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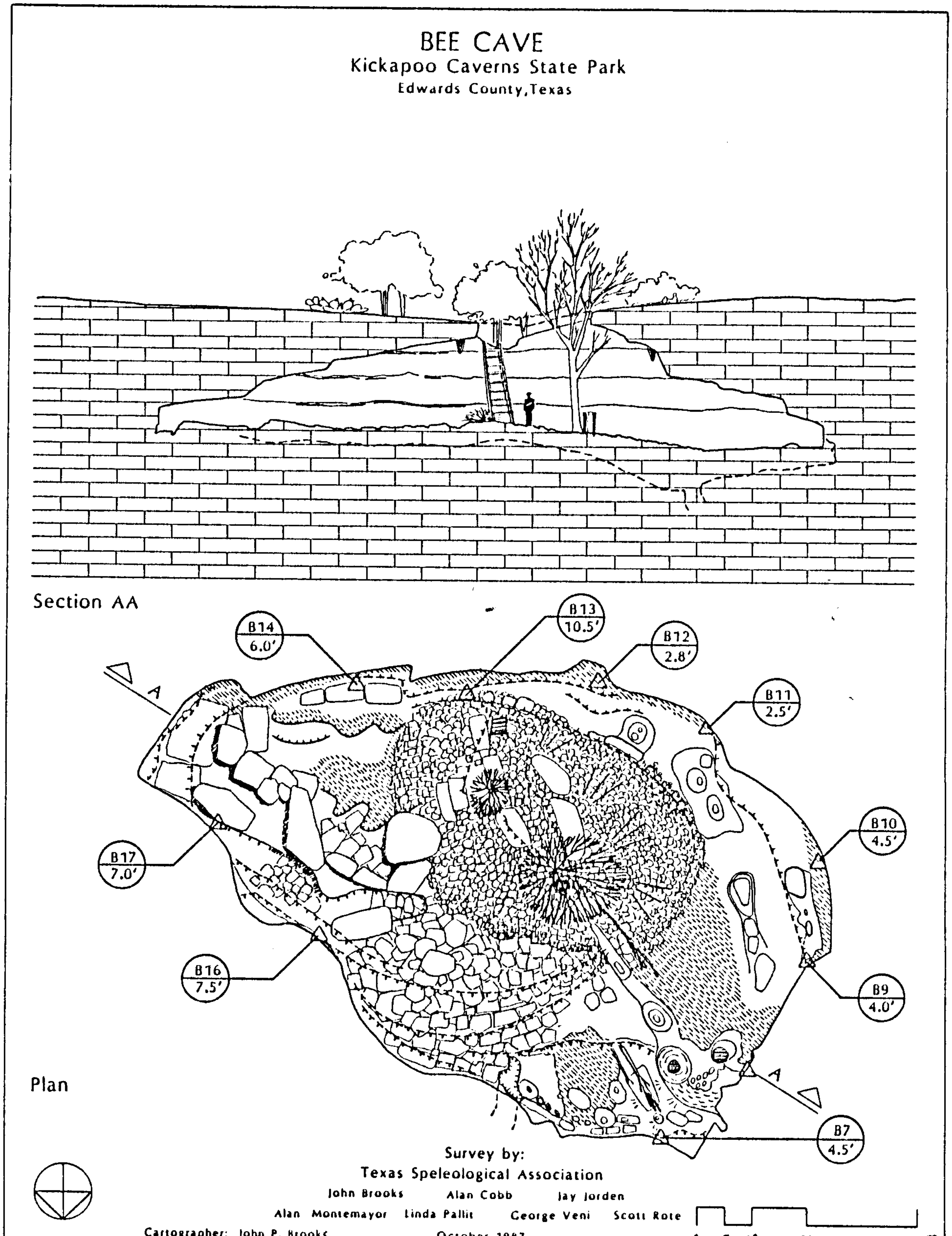

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A PARADIGM FOR DIGITIZED CAVE MAPPING

by John Fogarty

This article details a specific paradigm for the entry and editing of cave maps using computers.

