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GENERATING COLOR TERRAIN IMAGES IN AN EMERGENCY RESPONSE SYSTEM

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ABSTRACT

The Atmospheric Release Advisory Capability (ARAC) provides real-time assessments of the consequences resulting from an atmospheric release of radioactive material. In support of this operation, a system has been created which integrates numerical models, data acquisition systems, data analysis techniques, and professional staff. Of particular importance is the rapid generation of graphical images of the terrain surface in the vicinity of the accident site. A terrain data base and an associated acquisition system have been developed that provide the required terrain data. This data is then used as input to a collection of graphics programs which create and display realistic color images of the terrain. The graphics system currently has the capability of generating color shaded relief images from both overhead and perspective viewpoints within minutes. These images serve to quickly familiarize ARAC assessors with the terrain near the release location, and thus permit them to make better informed decisions in modeling the behavior of the released material.

INTRODUCTION

The primary activity which transpires at the interface between the user and the computer is information exchange. The user transmits information to the computer by operating a device such as a keyboard or a mouse, and the computer communicates to the user visually by means of a CRT display or an on-line printer. These different modes of transmission between the two nodes of the user-computer link reflect the dissimilarities in the way in which information is assimilated and stored at each end. User-supplied "input" must eventually be reduced to digital data for consumption by the memory and central processor of the computer, and computer "output" must be converted to an appropriate visual format in order to be understood by the human eye-brain system. In the latter case, the form of the displayed information plays a crucial role in the speed of human perception. The scanning of pages of linear text on line printer listings or video display terminals can be tedious and frustrating when looking for patterns and trends in numerical data. On the other hand, our well-developed eye-brain pattern recognition mechanism allows us to perceive and process many types of data very rapidly and efficiently if the data are presented pictorially. Speed of perception is not always an important consideration when discussing human assimilation of computer-generated data, but when the computer application is a component of an emergency response system, the choice of mode for data presentation becomes nothing less than critical. The application of these considerations to the graphical representation of digital terrain data is the subject of this paper.

BACKGROUND

The Atmospheric Release Advisory Capability (ARAC) project [1] is a real-time emergency response service available for use by both federal and state agencies in case of a potential or actual atmospheric release of nuclear material. The central component of the ARAC response capability is a diagnostic atmospheric model that simulates the transport and diffusion of an effluent through the atmosphere. This model is composed of two major programs, one that generates a mass-adjusted three-dimensional wind field from available meteorological data [2], and another that computes the advection and diffusion of a pollutant using a particle-in-cell technique [3]. The model accepts many types of data as input, such as pollutant source location and description, meteorological data, terrain data, and several inputs for parameterizing the state of the atmosphere. These latter inputs are selected subjectively by the meterological assessors who run the model utilizing all the information available to them during an emergency, and it is at this juncture that visualization of the surrounding terrain first becomes important. Upon notification of the release of hazardous materials into the atmosphere, the ARAC staff acquires pertinent meteorological data for points in the surrounding region from the Air Force Global Weather Central (AFGWC) and the National Weather Service (NWS) and, if available, from the site of the accident itself. These point readings must then be interpolated in three dimensions to obtain a complete meteorological picture of the area surrounding the site. The selection of the subjective parameters mentioned above can be very difficult without a clear picture of the local topography. For example, meteorological measurements may indicate an apparent mass convergence or divergence when, in reality, this effect is due to channel flow produced by the configuration of the local terrain. A clear picture of the terrain involved would quickly resolve this apparent paradox and would expedite the meteorological data screening process.

Though ARAC assessors could become familiar with supported facilities by visiting the area and by extensive exercises with the installations, experience has shown that more than half the incidents to which ARAC has responded have been away from supported sites. In these cases, and increasingly in the case of supported sites as their number grows (currently over 50), fast high quality terrain imaging is essential to orient or re-orient an assessor to the accident scene. This need was dramatically demonstrated early in the history of ARAC, first with the Three Mile Island accident in 1979, when the necessary topography was sketched out by hand, and later in 1980, with the Titan II missile accident near Damascus, Arkansas, when an improved approach yielded markedly deficient contour images from a human-assisted computer in 5 hours [4].

