Manfred Bietak (Ed.)

The Synchronisation of Civilisations in the Eastern Mediterranean in the Second Millennium B.C.

Proceedings of an International Symposium at Schloß Haindorf, 15th–17th of November 1996

and at the Austrian Academy, Vienna, 11th–12th of May 1998

Verlag der
Österreichischen Akademie
der Wissenschaften

2. METHODS OF HUMANITIES AND SCIENCES FOR RELATIVE CHRONOLOGY

2.1. DATA MANAGEMENT, ELECTRONIC COMMUNICATION AND APPLICATION OF QUANTITATIVE METHODS (RELATIVE CHRONOLOGY I)

Peter Stadler

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1. SUMMARY[1]

In this project a large amount of data is expected. These only can be collected and managed by using a good database design and evaluated by quantitative methods.

There are data from very different regions, so the database design shall be provided by a computer project co-ordinator. The databases filled in with data in different regions shall be compiled to a huge project data base. For these data a sound database shall be used. The use of a thesaurus for the description of Ceramics, which has been developed for the ceramics of Tell el-Dab°a and which easily can be adapted to the other regions, will be useful. This databases must be built up in connection to a geographical information system, thus the automatic creation of distribution maps, is an effort of seconds.

There shall be an electronic discussion forum for all project participants, if necessary subdivided after regions. All project intermediate results shall be published on a server in the TnterNet. Thus the whole community of project co-operators can easily be informed about interesting news. Over the long time of the project, computer technology will go on much further. So it is evident that the computer project co-ordinator must keep data management up with these unpredictable changes.

After data collection the huge amount of information can only be evaluated with the help of quantitative methods. Elementary statistics will provide basic information about abundances of features. Stratigraphy, seriations, horizontal stratigraphy of single sites will yield local relative chronologies. Links between regions may be used to connect local chronologies to supraregional ones. Absolute data, from history dendrochronology as well as radiocarbon dates may be used to calibrate these relative to absolute chronologies.

2. KIND OF DATA[2]

- Ceramics
  - typological information: shape, indices
  - material: petrographic analysis data
  - colour
  - paintings
  - technology
- Physical Anthropology
  - metrics
  - epigenetics
    DNA
- ^{14}C data etc.
- dendrochronological data

3. DATABASE DESIGN[3]

For these data a sound database shall be used. The necessity of a professional database design is evident, especially if pictures shall be involved. Digitalisation of pictures with scanners and use a of digital camera will be necessary, this equipment shall be provided by the infrastructure. "Automatic Picture Decomposition", which is currently developed at the Department of Pattern Recognition and Image Processing

[1] See overview Fig. 1.
[2] See Fig. 2.
[3] See Fig. 2.

