der Universität Hannover, Hannover.

Rohdenburg, H. and Sabelberg, U. (1972), "Quartäre Klimazyklen im westlichen Mittelmeerdebiet und ihre Auswirkungen auf die Relief- und Bodenentwicklung", *Z.Geomorph.*, N.F., 15: 87-92.

Rondeel, H.E. (1965), *Geological investigations in the western Sierra Cabrera and adjoining areas, south-east Spain*, Tesis doctoral de la Universdidad de Amsterdam, Amsterdam.

Rossignol-Strick, M. and Planchais, N. (1989), "Climate patterns revealed by pollen and oxygen isotope records of a Tyrrhenian sea core", *Nature*, 342: 413-416.

Ruiz, M., Risch, R., González, P., Castro, P. and Lull, V. (1992), "Environmental exploitation and social structure in Prehistoric Southeast Spain", *Journal of Mediterranean Archaeology*, 5/1: 3-38.

Rye, D. and Sommer, M. (1980), "Reconstructing paleotemperature and paleosalinity regimes with oxygen isotopes", in Rhoads, D. and Lutz, R. (eds), Skeletal growth of aquatic organisms. Plenum Press, New York: 169-202.

Sancetta, C., Imbrie, J. and Kipp, N.G. (1973), Climatic report of the past 130.000 years in North Atlantic deep-sea core V23-82: Correlation with the terrestial record", *Quaternary Research*, 3: 110-116.

Sánchez Gavito, L. (1979), *Guía del agricultor*. Aedos, Barcelona.

Schendel, U. (1967), *Vegetationswasserverbrauch und -wasserbedarf*. Habil-Schrift der Universität Kiel, Kiel.

Schoch, W. and Schweingruber, F.H. (1982), "Holzkohlenanalythische Ergebnisse aus der Bronzezeitlichen Siedlung Fuente Alamo, prov. Alemería, Spanien", *Archäologisches Korrespondenzblatt*, 12: 451-455.

Schulte, L. (1994), *Eingriffe des Menschen in die Reliefentwicklung des westlichen Vera-Beckens (Südostspanien). Natürliche und anthropogene Faktoren in Vergangenheit und Gegenwart*, Mag. Arb. Univ. Düsseld., Düsseldorf.

Schulte, L. (1995), "Jungquartäre Flussdynamik des Río Antas im zentralen Vera-Becken (SE-Spanien)", *Geoökodynamik*, 16: 173-196. Bensheim.

Schulte, L. (1996), "Morfogénesis cuaternaria en el curso inferior del Río de Aguas (Cuenca de Vera, Provincia de Almería)", in *IV Reunión Nacional de Geomorfología*. 18. a 20. sept. 1996. La Coruña: 223-236.

Scrimshaw, N. S. and Young, V. R. (1978), "Las necesidades de la nutrición humana", in *Alimentación y agricultura*, Libros de Investigación y Ciencia, Labor, Barcelona.

Shaw, B.D. (1982), "Lamasba: an ancient irrigation community", *Antiquités africaines*, 18: 61-103.

Simon, O.J. (1963), *Geological investigations in the Sierra de Almagro, SE Spain*, Doctoral Dissertation, University of Amsterdam, Amsterdam.

Stevenson, A.C. (1985), "Studies in the vegetational history of S.W.Spain II: Palynological investigations at Laguna de las Madres, Huelva", *Journal of Biogeography*, 12: 293-314.

Stevenson, A.C. and Harrison, R.J. (1992), "Ancient forests in Spain. A model for land-use and dry forest management in S.W. Spain from 4000 BC to 1900 AD", *Proceedings of the Prehistoric Society*, 58: 227-247.

Stika, H.P. (1988), "Botanische Untersuchungen in der bronzezeitlichen Höhensiedlung Fuente Alamo", *Madrider Mitteilungen*, 29: 21-76.

Vernet, J.L., Badal García, E. and Grau, E. (1983), "La végétation néolithique du sud-est de l'Espagne (Valencia, Alicante) d'après l'analyse anthracologique". *C.R. Acad. SC. Paris*, 296, III, 669-672.

Vernet, J.L., Badal García, E. and Grau, E. (1987), "L'environnement végétal de l'homme au Néolithique dans le sud-est de L'Espagne (Valence, Alicante), première synthese d'après l'analyse anthracologique". *Actes du colloque "Premières communautés paysannes en Mediterranée occidentale"*, Montpellier, 1983, CNRS, 131-134.

Völk, H.R. (1967a), *Zur Geologie und Stratigraphie des Neogenbeckens von Vera, Südost-Spanien*. Tésis Doctoral de la Universidad de Amsterdam, Amsterdam.

Völk, H.R. (1967b), "Relation between Neogene sedimentation and late orogenic movements in the Eastern Betic Cordilleras (SE Spain)", *Geologie en Mijnbouw*, 46: 471-473.

