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# Developing a Geographic Information System (GIS) for Mapping and Analysing Fossil Deposits at Swartkrans, Gauteng Province, South Africa

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The accumulation of fossil remains, bone tools, and stone tools at the Plio-Pleistocene site of Swartkrans has been attributed to a variety of depositional agents. These agents include hominin activity, carnivore activity, alluvial deposition, and gravitation. Based on recent studies, it is highly probable that the accumulations found at Swartkrans and other Plio-Pleistocene cave sites in South Africa have resulted from a combination of these processes. In order to explore further the taphonomic nature of Swartkrans, a Geographic Information System (GIS) was developed combining all existing information produced from the final seven-year period of C. K. Brain's excavations and a recent survey of the site. The amalgamation of this information into a GIS has resulted in a digital archive of Swartkrans information that allows the user to simultaneously visualize and analyse fossil, artifact, and geological materials within their original spatial contexts allowing a more comprehensive investigation of the site post-excavation. Three-dimensional reconstruction and GIS development for sites such as Swartkrans present many obstacles when using traditional GIS approaches. Due to the presence of overhanging features, certain limitations of conventional GIS software yield erroneous results. These limitations are based on the fact that conventional GIS packages interpret Z values as attributes rather than as true spatial coordinates. A brief overview of GIS and the challenges involved in the mapping and three-dimensional reconstruction of sites such as Swartkrans using traditional GIS approaches are discussed, as well as potential applications of the system. 

*Keywords:* GIS, SWARTKRANS, TAPHONOMY, CAVE ACCUMULATIONS.

## Introduction

Travertine caves in the Witwatersrand of South Africa's Gauteng province have yielded the remains of hundreds of Plio-Pleistocene hominins. The site of Swartkrans alone has produced more than 400 separately numbered specimens attributable to *Paranthropus* and *Homo*. This site has also yielded nearly 400,000 faunal specimens almost 900 stone tools and 85 bone tools (Brain, 1993; Brain & Shipman, 1993). How can we manage and make sense out of this volume of data? This paper describes the development of a Geographic Information System (GIS) for the storage and analysis of spatially referenced information pertaining to the bones, tools, and geological structure of the Plio-Pleistocene deposits at Swartkrans. This GIS synthesizes several categories of data into a cohesive system to allow researchers to test hypotheses concerning site formation processes and the spatial patterning of hominins, other fauna, and tools.

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### *Taphonomy of Swartkrans*

Researchers have been interested in South African hominin site formation since teams from the University of the Witwatersrand first explored the breccias at Makapansgat in the 1940s. In a series of papers spanning two decades, Raymond Dart concluded, based on faunal bone damage and skeletal element proportions, that early hominins inhabited the caves and selectively collected bones, teeth and horns to use as tools and weapons (see Dart, 1962, 1964 for review).

C. K. Brain challenged the notion that early hominins lived in, and accumulated the other fauna found in South African travertine caves. His pioneering research on the taphonomy of Swartkrans beginning in the 1960s suggested, on the basis of the geology of the site, skeletal element proportions, and surface



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modifications to bone, that the faunal remains were actually accumulated by carnivores (see Brain, 1981 *et seq*.). The South African caves were not inhabited by the australopiths, and the hominins were not the hunters, but the hunted.

While Dart's original vision of an australopith Osteodontokeratic culture was certainly problematic, the pendulum has begun to swing back. Subsequent work by Brain and coauthors (Brain *et al*., 1988; Brain & Shipman, 1993), and most recently Backwell & d'Errico (2001), have led once again to the idea that many of the bones at Swartkrans are indeed tools; used by hominins for digging tubers from the ground or extracting termites from their mounds. Further speculation that hominins at Swartkrans may have controlled and used fire (Brain & Sillen, 1988) evinces the possibility that the site was indeed occupied by hominins during the Plio-Pleistocene.

What seems clear at this point, is that neither simple hominin occupation nor simple carnivore accumulation models can alone explain the Plio-Pleistocene accumulations at Swartkrans. So how can we begin to isolate the various agents of accumulation responsible for the hundreds of thousands of faunal specimens and hundreds of tools collected at the site? We propose that a GIS including layers with information on geology, fauna and artifacts would allow storage and analyses of data that can show spatial patterning and reveal taphonomic agents responsible for the accumulations at Swartkrans. In this paper, we illustrate methods used to construct this GIS, and describe limits and potentials of this approach for analyses of other early hominin cave deposits.