For the past few years I have been following the ongoing discussions of computer use for cave mapping in C&T and elsewhere [see refs]. At the same time, I have been working on a set of programs to assist in cave mapping. This article details the direction I am following towards computer based cave cartography.

Existing Work

Much work on computerization has focused on survey data reduction [Bennett 87] [Crowl 88] [Dotson 881 [Kaye 81] [Kelly 88] [McKenzie 87] [Rutherford 74] [Thrun 76] and [Wefer 1971]. Reduction of survey data is essentially a "solved" problem. Interactive display and manipulation of line plot data still has some interesting aspects.

Cave mapping using CAL) systems is becoming common, [Crowl 88], [Ganter 89], [Hecker 88], and [Nepstad 88]. Hecker's AutoCad assisted map of Horsethief Cave is a good example of what can be done with CAD systems. Wind Cave has embarked on the more ambitious project of using AutoCad for entry of the entire Wind Cave system. Unfortunately cave maps entered using CAD systems lose much of the "deep structure" which is needed for ongoing survey projects, and detail entry is awkward.

A major reason for cave mapping systems is the adjustment of wall and floor detail when there are changes or adjustments to survey information. [McKenzie 88] details a method for maintaining such vector relative information.

[Ganter 88], [Wefer 83-90], and [Breisch 90] have discussed a number of interesting aspects of 'computerization'. These have been really far out, with little stress on the realities of cave cartography.

What is a Cave Map?

A good cave map is an accurate *2 dimensional visual representation* of all or part of one or more caves presented in a form which is both pleasing to the eye, and conveys the maximum information about the subject of the map.

Regardless of the display media (paper, microfilm, or computer monitor) a good map will contain the elements described above. The artistic elements of rendering a cave map cannot be over-stressed. When drafting a map, the mapper makes many decisions on placement, line widths, map symbols, label placement and content, fonts, etc. These are chosen to maximize the visual impact of the map [Ganter 86].

What is a Digital Cave Map?

A digital cave map is any cave map stored in digital form on a computer. The programs used to enter and modify the map and survey data are the *mapping system*. A map should include all of the normal details expected of a good map : floor details, profiles, cross sections, north arrows, scales, borders, and labels. A cave map that is stored on a computer should, in every way, be as complete as one produced with technical pens and ink. The fact that it is stored as an elaborate system of binary data is no excuse for any degradation in its functional or artistic merits. The map can be output to various media such as plotters, dot matrix and laser printers, as well as interactive monitors.

Mice, scanners and digitizing pads will be the primary method of entry for wall and floor detail. The requirements for artistic expression makes use of "generic!' floor detail questionable. Walls and floor detail will be entered by the human hand.

Automatic conversion of symbols between symbol systems (example : NSS to AMCS symbols) [Ganter 90] is not desirable. These would produce nasty, computerish maps instead of improving the map quality.

[Wefer 83-90] has done extensive work on the analysis of cave data, although he places focus on an interactive representation system (Stage-4 Cave Maps). This is not mapping, nor is it a suitable replacement for maps. The information required for arbitrary rotations of a map are not collected by existing surveying techniques.

Why Use Digital Cave Maps?

Adjustment : Changes to the survey data which cause minor changes in the overall shape or length of the cave, do not require editing of the map since detail can be stored in vector relative form. This is not possible with CAD systems and drawing programs; a cave mapping system is required.

Extension : Additions to the map can be made by editing the digital form. Changes to borders, scales, arrows and label positions are simplified.

Distribution : Maps can be distributed, and archived on digital media. Each digital map is as complete as the "original" so loss of the map is less likely.

Elaboration : Additional maps at differing detail levels can be made using the same initial data. The mapper can create special purpose maps which highlight specific aspects of a cave.

Combination : Multiple maps can be combined and re-edited to produce area maps for different caves. Scale adjustments are automated.

Note that CAD systems and paint packages can be adequate for many purposes. A cave mapping system may be only slightly more competent than a CAD system for most tasks. Its advantage will lie in its increased performance and ease of use for this highly specialized task.

