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A different perspective: spatial analysis of Hazendonk unit C by layer reconstruction based dimension reduction

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17.1. Introduction

The purpose of this study is the development and successful implementation of spatial analysis through reprojection. The method was devised to cope with an orientational problem of a co-ordinate system used at the excavations of the Hazendonk, a Neolithic site in the western Netherlands. Through three dimensional modelling based on lithological interpretations of stratigraphy a correction factor was found to rotate the original co-ordinate axes, dispensing with one dimension in the process. The remaining two made correct cross section views of the artefact clusters possible, as well as relating them to stratigraphic features and each other. Thus distinct concentrations of artefacts could be identified, related to archaeologically defined culture phases.

This article will attempt to describe the nature of the problem involved and the different steps taken to attain a solution, highlighting the various aspects necessary to place subject and analysis in a broader archaeological context. Both geomorphological and archaeological characteristics of the site will be investigated, as their particular interpretations laid the groundwork for the methodology. Although developed to deal with a specific case, the techniques used to resolve the problem might be of a more general interest to archaeology. Certainly similar circumstances could be envisioned where (stages of) the analysis could be helpful to construct analogous solutions.

17.2. Geomorphological background

If archaeological aspects of prehistoric settlement in the region of the western Netherlands are to be examined, the interpretation of the geomorphological development of the landscape is often essential, for few regions in Western Europe have undergone as many far reaching changes in their natural environment during the post-Pleistocene era (Louwe Kooijmans 1974).

Nearly half the deposits covering the Dutch landscape date from the Holocene (Pannekoek 1956). Some of these deposits, like the earlier Glacial Age substratum of coarse sands, were carried to the region by large rivers. Rhine, Meuse, Scheldt and some minor rivers and brooks spread out in the flatlands to form a delta, creating an irregular triangle with its apex near Nijmegen and its base along the coastline between Zeeland Flanders and the Isle of Texel (Louwe Kooijmans 1987). Sea and wind were the two other shaping factors in this area, creating a mixture of marine, estuarine, lagoonal, lacustrine and aeolic deposits, often upstaging the fluvial sedimentation typical of a traditional delta environment.

Within this delta several landscapes existed throughout the Holocene, varying in extent and position through time. The faces of most deposits in the area indicate that formation took place at the height of the local water level at that time (Louwe Kooijmans 1982). The thickness of the sediments (up to 25m in the coastal zone) is the result of the eustatic rise in sea level, with which sedimentation could keep pace (Pannekoek 1956). As Mean Sea Level (MSL) was linked to the local water level further inland, the advancing sea at the end of the Boreal not only shifted the intracoastal area (with marine sedimentation) farther eastward, it was also accompanied by flooding and marshy conditions in the hinterland (caused by in-flowing eutrophic river water), which in turn instigated the growth of clayey wood peat. This "Holland peat" (according to local geological nomenclature) formed a matrix, in which mineral deposits of former water courses of smaller creeks were to be embedded (Louwe Kooijmans 1980).

At the beginning of the Atlantic the sea passed its present day coastline of the western Netherlands (at about 20m below present day MSL), and continued to shift the coastal barrier eastward. During this period the rate of local water level rise was however decreasing as the Weichselian glaciers shrank ever faster, while new clastic sediments were constantly brought in (Zonneveld 1977). A balance between marine erosion and sedimentation was finally achieved by the beginning of the Subboreal; from then on new deposits (known locally as "Older Dunes") were formed seaward from the older ones, restricting the incursion of sea water into the intracoastal zone. The region behind the dunes changed from a tidal flat area with salt marshes, bordered by a narrow peat zone into a huge swamp forest of peat bogs, where creeks and lakes were fed through constant influx of fresh water by the now meandering rivers (Louwe Kooijmans 1987).

17.2.1. Islands in the peat

Between an area of Pleistocene sands with fluvial sedimentation to the east (the river clay area) and estuarine creek systems with marine sedimentation to the west (the sea clay area), the extensive peat bogs that came into being during the Atlantic remained relatively undisturbed through much of the Holocene. Particularly the southern half of this area (the Alblasserwaard) was spared the intrusions of saline tidal flats and salt marshes creeping eastward as a result of rising MSL and transgression phases (Louwe Kooijmans 1982) and thus (according to palynological indicators) always remained a tidal free freshwater environment (van der Woude 1981). The wetland region was doubtless rich in wildlife and easily accessible over water. When Neolithic man came to hunt, fish and gather, he sought a dry refuge to venture from into the wilds, to use as a seasonal hunting base camp or even for permanent inhabitation. He settled on *donken*, the surfacing tops of river dunes (Pannekoek 1984).

These sand hills were formed in the frequently dried out riverbeds of the Rhine and Meuse, coming into being as a result of aeolic deposition of river channel sands on top of a clay layer, laid down during the transition phase from a braided to a meandering river system (palynologically dated to Late Pleistocene and Early Holocene). Under the prevailing westerly winds, the dunes were formed in small groups, often on the eastern ends of east-west running gully stretches. Their shape is often elongated, oriented NE-SW. Whereas the slope on the north-eastern end (which accumulated most of the sand) is relatively steep (up to 20°), the south-western side stretches out in a low, gradually dipping tail. The Hazendonk is an almost perfect example of this.

Deposition took place up until the Boreal but ended before the Atlantic, when the younger sediments of peat and clay (8m-12m thick) started covering the sides under the influence of the rising ground water level. When further aeolic sedimentation was prevented by the increasing wetness of the river valley the dunes became a fossilised part of the landscape (Louwe Kooijmans 1982). The post-Boreal sedimentation sequence was characterised by a succession of peat formation (which later compacted) and clastic sedimentation (by lakes and creeks).

17.2.2. The coming of man

The peat marsh with its numerous waterways will have provided prehistoric man with ample opportunity to travel westward from the Pleistocene hinterland. On his journeys he would have easily recognised the donken by their divergent tall growing oak, elm, lime and ash trees (which need mineral soil and a sufficient height above local water level to grow). A donk furthermore provided adequate drainage and fresh water in the vicinity, two vital prerequisites for human inhabitation. Although the dry areas were generally too small for traditional agrarian subsistence economy, semi-permanent and seasonal encampments on top and at the bases of donken are likely. Evidence of hunting, gathering and fishing is known from a number of slightly earlier sites, although it is not always possible to determine whether a site was only seasonally in use.