### *Geographic Information Systems*

A Geographic Information System, or GIS, is "a powerful set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world for a particular set of purposes" (Burrough & McDonnell, 1998: 11). It is a system used to combine, manipulate, and analyse geographically referenced data of different types. The GIS acts as a spatial database containing attribute information in which specific data themes can be integrated and explored cumulatively in order to derive new information on a particular question. The strength of a GIS lies in its ability to facilitate the identification and comprehension of complex patterns and associations between spatial phenomena that may otherwise remain undetectable.

Archaeologists have used GIS technology to predict site locations based on environmental variables and to explore distributions of artifacts within sites since the late 1970s (Kvamme, 1995). GIS has been used more to explore a broad range of issues, from Maya settlement selection within the Peten landscape in Guatemala (Estrada Belli, 1999) to decision support and cultural resource management in Annapolis, Maryland (Buckler, 1998). Still, palaeoanthropologists have been slow to adopt GIS approaches, and the few studies published have focused on regional but not within-site analyses (Potts *et al*., 1996).

### *Swartkrans*

This paper describes our efforts to develop a model for GIS studies of Plio-Pleistocene palaeoanthropological sites in South Africa. We chose the Swartkrans cave system as the pilot site to develop a larger-scale GIS because of its relatively small size, and the existence of meticulously recorded fossil, artifact and geological data collected during C. K. Brain's *in situ* excavations.

The history of early activity at Swartkrans is presented in detail by Brain (1981, 1993). Robert Broom and J. T. Robinson first conducted fieldwork at the site in 1948. After Broom's death in 1951, the Transvaal Museum continued excavations at Swartkrans until 1953 when the site was left dormant. C. K. Brain began a subsequent cycle of fieldwork lasting from 1965 to 1986. After this date, the site became inactive again until new activities were commenced in 2001 that continue today.

Broom, Robinson and later Brain, recovered thousands of fossils, including many important hominins, during the first three decades of excavation. Unfortunately, however, these early discoveries lack the vital provenience information necessary to accurately reposition them in three-dimensional space, since the fossils are mostly derived from *ex situ* blocks of breccia removed by miners in their search for limestone during the 1920s and again in the late 1940s.

In 1979 Brain began *in situ* excavations of decalcified and uncalcified sediments in Members 1, 2, and 3. In order to facilitate the collection of spatial data for excavated remains he erected a permanent metal grid over the site. Positions of fossils within the decalcified and uncalcified matrices were recorded and within-grid intervals ranged from $0{\cdot}25 \times 0{\cdot}25 \times 0{\cdot}10$ m to $0{\cdot}50 \times 0{\cdot}50 \times 1{\cdot}00$ m. Therefore, fossils and artifacts recovered between 1979 and 1986 could be repositioned in the excavation to the precision of the grid-based position of the excavation units from which they came.

## Development of the 3-D Model of Swartkrans

This project had two principal goals. The first goal was to develop a 3-D model of Swartkrans to reconstruct the spatial contexts of *in situ* geology, fossil and artifacts removed during C. K. Brain's excavation; in effect, to "unexcavate" the site from grid-based provenience data. This provides a digital archive incorporating all available information, and allows virtual re-excavation of the site by researchers in any number of ways. The second goal was to devise a system to analyse site formation processes through the study of stratigraphy and associations between fossils and artifacts at Swartkrans. These goals were accomplished with a GIS consisting of three elements: a 3-D map of the Swartkans cave system, information from C. K. Brain's original excavation notes, and a database containing data on individual fossils and artifacts from the site.

### *Laser theodolite mapping*

The first step in establishing the GIS involved mapping the cave structure in its current form. This served two functions. First, it allowed for improved precision of provenience information if unexcavated material still remained in the grid-block from which breccia was originally removed. If, for example, much of the material within a given grid-square and spit (elevation) level remains unexcavated, precision of provenience for excavated breccia within that block can be increased accordingly. Second, a map of the current cave structure provides a 3-D environment into which the excavated data can be digitally repositioned.