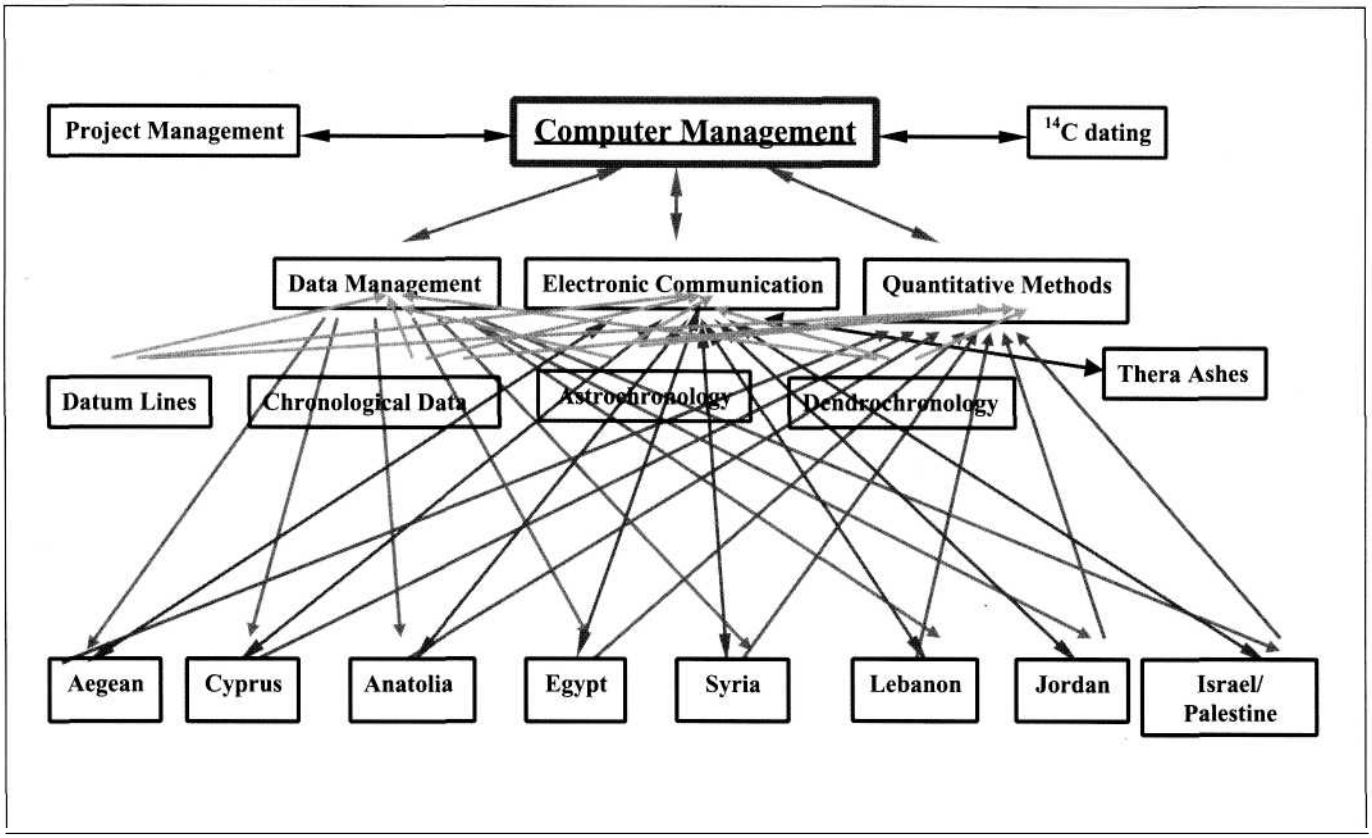

Fig. 1 Integration within the SFB

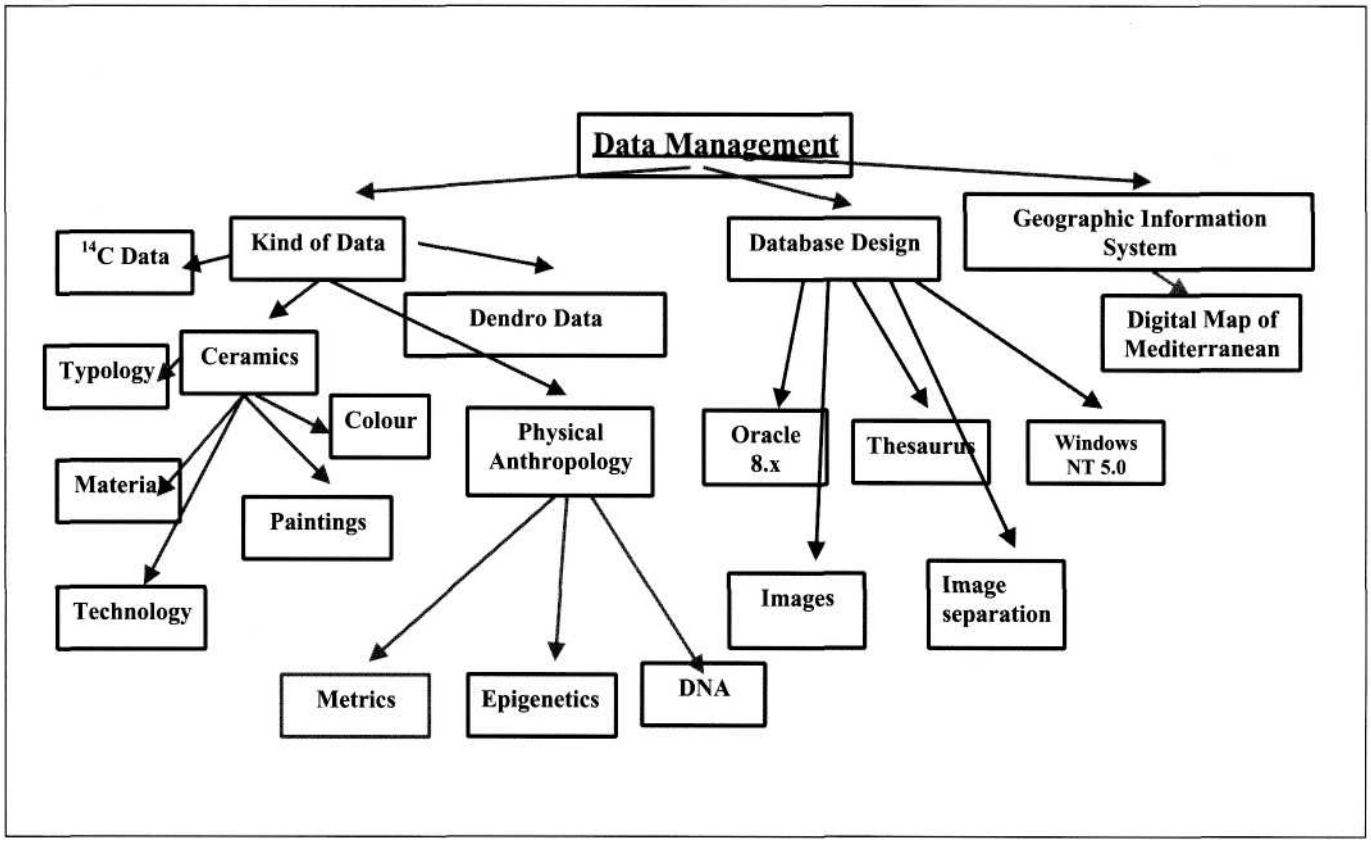

Fig. 2 Data Management

at the Technical University of Vienna, will be used to separate collection photos and publication tables to images of single objects. Also the database design **for** an archaeological situation is prepared and can be adapted with slight modifications for this project. The database will be Oracle 8.x or higher on Windows NT 4.0 or higher. The use of a thesaurus for the description of Ceramics, which has been developed by VERA MÜLLER, for the ceramics of Tell el-Dabᶜa and which easily can be adapted to the other regions, will be useful. It guarantees a consistent and enormously fast input of the data. This input time, which should be optimised, together with its reduction of human power, is a factor which has to be taken seriously into account.

