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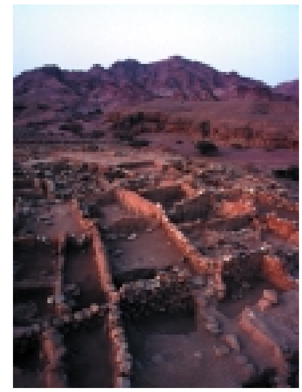

Cover photo: Storage and work rooms in the Early Bronze Age (ca. 2600–2300 BC) metal manufactory at Khirbet Hamra Ifdan, Jordan (Photo courtesy of Jabal Hamrat Fidan Project [Jordan]—UCSD, Patti Rabbitt, and Thomas Levy).

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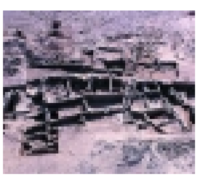

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INTERFACE: ARCHAEOLOGY AND TECHNOLOGY

DIGITAL ARCHAEOLOGY 2001: GIS-BASED EXCAVATION RECORDING IN JORDAN

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Time and space are the archaeologist's most precious commodities. While developments in geochronology provide us with the tools for gaining control of time, Geographic Information Systems (GIS) provide archaeologists with powerful tools to control the spatial aspects of our data. In order to streamline and facilitate archaeological data recording, analysis, publication, and presentation, GIS databases are rapidly becoming the norm for archaeological fieldworkers. There is a certain synergy occurring in our field where archaeologists worldwide are now applying GIS for both survey and excavation needs at sites spanning both prehistoric and historic periods. GIS is rapidly creating a new standard for data recording and analysis that is having the effect of ratcheting up the caliber of model testing for all subfields of archaeology. It is important to share developments in GIS-based archaeology as soon as possible to accommodate this research boom.

In the mid-1990s, the potential of GIS for anthropology was heralded by the publication of *Anthropology, Space, and Geographic Information Systems,* edited by M. Aldenderfer and H. Maschner (1996, Oxford University Press). Since then a wide range of digital technologies that are linked to GIS have been applied (e.g., see N. Craig, "Real-Time GIS Construction and Digital Data Recording of the Jiskairumoko Excavation, Peru," 2000, *SAA Bulletin* 18[1]:1–10; T. Ladefoged et al., "Integration of Global Positioning Systems into Archaeological Field Research: A Case Study from North Kohala, Hawai'i Island," 1998, *SAA Bulletin* 16 [1]:23–27). Here we report on our efforts to create a fully digital-based excavation recording system based on using traditional total station technology to facilitate immediate GIS applications.

The recording system reported here was applied to a large interdisciplinary field project in Jordan with 125 students and professionals in 1999 and a team of 75 in summer 2000 (See flow-chart, Figure 1; **weber.ucsd.edu/Depts/Anthro/classes/tlevy**). The portability, relative low cost, and high power of laptop computers made it possible to duplicate our UCSD Archaeology Lab in the field in Jordan. The mobile laboratory in Jordan included 10 Toshiba and 1 Compaq Laptops, 2 Backpack CD Writer/Burners, 2 Hewlett-Packard 1220 Series printers with tabloid capability, 1 Sony DCR-VX1000 Video recorder, and two digital cameras (a Sony DSC-50 and a Canon Pro 70). The Sony camera was used for both artifact and architectural digital photography. Reserve power was supplied by four 12-volt car batteries charged continuously by solar panels.

The Project—Sample Size and Data Flood

The project focuses on the role of early ore extraction and metallurgy on social evolution from the Pre-Pottery Neolithic Period B (PPNB) period (ca. 9th Millennium B.P.) to the Iron Age (ca. 1200–586 B.C.) in the Jabal Hamrat Fidan (JHF) region of southern Jordan. The JHF represents the "gateway" to the copper ore rich district of Faynan that is home to some of the largest copper ore deposits in the south-