Nearly 14,500 survey points were collected for the Outer Cave by one of us (JDN) using a Leica electronic distance metre attached to a Wild theodolite. The survey was limited to the Outer Cave (technically a sinkhole related to the collapse of dolomite roof blocks) because of availability of provenience information. The grid system used for this survey maintained C. K. Brain's original origin and north line to facilitate synthesis of data layers in the GIS.

Geological features and cave boundaries were recorded from survey points separated by 10 cm in vertical dimension and between from 25 cm and 50 cm in horizontal dimension, depending on a feature's degree of topographical complexity. These mapping intervals were selected to be consistent with Brain's excavation levels. Attributes of the survey points recorded include feature description, geological material, cave area, degree of calcification, sediment color, stratigraphic member, and the cardinal direction that the feature is facing. This last attribute was crucial for the interpolation of the survey points (see below).

Three-dimensional coordinates representing Brain's excavation grid and the Inner and Lower cave perimeters were imported into AutoCAD MAP R3 (Autodesk, Inc) software, where each point was connected using the 3D-polyline command, thus producing three-dimensional representations of each feature. Once this was completed, these features were imported into ArcView 3.2 (ESRI Corp), the software package that will serve as the primary GIS used to access and manipulate all of the Swartkrans data once it has been entered.

The remainder of the x, y, z coordinates presented a problem. Conventional GIS packages do not work for a truly 3-D environment. Those we examined were unable to interpolate point data that contains multiple z values for the same x, y coordinate pair. This is problematic given natural geological overhangs at Swartkrans, such as the Hanging Remnant (Figure 1(A)).

Voxel Analyst (Intergraph Corp) provided a solution to this problem, as this spatial modeling software recognizes three independent axes (x, y, and z). Indeed, this software is designed to interpolate subsurface data to allow examination of spatial relations within 3-D volumetric datasets. A voxel, or volumetric element, is a three-dimensional version of a pixel, usually depicted as a cube. The voxel data model was developed for oil and gas exploration, and is currently used for applications ranging from mining to reservoir engineering (Harris & Lock, 1996; Turner, 1989).

Voxel Analyst was employed to interpolate the terrain model of the Swartkrans cave system in 3-D space. The software was able to delineate the interface between air and land once duplicate survey points were introduced and positioned 1 cm (the distance between the centres of two adjacent voxels) from the surface in the appropriate cardinal direction. The survey points were then interpolated using the Shephard's Method algorithm, an inverse-weighted approximation well-suited for rough and unevenly distributed data (Intergraph, 1994). The final model was then imported into ArcView 3.2 (Figure 1(B, C)).

### *Incorporation of the original excavation notes*

C. K. Brain produced several notebooks detailing the geology and fossil content of each excavated grid unit. This information was converted to digital format to further facilitate examination of specimens in context, and allow virtual "re-excavation" of the site. Original diagrams were digitized by hand, then rescaled and re-projected to their original dimensions using AutoCAD MAP R3 (Autodesk, Inc) software. Elevation layers for each diagram were assigned in 10 cm intervals. A table of geological features was compiled based on attributes taken from the excavation notes. These diagrams were then imported into ArcView 3.2 software where the attributes in the table were linked to the appropriate feature.

### *The fossil database*

A database containing several fields of information for nearly 60,000 fossils and artifacts from Swartkrans was created in Access (Microsoft Corp) software by one of us (DJD). The database was constructed by examination of collections and documents at the Transvaal Museum in Pretoria. Specimens included were derived from Members 1, 2, and 3 assigned accession numbers beginning with SKX, indicating *in situ* excavations. Coordinates for each specimen were converted to points by assigning random numbers to position them within their grid squares using ArcView 3.2 and SPLUS 2000 (Insightful, Inc) softwares. This technique