4. GEOGRAPHIC INFORMATION SYSTEM

A digitised/vectorised map of the Mediterranean World with all sites in this project will be used. With the help of a GIS (Geographical Information System) e.g. Arclnfo or SERION, it will be possible to analyse distributions in the Mediterranean. Thus the automatic creation of distribution maps, for publication in printed form and - much cheaper - in the World Wide Web, is an effort of seconds, if the necessary data are provided by the database.

5. ELECTRONIC PUBLISHING AND COMMUNICATION POSSIBILITIES[4]

There shall be an electronic discussion forum for all project participants, if necessary subdivided after regions. The infrastructure should provide the necessary InterNet connections. All project intermediate results shall be published on a server in the InterNet. Thus the whole community of project co-operators can easily be informed about interesting news - without the normal delay of print media of more than 1 year or much longer - almost immediately. Many results can be published only in an electronic form or never. If for example the output of the ceramics database yields 2500 distribution maps. only a publication in the InterNet can be considered as realistic, at practically no costs. Only the hard disk with 2 GB must be provided. Over the long time of the project, computer technology will go on much further. So this unpredictable development must be watched and the usage possibilities for this project must be under a regular revision.

6. EVALUATION'

6.1. Elementary statistics

Elementary statistics like frequencies and chi-squared Tests can be used to examine the association of ceramic features, with statistical programs like SPSS (Statistical Package for Social Sciences) 8.0 or higher.

6.2. Absolute Chronology[6]

For absolute dating, Radiocarbon dates are important. At the moment there exists a database of about 30000 ^{14}C dates, which is the result of systematic data collection from literature, from European Prehistory, but also from Egypt and the Mediterranean, within another FWF project.' With these data at present it is easily possible to obtain group calibrations from more than 500 cultural groups[8]. In this project also Oxcal 3.0 is developed in collaboration with Bronk Ramsey from Oxford. ^{14}C data can be combined with dendro-data and archaeological seriations. Thus from a relative chronology it will be possible to obtain an absolute chronology.

6.3. Relative Chronology and Chorology

Seriations, horizontal stratigraphy of single sites, local chronologies, connection with import-export vessels to supraregional chronologies can be obtained with SERION[6] 7.0 or higher and WinBASP[10]. Only the different methods of seriation technique will be discussed in the following, because a text about all quantitative methods usable for this project would cover a whole book.[11]

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[4] See Fig. 3.

[5] See Fig. 4.

[6] See also the section VIII.

[7] Together with HERWIG FRIESINGER, WALTER KCTSCHERA und EVA WILD, Homepage of the FWF Project: *Absolute Chronology for Early Civilisations in Austria and Central Europe, using "C Dating with Accelerator Mass Spectrometry.* URL: http://www.nhm-wien.ac.at/NHM/Prehist/Stadler/14C_Project/14c_main.html

[8] P. STADLER, *Ein Beitrag zur Absolutchronologie des Neolithikums in Ostösterreich aufgrund der "C-Daten.* In: EVA LENNETS, CHRISTINE NEUGEBAUER-MARESCH, ELISABETH RUTTKAY, *Jungsteinzeit im Osten Österreichs,* Wissenschaftliche Schriftenreihe Niederösterreich, 102-105, 210-224.

[9] SERION - Programmpaket zur chronologischen und chorologischen Auswertung Archäologischer Daten. In: H. GOEBL, M. SCHADER Hrg., *Datenanalyse, Klassifikation und Informationsverarbeitung, Methoden und Anwendungen in verschiedenen Fachgebieten,* Physica-Verlag Heidelberg, 69-86.

[0] *"The Bonn Seriation and Archaeological Statistics Package",* The Unkelbach Valley Software Works, Manual, (no author, no year).