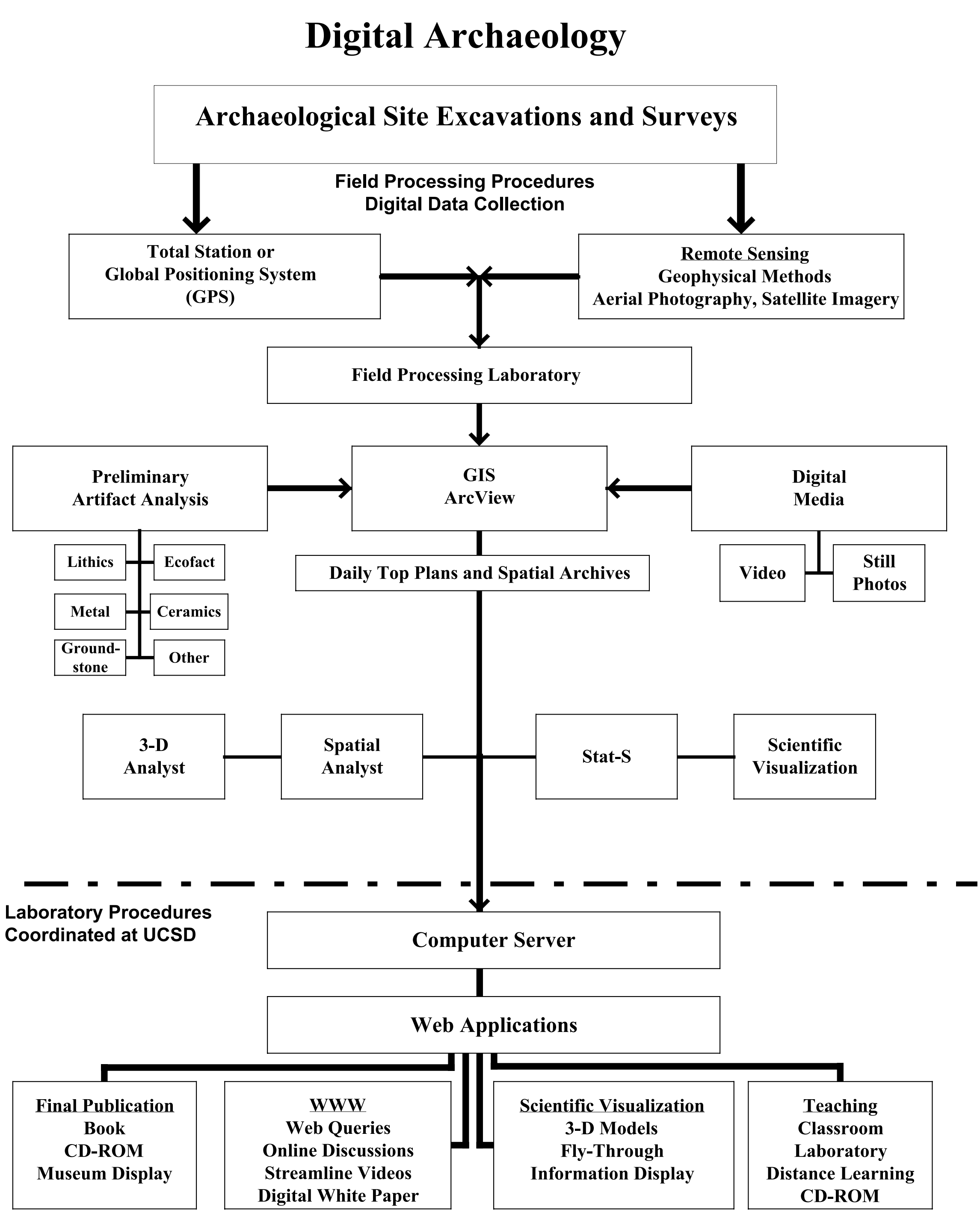

Figure 1. Flow-chart.

ern Levant. In 1999, a PPNB Neolithic village—Wadi Fidan 001 (Figure 2)—was excavated with an exposure of ca. 350 m^2, depth ranges from ca. 5–.5 m and an average depth of ca. 1.0 m. Five major strata were defined at WFD 001. Approximately 3,500 artifact locations and 4,676 other shots were recorded using the total station.

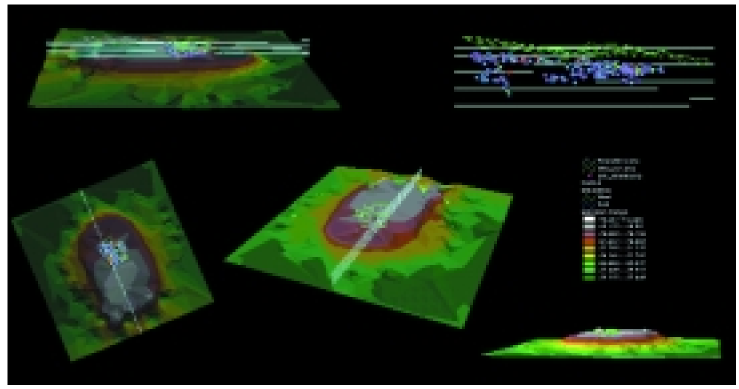

Figure 2. Cosmo 3-D views of WFD-1 Neolithic site.