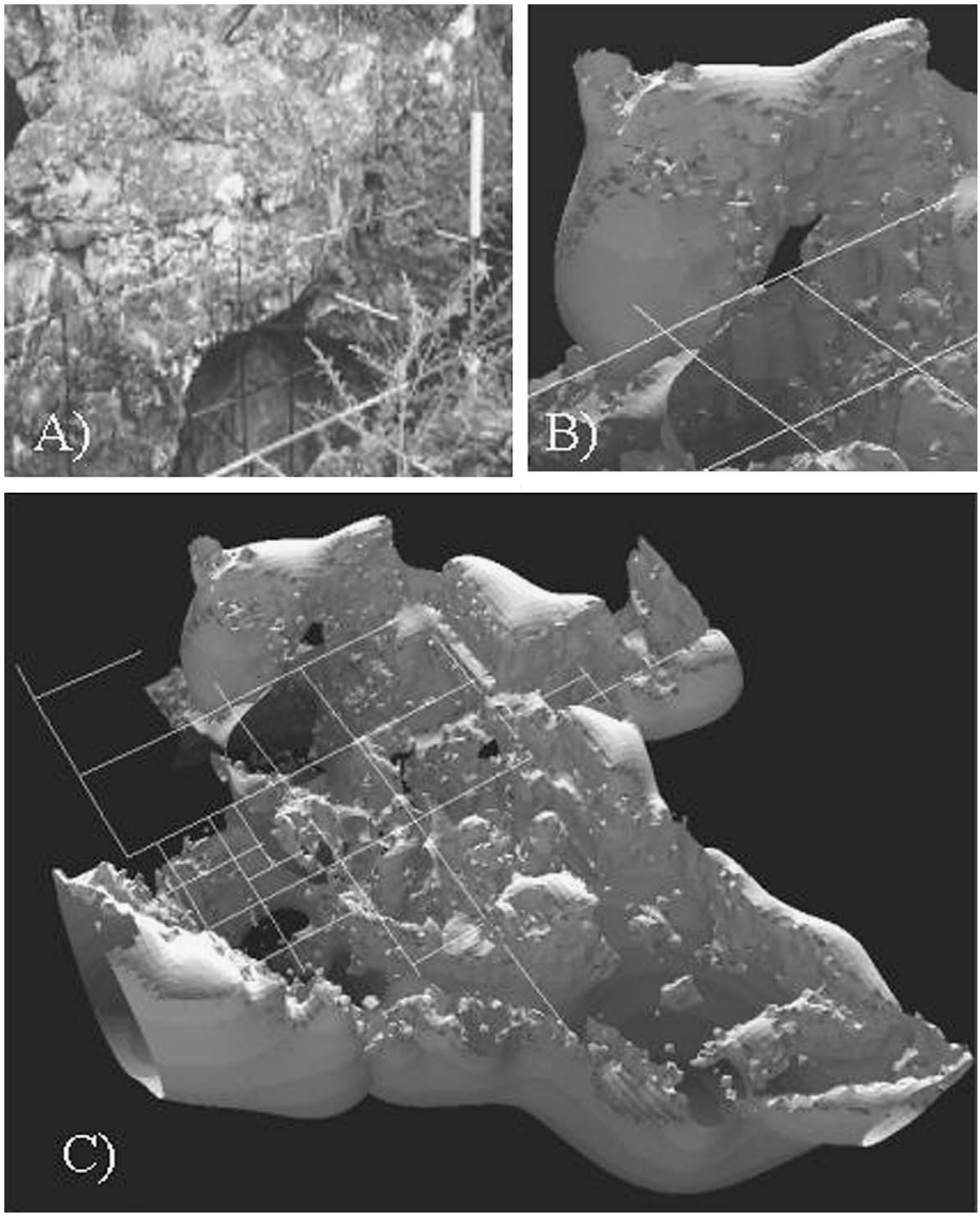


Figure 1. Three-dimensional interpolation of existing Swartkrans geological features. A. Photograph of the Hanging Remnant overhang, B. Hanging Remnant reconstructed using Voxel Analyst (Intergraph Corp), C. full view of the site reconstruction.

was necessary since all of the specimens found in an excavation square were assigned the same coordinate and were represented by a single point, due to the level of recorded provenience. As a result, in order to view the data density in a square, these coordinates were dispersed within the square using random numbers. This process is cosmetic, but necessary to view data densities. The resulting point theme allowed visualization of fossils and artifacts in the general vicinity of their discovery. The fossil and artifact database was then linked to these points using unique ID numbers as the primary key.