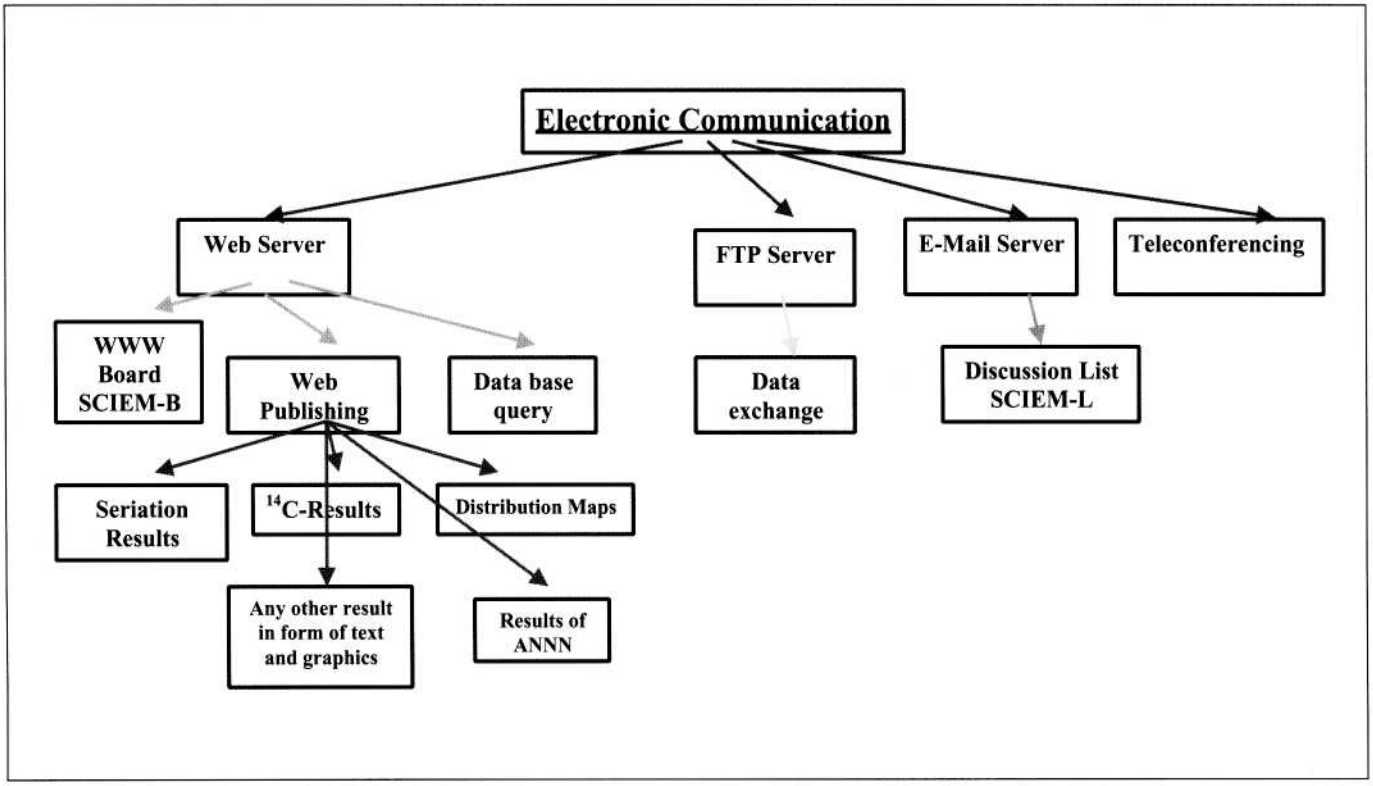

Fig. 3 Electronic Communication

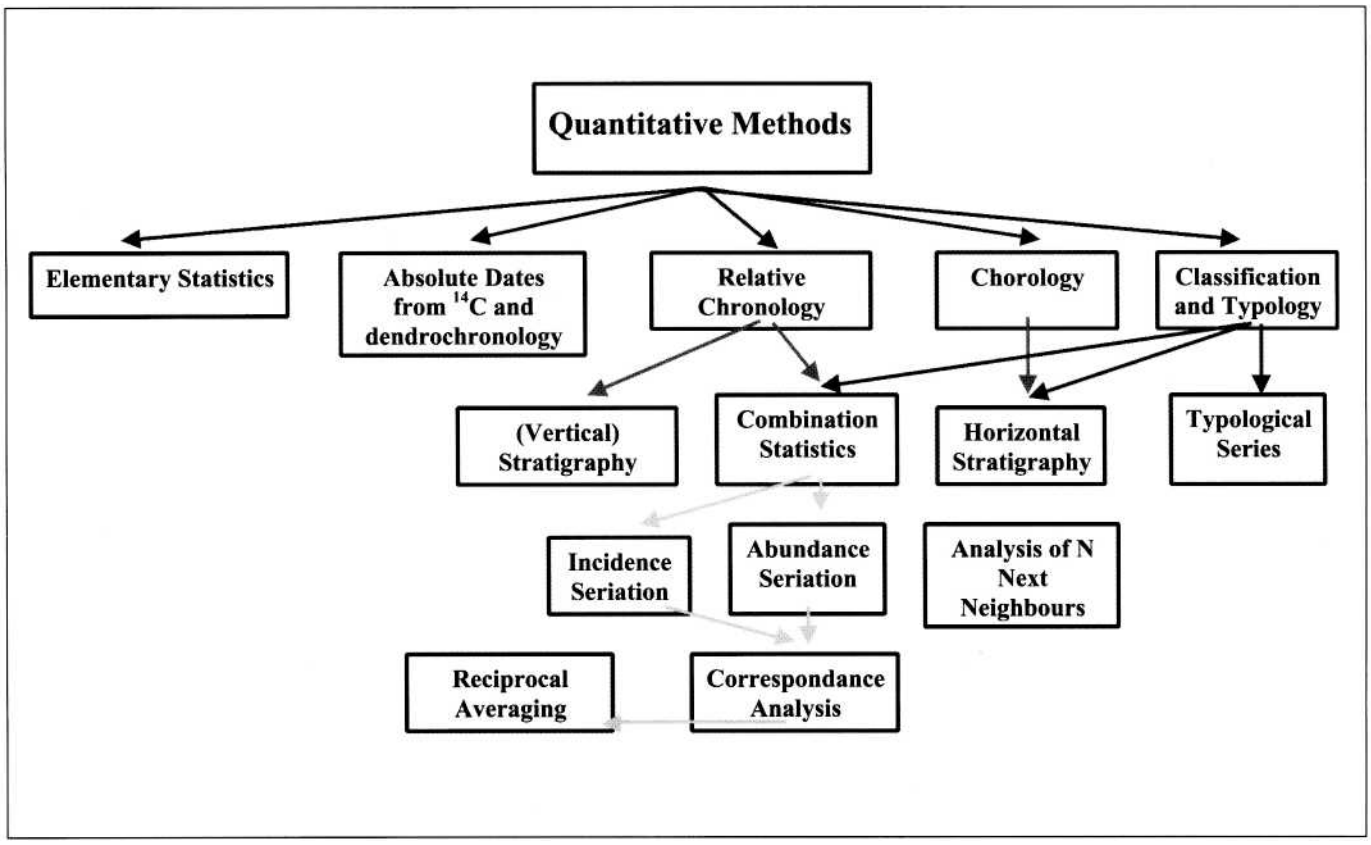

Fig. 4 Application of quantitative Methods

6.3.1. Basics of Relative Chronology

The remains of material culture have to be studied according to their subtle changes in the course of time. This is done normally in a periodisation system, i.e. Late Bronze Age I II, Iron Age I—III, etc. As long as only vague absolute dates are attached to this periodisation system we call it "Relative Chronology". Relative chronologies differ from one region to the other and are results of individual regional studies. The relationships of regional relative chronologies have to be defined according to other regional chronologies, especially of such regions which have a more solid relationship to absolute chronology, as for example Egypt in particular. Besides the periodisation modern archaeology uses sedation studies in order to refine regional relative chronologies. The aim is to assess the continuous flow of artefacts specific for a time-span and to define time levels according to its artefact composition.

- *Classification and Type selection*

Before using archaeological materials for chronological evaluation a rigorous classification system has to be applied. Normally it is based on a combination of material and function. Especially difficult to classify is pottery as fabric, surface treatment, ornamentation, size, form, production technique, and function are variables which have to be considered all together. In a strictly hierarchical system there is the problem which of the variables has priority over the others. It will lead to cutting up type groups under too many headings. A pure combinatorial approach leads to problems in dealing with big quantities of materials. Classification of pottery needs enormous experience with the material under study to decide the right mixture of hierarchy and combinatorial approach. For finding the right system, experience shows that a hierarchical approach, based on fabric in combination with production technique, surface treatment, ornamentation and form with its attributes is a good beginning. Later it may be favourable to decide that for example form should have priority over surface treatment or even fabrics and how functional aspects should lead into divisions as "household ware", "offering pottery", "votive pottery", "pottery for specialised professional activity" (breadmoulds, spinning bowls etc.). Only a refined classification system can be a suitable tool for recognising changes in time accurately.

- *Typological Series*