Völk, H.R. (1979), *Quartäre Reliefentwicklung in Südost-Spanien*, Heidelberger Geographische Arbeiten 58, Heidelberg.

Völk, H.R. and Rondeel, H.E. (1964), "Zur Gliederung des Jungtertiärs im Becken von Vera, Südost-Spanien", *Geologie en Mijnbouw*, 43: 310-315.

W.H.O.-O.M.S. (1974), *Handbook on human nutritional requirements*, WHO Monograph Series, 61, Geneva: World Health Organization (Organización Mundial de la Salud-OMS).

Wenzens, G. (1991), "Die mittelquartäre Reliefentwicklung am Unterlauf des Río Almanzora (Südostspanien)", *Freiburger Geogr. Hefte*, 33: 185-197. Freiburg.

Wenzens, G. (1992a), "The influence of tectonics and climate on the Villafranchian morphogenesis in semiarid Southeastern Spain", *Z.Geomorph. N.F.*, 84: 173-184.

Wenzens, G. (1992b), "Mittelquartäre Klimaverhältnisse und Reliefentwicklung im semiariden Becken von Vera (Südostspanien)", *Eiszeitalter u. Gegenwart*, 42: 121-133.

Wigley, T.M., Jones, P.D. and Kelly, P.M. (1980), "Scenario for a warm, high-CO2 world", *Nature* 283: 17-25.

Yelo, A., Martínez, P., Salmerón, J. and Ruiz, J. 1988. "Aportación al estudio del poblamiento y los regadíos de época romana en la cabecera del valle del Segura: fuentes documentales y arqueológicas", *Antiguedad y Cristianismo*, V: 599-611.

Yll Aguirre, E.I., Roure, J.M., Pantalesn-Cano, J., and Pirez-Obiol, R. (1994), "Analisis polmnico de una secuencia holocinica en Roquetas de Mar (Almería)", in *Trabajos de Palinología Basica y Aplicada*. X Simposio de Palinología (A.P.L.E.), Valencia, Universitat de Valhncia: 189-197.

Zazo, C., Goy, J.L., Dabrio, C.J., Bardaji, T., Somza, L. and Silva, G.P. (1993), "The Last Interglacial in the Mediterranean as a model for the present interglacial", *Global and Planetary Change*, 7: 109-117.

Roeder, S. (1990), *Das Poqueiratal: ein peripherer Raum zwischen Fremd- und Eigenbestimmung*, Diplomarbeit der Universität Hannover, Hannover.

Rohdenburg, H. and Sabelberg, U. (1972), "Quartäre Klimazyklen im westlichen Mittelmeerdebiet und ihre Auswirkungen auf die Relief- und Bodenentwicklung", *Z.Geomorph.*, N.F., 15: 87-92.

Rondeel, H.E. (1965), *Geological investigations in the western Sierra Cabrera and adjoining areas, south-east Spain*, Tesis doctoral de la Universdidad de Amsterdam, Amsterdam.

Rossignol-Strick, M. and Planchais, N. (1989), "Climate patterns revealed by pollen and oxygen isotope records of a Tyrrhenian sea core", *Nature*, 342: 413-416.

Ruiz, M., Risch, R., González, P., Castro, P. and Lull, V. (1992), "Environmental exploitation and social structure in Prehistoric Southeast Spain", *Journal of Mediterranean Archaeology*, 5/1: 3-38.

Rye, D. and Sommer, M. (1980), "Reconstructing paleotemperature and paleosalinity regimes with oxygen isotopes", in Rhoads, D. and Lutz, R. (eds), Skeletal growth of aquatic organisms. Plenum Press, New York: 169-202.

Sancetta, C., Imbrie, J. and Kipp, N.G. (1973), Climatic report of the past 130.000 years in North Atlantic deep-sea core V23-82: Correlation with the terrestial record", *Quaternary Research*, 3: 110-116.

Sánchez Gavito, L. (1979), *Guía del agricultor*. Aedos, Barcelona.

Schendel, U. (1967), *Vegetationswasserverbrauch und -wasserbedarf*. Habil-Schrift der Universität Kiel, Kiel.

Schoch, W. and Schweingruber, F.H. (1982), "Holzkohlenanalythische Ergebnisse aus der Bronzezeitlichen Siedlung Fuente Alamo, prov. Alemería, Spanien", *Archäologisches Korrespondenzblatt*, 12: 451-455.

Schulte, L. (1994), *Eingriffe des Menschen in die Reliefentwicklung des westlichen Vera-Beckens (Südostspanien). Natürliche und anthropogene Faktoren in Vergangenheit und Gegenwart*, Mag. Arb. Univ. Düsseld., Düsseldorf.

Schulte, L. (1995), "Jungquartäre Flussdynamik des Río Antas im zentralen Vera-Becken (SE-Spanien)", *Geoökodynamik*, 16: 173-196. Bensheim.