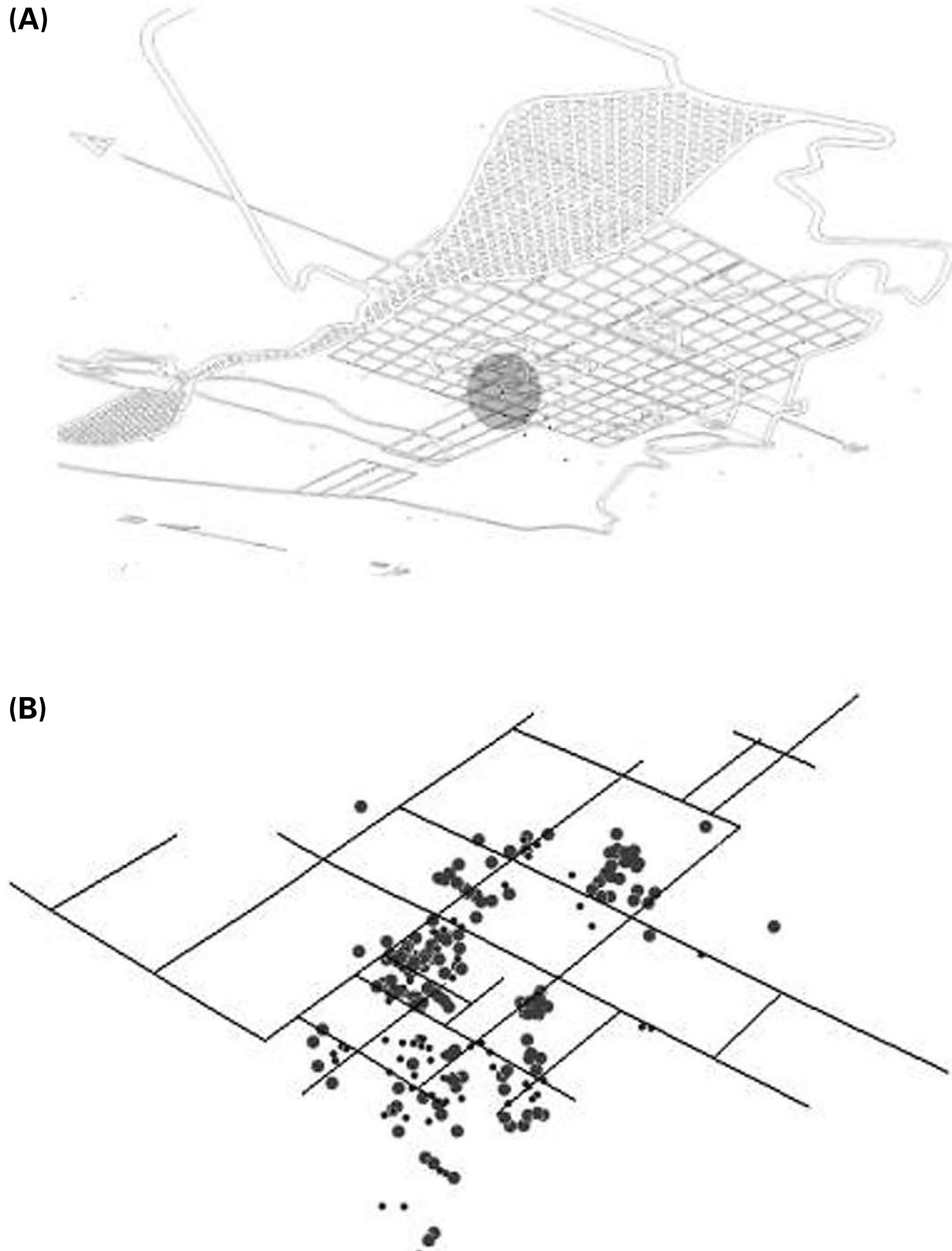


Figure 2. Three-dimensional representation of excavated material locations visualized using ArcView 3D Analyst (ESRI Corp). A. 3-D buffer centered on a selected fossil, B. Distributions of fossil hominins (larger circles) and bone tools (smaller circles).