After the Early Subboreal the environment changed, as fluvial deposition strongly increased and a branching river pattern favoured the development of stream ridges. When local drainage patterns were altered, older creeks silted up, peat growth extended and the donken became less accessible. By the Middle Bronze Age a preference for stream ridge habitation had been firmly established (van der Woude 1981).

Donk stratigraphy however recorded the traces of man. Erosion did not efface all evidence, and layers of occupational refuse were soon covered by new deposition. Though the base of the settlements was always made on dry, more or less sandy deposits well founded on the subsoil, artefact layers did extend to the slopes and further, down to the level of the peat (which approximately equalled local water level at the time). Compaction led to a general sinking of these layers, where they extended beyond the stable sand body. This also implies that if the level corresponding with inhabitation can be indicated in the peat covering the slopes of the donk, then the compaction free "juncture-point" of peat and sand renders the original level corresponding roughly to local water level at that time. This in turn can be helpful in correlating radiocarbon dates with local and regional stratigraphy and MSL rise, as well as establishing a relative chronology. Analogous juncture-points of culture layers can likewise be attributed (Louwe Kooijmans 1982).

17.3. The Hazendonk

In the middle of the Alblasserwaard, west of the municipality of Molenaarsgraaf lies the Hazendonk. This particular river dune had many advantages to become an interesting archaeological site. The depositional features of the environment and the resulting stratigraphy have been discussed in the preceding paragraph. The favourable conditions for palynological research (up to 10m of Holocene peat deposits right next to the donk) are also evident. In addition, the Hazendonk is both small and isolated, resulting in densely concentrated artefact scatters.

The settlement location itself was not covered by later deposits until comparatively recently. Thus all former settlement structures have been lost because of erosion and biological activity. Fortunately due to the small top surface (which shrank during prehistoric use from 250m x 50m to 100m x 40m, as ground water and sedimentation rose from NAP-4.5m to NAP-2m) former living areas extended down slope and into the surrounding sedimentation zone. (NAP stands for "Normaal Amsterdams Peil", or Dutch Ordnance Datum.) There surfaces and refuse concentrations are well preserved in and between the Holocene deposits covering the slopes (Courty 1989, Louwe Kooijmans 1987).

17.3.1. Excavation

After several amateur finds in the sixties had unearthed grindstones, flint and pottery (some of a hitherto unknown type), a test excavation of the site followed in 1967. Three pits of 3 x 10m (numbered I, II, III on the pit map, see Fig. 17.1) were dug on the donk slope, their location based on evidence in borings of old surfaces in the peat. The stratigraphy in the vicinity of the donk was examined with a series of gouge-auger borings (which also yielded pollen samples, indicating repeated anthropogenous disturbances). Thus the extent of the outcropping sand was mapped and cross sections of the deposits could be constructed. As layers lost contact with the stable sand body they all sank away (due to compaction); only the well-founded juncture-points rendered the original height and consequently the degree of compaction (Louwe Kooijmans 1974). The finds from the pits, the pollen diagram and the stratigraphy all indicated several phases of human activity during the Neolithic.

A more thorough, large scale investigation took place during three campaigns of the National Museum of Antiq-

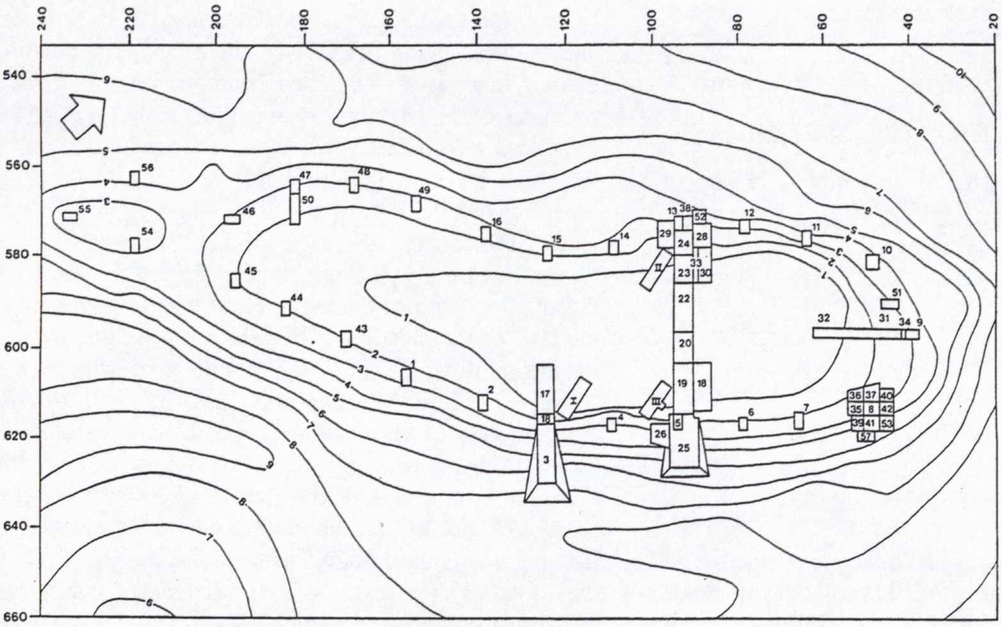

Figure 17.1: Pit map of the Hazendonk excavations. Unit C comprises the pits around pit 8.

uities under Dr. Louwe Kooijmans in the period 1974–1976. Both the dune top and the slopes were tested for Neolithic artefacts in an effort to establish the nature and extent of the different settlement phases. As the excavation of the whole terrain was impossible, small test pits around the donk at regular intervals probed for undisturbed culture surfaces on the slopes and intercalated between peat and clay. On rich refuse points these pits were further extended.

The pits eventually yielded over 30,000 finds, which were individually plotted in three dimensions. Besides huge quantities of pottery, quartzite grindstones, flint scrapers, axes, arrowheads and blades, the wet environment helped to preserve organic remains such as wood (axe handles, a palisade, part of a paddle and a dug-out canoe), bones (of domestic and hunted animals, fish and bird vertebrae) and charred apples, hazelnuts, and grains. Many small finds were obtained through meticulous wet sieving of samples of the archaeological layers. New pollen cores were examined and carbon dated. An extensive system of over 800 borings radiating in all directions from the donk top made a more detailed reconstruction of the former Holocene landscapes of the Hazendonk region possible. Extensive research in many scientific disciplines followed in the ensuing years.