Reality

It must be emphasized that a cave mapping system must work within the constraints of data that is collected using current cave surveying techniques.

The existing data available to the cave mapper is

1) Trip reports, personal recollections and communications.

2) Date, instrument types, personnel, and notes about surveys performed in the cave.

3) *Inclination, distance, and azimuth* numerical data recorded from station to station.

4) *Plan* drawings of passage walls and floor detail of segments which were surveyed. While this is usually to scale in good surveys, it will not accurately follow a line plot since it involves considerable estimation on the part of the sketcher.

5) Drawings of passage *cross sections.* The relationship of a cross section to the passage walls is usually noted by a position, and direction of view. The point at which the passage walls have been drawn in the plan is often noted.

6) Drawings of an *extended profile* of segments which were surveyed.

7) High accuracy *surface maps* of various types. Topographical maps provide the greatest additional information to the cave mapper, although other types are referenced as well.

8) Additionally, some surveyors record distances to walls, floor, and ceiling which I consider redundant since the same data is present in a more useful form in the plan and profile drawings.

9) Backsights may be used in some surveys for detecting blunders.

Using only 3) from above, vectors are converted to rectangular coordinate *vectors.* The addition of the *date* from 2) and a *declination* from 7) allows the rectangular coordinates to be adjusted to *true north* or *grid north.* An *accuracy* is assigned to each vector using information about the type of survey from 2) and various weighting techniques which have been extensively discussed by [Wefer 74] and others.

This data is then analyzed using a least squares adjustment program [McKenzie 87] [Kelly 89] [Kaye 81] which produces a set of *adjusted vectors.* Error analysis can be used to indicate any poorly surveyed strings which should be resurveyed.

The adjusted vectors are then used to create *line plots.* These are wire frame representations of the survey vectors at a specific orientation.

Finally, using mostly *line plots, plan, extended profile,* and *cross section drawings,* the cave mapper can begin working on a map.

Digitized Cave Maps

My discussion has been very generalized until this point. From here on I will describe a specific set of steps for entry and editing of map information. There are many different approaches to map construction. The one I describe here is a self-consistent method that I am using in my own designs.

Only the data described in the previous section is assumed to exist for creation of maps. The end product of using the mapping system is one or more maps of publications quality which may be continuously updated as the survey data for the cave changes.

Numerical Survey Data Entry

Numerical and descriptive survey data is entered as individual *Survey Description* text files. Each file describes a single survey. The data in the survey files may be edited with either a specialized editor or an off-the-shelf text editor. Specialized editing allows users to have many of the features of special purpose survey data editors such as those in SMAPS [Dotson 88] and my own Cave View 4.0.

An additional text file enumerates all of the survey files which compose a single cave. This is the *Cave Description* file.

When multiple caves are to be used together for a single system, they are tied together using a *System Description* file. This is a file which references multiple cave description files, along with surface surveys used to tie the system together.

Caves and systems are processed by a variety of means to produce two files : a *Stations* file and a *Vectors* file. Processing consists of the execution of compilers and closure programs. The stations file describes the true or grid north adjusted, UTM relative coordinates of every station within a cave, and the station names. The vectors file is a list of the *from* and *to* stations for every vector in the cave.

After creation of a Vectors and Stations file, no further reference to numerical survey data is required. Note that the Vectors and Stations files can be used in a number of independent applications such as line plot display and plotting programs.

Survey Drawing Data Entry

Each survey also has a set of drawings, referred to here as *map segments.* Each map segment is a single connected drawing, created from the survey book. Each segment is either a *plan, true profile, extended profile, or cross section.* The drawing entry process creates a single file for each survey segment. A survey whose drawings consisted of a plan, extended profile, and 5 cross sections would create 7 segment files. The survey book may have multiple small drawings which will be connected to compose a single segment for the plan or profile drawing of the survey.

