Handling digital 3-D record of archaeological excavation data

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Abstract: Inspired by the evident methodological stagnation of the archaeological science in Russia the workgroup of Smolensk archaeological expedition launched a fundamental research project in summer year 2000. The expedition has been conducting a research work on the largest medieval complex of archaeological sites - Gnezdovo, belonging to the Viking period, for more then 50 years.

The mainstream of efforts of our workgroup was concentrated on the development of excavation data recording techniques. In fact, excavation process is a mean of analytical transformation of a raw data "buried" in soil into an array of archaeological information, followed by inevitable data losses and distortions. The draft survey showed a very dull picture of 50-60 % of data, that could be traced and recorded, neglected in the process of excavations on Russian archaeological sites. One of the main reasons affecting such a dramatic loss is the very principle of traditional paper-form recording of stratification, when originally 3-D spatial archaeological data (deposition lithography, artificial and natural remains, distribution of finds, etc) is projected or "compressed" onto consequent 2-D sketch plans drawn with fixed elevation interval. Therefore, the sketches contain the discrete data from the layer borders, while the evidence concealed within the layer is generally roughly recorded or even neglected. All finds and other artificial evidence are registered within logical squares with uneven precision in each individual case.

This paper is focused on an alternative strategy of handling excavation record: direct copying of evidence data from a true 3-D space of an excavation ground to a modeled 3-D virtual space. AutoCAD 2000 was used as a core modeling environment for the project. A notion of all-embracing digital environment for handling archaeological data is introduced; and the crucial problems of recording stratification, artificial and natural remains, and finds are successively discussed in the presented paper. An overview of major innovative capabilities and its immerse potential for development is given. Finally, an issue of applying the digital excavation record technique to previously collected archive excavation data is discussed.

Key words: methodology, excavation, stratification, 3-Dimensional, record, virtual data, database, hyperlinks

Introduction

Research is brought to life by information. Archaeological information is extracted from a great variety of sources. In the last years, their number is being multiplied, while the information, as a whole is getting increasingly diverse and heterogeneous. Archaeology seems to shift to ever widening use of non-destructive methods of survey, such as remote sensing or geophysical survey. Still, excavations remain major providers of archaeological data. The results of non-destructive surveying are commonly tested against sample excavations. Another prominent tendency is research concerned with re-utilization of previously obtained excavation data. This awareness is marked by a growing number of publications, presenting re-evaluated, re-processed, re-analyzed archive data from excavations and surveys, conducted for the last two centuries. This can be regarded as a manifest of the major significance of excavation record in a mass of archaeological information.

The excavation techniques have been rapidly developing and improving in the last decades, but still very unevenly in different countries, especially those with limited international scientific links. Methodology, forms of record, storage and representation of data collected in a course of archaeological excavations are very far from international or even regional level unification.

Russian archaeology today

Generally, the present state of Russian archaeological science can be described as conservative methodological stagnation. The main efforts of research are concentrated on extensive continuous excavations. This major preference to wide-scale fieldwork results in lack of attention and enthusiasm to the collected data analysis, interpretation, and publication. It is being piled year after year, waiting for the researchers for decades. From the other hand, the excavation technique, which is currently widely used in Russia show no significant development since 1950-70-s.

In fact, excavation process is a mean of analytical transformation of a raw data, "buried" in soil into a systemized array of archaeological information, followed by inevitable data loses and distortions. A draft survey showed a very dull picture of 40-50 % of data, that could be traced and recorded, neglected in the process of excavations on Russian archaeological sites.

To some extend it is provoked by the notion of wide-scale excavations, when quality is sacrificed to speed. Although the main reason, effecting in such a dramatic loss, is within the technique of excavation record itself.

Methodological dead-end

The dominating excavation strategy used in Russia is planar/section method (planum system). The future excavation ground is regularly divided into 1x1 or 2x2 m logical squares. After that, a site is excavated by consequent strictly horizontal layers with predefined elevation interval set most commonly to 10/20 cm – or spits. The revealed archaeological evidence is manually recorded at sketch plans made after each spit is removed (fig. 1). Therefore, the sketches contain the discrete data from the "logical layer" borders, while the evidence concealed within the spit is generally roughly recorded or even neglected. All finds and other artificial evidence are registered within logical squares with uneven precision in each individual case, and are drawn in index books (fig. 2).

Much more attention is paid to vertical sections, which are thoroughly drawn with great detail once the excavation is finished. Thus, vertical stratification is regarded as the major source for chronological/periodic reconstructions and archaeological interpretation of the revealed evidence (fig. 3). For more detailed description of the planum system refer to the recently published article by Darvill (Darvill 2000:30-36).