17.3.2. Interpretation

The landscape in the immediate vicinity of the Hazendonk as reconstructed by van der Woude (1981) correlates to a high degree with earlier palynological and stratigraphical interpretations of the geomorphological processes involved and the general picture of the Holocene delta. Considerable peat formation had already taken place before the first human influence is visible. Amidst the marshy wetlands the permanently drained, nutritious donk soil was able to sustain a small forest (oak and elm dominating) with hazel undergrowth. The extent to which this dry vegetation was affected by human presence was made apparent in the pollen sum (by exclusion of the water species). Visible in the diagram (besides the evident human influence on the landscape during periods of occupation) is nature's ability to recover during undisturbed phases, which is also mirrored in the "sterile" peat and clay (that is, without artefacts) in between the old surfaces.

In view of the extension of the site (fifteen large artefact scatters), the amount of refuse, the thickness of the culture layers and the typological variation of the pottery (the prime cultural guide fossil) between successive occupations, seven main phases of occupation of varying character, extent and duration were postulated. Most of the material is attributed to the Middle Neolithic, which in the (southern) Netherlands is defined from the time polished flint axes came in use to the introduction of Protruding Foot Beakers.

When the different parts of the cultural sequence were pieced together, there appeared various forms of Bell Beaker follow several phases of Vlaardingen culture. The three deepest layers yielded pottery of a type previously unknown in the Netherlands, making the Hazendonk an eponymous site (Louwe Kooijmans 1974). The Table 17.1 renders some basic characteristics of these layers.

The occupation phases seem to have spanned almost two millennia. No distinct human interference with the vegetation is apparent in the pollen diagram before this time (4100 cal BC), although earlier hunting, fishing and gathering activities in the region are not unlikely. The precise nature and extent of movements and contacts of the Neolithic delta settlers remains a subject for further investigations (Louwe Kooijmans 1987).

17.4. The problem of spatial reconstruction

The excavation of the Hazendonk had been far from easy. In the early seventies many techniques now considered

Phase	*cal BC*	*Juncture-Point*
Bell Beaker	2250	NAP -1.90m
Vlaardingen-2b	2600	NAP -2.10m
Vlaardingen-1b	3150	NAP -2.55m
Vlaardingen-1a	3250	no juncture point
Hazendonk 3	3600	NAP -3.50m
Hazendonk 2	3800	NAP -3.80m
Hazendonk 1	4100	NAP -4.30m

Table 17.1: Basic characteristics of the layers of the Hazendonk.

standard procedure were only just being developed. It was one of the first Dutch archaeological projects with computer data management in mind, and a conscious effort was made to make the most of the emerging technology by storing as many (potentially important) variables per artefact as possible. Nevertheless not everything could have been taken into account in advance; the consequences of certain field decisions would not become apparent until long after the last find was recorded.

Whilst the pottery was meticulously examined at the National Museum of Antiquities (Leiden) and the Holocene landscape was reconstructed by a new broad survey of pollen analysis and (another 750) borings, the site became known through numerous articles and references, based on the artefacts and the field interpretation of the stratigraphy. The key to the reconstruction thereof was Work Unit C, the complex of ten pits on the eastern tip of the donk (Fig. 17.1). At this location traces of no fewer than five of the seven postulated culture phases had been found (Hazendonk 1, 2 and 3, Vlaardingen 1a and 2b), most of them in dense scatters covering several pits. In short, it was the foundation for the chronological sequence of culture phases in the region, with radiocarbon dates from the (often thick) surface layers and juncture-points linked to local ground water rise curves. Inasmuch as one location could represent the significance of the whole site, unit C was definitely it.

Although the complex was located dead east of the donk top, the axes of the co-ordinate system used to map the entire site were *not* likewise oriented (as can readily be discerned from Fig. 17.1). They followed the elongated sand body instead, the east-west axis running in reality from north-east to south-west, the north-south axis extending from north-west to south-east. The origin of the grid thus lay northwards, and not south-west of the site, as is usual nowadays. This orientation was chosen to keep all pits relative to one grid, while keeping as many pits as possible oriented perpendicular to the slope contours. In accordance with Murphy's Law, the cross section angle of the most important find complex was located almost precisely in between the two axis angles.

If unit C had been located some 20m northward of its real position there would not have been a problem; in that case one of the axes would have run about parallel to the contour lines (or isohypses, Monkhouse 1963) of the layers and the underlying donk body, the other perpendicular to them. That way it would have been possible to plot the co-ordinates of the artefacts in a two dimensional grid, of which the x-axis would be formed by the perpendicular axis (and the y-axis by the height below NAP). This would result in a perfect profile, cutting the donk slope plane at right angles. Unfortunately this dream did not come true. No matter which of the two axes was disregarded, looking at unit C from the south or the east created a serious distortion as the clay and archaeological layers followed gravity's commandment down the slope and into the peat, whilst the axes continued to follow the compass (Fig. 17.2). Unfortunately the complicated stratigraphy had also made artefact attribution to layers *in situ* virtually impossible. Fewer than a thousand artefacts were given an "impressionistic" culture attribution during excavation; another 900 (sherds) were later typologically classified with varying degree of certainty. On a total of over seven thousand artefacts (within unit C) this result was not satisfactory.

Starting in the autumn of 1989 the current Hazendonk research got under way. The investigations took many months to complete and can be divided in two unequal parts. During the first phase, the rough data were extracted from the old storage media, chopped up into separate variables and stored in databases. A lot of data maintenance took place to standardise data formats as far as possible. Unit C was extracted for more detailed analysis. Preliminary statistics were performed to get to grips with the problem and to try (in vain) to find a quick solution. Finally a strategy was devised to deal with the spatial problem using modelling and mathematics.

The early phase gathered pace very slowly. Familiarising oneself with an alien dataset can be as reading a centuries old manuscript; even if you recognise the words, you still can not always be sure what was meant. When initial bearings had ultimately been taken, statistical analysis was performed to separate the artefact clusters of unit C. This was attempted through various techniques, the most important one being cluster analysis. In this particular case, characterised by spatial scatters in stratigraphic units deposited over different periods, research was focused on disjoint clusters (to avoid overlap, or fuzziness by probability of membership). A general problem involved with clustering techniques is that most methods are biased toward finding clusters featuring a certain size, shape or dispersion. Many produce compact, roughly hyperspherical groups; irregular or elongated shapes (such as the Hazendonk artefact pancakes) generally are at a disadvantage. Only methods based on non-parametric density estimation (like single and density link) were deemed to have a fair chance of recovering the correct artefact clusters.