## Analysis and the 3-D Model of Swartkrans: Illustrative Examples

The 3-D map, excavation notes, and specimen database were displayed together using the 3D Analyst extension within ArcView 3.2 software. This allows visualization of spatial relationships between specimens, data from Brain's excavation notes, and existing walls of the cave. Unfortunately, ArcView's 3-D analytical tools are limited, and do not include 3-D topology functions, such as nearest neighbor and buffering operations. If a researcher wanted to identify those fossils within a given distance of a fixed point in the GIS, for example, 3D Analyst could only output the specimens within that distance on the same horizontal plane, not taking into account fossils or artifacts that lie above or below the point of interest.

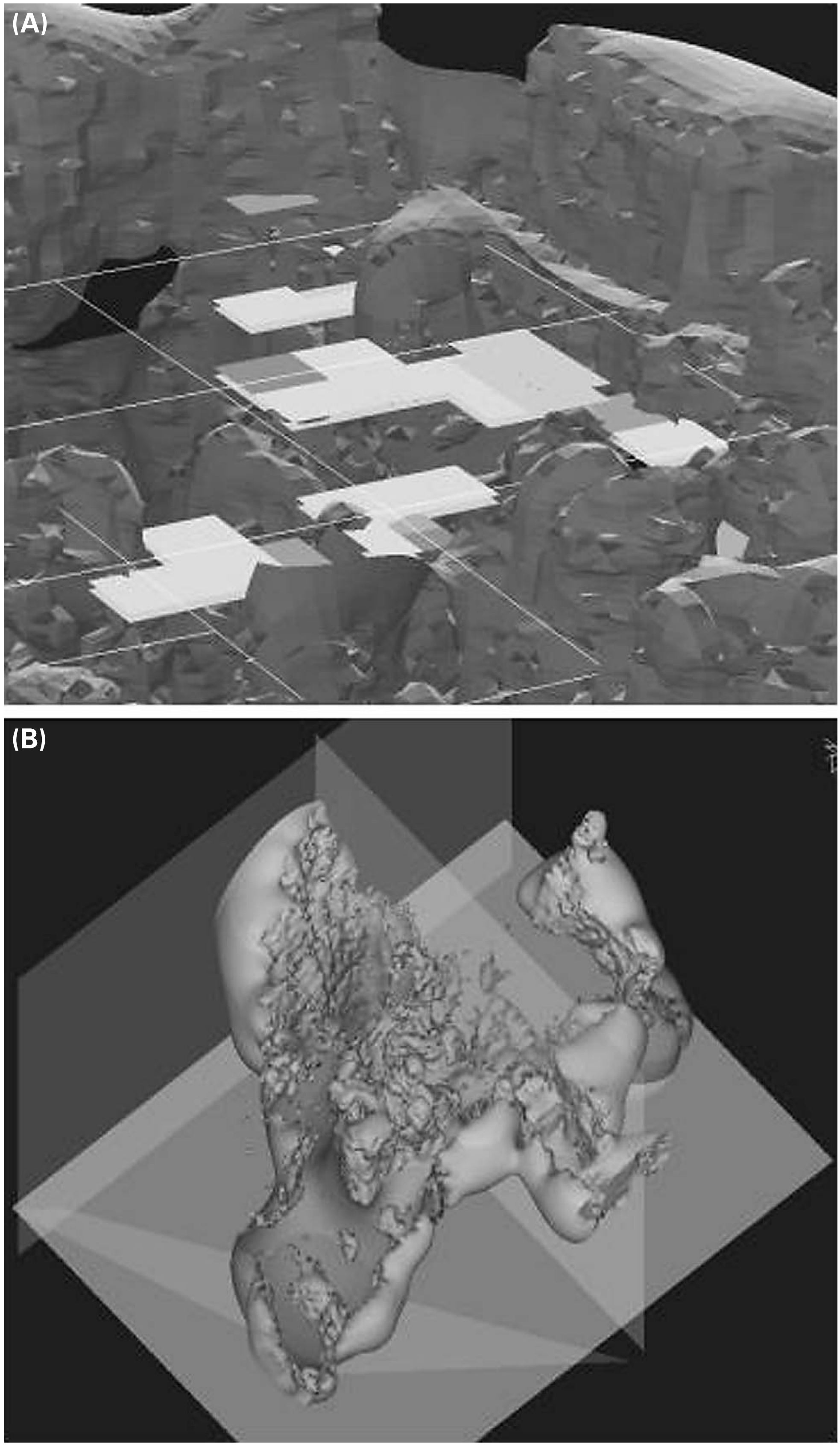


Figure 3. Geological investigations of Swartkrans using Voxel Analyst (Intergraph Corp) and ArcView 3D Analyst (ESRI Corp). A. visualization of excavated material relative to existing geology, B. creation of stratigraphic profiles.