A peculiarity for classification are typological series. Here we aim at recognising the development of original functional attributes of swords or axes which shows the chronological direction of development as demonstrated by OSCAR MONTELIUS for the European prehistory.[12] Attention should be directed in this connection to shape types which change their form in course of time more or less steadily according to a trend. In Egypt, an example are hemispherical cups which have the tendency from the 12th Dynasty onwards to become deeper and deeper. The general definition of those cups remains the same from the beginning to the end. Attempts to break them up into subtypes do not work because the changes can only be assessed by statistics. Within one and the same time horizon the variability may be large. Only by application of a median value of the vessel indices[13] for each consecutive stratum the subtle changes can be revealed. As soon as the development of such typological series is accurately evaluated, it can be a very sophisticated tool for relative dating. The more such typological series can be discovered, the more reliable the definition of relative chronology will be.

— *Vertical Stratigraphy*

The enormous tell stratigraphies in the Near East helped to bring about a classification of materials according to the superposition of layers. The succession from older to younger materials is quite clear.[14] The repetitive observation of time-specific contexts can be followed from one site to another. Strata designations of important sites as e.g. Troy VI or Megiddo XIV[7] are still used for the definition of relative time horizons besides the general periodisation terminology. The finer the excavation and the recorded stratigraphy, the more precise is the observation of time spans of artefact types in occurrences but also in frequency. With the help of the Harris matrix[11] and with a specific computer implementation of this

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[1] P. STADLER 1997, *Die quantitativen Methoden in der Archäologie.* Internetskriptum zur Lehrveranstaltung.

[2] 0. MoNTELIUS, *Die älteren Kulturperioden im Orient und in Europa. I. Die Methode,* Stockholm 1903.

[3] Major diameter x 100, divided by the overall height of the vessel. Cf. Do. ARNOLD, Keramikbearbeitung in Dahschur, *MDAIK* 38 (1982), 60ff. - M. BlETAK, Egypt and Canaan in the Middle Bronze Age, *BASOR* 281 (1991), fig. 13.

[14] As far as we have not one of the rare cases of a reversed stratigraphy.

matrix in a program"' it is possible to enter all the relations[11] between strata and to automatically check them within the logical system of the Harris matrix. Errors of the documentation can thus be recognised on the excavation and can be corrected instantly.