After many SAS sessions (a statistical analysis software package), defeat had to be admitted. None of the tried methods came even close to a clear dissection of scatters with any degree of significance. Often the analysis interpreted the whole of unit C as one giant cluster (which it is to some degree, of course) with a few outliers (due to incorrect co-ordinates). In a few (subset) instances two were detected, and two-stage density linkage with varying *k*th

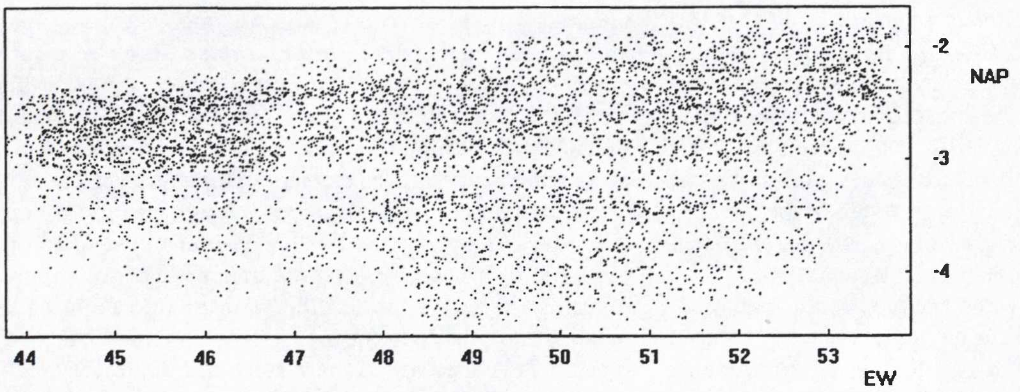

Figure 17.2: Traditional projection view of EW by NAP (generated with MOLE).

nearest neighbour test on the typologically identified pottery would have created interesting results, if limits in memory and processing capacity had not untimely cut short the series. In addition, the calculations were extremely time consuming and bad for morale. So in the spring of 1990, energies were redirected towards the fundamental issue of reprojection. Only if the serious distortion in representation could be corrected would any substantial analysis have a fighting chance.

17.5. Methodology

With the exhaustion of the traditional methods for dissecting scatters into culture layers, a stalemate seemed to have been achieved. Three dimensional co-ordinates were available, but their spatial context remained as intangible as top quarks in a cyclotron. Although some methods had failed, several others had yielded tantalising results, but without establishing a firm and lasting hold on the data. After more than a decade the Hazendonk still defied comprehensive analysis, as the spatial problem rested unsolved. The aim of this study therefore was to devise a strategy by which stratigraphy could be linked to artefact scatters, thus enabling establishment of position of all artefacts relative to each other and to relevant layers. To this end all finds would have to be reprojected onto a new axis running down slope at the designated location, combining the co-ordinates of the older EW and NS grid system. Before developing the separate steps involved in this technique, the following general assumptions were made:

A. The Hazendonk is a river dune in the peat district of the western Netherlands, and was therefore part of the general regional environmental development during the Holocene. Formation processes in evidence in the regional and national palaeoenvironmental reconstruction are applicable to explain specific local stratigraphic characteristics.

B. Artefacts in surface layers are the result of deposition; they are not consciously buried at a level deeper than the contemporaneous surface.

C. An archaeological layer is subjected to the same pedogenetic processes as are naturally formed peat and clay layers.

D. Once fossilised (that is, after the cessation of aeolian sedimentation and the start of deposition of new layers on the slopes), a donk becomes a fossilised part of the landscape. Because it is founded on Late Glacial clastic beds, vertical displacements are not attributable to compaction and thus rare. In this particular case, the donk is assumed to be completely stable.

E. An archaeological layer is created as "old surface", approximately equalling local water level at the time of formation. The compaction free juncture-point of layer and donk sand retains this original level. The layer itself can extend further up the slope.

F. Individual artefacts may be subject to vertical movement relative to their original position in both directions; undisturbed layers in the peat matrix will only have sunk.

G. Co-ordinates taken during excavation accurately represent the original position of the artefact.

H. The sample of information gained by the excavation is representative of the population of all possible archaeological data obtainable from the site.

I. A cross section of the stratigraphy perpendicular to the isohypses (or directly down slope) renders the best possible view for interpretation of (deposition of) layers. Likewise, this perspective holds the best prospects for the separation of layers as well. Any view under a different angle will be distorted to a degree comparable to the sine of the angle difference.

The last assumption already anticipates the solution; the reprojection of the co-ordinates of the artefacts to create a cross section view. This involved three distinct stages: the reconstruction of the relevant stratigraphy (to define the correct reprojection angle), the reprojection itself, and the analysis of the results, leading to attribution of all artefacts to larger spatial units. Following is a description of each of these steps.

17.5.1. Donk reconstruction

In accordance with assumption D and the discussion of pedogenetic processes in the second paragraph, the sand body of the donk seemed the only relatively stable element in an unstable environment, and thus naturally formed the basis for stratigraphic reconstruction. The artefact scatters were located at and near the slopes, so some influence of the shape of the donk on the relief of the covering layers seemed likely. The donk sand directly below and in the immediate vicinity of the artefact scatters of unit C therefore became the guiding fossil for reconstruction.

The existing datasets could obviously not provide significant information about the subsoil; not only were they part of a different matrix, "hovering" above the dune; their spatial relationships were also the ultimate goal of the enterprise, and including them in the first step of the solution would create a circular argument. Donk data therefore had to be independent of archaeological interpretations.

Two other sources provided the required information. Part of the documentation of the geological survey executed in 1976 still existed, and the lithological descriptions of 102 borings were among the material, as was a map of their positions. These locations were digitised in AutoCAD and stored in a database with their respective depths of the donk sand (as lithologically identified). Although covering only a fraction of the total amount of borings, most rays north, north-east and south-east of the donk top were represented, allowing a reasonable degree of confidence in the reconstruction under unit C.