The Segment Editor is a computer aided design (CAD) tool for the entry of map segments. It contains many of the elements of a 2 dimensional CAD system (line drawing, cross hatching, fill patterns, background grids, etc.). Unique elements of the segment editor are :

- A line plot overlay can be displayed, scaled and rotated along with the drawings during the entry process. This is derived from the Vectors and Stations files.
- An extended profile line plot overlay can be displayed, starting at any given station to facilitate editing of extended profile segments.
- Data is stored in vector relative coordinate form to allow adjustment based on changes in the line plot.
- As lines, symbols, and attributes are entered, each is assigned a type, subtype and a level. Possible types are : wall, ceiling/floor, floor type, major detail, minor detail, other. Subtypes are specific to the type and may include such classes as : below, above, normal, breakdown, bedrock, sand, gravel, etc. The level is used for detail control during map display.
- Color assignment is by the type of object being displayed in order to cue the mapper during data entry.
- Other survey segments can be displayed and positioned on the screen to aid in connecting the lines between different segments.
- Image files recorded from scans of the survey book can be displayed, positioned, and scaled for "tracing" the survey data.
- Rubber band scaling by rectangle allows selective distortion of the entered segment to assist in placement.

The mapper begins by executing the segment editor. A line plot from the previously entered numerical data is displayed as a plan, profile, or extended profile. The mapper positions the line plot at a scale that is appropriate for entry of the survey drawing at hand. In order to aid in accurate drawing, a grid may be placed on the screen and scaled and positioned appropriately. Plan segments should all be created at the same orientation of the line plot since some symbols such as mud look best at the same orientation.

Previously saved segments may be displayed on the plot so that the connections and orientation to other surveys is apparent. Previously scanned survey book pages may be positioned and scaled as backgrounds to make mouse tracing easier.

The mapper begins drawing by selecting a current survey vector with the mouse (or digitizing pad) from the line plot. This vector is highlighted to make it apparent which vector the entered elements will be relative to. The type and subtypes of the entered elements are selected from a graphical menu. The mapper can draw lines, dots, and circles, or select predefined map symbols such as breakdown blocks, bedrock symbols, flowstone curves, etc. Predefined symbols become a collection of lines to allow further editing after placement.

As the drawing progresses, the mapper will continue to select new vectors along the survey. At any time during the editing process, the mapper can drag, orient, and rescale backgrounds, line plots, etc.

When drawing is performed using the mouse, it must be at a greatly enlarged scale, since hand coordination using a mouse is minimal at best. Digitizing pads offer superior control and drawings may be entered at a reduced scale without loss of quality.

After completing a segment, it is saved as a disk file. The mapper then enters additional segments or reedits previous ones until the desired appearance is achieved.

Scanning of Survey Book Pages

Pages from the survey book may be scanned using handheld and page scanners such as SCANMAN, NISCAN, or SCANJET in order to produce bit mapped images of a given page. These images can be used as *backgrounds* during the entry process. They can be scaled, translated, and rotated to match the line plot. These backgrounds can be dragged around the screen and scaled to make them easy to trace.

People have asked me why survey notes cannot be 'digitized' directly into mapping information. Conversion of bit mapped, scanned images into vectors is an inexact process at best. The quality and uniformity of survey sketches is insufficient to allow them to be converted directly into publication quality maps. Finally, each point within the segment must be classified as to 1) the vector it is relative to, and 2) the type of data which is being represented. These restrictions make it most practical to use the drawings as guides for the mapper.

Profile and Cross Section Data Entry

Profiles must all be created at a specific orientation of the line plot. Rotations cause distortion in the drawn profile which cannot be corrected by automated techniques.

When extended profile segments are displayed on a normal profile line plot, the X axis of the profile is compressed. When the mapper is creating true profile segments, the elements of an extended profile will be imported at a given orientation. The distorted profile will then be re-edited : rescaling, deleting, and redrawing until the desired appearance is obtained.

Cross sections are somewhat unique since they do not have a location which is constrained by the line plot. After a cross section is entered, the section is linked to the plan or profile at 4 points. These are the two walls on the plan/profile and the corresponding walls on the cross section.