The first step in developing the means for producing real-time terrain images was taken in 1981, when Defense Mapping Agency (DMA) topographic data for the entire continental U.S. obtained from the National Cartographic Information Center was transferred to the central storage system of the Lawrence Livermore National Laboratory (LLNL), the site of ARAC. The 4.3 Gigabyte DMA data base consists of surface elevations at a grid spacing of 63.5 meters. Next, software was produced by ARAC computer scientists to access, transform, and average the DMA data onto grids that were appropriate for ARAC's use [5]. In addition, a smaller (109 Megabyte), coarser resolution (500 m) data base was created. During an accident response, a regional terrain file is generated from this smaller data base which typically covers a 200 km square area centered on the release point. Having installed the data base system on the LLNL central computer system, ARAC scientists then moved it to the ARAC computing facility. By late 1984, the system was operational on ARAC's VAX 782's, and it then became possible to generate a regional terrain file centered at any point in the contiguous U.S. within 3 minutes.

Concurrent with the effort to develop the terrain data base and its attending programs, work was being done to develop software for creating and displaying realistic images of the terrain data. It was clear from the Titan II accident that contour maps are notably weak in the area of human perception (Fig. 1). This is especially true in the case of complex terrain, where contours tend to crowd each other, and hills and valleys become indistinguishable. Wire frame plots and block representations have similar shortcomings (Figs. 2-3). It was decided to investigate the feasibility of creating color shaded raster images, and in 1982 software was created on LLNL's CRAY-1 computers to generate terrain views for the simplest case, that is with the observer directly above the center of the terrain grid looking down, i.e., an overhead view. However, for an assessor to visualize the topography of a given area, it would be helpful to view the area from any arbitrary vantage point. Introducing this generalization increases the complexity of the calculation by an order of magnitude, since one can no longer make the simplifying assumption that all points on the terrain surface are visible to the observer, as can be done in the overhead case. In calculating arbitrary perspective views, the complication of hidden surfaces is introduced, thus increasing the calculational time significantly. By the end of 1983, the more general perspective program had been completed and was capable of calculating a terrain image in approximately one minute on the CRAY-1 [6].

REAL-TIME IMAGES

Generation of high-quality images in real time had been successfully demonstrated on LLNL's CRAY-1's. However, two aspects of this prototype system excluded it from being useable in an operational sense. First, the software which created the image data resided on the LLNL central computing facility, with a timesharing operating system whose users, of which ARAC scientists comprise a small segment, compete for access. The software was ultimately required to run on ARAC's dedicated VAX-based computer system. The projected time for creation of a terrain image on ARAC's VAX computers was 10-15 minutes, clearly an unacceptable timeframe for emergency response, especially when the need for creating many different images clearly exists. The second aspect to be addressed was the actual displaying of the images in real time. Each element in the color image data consists of three integers in the range 0-255 representing the intensities of the red, green, and blue components at each point in the image, thus allowing a range of over 15 million composite colors. Barring the procurement of some prohibitively expensive hardware to display its images, ARAC would have to rely on LLNL's Dicomed film recorder which produces 35mm slides from digital data in a turn-around time of a day or more.

The second difficulty, that of displaying the terrain image, was overcome by a judicious subdivision of color space coupled with a graphics technique known as "dithering". The display device used by ARAC assessors is a Tektronix 4115, which accomodates 256 user-definable colors. By carefully assigning colors to terrain elevations (ARAC terrain images display terrain as green at low elevations gradually turning to brown at higher elevations), the color set of 15 million was reduced to about 16000. By taking advantage of the fact that the human eye cannot distinguish between adjacent colors on the 0-255 scale, and that the eye can be fooled into seeing the "average" color produced by slightly different colors in close proximity (dithering), the ARAC "palette" was reduced to 250 colors. In spite of this drastic reduction in color "building blocks", the images when displayed show negligible loss of detail or clarity.