The second source of donk data was even more concentrated around the pit complex. These depths were obtained by measurements taken from the pit profile drawings. Their higher resolution was however somewhat offset by the fact that they had been drawn after the initial excavation, using older, incomplete material. Furthermore the interpretation of the lithological boundary of donk sand and deposits was not always clear; several profiles just recorded as deepest layer "sand", without further distinction, which left doubt whether the deposition was a sandy clay layer of fluvial or lagoonal origin, a sandy peat layer, the mixed sandy (but maybe also clayey or peaty) layer on top of the slope (created at and below the borderline of deposition), or the donk sand proper. For the moment the last assumption was presumed to be correct. Their height below NAP was measured at 0.5m intervals and appended to the borings database.

The next segment of the process would involve the translation of these (484) irregularly spaced three dimensional co-ordinates of the donk into a regularly spaced grid model of the dune surface. This was achieved with the aid of the SURFER software package. An area measuring 30 x 30m around unit C was selected for reconstruction. Due to the limits of the program (being 16 bit oriented not only caused execution to be slow, but also limited all internal variables to a maximum of 65,536), the generation of an acceptable representation took up a lot of time and made the initially desired resolution of 10 x 10cm for each grid cell impossible. Nevertheless, 20 x 20cm still seemed dense enough to represent the peculiarities of a landscape area of 900m^2.

One aspect of this analysis was the interdependence of control values from borings and profiles; neither could independently provide enough information about the contours of the sand body, although the boring rays did an over all better job than the (densely spaced) profiles. Used in conjunction they yielded 22,500 calculated, regularly spaced heights and several visual interpretations (Fig. 17.3).

The technique involved in generating the grids was kriging, a regional variable theory technique, which assumes an underlying linear variogram. Although execution takes significantly longer than simple inverse distance calculations, the resulting grid has more accurate contours than can be obtained through traditional means. The search method could normally have been a nearest neighbour analysis of *n* points around the element. This approach would be best suited for a sample of control values from only a single direction. The grid would be unconstrained except in one dimension. Instead, an octant search method was applied, dividing the space around the element into eight equal octants, and searching for the *n* nearest points within each octant. This approach is more suited for control values at closely spaced intervals (pit profiles) and along widely separated lines (boring rays). The octant search forced the estimating procedure to use data points radially distributed around the estimated element, instead of just the *n* nearest points regardless of direction. Thus search method and estimation technique were chosen to produce the best possible grid in the given set of circumstances. Unfortunately, the output of SURFER did not abide by the rules of standard exchange formats, so a separate program (RECALC) was written to reshape the results into a structured database of three co-ordinates (of course still relative to the original Cartesian grid). With the output in a accessible format for further processing, the first step of the analysis was completed.

17.5.2. Cutting the cake

The development of a solution to a problem of sufficient magnitude bears some fractal characteristics, as every step can be further subdivided in smaller ones. In accordance, the reprojection stage can be split in two parts: the determination of the slope (and the intercept) of the slicing function, and the actual reprojection itself.

The first of these steps was given substance in REGRES, another custom made program. When given a set of coordinates and a height interval, it would locate the depth of the donk sand at that position on the grid map generated with SURFER. Then it would proceed by searching all nearest points, of which the donk depth was a (given) multiple of the height interval above and below the central point. These locations were subsequently stored in a separate database. This process was repeated many times, each iteration with a different base point and yielding another set of nearest points on a number of contour lines. All these data points were finally submitted to simple linear regression analysis in SAS, resulting in a number of slicing functions through unit C, perpendicular to the isohypses of the donk. Several functions (covering all pits) were subsequently combined into one average.

Because the slope difference (or angle relative to an axis) between the most diverging function was relatively small (about 10°), the local distortions on the fringes of the pit complex resulting from the use of only one averaged function were minimal. In addition, using only one function to reproject all data points had enormous advantages for later software implementation. Last but not least, the use of multiple functions fanning out down slope would give rise to a coverage problem; where near to each other, several functions could lay claim to the same data point at a given distance from the function, but far from the top the

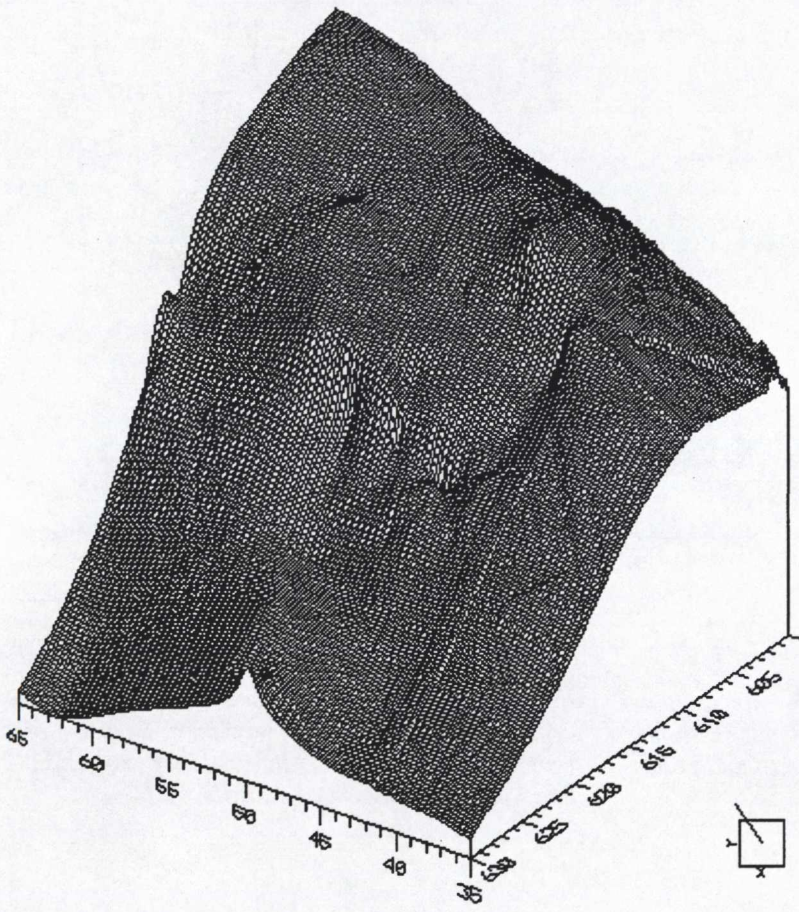

Figure 17.3: Orthographic 3D projection of Unit C and vicinity (30m x 30m). Rotation about Z-axis: 120°; tilt after rotation: 30°; resolution: 150 x 150 cells (generated with SURFER).

vectors would be much farther apart. This could create holes in the coverage of data points, and would certainly cause artefact density to drop down slope. All these problems could be avoided by using only one averaged regression function. Based on numerous test slices, this combined function became:

$$y = -1.4\ x + 682.4$$

Fig. 17.4 renders a plot of some of the functions used for the equation, as well as all reprojected data points. The equation intersects the co-ordinates (48.5, 614.5), roughly the middle of unit C and near the centroid of the data cluster. Of course the intercept of the function is arbitrary and irrelevant, as only the distance of reprojection is altered. By positioning the cross section near the middle of the data cluster, the longest reprojection is minimal (in this case within 7m on both sides), thus keeping aberrations caused by rounding down and small angle faults to a minimum.