- Horizontal Stratigraphy

On many excavation sites a vertical stratigraphy is only seldom possible. Therefore the concept of "Horizontal Stratigraphy" was developed. By mapping certain features or types on the plans of settlements and cemeteries it became apparent that these distributions clustered in certain regions. For a cemetery this can be explained as follows: Graves were not set up randomly at the area of the cemetery but followed certain directions, in which the cemetery was developed. Related and contemporaneous individuals were positioned in the neighbourhood. In the course of time the cemetery expanded. These are the modelling ideas behind horizontal stratigraphy.

Before the use of computers the production of distribution maps was limited by the enormous amount of work to get them. Thus few maps were produced - if at all - and they were selected subjectively by the archaeologist. These few maps were taken into account for the interpretation of cemetery or settlement development. Today the picture has changed: By using databases and geographical information systems (GIS) a huge amount of maps can be obtained. Thus an interpretation becomes more and more difficult. Here methods for automatic classification of distribution maps may start. A good overview is given in the book "Spatial Analysis in Archaeology"[18].

-Analysis of the "NNext Neighbours"

This new method, - a kind of spatial analysis - can be applied to different data from cemeteries or settlements, but also on supraregional maps. In some publications I was able to demonstrate the principles of this method.[19]

The mapped data may comprise archaeological finds, and situation of finds as well as anthropological data and various other data. The methodology starts with distribution maps of different types or features.

Analysis of the Next Neighbours concerning *one* type: Distribution maps of one type are evaluated with statistical tests to find out whether the distributions show significant deviations from randomness. If the distributions are non-random, they can be used to form a matrix for relations between finds.

Analysis of the Next Neighbours concerning *two* types: Here the distributions of two types are compared with each other. Distributions showing significant similarity are used to form a matrix for relations between finds. With this step it is also possible to find graves where men and women belong to each other, even though they usually have few objects in common.

In both cases seriation is made with these matrices. Afterwards the *Eigenvectors* of these are clustered in groups, which are then plotted on the map of the cemetery. These groups may be interpreted as a chronological sequence, even though some of them may also be contemporaneous.

Both procedures, seriation and Analysis of the Next Neighbours, result in relative chronologies, which can be mapped on the cemetery plan, thus showing different stages of the horizontal development of the cemetery.

- Combination Statistics

Archaeological contexts as closed tomb groups or a series of single short lived sites or stratigraphical collections reveal a combination of artefact types which are typical for a specific span of time and a specific region. We may expect that the same or similar combinations appear again and again under the same

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" E. HARRIS, *Principles of archaeological stratigraphy*[2] London 1989.

[16] The only currently available program can be found as an addition to the *"The Bonn Seriation and Archaeological Statistics Package",* The Unkelbach Valley Software Works, Manual, (no author, no year). I. HERZO«, *Computer aided Harris Matrix Generation.* In: E. C. HARRIS, Practices of Archaeological Stratigraphy, Academic press 1993. Chapt. 13, 201-217.

[11] These relations are: above, below, equal.

[18] A good introduction: I. HODDER and C. ORTOX, *Spatial Analysis in Archaeology,* Cambridge 1976.

PETER STADLER 1990. Kombinierte Auswertung archäologischer und anthropologischer Daten eines Gräberfeldes. *Archäologische Informationen* 12/2, (1990), 249-250. - PETER STADLER 1995, *Auswertung der Perlen aus dem Reihengräberfeld von Altenerding in Bayern.* In: Hrg. UTA VOX FREEDEX und ALERED WIECZOREK, Archäologie, Techniken, Analysen. Akten des Internationalen Perlensymposiums in Mannheim vom 11. bis 14. November 1994. - PETER STADLER 1996, *Horizontalstratigrafische Auswertungen mittels Analyse der Nächsten Nachbarn,* Archäologie und Computer 1996. Workshop 1, 37 48.

time and regional conditions. Similarly, as under modern market conditions, certain objects, among them imports, appear, have a floruit and finally disappear; some of them have only short spans of time, some are in use for a longer period. Imports may stop suddenly if trading connections are disrupted. Seriation has the task to discover the continuous flow of living time of artefacts.

- *The Incidence (Occurrence) Seriation*[10]

This kind of seriation only assesses the presence or absence of types within a context. The quantity of a given type is neglected. This method is normally applied with tomb contexts. The assumption is that it is the purchasing power of the individual tomb owner which would bring about significant variations in the quantity of types, rather than a chronological meaning.[21] The graphical presentation is done with the help of a 0/1-matrix where the context units (e.g. graves: gl-gx) are entered along the vertical column and the type numbers (tl-tx) along the horizontal rows (or vice versa). The presence of a type is entered with a 1 along the line of the context unit, the absence with an 0 or is left blank. It is our task now to order columns and rows in such a way as to bring about an optimal diagonal order of the 1 signs within the matrix by permuting columns and rows in several steps till a concentration[22] of the positive entries (non zero entries) on the matrix should show a maximum of continuity and a minimum of zero pockets.[23] There are different possibilities to bring about an optimal concentration. According to Doran the concentration principle can be expressed with the formula:

$$\frac{\Sigma Ri}{\text{cols (Ri means value difference in the } i^{th} \text{ column)}}$$

Following the Brainerd-Robinson technique on the abundance matrix seriation *(infra)* the most ideal sequence is evaluated on secondary matrices, square in shape, listing along the columns and the rows either the types (Q-matrix) or the context units (R-matrix) which enables to compare each pair of them according to the types (or attributes) they have in common. This can be expressed in the simple number of agreement or in the percentage of agreement. If 8 types are involved the highest score can be 8 which is 100%. An optimal seriation shows up in the highest scores along the diagonal of the Q- or R-matrix with a decline of values running up or down or left and right from the diagonal axis. Matrix seriation allows already a high degree of phasing as soon as clusters of high agreement scores can be observed.