Topographical Data Entry

Topographical map data entry requires a Landform Map Editing System. While such maps are an important element of many cave maps, I have not included a discussion of such entry for this article. Topo maps may also be entered using a variety of techniques on conventional CAD systems.

Map Composition

The map segments created during segment editing do not comprise a usable cave map. A cave map will include a *border, scales, north arrows,* and *labels*. Occasionally there are topographical overlays, small geological maps, area maps, etc. A finished digitized map must be one which can be output as hard copy and have the same merits as a traditional pen and ink drawing.

The *Map Composer* is a tool used to assemble the segments from many surveys onto a logical drawing. The Map Composer contains many of the CAD elements used by the Segment Editor, although it does not record elements in vector relative form. Unique elements of the Map Composer are :

- Line plots from multiple caves may be displayed at various scales and orientations. These may be output on the finished map or hidden for use in placing segments.

- Plan and profile map segments are placed onto the line plots to form the major drawings for the map. The various element types may be selectively or globally toggled by level to control clutter on large scale maps.

- Cross sections are placed on the drawing and may be inverted (left/right/up/down) during placement. Passage reference lines may be placed automatically or using manual line entry.

- The line attributes for the various element types (walls, water, breakdown, etc.) can be set globally.

- Selected segment elements may have line attributes overridden for passages below/behind or for artistic effect.

- North arrows and scales of various styles can be generated. These can then be edited as normal lines.

- Text can be placed and scaled at any position on the drawing. Fonts can be selected from HP LaserJet compatible font files, or from the vector font library.

- Drawings (HPGL files) can be imported, positioned and scaled. This allows drawings to be created with existing CAD packages for display on the map.

- Images (TIF files) can be imported, positioned, and scaled. This allows images from scanners, and paint packages to be included as part of the map.

The mapper executes the map composer and begins by selecting a *logical page size.* While the page size may be changed later, this may affect lettering which is defined at specific point sizes.

Line plots are placed on the drawing in the positions that appear most pleasing for composing the map. Plan, profile and cross section segments are enabled. Borders are drawn using rectangles. Additional lines are drawn using the mouse. Text is keyed in or read from files, and placed with the appropriate positions and attributes on the map. Any additional drawings or images may be imported and placed. North arrows and scales may be drawn automatically and placed by hand, or they can be constructed directly from line segments.

The map composer creates a *Map Description* file. This file details all of the elements of the map, including references to line plot files, segment files, drawing files, and image files. Since the map description does not contain the actual contents of these files, they are free to be modified separately, with changes reflected when the map is next viewed or printed. If a map is to be "cast in concrete", then all of the relevant files must be copied to a new directory.

Map Production

Map production is the process of actually printing the map to a physical media. There are number of devices which can be used for output :

- Plotters are vector only devices that do not reproduce bit mapped images well, but they can produce very large format pages. They handle multiple colors quite nicely.

- Laser printers and phototypesetters can produce high quality bit mapped images but are limited in paper size. A single color is typical.

- Electrostatic plotters provide a good compromise between the quality of laser printers and the size of plotters, but they cost a fortune.

- Large format color printers exist, but are wildly expensive.

The *Map Producers* are programs that combine the elements from a map description into one or more output files. Large maps are broken up into as many quads as will be required for the supported output device. Typical Map Producers are :

- HPGL Producer : creates files in Hewlett Packard Graphics Language format.

Conversion of bit mapped fonts and image files is controlled by various options. Files are segmented according to the type and size of the destination plotter.

- HP LaserJet Producer : creates files in raster graphics form for HP compatible laser printers. This is a good format for small maps. Large maps can become a large number of pages which must be assembled with glue or tape.

- Postscript Producer : creates file suitable for phototypesetters and postscript printers. This is the most desirable format since it retains all characteristics of the map. The disadvantages are speed and cost of output.