The second step involved the actual reprojection. Once again this task was performed by a tailor made program (PRO). It involved a dimension reduction; the Cartesian EW-NS grid had to be reduced to one dimension. The angle relative to the original grid was equal to the slope coefficient of the slicing function. The third cartesian dimension (height below NAP) would become the second (vertical) axis in the reprojection plane. This was achieved by using known artefact data (EW, NS co-ordinates) and applying general trigonometric principles. Thus for each artefact were recorded: A) its "plotted" location on the regression function through Unit C, relative to a new origin (the intersection of the function with NS in original grid), and B) the (positive or negative) distance between the data point and its reprojected equivalent. This last variable proved of great value when sections of certain width had to be extracted for further analysis.

An instructive cross check for the success of the method was provided by reprojecting the donk depths to a similar two dimensional grid, consisting of the new *x*-axis and the distance from the regression function (*y*-axis). This is basically the same plane as the original (EW-NS) grid, but translated and turned -54.46 degrees. The zero line is in the middle of the grid, just as the reprojection function resides in the middle of the data cluster. Top and bottom represent the maximum distances in both directions of reprojection. To facilitate the imagined shift in perspective, the markers of donk depth from pit profiles (formerly parallel to the grid) and borings have been plotted as well. The check element consists of the orientation of the contour lines, now in the middle more or less vertical, or perpendicular to the slice vector denoted by the *y* zero line. This illustrates the success of the second stage of dimension reduction (Fig. 17.5).

17.5.3. The mole, the bird and the fisherman

Named after a large and destructive bioturbation agent, the MOLE program was the most sophisticated of the small family of software tools developed for the Hazendonk project. It

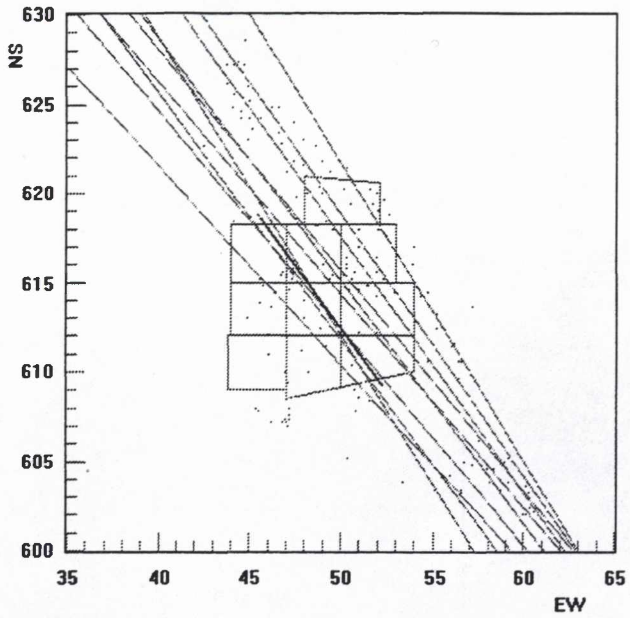

Figure 17.4: Sample points (at contour line intervals) and regression functions through Unit C. The thick line in the middle is formed by all reprojected (artefact) data points together.

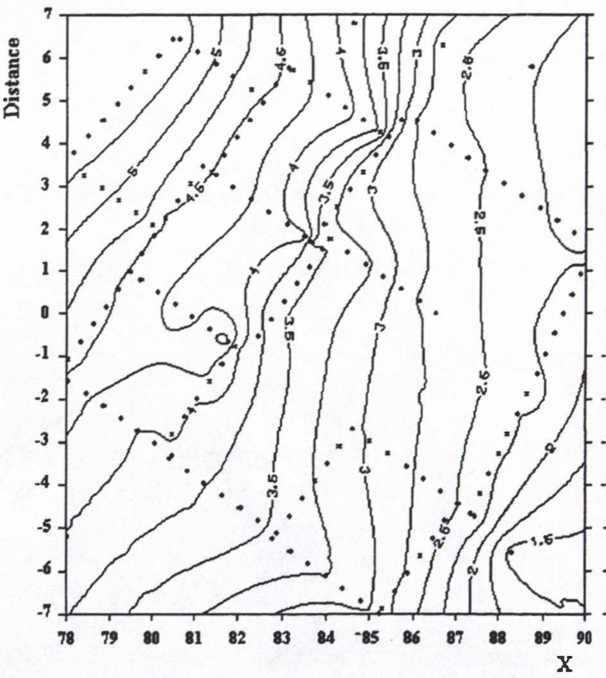

Figure 17.5: Contour plot based on reprojected donk depths. The area covers the maximum extension of the Unit C artefact cluster relative to the reprojection function (generated with Surfer).

combined graphic displays of reprojected artefacts and the donk subsoil, a powerful user definable set of variables, a dynamic flow analysis, a data interface to link output to its sister program Bird and to Surfer, and a digitiser to define layer boundaries. Most important was the visual aspect; for the first time a slice of designated thickness at a specified location (that is, positive or negative distance relative to the central reprojection function) rendered a real down slope cross section of the strata, making for interesting viewing.

While developing Pro, an attempt was made to deal with the variance of the z co-ordinate as well, trying through different mathematical techniques to shift artefacts vertically to get them all in one horizontal (reprojected) plane. If successful, one reprojection picture plotting all artefacts would suffice for spatial attribution. Once again the donk depths were the only lead to the degree of vertical distortion. Unfortunately this data proved insufficient to "stabilise" the tilting layers, as was clearly demonstrated by Mole's section views. Whereas a slice of limited thickness showed clear horizontal density partitions when using the original NAP z co-ordinate, the various corrected z values mixed the clusters into one amorphous mess, making further separation impossible. The reason for the poor performance of these vertical corrections could lie in the distance between donk and artefact layers, local stratigraphic disturbances and the amount of variance in compaction.