The disadvantages of the described excavation technique are evident:

1. The archaeological evidence concealed within cultural layers is recorded with insufficient detail and recision.
2. Vertical sections are used as a primary source of stratification sequence record and archaeological interpretation of excavated evidence only once the excavation is finished. This makes a flexible and efficient direction of excavation process and on-the-fly interpretation of data impossible. From the other hand, vertical sections disintegrate the whole archaeological context of a site into regular yet incoherent mosaic.
3. Archaeological evidence revealed in the course of excavations in true 3-D space is projected or "compressed" onto consequent planar sketches with considerable data loses and distortions
4. Finally, excavation record is stored in a paper-form in a sole copy, dramatically limiting the access and interpretation of data by multiple researchers, especially those not involved in particular excavations, as well as possibilities for its safe storage, publication and wide-scale distribution.

Further refinement of the described excavation and recording technique is dead-ended, providing no noticeable data surplus and overburdening the excavation process.

Seeking for solutions – a 3-D approach

Inspired by the evident methodological stagnation of the archaeological science in Russia the workgroup of Smolensk archaeological expedition launched a fundamental research project in summer year 2000. The expedition has been conducting a research work on the largest medieval complex of archaeological sites in Russian inland - Gnezdovo, belonging to the Viking period for more then 50 years.

The mainstream of our efforts was concentrated on the development of digital excavation data recording techniques. In recent years, there have appeared a number of publications proposing different strategies for computerization of excavation record (e.g. see Huggett 2000:117-122; Ryan, Pascoe, Morse 1999: 269-274; Norbach 1999:275-278 and other), handling particular blocks of excavation record; though no versatile digital technique covering all stages of excavation process and all types of excavation data was suggested. Our workgroup has presented an initiative of an all-embracing recording strategy rejecting the principle of data projection. Instead, the notion of direct copying of evidence data from a true 3-D space of an excavation ground to a modeled 3-D virtual space was introduced. The completeness and integrity of a recorded data, which is neither "compressed" nor projected, thus, is limited only by the capability to trace it. Thereby, the complete change of a recording technique demands a change in an excavation methodology. The single context method seems to suit the best the contemporary requirements for precision and integrity of recovered archaeological data. At the same time, the excavation sequence implied by the method, when each archaeological context is excavated, examined, and recorded individually in a successive order, fits the demands of a 3-D digital data record in a computer. While the combination of the introduced recording technique and the single context method is the most efficient for the future excavations in Russia, there is a vital need for utilization and re-interpretation of previously collected excavation data. Therefore, the capabilities of digitized data for 3-D excavation record reconstruction are also to be examined.

In order to fulfill both tasks it was proposed to test direct 3-D recording technique against traditional excavation strategy in a sample excavation. Thus, along with the in-the-field elaboration of the computer recording methods the potential of the traditionally recorded evidence was evaluated.

Digital excavation record. Theory and practice

Software environment

The excavation record is a complex of spatial (geometrical), text, and photo and video data. Digital data procession unleashes rich potential for its integration, unification, and analysis. Thereby, evidently the most powerful solution for handling digital excavation record is a GIS-based approach. At the same time, while GIS software systems have proved their efficiency with 2D spatial data archives, their 3-D modeling and analysis capabilities are insufficient.

Spatial data is either the most important excavation record or the most difficult to obtain and process digitally. Taking all these points into consideration, AutoCAD 2000 was used as a core modeling environment for the project. Its powerful

COGO (coordinate geometry) engine satisfies strict requirements for accurate and fast direct recording of excavation record on-the-fly in situ, and paper-form data digitizing and procession with minimum of conjectures and approximations. Both vector and raster data support along with integrated database engine for all common formats and internet/intranet support make AutoCAD 2000 the preferable solution for mixed-type and mixed-format data integration.

Experimental excavations: extending theory in the field

The huge complex of archaeological sites, situated on the upper of the Dnepr river, – Gnezdovo – consists of the central fortified settlement, the hill-fort or "gorodishe", surrounding rural settlement with area totalling c. 16 hectares, and four groups of mounds, which number little less then 4000 burials (figs 4-5). Belonging to the Viking period, Gnezdovo is considered the major principal proto-urban trade center in the Russian inland on the way from Scandinavia to Byzantium. It has been strongly believed, that the archaeological complex is limited by the first riverbed terrace until mid-1990-s, when the traces of the settlement in the flood-lands of Dnepr was discovered. A series of prospecting excavations has revealed wet cultural layers rich of organic material of an excellent preservation.

The experimental excavation ground was started on a slope on a terrace edge covering both terrace and a flood plain on an area of 40 m². Thus, the stratification link between flood plain and terrace was intended to be examined. The excavation record has been kept either traditionally, with paper-form sketch plans and drawings, or directly modeled in AutoCAD; for the potential of both recording strategies could be explored and compared, and the integrity of record mutually checked one against another. At the same time the excavation technique, based on the principle of the described above planar/square system, was modified, where it was possible, so that each major stratification unit was excavated individually in a strict consequence of their deposition (fig. 6).