To this end, an Avenue programming script was created to generate three-dimensional buffer zones within ArcView 3.2. This script combines a routine to create a spherical graphic at a user-defined radius (Guillotin, 1999) with a routine that uses a 3-D Euclidean distance calculation to measure the space from a user-defined point to all other points in the dataset (Figure 2(A)). This function is of great potential interest to palaeoanthropologists studying relationships between specified skeletal remains and artifact distributions. Three-dimensional buffering would allow, for example, the identification of all bovid class II metapodials within a given distance of another, all hominin fossils within a given distance of a bone tool scatter, or all recorded lithic flakes within given distance of a core.

The GIS can also be used more generally for studies of the distributions and densities of fossils and artifacts, and aspects of the geology of the site.

*Distribution of fossils and artifacts*

Patterning of the spatial distribution of specimens found in the Swartkrans cave system can potentially reveal important aspects of site formation. For example, hyena dens usually consist of highly fragmented bone and scattered carcass elements, while felid activity within caves often results in the presence of numerous articulated skeletons (de Ruiter & Berger, 2000). Because of the complex nature of the accumulations at Swartkrans, many factors, including both associated carnivore guild structure and palaeoenvironmental conditions need to be considered for a complete understanding of these distributions.

The GIS described here allows the researcher to view and rotate a combination of elements in 3D space (Figure 2(B)). The query builder in ArcView 3.2 software can be used to extract a subset of features restricted to attributes of interest (e.g., proximal limb sections of all bovids possessing tooth marks). Descriptive statistics, such as minimum numbers of individuals or minimum numbers of elements, can be calculated quickly from the data set. Finds can also be examined within their original geological context, possibly providing further insights into processes responsible for the accumulations. Finally, statistical tests can be performed on spatial patterning of data within the GIS using the SPLUS extension.

*Fossil and artifact densities*

Density maps are useful in locating patterns in the data by identifying high and low concentrations of specified parameters (Mitchell, 1999). Although this function is limited to two-dimensional space in ArcView 3.2 software, it can still allow detection of clusters indicative of vertical filtration of fossils and artifacts into the cave. Differences between the horizontal and vertical distributions of find at Swartkrans may indicate whether the cave system represents, in part, a living floor or whether remains simply fell into the cave through an opening on the surface (Clark, 1993: 167).

*Geological applications*

Geological features such as waterworn pebbles can also be queried and displayed using 3D Analyst (Figure 3(A)). Resulting output may allow detection of paths and clusters of elements transported by water into the cave (Brain, 1958). Such a query might even reveal previous locations of cave openings that permitted transport of materials to lower levels. Voxel Analyst software can also be used to further explore the geology of the cave system, allowing the user to slice and dice features by defining the yaw, pitch, and distance of a plane to extract strata sections, profiles, interfaces, and iso-surface values (Figure 3(B)). Voxel Analyst is capable of calculating volumes and surface areas and so the amount of geological material in an area of interest can easily be calculated.

## Conclusions

Because most Geographic Information Systems are limited to two and a half dimensions, most archaeological GIS studies been limited to regional level models. Indeed, few GIS studies have considered intrasite data at all given that these may require more than one z-value for a given x, y pair (Harris & Lock, 1996). This project set out to develop a method to circumvent the 2·5-D problem to facilitate modeling, archiving and analysing 3-D data collected at South African travertine cave sites using GIS.

The model developed for Swartkrans can be broadly applied to other similar sites, both those in the Sterkfontein Valley, and elsewhere. The Swartkrans GIS has clear potentials, both for storing and organizing the huge volume of data generated by excavations, and for unraveling the complex processes responsible for the formation of sites such as Swartkrans through the study of the spatial interrelations of fossils, artifacts, and aspects of geology.

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