To avoid this problem, the extra variable Distance (to the regression function) obtained in the reprojection process was used to order the artefacts from the extreme south northward. This made user defined slices of varying density possible, by which the touching and overlap of different spatial units could be controlled. At every position a balance could be struck between the minimum number of points necessary to identify the extent of the visible units, and the maximum z difference not yet resulting in the mixing of clusters. Since density was relatively uniform throughout unit C, slices of a fixed number of artefacts could be used throughout the complex, excepting the outer limits (where the number of artefacts notably decreased) and one area where a collapsed profile had created a large gap in the stratigraphy.

The insights gained with Mole were substantial, but had yet to be substantiated. On first examination, the deep southern part contained three or possibly four layers (shaped like tilted pancakes), of which the deepest two gradually disappeared when the section was shifted northward. Of the three or four scatters, the second highest was at places the best defined (i.e. the densest), clearly separated from the artefacts below and above it. These sterile strata would eventually provide the key to translating the visual impression into spatial attribution through Surfer. So far, grids generated by Surfer had always represented parts of the landscape. Their similarity to fishing nets, however, helped to inspire a new usage. If by some means a sufficient number of three dimensional co-ordinates in the sterile layers between the artefact clusters could be extracted from the Mole views, these control values could function as hooks to hang a grid net from, taking the place of the sterile stratum. If the mesh was small enough, a handy fisherman should be able to catch all artefacts swimming above or below the grid. When taken one step further, a system of several nets

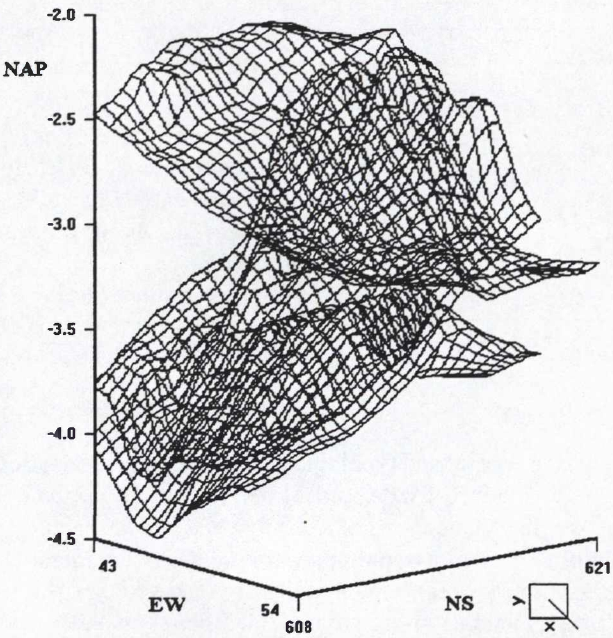

Figure 17.6: Abstracted impression of separator gridnets (22 x 26 cells). The actual grids used for attribution were five times as dense. Orthographic projection; Z-axis rotation: 150°; tilt after rotation: 10° (generated with Surfer).

hovering at different depths below NAP simultaneously, could likewise separate all artefacts in one major haul, simply by establishing each artefact's vertical position relative to the different grid nets (Fig. 17.6).

The addition of a digitiser module to Mole reduced the definition of the boundary planes to less than an hour's work. Hundreds of points were stored, Surfer calculated dense nets, Recalc turned them into databases, which were loaded and combined with the artefact database in Fisher.

Of course reality was slightly more complicated. No matter how small the mesh, always there would be dozens of data points, with ostensibly the wrong spatial attribution. When seen as the first artefact of a slice, such a point would seem to belong to one cluster, but if the slice was shifted far enough to make it the last one (as hundreds of new points had been plotted on one side and as many had been erased on the other), it would clearly seem to belong to another cluster. This was mostly due to the vertical variation. Broadening the slice could not clarify the attribution either; the disputed location then became part of a vague, dense zone of overlap, where even more points seemed wrongly attributed. A solution to this dilemma was not found. In the end 158 (of a total of 6671) data points were given separate spatial codes, designating them as 'in-betweens.' This was done by individual encoding of the questionable artefacts (a separate feature of Mole).

Though the process was relatively successful, the important question remained to what extent the perceived density differences truly represented local minima. This was especially pressing in the deep south (of unit C), where a large cluster could be interpreted as consisting of two smaller ones. Only after detailed density analysis could a local minimum be established, although extremely weak and subsequently difficult to detect. Thus Hazendonk 1 and 2 were finally (spatially) appreciated as separate phases. To what extent the weakness of the separation will lead to a review of the relation between H1 and H2 (which in pottery typology is also rather vaguely distinguished) remains to be seen. The other two strata were labelled H3 and VL-1b, based on earlier radiocarbon dates, pollen diagrams and typology. No separate Vlaardingen-1a layer could be spatially identified.

Another validation of the four layer hypothesis for unit C came from the realm of micromorphology. In 1976, near the end of the last season of the excavation eighteen thin-section samples had been taken from pit profiles of unit C for micromorphological investigation of geological and pedological phenomena. An almost complete vertical profile was sampled, as were the *four* culture layers identified by the investigators. These descriptions of thin-sections were not merely of archaeological interest. They also provided some indication of the pedogenetic processes involved. When examining traces of man on donken, it has to be kept in mind that the river dunes did not undergo drastic natural changes after their initial formation, implicating that artefacts deposited as a result of repeated human activity during different periods could have become mixed and within the same stratum on top of the sand. Moreover, the transportation of dune sand down slope and into the old surfaces (by human or natural causes), clearly attested by the descriptions of the thin-sections, can have had the effect of forming an extremely sandy "crust" zone, intermixed with natural deposits and artefacts from all preceding phases. Besides simply disturbing the spatial units, this process could also have disguised the transition from depositional layers to donk sand; the crust would make the donk appear to extend further than it actually does, thereby lowering the juncture-points of the strata (Courty 1989).