The digital excavation record was held with a Notebook computer in three main parallel directions:

Stratification record

Stratification record was the most difficult to handle digitally in 3-D modeled space. Geometrically each stratification unit is a solid of a complex irregular shape. Two main techniques were used to measure its surfaces. In case the "upper" surface of a stratification unit was completely and clearly revealed, the measurements were taken by a 40x40 cm elevation grid, while the horizontal contour of a SU was limited by the vertical sections going along the borders of the excavation ground, or by a contour line/multiple lines with a fixed elevation mark (fig. 7). The "lower" surface of a SU coincides with the "upper" surface of the consequent stratification unit/units.

The rather different strategy was used when stratification units were sliced by horizontal spits with an elevation interval set to 10 cm. In this case, the SU limits were traced on a planar surface of a spit and marked by one (SU completely inside the excavation ground) or two (SU extends the excavation ground) contour lines (fig. 8). In both cases, if a SU border exceeded the borders of the excavation ground, vertical sections, which stratification was thoroughly recorded once the excavation was finished, provided the wireframe 3-D "upper" and "lower" contours of each stratification unit (fig. 9).

Due to budget limitations, the data collection was limited to manual and optical theodolite measurements. When it was possible, the stratification record, elevation grid points, contour lines, and all other graphical data were directly input or copied in AutoCAD-based virtual 3-D excavation ground environment. Though, weather conditions, battery life limitations, and other unpredictable circumstances made direct on-the-fly computer record impossible. The voids in digital record were compensated with traditionally taken paper-form plans, drawings and sketches, which were scanned and then manually vectorized in AutoCAD module – CAD Overlay (fig. 10).

Thus, raw data of stratification units' measurements were collected. The next step was to create the most precise 3-D virtual solids of SU from the obtained elevation points and contour lines data array. The extrapolation principle of digital relief reconstruction was assumed to be the most appropriate. Stratification unit's surface is very similar, not to say - exact, to a relief surface. We strongly believe, that elevation points extrapolation in this case is not less precise and accurate then those used in digital cartography. The most common technique, which was chosen, is geometrical extrapolation. The initial points and contour lines for each SU were integrated in a triangular irregulated network (TIN) (fig. 11), which was followed by creation of a regular extrapolation grid with 20x20 cm cell density (fig. 12). Merged together, the extrapolated surfaces formed the final shape of stratification units' virtual 3-D solids (fig. 13-14).

Artificial and natural remains record

Natural stone scattered chaotically or organized geometrically in the cultural layers; chopped, cut or broken wood of both natural and artificial origin; bones were recovered in hundreds in the process of excavation. Some of them appeared in the cultural layers accidentally, being a natural deposition, the rest were intended by inhabitants of Gnezdovo as parts of different structures and hearths. Large amount of these remains along with very slow speed of manual and optical theodolite measurements made it impossible to transmit their shape to the 3-D modeled AutoCAD environment identically. A series of approximations had to be accepted.

All unearthed stone was of irregular natural shape; its dimensions did not exceed 20x20x20 cm. Therefore, after its' precise position and dimensions were marked in the virtual excavation ground, the sample stone library, consisting of about two dozens of common stone shapes, was used to find the most similar shape to fit the original (fig. 15).

This kind of approximation strategy, appropriate for stone, could not satisfy the wooden remains and bones. No sample would fit their individual unique shape and represent the significance of small details of appearance. 3-D solids of wooden and bone remains were substituted by their 2D contour outlines taken from the top view and several thickness measurements as it is done in a traditional paper-form excavation record. In some cases, multiple contour outlines could be recorded to give a rather rough idea of its 3-D shape (fig. 16).

Finds record

All artificial finds were registered in a common format Access database with a traditional "logical square" reference. A range of standard fields contain find's id numbers; year, id and author of an excavation ground; position within cultural layer, "logical layer", "logical square", context and a description of each find. A description record is split between "functional group", "name", "shape", "material", "colour", and "state of preservation" fields. Precise location of a find was marked in a virtual 3-D excavation ground space. AutoCAD database engine allowed to integrate an Access database in the modeled excavation record environment and establish links between spatial location points of finds and database records (fig. 17). Thus, common GIS spatial databases analysis features were added to the CAD environment, enabling visual estimation of standard database queries along with "visual queries" to a database. In addition, finds' records are referenced to 3-D stratification unit solids, what definitely extend the capabilities for data analysis.

Results

The final integrated digital excavation record encourages us to consider this ambitious initiative to be generally successful. The experiment showed that digital and traditional record could be used for virtual excavation record reconstructive modeling, for two stratification-recording techniques have been tested for both types of record. Paper-form find indexes could be easily transformed to a database format, though this technically evident process is very time consuming. The potential of digitally obtained, processed, modeled, analyzed and represented excavation record is immense and is summarized below:

- Digital format ensures not only safety of data storage and back-up copying, and significantly reduces the risk of its damage or loss, but also provides multi-user access to the data and unlimited potential for its distribution, publication and representation.
- Direct copying of excavation record into a 3-D virtual modeled environment permits to avoid data projection or "compression", resulting in its inevitable loses and distortions, and makes it more precise, comprehensive and integrated.
- Archaeology has always been a destructive science. Digital record grants a researcher a unique chance to re-excavate a site virtually in any sequence from any point, and to re-estimate and re-analyze excavation data.
- Virtual modeling environment immensely extends the potential of stratification analysis. A stratification record may be filtered to show only individual stratification units, or be examined as a whole system. Virtual environment enables a researcher to navigate freely in 3-D excavation record modeled space and to estimate it visually from any viewpoint, distance, or angle, inside or outside an excavation ground. Virtual profiles and vertical sections may be cut through cultural deposits in any direction and plane, or true vertical sections may be easily hidden, so a site could be visually estimated as an integrated whole. Virtual modeling environment provides tools to analyze slope/elevation of stratification units, to calculate area and volume of any natural or artificial evidence (stratification units, structures, hearths and any type of other remains), and to measure any distances in 3-D space.
- AutoCAD provides full common format database support. Besides standard set of features, it enables to link database records with 3-D objects and to construct both common and "visual" queries to a database, thus adding GIS system capabilities to an AutoCAD environment.
- AutoCAD allows to hyperlink each object in virtual 3-D environment with Internet resources, containing video, photo, text, and any other data. Thereby, powered with barely unlimited Internet potential for data integration, CAD integrates the whole complex of data collected in the process of excavations. At the same time, Internet technology provides multi-user remote access to data.

The potential for development

Though these are the major features of digital excavation record, their range is much wider. Some of them become prominent only after a certain period of practical work. One of the noticeable capabilities, not mentioned above, is the potential for development. Inspired by an evident success of the initiative, we have planned to proceed with further improvement and extension of digital recording technique in two parallel directions: continuation of sample excavations in years 2001-2002 and digital re-procession of data obtained in previous excavations.

The fieldwork is intended to introduce some new features:

- One of the most crucial points of digital excavation data record is speed and precision of measurements. It makes the use of laser Totalstation indispensable for recovered data integrity and completeness. Totalstation permits not only to get much more accurate stratification record, but to provide direct 3-D record of artificial and natural remains, which was impossible with manual measurements. As a result, the whole excavation record becomes 3-dimentional, thus minimizing distortions of initial data.
- Digital photography and video shooting of stratification and artifacts are to be used more extensively, which will particularly allow creating photogrammetric coverages for surfaces of stratification units.
- Database support for all types of data/objects in digital excavation record. In its present state, solely a descriptive database for finds is integrated in the 3-D environment. Each object is to be linked with a

database record, containing its extensive photo, video and text description.

- All data is integrated in AutoCAD environment and accessed through Internet interface. Data exchange and interlink with GIS systems is provided by ArcCAD – the GIS extension to AutoCAD.

Conclusion

The digital excavation record technique is designed to overcome the methodological stagnation in Russian archaeology. We strongly believe that our efforts will stimulate the development of both the methodology of excavations and the technique of excavation data record on Russian archaeological sites. However, the initiative that we have introduced is directed either in the future or in the past. The Gnezdovo complex of archaeological sites has been excavated for more then 125 years, which makes the re-procession of all of the collected data indispensable for the research. Digital integration of these data is our main goal, where the presented technique is only one small step.

Acknowledgments

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Figures

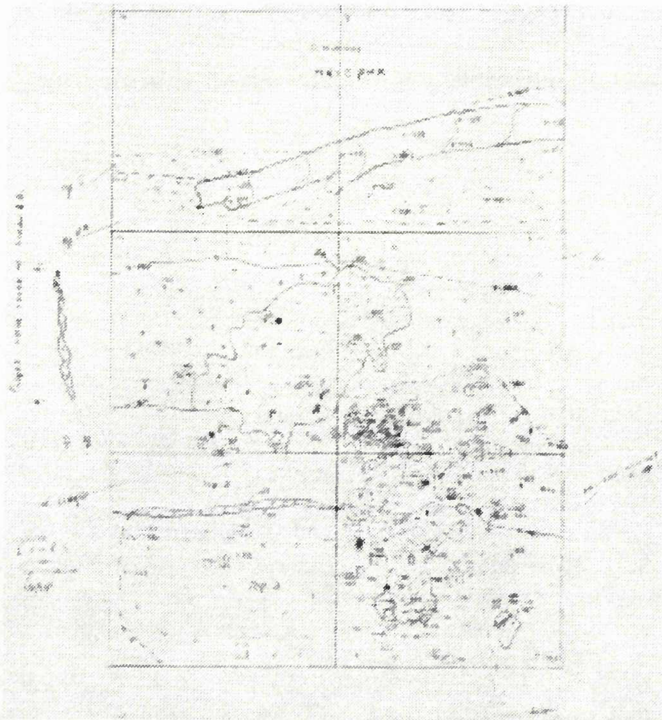

Figure 1. A sketch plan of a spit ("logical layer")