During the 1999–2000 seasons, an Early Bronze Age (ca. 2300–2600 B.C.) metal "manufactory" was also investigated with an exposure covering a total of ca. 1200 m^2, depth ranges from 2.3 to .5 m, and an average depth of 1 m across the site (Figure 3). Six major strata were exposed with a total of 10,569 individual artifacts, including more than 1,000 casting molds found (Figure 4) and a total of 3,347 other shots recorded.

Artifacts, architecture, sediment layers, and features were plotted at each site with x, y, and z (elevation) coordinates providing a rigorous database for 3-D spatial analysis. Embedded in these data are the keys to understanding the spatial dynamics of the ancient societies that exploited ore and worked with metal in the region. Given the constraints of time and money—two six-week excavation field seasons—the wealth of total station data collected precludes the use of simple plotting of artifact and architectural data on paper printouts. GIS has provided the nexus for recording and linking *all* data from our project. This is done in the field with survey and excavation data, specialist data (archaeozoology, archaeobotany, lithics, ceramics, geomorphology, etc.), digital photography, and an array of remote sensing data collected on site, such as geophysical surveys.

GIS in the Jabal Hamrat Fidan

During the 1999 field season, the implementation of GIS radically changed many of the recording procedures previously employed on-site. Paper forms, refined and developed over 20 years of fieldwork in Israel and Jordan, were tossed out and new digital forms introduced. These record data in a format compatible with other GIS data files. It was decided to maintain a paper backup, which in the post-processing phase proved to be a good idea. During the data cleanup (practically an entire academic year), it was necessary to refer to the paper backup on numerous occasions to identify duplicate or stray total station shots. Data transcription proved to be a bottleneck, as weary students were employed to do data entry after digging all day in the hot sun. In 2000, most of these annoyances were resolved with a rewrite of the data collection software, which was enhanced to support user-defined feature files. The entire GIS operation was now 100 percent digital. ArcView shapefiles were generated directly from the data collector, which is as close to "real-time" as one would want to be. Amazingly, we can say that 99 percent of the data was clean and ArcView ready when it left the excavation areas.

Figure 3. Aerial View of Khirbet Hamra Ifdan, Jordan.

Figure 4. Collection of Clay Casting Molds, Early Bronze Age (ca. 2300–2600 B.C.), Jordan.

The GIS systems employed at JHF were chosen for a number of reasons. ESRI's ArcView, Spatial Analyst, and 3D Analyst are the key software components used. ArcView is used because it does not require massive computing power in the field, it is easy for students to learn, and it does almost everything required. Given the international makeup of the research group, it is important to have the ability to share findings over the Internet. The 3D Analyst extension exports to VRML format, which we can view over the Web using the COSMO VRML plug-in for Netscape (see Fig. 2).

The Role of Students in GIS-Based Field Archaeology

On-site GIS artifact recording is only as good as the person identifying the artifact in the field. To streamline on-site artifact recording using GIS-based techniques, it is essential for excavators to be familiar with the material culture and descriptor codes. The JHF project is part of UCSD's archaeological field school program in the Levant. To facilitate both the pedagogic and research goals of the project, undergraduates are involved in the GIS aspect of the work in a number of ways. Prior to the excavation, students were trained with the total station and computer system at the UCSD Archaeology Lab.

For the 2000 season, all students were issued a handbook (see **weber.ucsd.edu/Depts/Anthro/classes/tlevy/Fidan/handbk/sfh_2000.html**) containing a complete inventory of the artifacts known to characterize the Early Bronze Age site of KHI. Each artifact type is illustrated with a digital photograph, artifact description, and GIS descriptor code. To familiarize the students with the material culture, a "show and tell" display of the typical KHI artifacts is given,thus enabling the student excavators to hit the ground running and play an essential role in the on-site recording system by yelling out the nature of their artifact discovery so that the Total station operator can point, shoot, enter data collector, and then bag and tag the artifact. The artifact is recorded with distinct records and basket numbers so that these data can be linked to other databases.