Conclusions

[Ganter 89a] described a new cave ethic of "Map What You Survey" to go along with "Survey as You Explore". The nature of paper maps has made mapping of large systems such as Purificacion, Wind Cave, and Huautla almost impossible. A well designed cave mapping system that allows for interactive and incremental map development is a logical direction to proceed in computer use for mapping. In this way we can begin mapping very large systems which have ongoing survey projects.

In using a computer for cave cartography, we must not lose any of the elements of pen and ink. Instead we should gain additional capabilities for editing, extension, and distribution which were not present before. Overly ambitious systems should be avoided until we have solved the more fundamental problems of high quality cave map production via computer.

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MACINTOSH GRAPHICS FROM SMAPS

by Tim Kilby

Two computer programs have been written for using SMAPS cave coordinate data, generated on an IBM-PC, in applications on an Apple Macintosh. One program may be used to create vector drawings compatible with drawing and CAD applications. The other program produces files compatible with SUPER-3D, a modeling and animation application.

"SMAPS-to-PICT" is a Macintosh conversion utility that reads the coordinate data from an ASCII file generated on a PC by SMAPS and creates a PICT-format vector drawing on the Macintosh screen. The map can then be pasted into most any Macintosh drawing or CAD program via the Macintosh clipboard. "SMAPS-to-PICT" can draw plan or profile views at a scale selected by the user. The user may also select or deselect junction labels, junction markers, and lines between stations so that separate drawings can be made for programs utilizing drawing layers. The number of stations a single map may have is limited by the computer's available memory. The author uses the Canvas 2.1 drawing program on a Mac II with 5 MB RAM.

"SMAPS-to-SUPER 3D" converts ASCII cave data files produced by SMAPS into files directly readable by SUPER 3D. SUPER 3D is an popular three-dimensional graphics application from Silicon Beach Software used for 3D modeling and animation. SUPER 3D may be used to view a cave stick map from any viewing angle. Maps may be viewed in perspective. Both black & white and color versions of the utility are available, the later being able to assign colors depending upon passage depth. Animations may be created which rotate the map about any point, pan or dolly along any path, or even "fly" along a path you specify. Animations may be recorded and then played back in movie fashion, or recorded on videotape using appropriate hardware.

"SMAPS-to-PICT" and "SMAPS-to-SUPER 3D" are available via the NSS Bulletin Board at (317) 745-2197. The filenames are SMAPPICT.1 and SMAPS-3D.CPT, respectively. QuickBasic source code is included in the two self-extracting archive files. All files are also available by sending a 3-1/2" floppy diskette and a stamped return mailer to Tim Kilby, 10607 Howerton Ave., Fairfax, VA 22030.

NEW LASER PRINTER MATERIALS MAY INTEREST CAVE MAPPERS

by Tim Kilby

Two newly-available laser printer materials may be of special interest to cave mappers. The plastic materials are used like regular 8-1/2"x11" paper, but they offer advantages when used for certain mapping applications.

First there is applique film, an adhesive-backed thin translucent film, slightly thinner but much like frosted Scotch tape, only in full-sized sheets (with backing paper, of course). The cave map drafter could print all the necessary lettering, some symbols, compass and scales using an office laser printer on this new material. Then it would be quick and easy to cut out the components and stick them in place on drafting film. Since the applique film itself is nearly transparent, it should appear invisible during most duplication processes. Two known sources: Visualon, Inc., (800) 321-3860 (clear matte or colors--they will send samples on request), and Rayven, Inc., (612) 642-1112 (available in glossy, matte, or opaque white). This material is becoming rapidly available from various manufacturers and may be available in your local art/drafting supply store.

A second material of interest is Dura/Copy. This material looks like plain white paper, but it is made of heat stable tearproof--this stuff is really tough!--matte white plastic. It can be used in copy machines or laser printers as well as drawn on with pencil or pen. Sounds like a winner for mapping in wet, muddy caves. However, Dura/Copy is expensive at $45 per box of 100 sheets. Visualon, Inc. carried this material recently, but it is not listed in their current catalog. Look for similar products from other sources.

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