The first problem (execution time) was solved by rethinking the algorithm used to create the color image from the terrain data. In order to explain the algorithm, a brief discussion of some concepts in computer graphics is required. The terrain images being described are made visible by display on a graphics device, for example a color graphics monitor. The screen of a display monitor is not a continuous medium, but is actually made up of a raster of discrete points or elements called "pixels" which are laid out on the screen in rows and columns (for example, the Tektronix 4115 screen has a resolution of 1024 × 1280 pixels). A color image is portrayed on the screen by "painting" each pixel an appropriate color, and at normal viewing distances the indvidual pixels blend together to create a total impression of shapes and colors which comprise the "picture". The mathematical calculation of an image therefore, could be compared to an observer looking at a scene in the real world who removes a blank screen from a display monitor and holds it at arms length between himself and the scene so that the screen becomes a window. "Painting" a pixel on the screen (or "window") is then simply a matter of projecting a straight line, called a view ray, from the eye of the observer through the pixel and following the ray until it strikes the surface of an object in the scene. The color of the surface at the point of intersection with the view ray determines the color of the ray's corresponding pixel. Repeating this process until all pixels on the screen have been painted will produce a color image of the scene on the display screen. If all surfaces in the scene are visible to the observer with no surface hiding a portion of any other surface, the image calculation becomes little more than a coordinate transformation from 3-D scene coordinates, called object space, to the 2-D screen coordinate system, or image space. The difficulties arise when some surfaces in the scene are obscured from view by the observer, that is, when a projected view ray intersects more than one surface in the scene. It then becomes necessary to determine which of the intersected surfaces is visible, i.e., nearest the observer, as it will govern the painting of the corresponding pixel. This operation, known as hidden surface removal, is simple enough to state, but requires a large amount of computer time to perform, and has given rise to numerous carefully constructed algorithms in the last decade [7].

Regardless of the approach taken, hidden surface removal can be described generally as a large sorting process. The polygons which comprise surfaces in the scene, their vertices, or their intersections with other surfaces are common candidates for sorting. The typical 3-D raster image calculation thus becomes a three-step process: coordinate transformation, hidden surface removal, and reflectance calculation ("pixel painting"). The time required to remove hidden surfaces can account for 90 per cent of the total computation.

The method used in the first ARAC terrain image generator was to handle one vertical column of pixels at a time. The set of view rays passing through all pixels in a given column, or vertical scan line, define a plane, and a precalculation was performed to derive the terrain profile determined by the intersection of that plane with the terrain surface (Fig. 4). The view rays were then projected onto this profile one at a time, beginning with the ray passing through the "lowest" pixel in the scan line. The coordinates of the terrain profile were sorted in order of their distance from the observer to shorten this last step. Also, to facilitate the profile calculation, a restriction was placed on the orientation of the view window (the detached display screen held at arms length), namely that it must be perpendicular to the terrain grid. This restriction introduced slight distortions in the terrain image when the terrain was viewed from "non-horizontal" angles of view. The distortion increased as the view angle approached 90 degrees (overhead viewing), at which point the image would completely disappear, since the observer would then be seeing the view window "edge-on".

In 1984, a new approach was taken which resolved the distortion problem while at the same time yielding a significant gain in execution speed. This new approach completely eliminates the need for hidden surface removal by recognizing that the terrain data is in a sense "pre-sorted" in two dimensions since it is stored as a 2-D array. Defining the zero elevation or "sea level" plane of the terrain data as the X-Y plane, the terrain elevations become a discrete single-valued function of X and Y, or $Z(X,Y)$, where, in the case of the ARAC regional terrain data, X and Y take on values from 0 to 200 km in increments of 0.5 km. The new algorithm (Fig. 5) defines a "scanning origin" at $(X0,Y0,0)$, where $X0$ and $Y0$ are the X- and Y-coordinates of the vantage point (location of the observer's eye). The lines $X = X0$ and $Y = Y0$ divide the terrain data base into 1, 2 or 4 sections (1 if the observer is not above the terrain grid or is above one of the grid corners, 2 if he is above a grid boundary, and 4 if he is above any other point within the grid boundaries). These sections are then taken one at a time (the order is not important), and the grid cells in each section are "scanned", beginning with the cell which is nearest to $(X0,Y0,0)$. The remaining cells in this row are then scanned in the order of their distance from the scanning origin, then the next row of cells from the scanning origin is processed in the same fashion, and so on, until the entire section has been scanned. Scanning a cell consists of defining a 3-D "quadrilateral" with the terrain points for the cell corners (the quadrilateral is 3-D because the four terrain points are typically not coplanar). The quadrilateral is then subdivided into two triangles by choosing an appropriate diagonal (the choice of diagonal is determined by the orientation of the grid section with the scanning origin, and is the same for all cells within a given section). The triangles are then projected onto the view window in the order of their distance from the scanning origin (this corresponds to the coordinate transformation step mentioned earlier). The "unpainted" pixels contained within the projected triangle are then painted, and those that have been painted previously are left alone. Due to the nature of the scanning algorithm, the first triangle to contain a particular pixel determines that pixel's color, since no triangle encountered in the scanning can obscure any part of the triangles which precede it. This is true because of 1) the method of subdividing the grid cell quadrilaterals, 2) the order of the selection of the triangles, and 3) the fact that $Z(X,Y)$ is a single-valued function.