Students with an interest in computers and archaeology were given an opportunity to train to be GIS assistants prior to the 2000 field season. Three months before the season began, the UCSD GIS lab offered tutorial classes in the use of GIS and its application to archaeology. Four students from this class became GIS assistants in the field. Under the guidance of supervisors and our GIS specialist, Neil Smith (another undergraduate), these students produced daily top plans for their excavation areas. The adoption of GIS and digital survey methods has opened new opportunities for undergraduates to gain vital experience to prepare them for the field and graduate level research.

Digital Surveying—Why On-Site Total Station and not GPS

Total Station electronic surveying instruments were chosen for the regional survey of JHF in 1998 due primarily to monetary restraints. Our goal was to survey a very large area with high accuracy at a first order of relative precision (better than 1:5000; the accuracy attained on the survey was .033 m over 4.5 km). Furthermore, the terrain required surveying for several hundred meters along tributary *wadis* (seasonal drainages) between very steep cliffs. The GPS units that could have attained such precision, accuracy, and real time kinematic surveying were far beyond our means. While the cost of such GPS units have dropped considerably in the past three years, we have remained wedded to our Leica total stations primarily for flexibility, robustness, and ease of use.

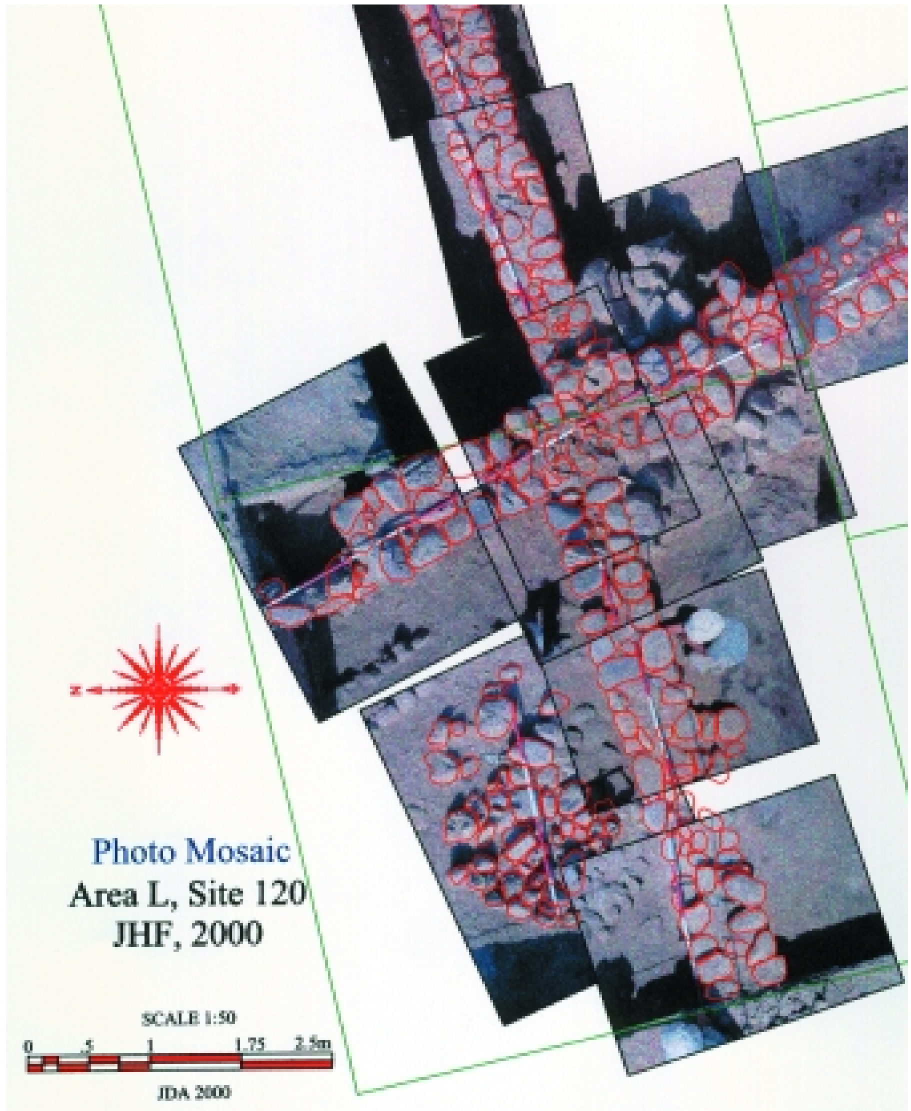

Figure 5. Mosaic of Digital Stills and Wall Photos.