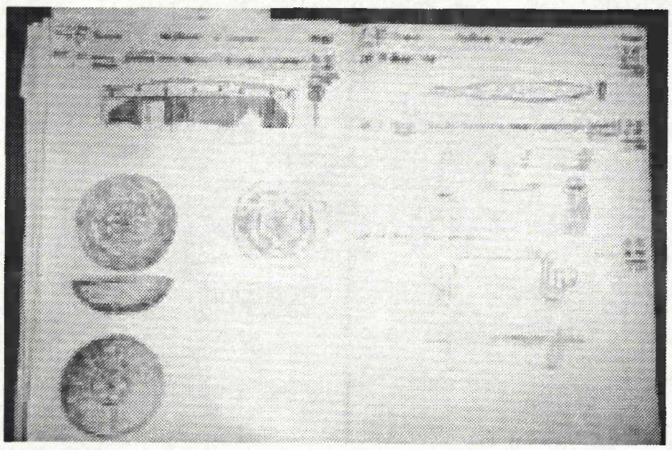

Figure 2. A finds' index book

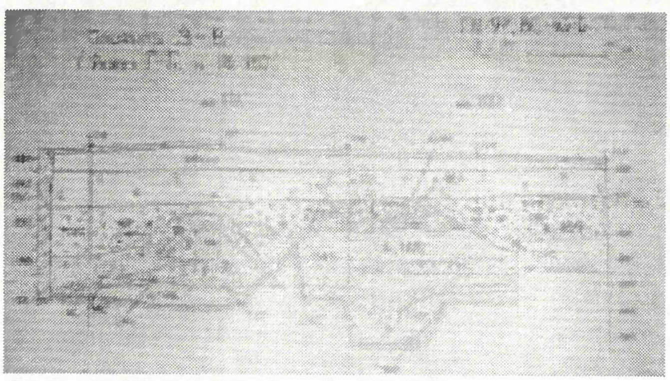

Figure 3. A vertical section sketch plan

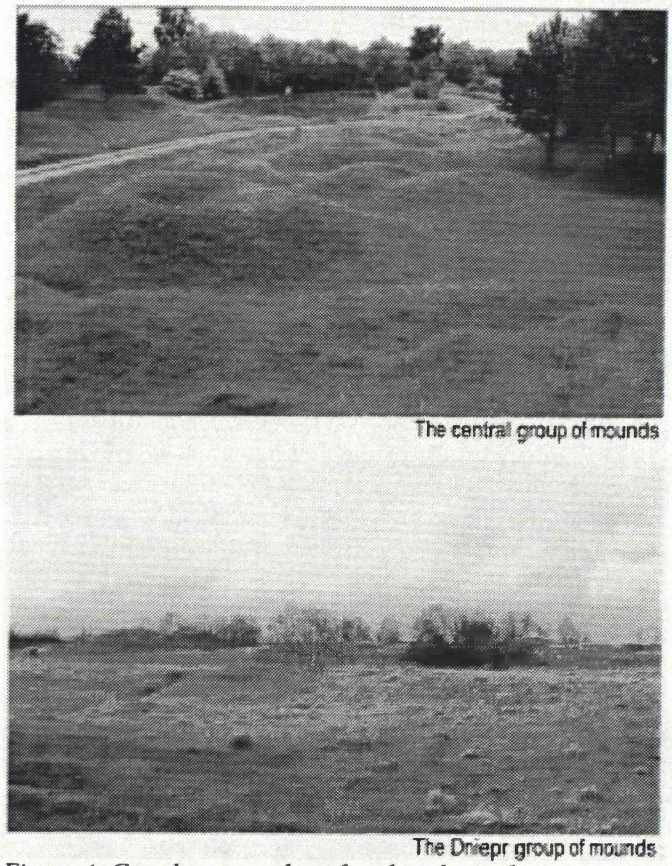

Figure 4. Gnezdovo complex of archaeological sites

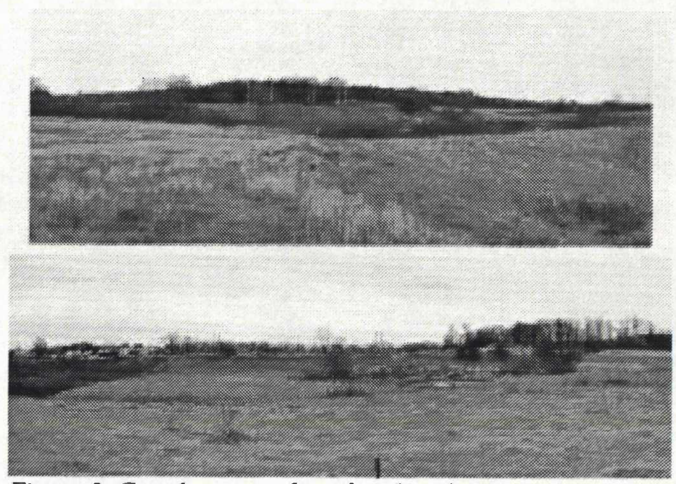

Figure 5. Gnezdovo complex of archaeological sites

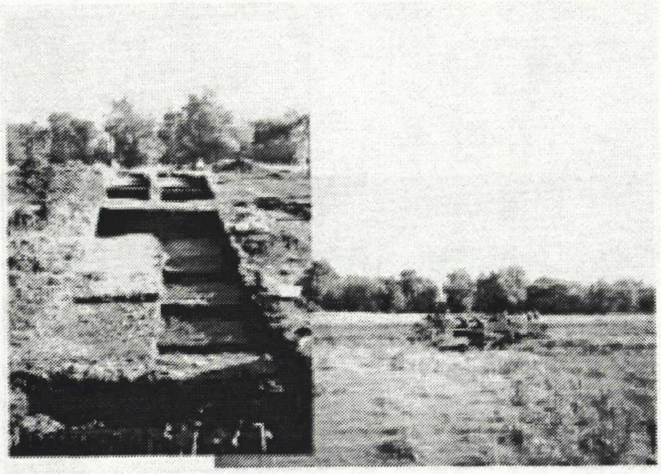