It is clear that already a seriation of a matrix with 20 units on one side would involve a laborious sorting by hand. Larger matrices have to be evaluated with the help of a computer. The mathematical problems involving seriation of big matrices were overcome by WILKINSON[24], LEGOUX[2"] and GOLDMANN[2"], who developed independently an algorithm (AXIS Algorithm). Its essence consists in WILKINSON'S words:[27]

1. Calculate the mean position of the l's in the columns.
2. Order the columns according to these means.
3. Calculate the mean position for the l's in the rows.
4. Order the rows according to these means.
5. Return to 1 if necessary.

The procedure has to be repeated till the mean of rows and column scales is in ascending order, thus they need not to be reordered anymore. This method does not produce an optimal sequence but has the advantage of being suitable for handling huge matrices in minimal computer time. The best order of succession of context units and arrangement of types is finally presented in a sorted A-matrix.

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20 For the terminology see: D. G. KENDALL, 1969. - G. L. COWGILL 1972, 388.

21 B. J. KEMP, Dating Pharaonie Cemeteries, Part I: Non Mechanical Approaches to Seriation, *MDAIK* 31 (1975) 262. - D. G. KENDALL, 1982.

22 The first who introduced the principle of concentration in archaeology was W. M. FLINDERS PETRIE, Sequences in Prehistoric Remains, *Journal of the Royal Anthropological Institute* (N.S.) 29 (1899) 295-301. - D. G. KENDALL, A Statistical Approach to FLINDERS PETRIE'S Sequence Dating, *International Statistics Institute 34th Session,* No. 40. Ottawa 1963, 657-680. - B. J. KEMP, Dating Pharaonic Cemeteries, Part 1: Non Mechanical Approaches to Seriation, *MDAIK* 31 (1975) 259-291.

J. E. DORAN and F. R. HODSON, *Mathematics and Computers in Archaeology,* Edinburgh Univ. Press 1975, 276f. E. M. WILKINSON, Techniques of Data Analysis - Seriation Theory, *Archaeo Physika* 5 (1974) 1-142. R. LECOL'X. Le recours ä Finformatique: La chronologic relative par permutation matricielle automatique. In: PATRICK PERIN, *La Datation des tombes Merovingiennes. Hautes etudes Medievales et modernes* 39 (1980) 138-155. K. GOLDMANN, Zwei Methoden chronologischer Gruppierung, *Acta Praehistorica et Archaeologica* 3 (1972) 1-34.

WILKINSON, *op. dt.,* 23f, who publishes in an appendix (A) a computer program.

An important point in connection with matrix sorting is the problem of arranging the types in an A-matrix according to their first appearance or according to the midpoint in their time of living or according to their last appearance. For chronological studies the aspect of first appearance may be considered the most important. Mechanical analysts prefer, however, the midpoint, which would be the best for the concentration principle, besides that computers cannot determine the chronological direction. Therefore the midpoint programme would offer for the beginning the least difficulties.

For any kind of seriation it is valuable to have a good starting position in the chronological pre-arrangement of the context units or the types. Information for forming a good starting order can be obtained from results of horizontal or vertical stratigraphy.

- The Abundance Seriation (The Brainerd-Robinson Technique)

Artefacts have, provided their development is undisturbed, a beginning, a quantitative increase, a zenith, a decrease and an end. Tn chronological graphs this shows up in optimal cases in lozenge shaped curves ("Battleship"-graphs or Gauß-curves[28]). We may expect that in specific regions one and the same artefact would be represented in the material culture within one and the same time horizon in very similar percentage representation. This representation would increase or decrease if one would move forwards or backwards in time. The abundance matrix is. especially for settlement material, a very precise method of artefact analysis.

The method of abundance seriation was developed by G. W. BRAINERD[20] and G. W. ROBINSON.[30] Again an unsorted matrix of context units against types is used. The entries, however, mention first the number of occurrences per type which are transformed in a second matrix into percentage calculations. The sum of all types in a context unit (a row) should be 100%.

Now a square similarity matrix (R-matrix) is formed which allows the comparison between all units with an agreement coefficient. The latter is calculated by the sum of the percentage-differences of the artefacts between two context units, subtracted from 200 (i.e. the sum of two times 100% for each unit). The agreement coefficients are then printed into the proper squares of this similarity (R) matrix. Now by permuting the rows and columns a matrix order has to be achieved with a concentration of the highest scores along the diagonal identity (200) score line. It is easier to calculate the right succession of units than with the incidence matrix. Nevertheless the Brainerd-Robinson technique of seriation is very time consuming and laborious when the matrix is used. Therefore several computer programmes have been written which have to avoid the problems of astronomically high permutation possibilities by the help of shortcuts. Additional methods to refine seriation are frequency histograms, cumulative graphs, and dendrograms[31] based on the Robinson values (abundance R-matrix).