This evidently has serious consequences for stratigraphic dating (based on local water level). The effect became visible when the Mole views were further enhanced by adding the data points from a (reprojected) donk depth grid. Whenever possible, the lithologically defined "yellow donk sand" had been taken as representing the top of the fossilised river dune. Especially away from the top, the aforementioned crust can be discerned as a sterile zone following the slope (thinning out towards the top). Neighbouring artefacts belonging to the deepest clusters actually touch the donk sand up to 30cm higher than the juncture-points of the culture strata proper (as recorded in the profiles). This led to three conclusions:

1. Extreme care should be taken in establishing the location of transition of strata when measuring heights of juncture-points, especially when used for dating purposes.
2. Spatial attributions near to the slope (crust) are to be considered with reservations, as various morphological processes (foremost graviturbation) may have disturbed the pristine depositions. The lithological properties of the strata under investigation could

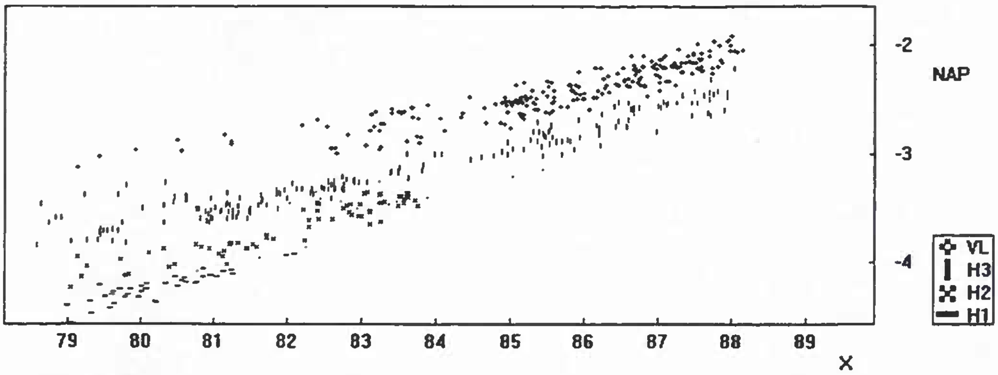

Figure 17.7: Result of reprojection: a clearly separated H3 level (see legend). Above it hovers Vlaardingen (1b) material, and below it two older strata (H1 and H2) can be discerned.

possibly give some indication how far slope disturbances extend.

3. Spatial clusters are not inherently identical to culture layers.

Following these cautions, it could be defended to discard all attributions within a certain radius from the donk. Practical objections based on the uncertain extent of donk and disturbed topsoil, as well as the lack of sufficiently detailed lithological descriptions from samples taken at several different radial distances along a culture layer prevented this. The attribution problem implied by the third conclusion thus remains.

The above notwithstanding, it should be recalled that the objective of the method described pertained to *spatial* analysis. Although the pedogenetic circumstances may have cast some doubt on the validity of cultural attribution, spatial clusters were successfully identified, based on varying artefact density in (correctly reprojected) cross sections of the strata. When the results of MOLE were deemed satisfactory, another program (BIRD) was written. In internal structure it closely resembled MOLE, but instead of a subterranean view, the old EW-NS grid was resuscitated to generate a bird's eye view of unit C. Data points were sorted by depth (variable NAP), creating horizontal section views of specified thickness. BIRD also identified another few points with obvious incorrect co-ordinates, and had the option of showing all artefacts of a selected spatial code. Between the two, MOLE and BIRD shared perspectives based on four coordinate axes (NEW_x, NAP and EW, NS respectively). After MOLE had placed the separator grid nets at the appropriate depths, FISHER could haul in the clusters one by one. Following separation, BIRD supplied further information on the extent of the artefact concentrations. This completed the last stage of the analysis.

17.6. Conclusions

When all is said and done, what then is the net result of the current investigations? This is perhaps the most difficult question to answer. Maybe the researcher most closely associated with the developed technique is also too involved to render unbiased comments on the amount of progress made. Nevertheless a few observations can be noted.

The method is only indirectly connected to archaeology. This is both its forte and its weakness. Omitting most earlier interpretations from the analysis (based on stratigraphical and typological characteristics) adds strength to the claims of independent results, but at the same time loses the foundations of a firmly established scientific discipline. A functional approach of the site, incorporating assumptions regarding activity areas (based on specific artefact context) might have yielded better spatially defined units, with a more vivid human component as well. Further typological evidence from related sites could possibly also provide a less sterile picture of regional culture complexes. Subsistence models based on palynological evidence and landscape reconstruction likewise present a vision, whereas this technique only creates a (slightly different) view. The "hard" mathematical and statistical evidence supporting this technique are of little comfort to those who want to gain knowledge of activities and motives of prehistoric man, and quantification can often be more concealing than illuminating.

The technique is also limited. It was designed to cope with a specific problem, resulting from a unique set of circumstances. If the axes had been otherwise oriented, if the profiles had only been summarily sketched, if the data from geological landscape reconstruction had not been available, if computers and software had been a trifle less advanced, or if any other conditions had not been met, the problem would not have existed or this solution would not have been found. Doubtless other techniques would have been devised instead. The current association of software environments is only one way to reach the desired destination. The limitations become apparent in attempts to apply the technique outside of its original domain. Those familiar with programming will appreciate the amount of work needed to convert data and software to solve related, but always slightly dissimilar problems. It might very well be more effective to take and modify only the basic concepts involved to meet new demands, moulding them into more effective tools, built to future (technological) standards. The continuing advances in computer sciences, statistics and modelling techniques are a source of constant frustration for those trying to keep up. It is no fun knowing today's innovations will become tomorrow's scrap heap.

So nought remains but pixels in the wind? Perhaps not. The method under review might be limited and lacking something in human interest, it *did* however succeed within the confines of the spatial interpretation. Stratigraphic data were used to build a model, which did yield the desired slope coefficient information. The reprojection itself was successful, and the custom made programs performed more than adequately to render hitherto unseen (virtual) subterranean images. The angle correction also resulted in distinct, spatially defined artefact clusters, to which over 97% of the data points could be attributed. When combined with knowledge from related disciplines (notably archaeology, palaeo-ecology and geology), these scatters can be dated and culturally attributed, thus rendering information on artefact assemblages representative of the phases under investigation. Maybe the most enduring quality of this investigation is this combination of knowledge from many fields (archaeology, geology, mathematical modelling, statistics, spatial reprojection, computer sciences, palaeo-ecology, physics, micromorphology, methodology) to deal with a specific problem. It illustrates the versatility of information exchange and creates favourable conditions for creative cross breeding. If the current analysis can serve as an example in that respect, it will already have transcended its initial purpose.

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