Figure 6. The experimental excavation ground, year 2000

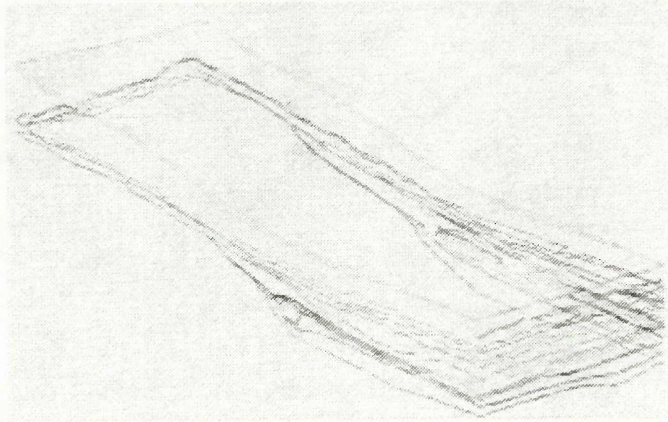

Figure 9. Vertical stratification wire-frame 3-D record

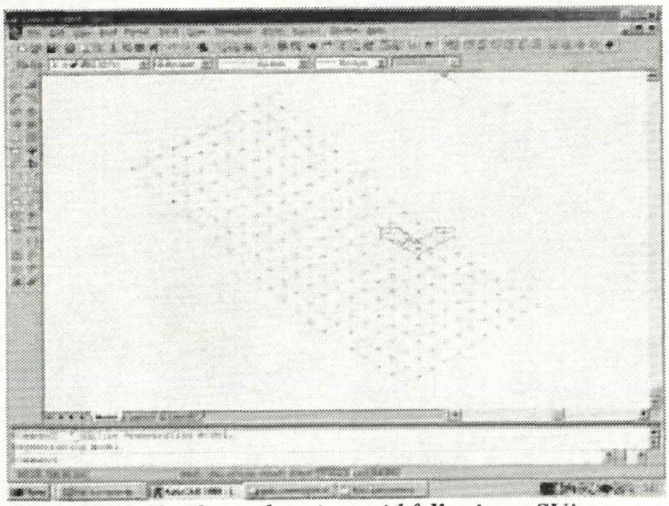

Figure 7. A 40x40 cm elevation grid following a SU's surface

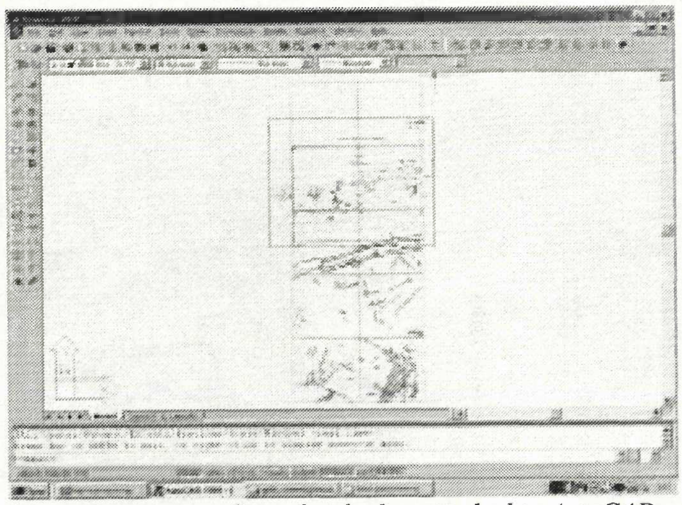

Figure 10. A paper-form sketch plan attached to AutoCAD