An unforgettable lesson learned in the 1999 field season was that data collected at source should be culled into channels leading directly to GIS. The Tripod Data Systems (TDS) data collectors used in 1999, while remaining the project surveyor's first choice as a general survey tool, fell short as a data collector for on-site archaeology. Four discrete steps were required to massage the day's data for ArcView to be able to process it. As above, much of this work was done at digging day's end, and continued throughout the off-season. What was needed was a data collector that could stream the data into either point (artifacts) or polygon (contexts) models, thus making data GIS ready at the source of recovery. The TDS Ranger GPS data collector was perfect for our needs. With some persuasion, the programmers at TDS tweaked the Rangers for us, so point and polygon data could be collected with total stations for direct GIS downloading.

The 1999 season also taught us that total stations should not be used to aid in draughting rock features since these are eventually drawn in CAD, in effect doubling the amount of work. In anticipation of the 2000 season, we developed a system whereby a small Sony Cybershot digital camera was held securely and normal to the gravity vector in a cradle, which was suspended from a boom (developed by Sher-

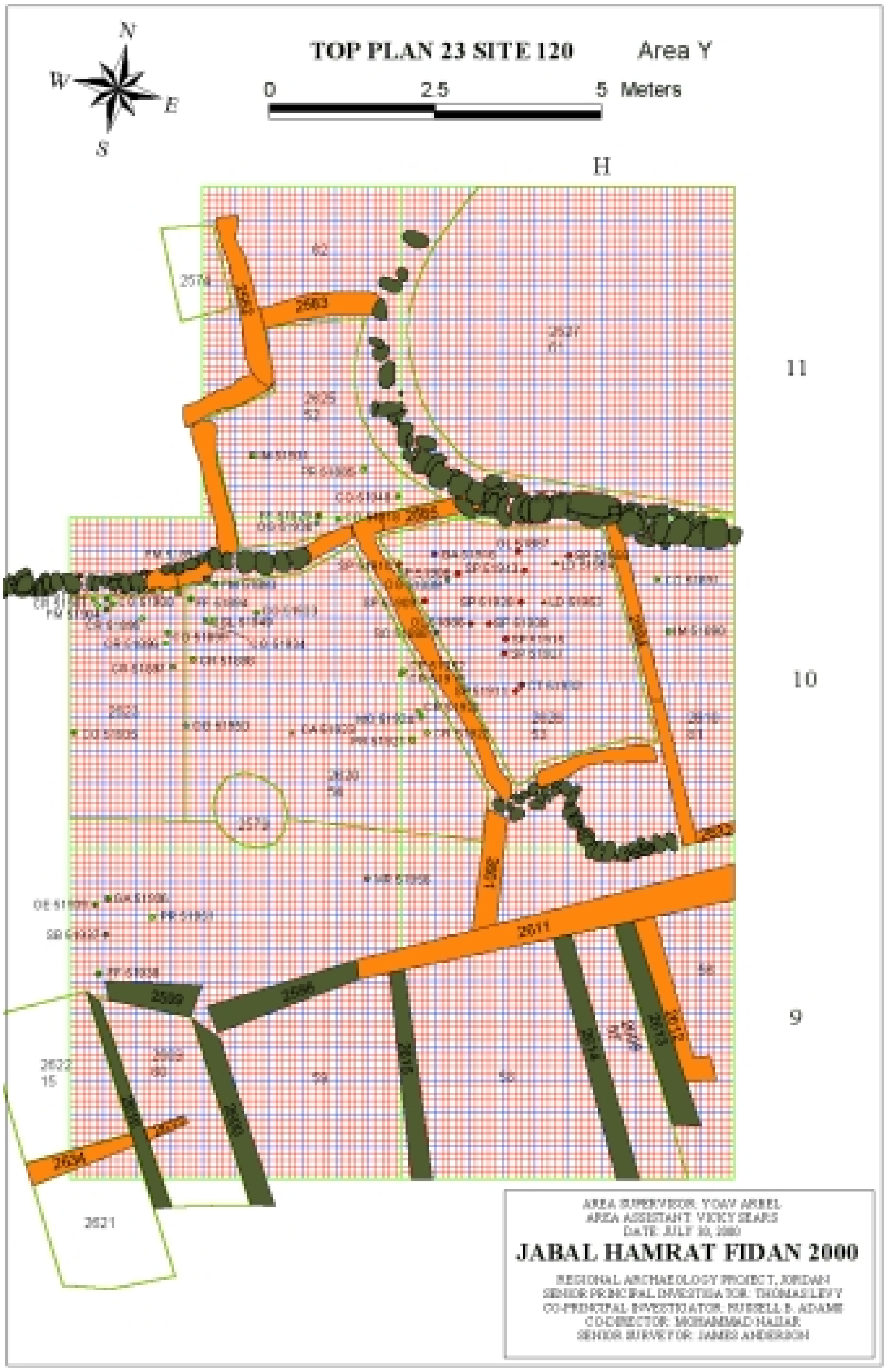

Figure 6. Image of Daily Top Plan.