- The Reciprocal Averaging (Correspondence Analysis)

As from a mathematical point of view the seriation methods and algorithms described till now are not satisfactory. To obtain a better mathematical background it is necessary to use a more sound mathematical method, the correspondence analysis. Introduced to archaeology by P. lHM[i2], there could be made some more simplifying assumptions which result in an algorithm, very similar to that of Goldmann etc. But there is not really a matrix with columns and rows but (at least) a two dimensional space of Eigenvectors. Thus two identical columns or rows in the result are not located one after the other, but on the same place. Another advantage of this algorithm is that different starting orders always yield the same result. This method will be used in our project, as well as incidence and abundance seriations.

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[28] After the German mathematician and astronomer CARL FRIEDRICH GAUSS (1777-1855). [28] G. W. BRAINERD, The Place of Chronological Ordering in Archaeological Analysis, *American Antiquity* 16.4 (1951) 239-301. [:i0] G. W. ROBINSON, A Method for Chronological Ordering Archaeological Deposits, *American Antiquity* 16.4 (1951) 239 301.

[3] R. R. SOKAL and P. H. A. SNEATH, *Principles of Numerical Taxonomy,* San Francisco 1963, 310 f. - L. JOHNSON Jr., *Introduction to Imaginary Modeln for Archaeological Scaling and Clustering,* Models in Archaeology, ed. by D. C. CLARKE. London 1972, 309-379 (336-342).

[2] P. IHM 1983, Korrespondenzanalyse und Seriation. *Archäo logische Informationen* 6/'1 (1983) 8-21.

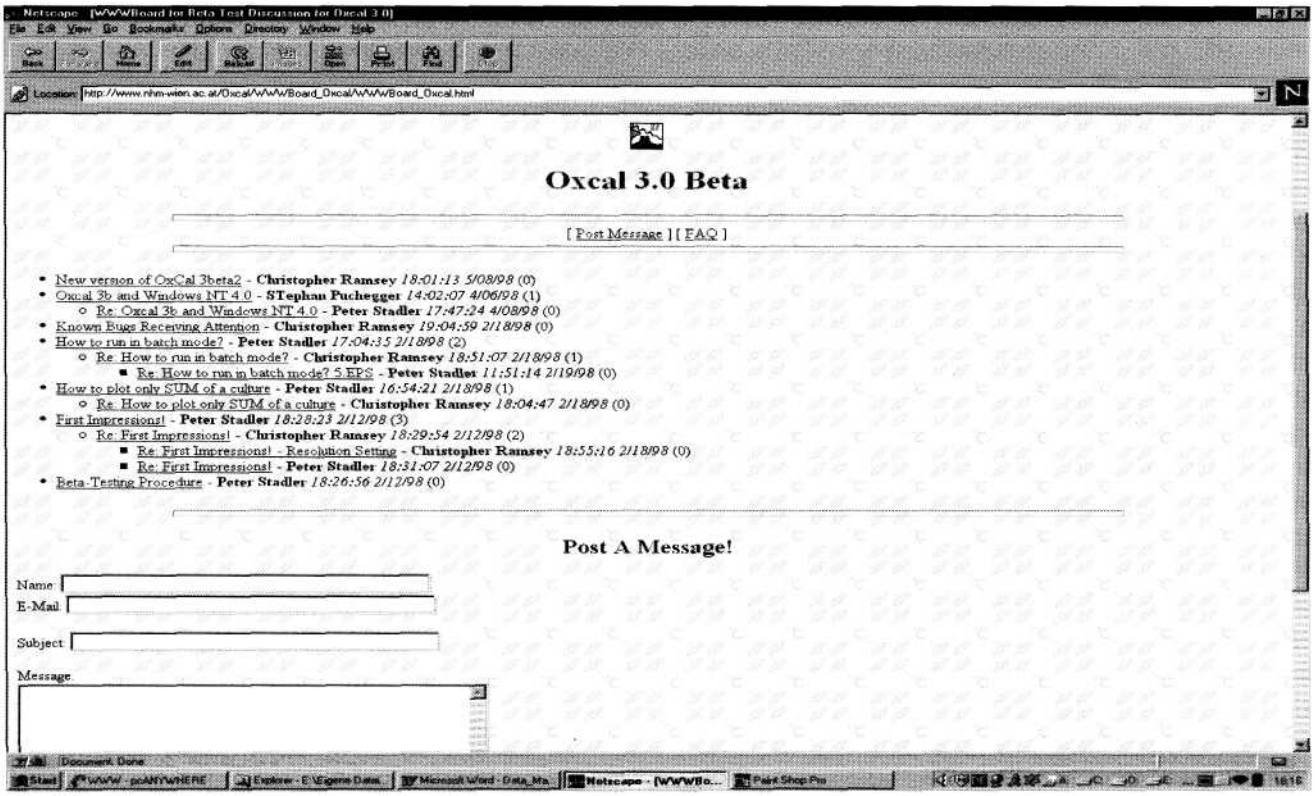

Fig. 5 Example for WWW Board