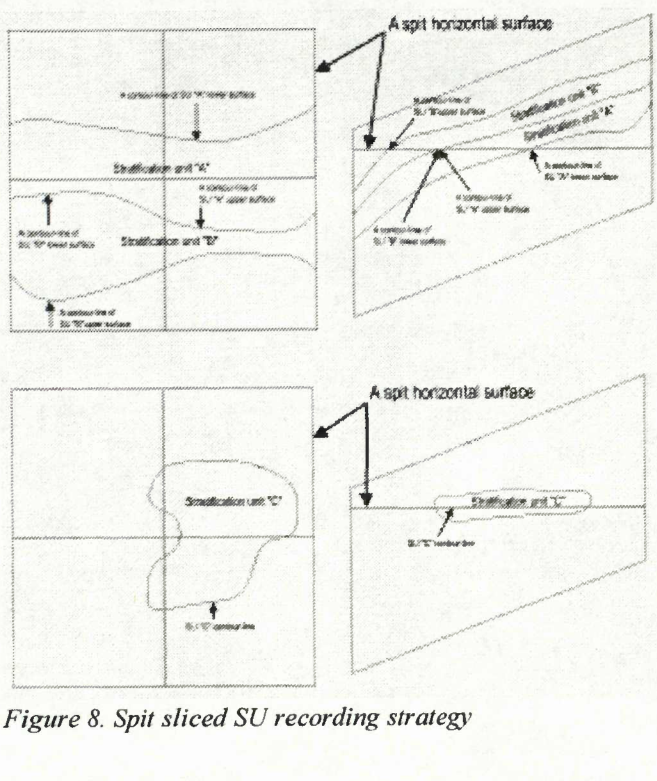

Figure 8. Spit sliced SU recording strategy

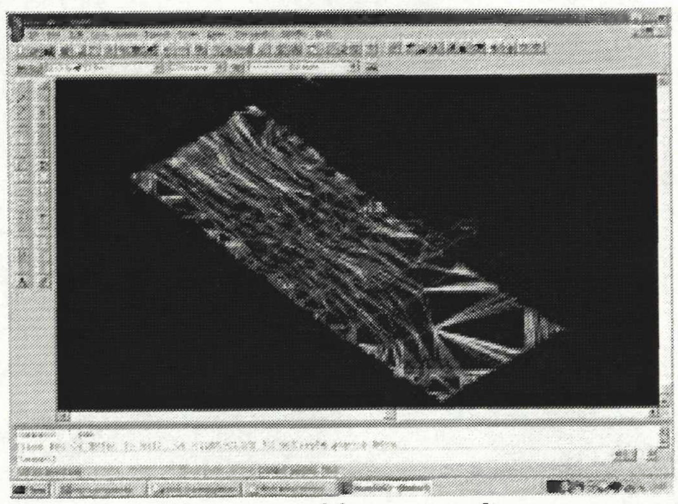

Figure 11. A TIN constructed from contour lines

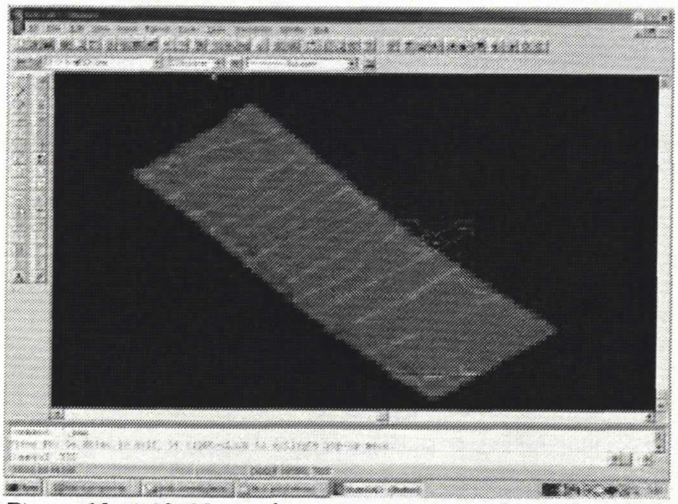

Figure 12. A 10x10 cm elevation grid extrapolated from TIN

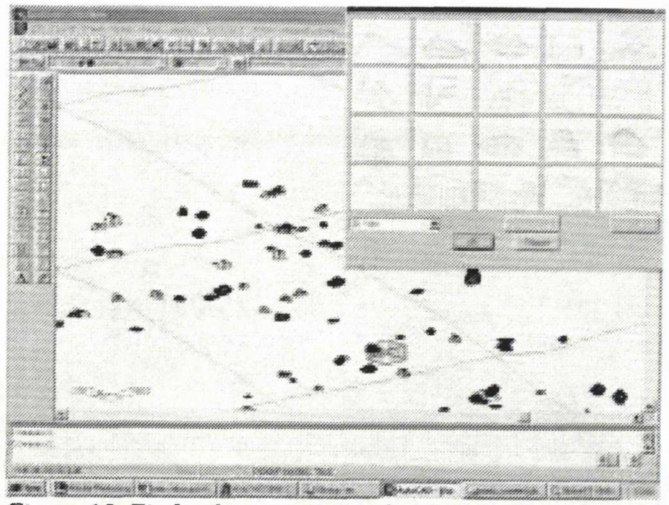

Figure 15. Finds of stone presented in 3-D environment

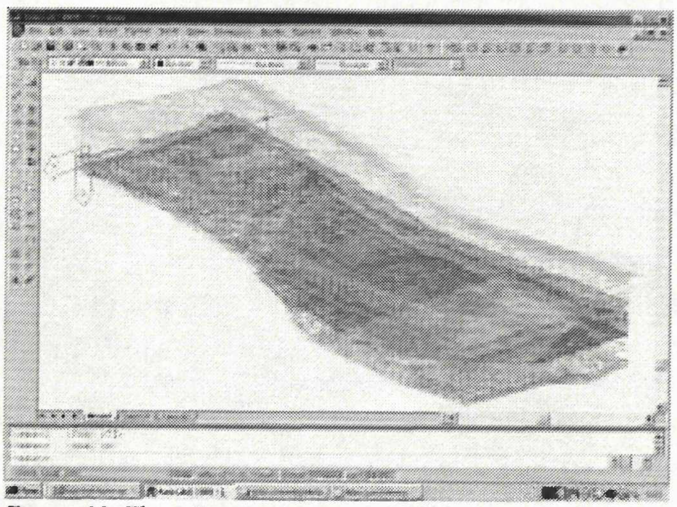