man George of the UCSD Media Center), and held over the feature to be drawn. Lying horizontally in each photo was a range pole (see Figure 5). Two total station shots were taken at the 1-m interval of the range pole, and these coordinates linked with the photo number. In the lab, the photo was imported into AutoCAD, together with the coordinates of the range pole. By scaling the range pole in the photograph, and then shifting and rotating the photo to the actual coordinates of the range pole, the photo was then moored (geo-referenced) correctly in 3-D space. Using splined polylines, the rocks of each feature were drawn. As each photo was moored independently to 3-D space, errors were not cumulative. This system proved time saving, and much more accurate than conventional drawing.

The wholly digital Daily Top Plans of 1999 were created first in a surveying program called Rapid Transit, and then loaded into AutoCAD for printing. As this process was a minefield of potential error, it was determined that we would press forward to Daily Top Plans generated directly from GIS for the 2000 season. At day's end last summer, polygon and point shape files were loaded directly into ArcView by a dedicated team of GIS students, who then produced a top plan for each area (see Figure 6). To prevent potential sources of error, GIS students did not put in a full day of digging so as to save their energy for the task at hand.

The virtues of digital maps moored to a Cartesian coordinate system are legion. When fully 3-D, contexts and artifacts can be rendered at any scale, in plan, section, or obliquely (see Figure 2). Such data does not distort over time and can be used for several applications.

Tying All Digital Data Together with GIS

Arcview GIS at its core is a relational database, which means that a common data table field links different forms of data. The relational database structure is advantageous to archaeologists that want to use GIS, because field practices and the goal of spatial analysis dictate that each special find have exactly one basket code number (a common field). Data recorded from later studies by specialists in different fields (e.g., archaeobotany, archaeozoology, lithics, pottery, metallurgy, etc.) continue to use the basket code to distinguish between finds and for their final reports. This allows all basket information and later studies to be joined using this common field. For example, a groundstone specialist's analysis that would involve tables of functional type, weight, stone type, and dimensions can all be joined by the common field into a master table including common information to each of the finds. The JHF Project has taken this one step further by assigning the records number with the basket number for each find shot in the field. The basket code preserves the "old Near Eastern archaeology school" method of recording and serves as a check on the EDM number.

The records number includes the ability to assign a common field to things that are not necessarily special finds (e.g., profile shots, digital field photos, survey datums, elevations, etc.) as well as display visually the location of each find in a GIS map plot. Thus, advanced queries involving variables collected from different specialists data can be quantified together. Ultimately, specific research queries of multiple users over the Internet can be entertained without having to consult each specialist. One of the keys to the interdisciplinary approach to GIS is that a master locus list (or context list) exists which contains all the basic excavation data (locus/context, spatial definition [polygons], stratum number, etc.) that is hammered out by the team before GIS plots are used for publication.

Figure 7. GIS Plot of Molds and Hammerstones with pop-up artifact image.

Future Plans

The discovery of the Bronze Age metal manufactory at KHI with thousands of archaeometallurgical and other artifacts highlights the need, applicability, and utility of GIS on-site data recording. At JHF, without GIS, it would take years to define the Bronze Age metallurgical chain of production (Figure 7). ArcView makes activity area analysis simple. However, spatial analysis with GIS is only as good as the artifact definitions used in data collector. Therefore, it is essential that every special find artifact shot in with the total station has an accompanying digital photograph (shot in the field lab) so that checks can be made of field data and more fine-grain artifact typology categories developed. For the future, we are currently working on Web-based implementations of GIS using AXIOMAP, and visualization using the World Construction Set with the San Diego Super Computer Center. These are important visualization tools, which enable us to simulate re-forestation, ground water contamination from smelting sites, population dynamics of the site areas, and other problems. In addition, we are currently devising a plan for 3-D artifact imaging and printing and hope to incorporate this as part of a Web-accessed database.