Schulte, L. (1996), "Morfogénesis cuaternaria en el curso inferior del Río de Aguas (Cuenca de Vera, Provincia de Almería)", in *IV Reunión Nacional de Geomorfología*. 18. a 20. sept. 1996. La Coruña: 223-236.

Scrimshaw, N. S. and Young, V. R. (1978), "Las necesidades de la nutrición humana", in *Alimentación y agricultura*, Libros de Investigación y Ciencia, Labor, Barcelona.

Shaw, B.D. (1982), "Lamasba: an ancient irrigation community", *Antiquités africaines*, 18: 61-103.

Simon, O.J. (1963), *Geological investigations in the Sierra de Almagro, SE Spain*, Doctoral Dissertation, University of Amsterdam, Amsterdam.

Stevenson, A.C. (1985), "Studies in the vegetational history of S.W.Spain II: Palynological investigations at Laguna de las Madres, Huelva", *Journal of Biogeography*, 12: 293-314.

Stevenson, A.C. and Harrison, R.J. (1992), "Ancient forests in Spain. A model for land-use and dry forest management in S.W. Spain from 4000 BC to 1900 AD", *Proceedings of the Prehistoric Society*, 58: 227-247.

Stika, H.P. (1988), "Botanische Untersuchungen in der bronzezeitlichen Höhensiedlung Fuente Alamo", *Madrider Mitteilungen*, 29: 21-76.

Vernet, J.L., Badal García, E. and Grau, E. (1983), "La végétation néolithique du sud-est de l'Espagne (Valencia, Alicante) d'après l'analyse anthracologique". *C.R. Acad. SC. Paris*, 296, III, 669-672.

Vernet, J.L., Badal García, E. and Grau, E. (1987), "L'environnement végétal de l'homme au Néolithique dans le sud-est de L'Espagne (Valence, Alicante), première synthese d'après l'analyse anthracologique". *Actes du colloque "Premières communautés paysannes en Mediterranée occidentale"*, Montpellier, 1983, CNRS, 131-134.

Völk, H.R. (1967a), *Zur Geologie und Stratigraphie des Neogenbeckens von Vera, Südost-Spanien*. Tésis Doctoral de la Universidad de Amsterdam, Amsterdam.

Völk, H.R. (1967b), "Relation between Neogene sedimentation and late orogenic movements in the Eastern Betic Cordilleras (SE Spain)", *Geologie en Mijnbouw*, 46: 471-473.

Völk, H.R. (1979), *Quartäre Reliefentwicklung in Südost-Spanien*, Heidelberger Geographische Arbeiten 58, Heidelberg.

Völk, H.R. and Rondeel, H.E. (1964), "Zur Gliederung des Jungtertiärs im Becken von Vera, Südost-Spanien", *Geologie en Mijnbouw*, 43: 310-315.

W.H.O.-O.M.S. (1974), *Handbook on human nutritional requirements*, WHO Monograph Series, 61, Geneva: World Health Organization (Organización Mundial de la Salud-OMS).

Wenzens, G. (1991), "Die mittelquartäre Reliefentwicklung am Unterlauf des Río Almanzora (Südostspanien)", *Freiburger Geogr. Hefte*, 33: 185-197. Freiburg.

Wenzens, G. (1992a), "The influence of tectonics and climate on the Villafranchian morphogenesis in semiarid Southeastern Spain", *Z.Geomorph. N.F.*, 84: 173-184.

Wenzens, G. (1992b), "Mittelquartäre Klimaverhältnisse und Reliefentwicklung im semiariden Becken von Vera (Südostspanien)", *Eiszeitalter u. Gegenwart*, 42: 121-133.

Wigley, T.M., Jones, P.D. and Kelly, P.M. (1980), "Scenario for a warm, high-CO2 world", *Nature* 283: 17-25.

Yelo, A., Martínez, P., Salmerón, J. and Ruiz, J. 1988. "Aportación al estudio del poblamiento y los regadíos de época romana en la cabecera del valle del Segura: fuentes documentales y arqueológicas", *Antiguedad y Cristianismo*, V: 599-611.

Yll Aguirre, E.I., Roure, J.M., Pantalesn-Cano, J., and Pirez-Obiol, R. (1994), "Analisis polmnico de una secuencia holocinica en Roquetas de Mar (Almería)", in *Trabajos de Palinología Basica y Aplicada*. X Simposio de Palinología (A.P.L.E.), Valencia, Universitat de Valhncia: 189-197.

Zazo, C., Goy, J.L., Dabrio, C.J., Bardaji, T., Somza, L. and Silva, G.P. (1993), "The Last Interglacial in the Mediterranean as a model for the present interglacial", *Global and Planetary Change*, 7: 109-117.

Zagwijn, H. and Suc, J.-P. (1984), "Palynostratigrahie du Plio-Pleistocene d´Europe et de Mediterranee nord-occidentales: Correlations chronostratigraphiques, histoire de la vegetation et du climat", *Paleobiologie Continentale*, 16 (2): 475-483.