Figure 13. The 3-D wire-frame model showing the whole stratification

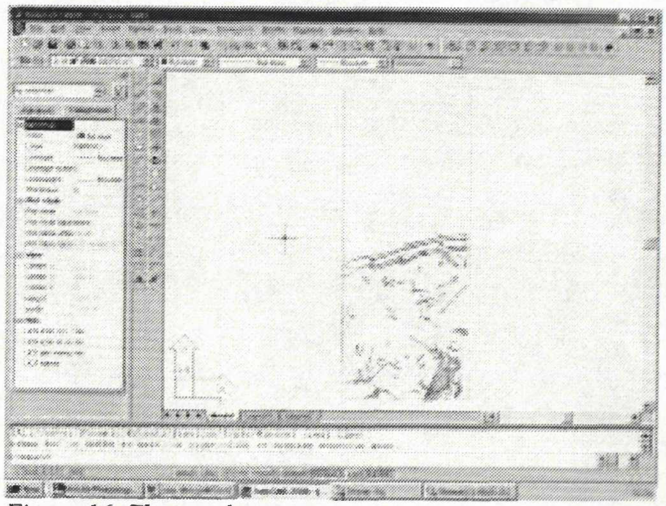

Figure 16. The wooden remains

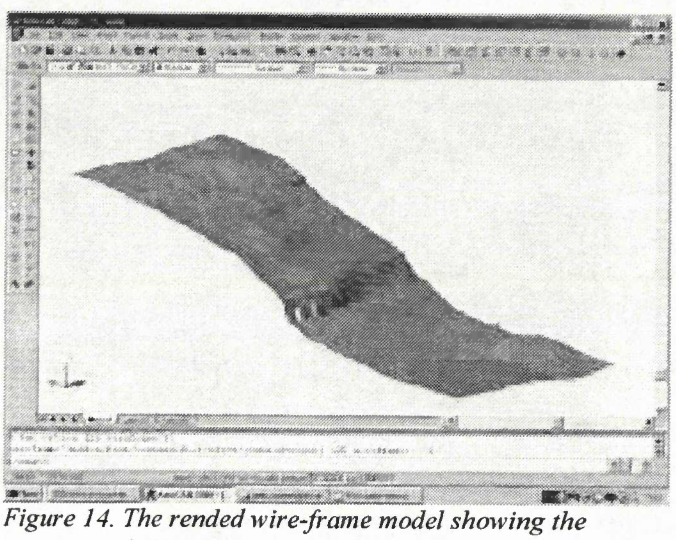

Figure 14. The rended wire-frame model showing the sequence of SU's deposition

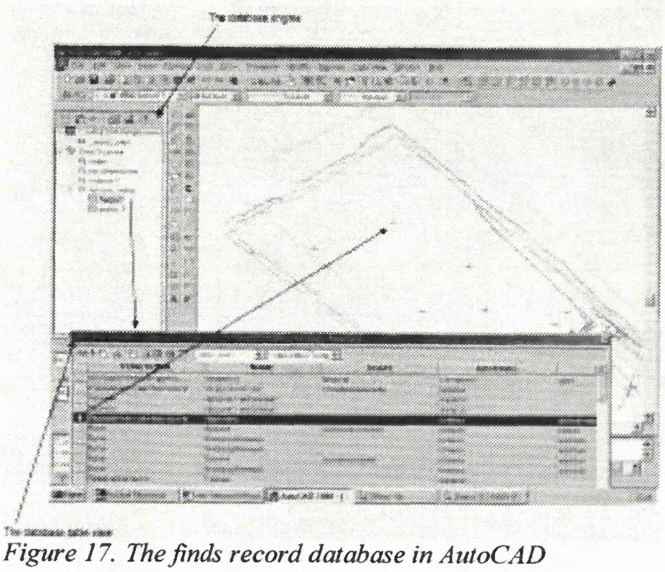

Figure 17. The finds record database in AutoCAD environment