By eliminating the hidden surface removal step, this new scheme will permit any orientation of the view window without introducing any distortion into the final image (Figs. 6-8). On the ARAC VAX 782's, it requires approximately a minute to create a terrain image, which is sufficiently fast to allow an assessor to generate several views of unfamiliar terrain at an accident location within an acceptable emergency response timeframe.

FUTURE EFFORTS

The value of fast high-quality color terrain images is clearly not restricted to their use in assessor orientation. In fact, they have already proved effective as a data base quality control tool in revealing erroneous or missing data in the DMA data base. These problems are now seen at first glance, whereas, with contouring, they escaped undetected. Besides broadening the terrain data base to include Western Europe, future goals include the addition of other features to the terrain images, such as base map information, land use/land cover, demographic information, and the position and extent of the released material (i.e., the pollutant "cloud").

CONCLUSION

Upon notification of a release of radioactive materials into the atmosphere, personnel in an emergency response facility such as ARAC are literally inundated with numerical data of many types. The importance of prudent selection of the form in which data is presented to users of an emergency response system therefore cannot be overstated. Realistic graphical representations, such as color terrain images, not only convey a greater quantity of information to the user, but they also greatly reduce the time required for the understanding of that information. The time-critical nature of emergency response also demands that such representations be generated quickly so that the advantages gained by greater realism are not lost. As the role of color graphics expands within the ARAC response system, it will serve tremendously in helping users to make more informed decisions at all stages of the emergency response process. In addition, there is a powerful future spinoff for the modelling R & D and operational process through the graphical depiction of the evolution, transport, and dispersion/depositon of a toxic material release.

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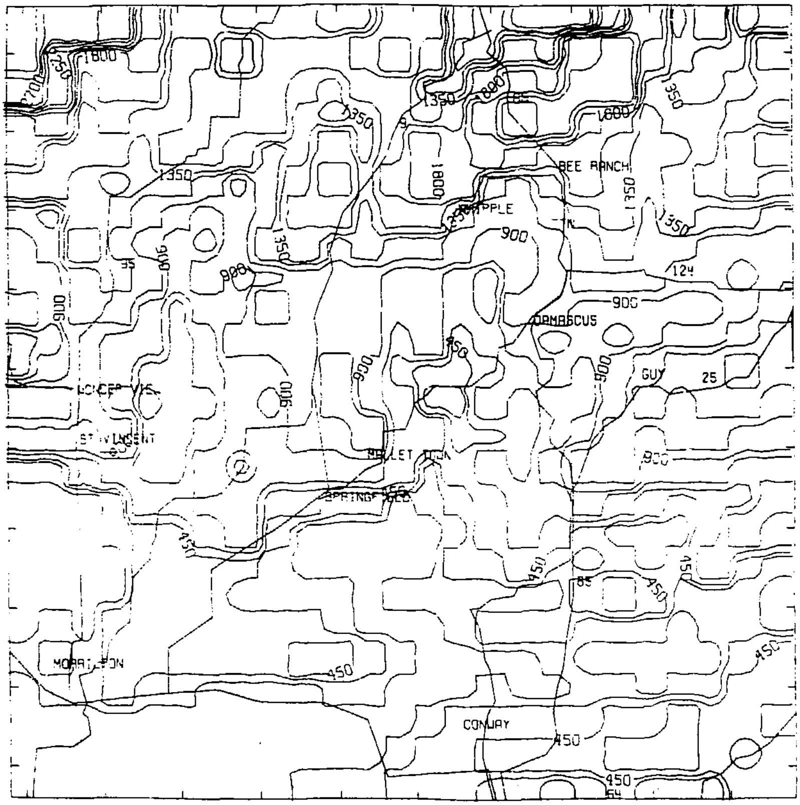

FIGURE 1.

Computer-generated contour map centered near Damascus, Arkansas, site of the 1980 Titan II missile accident. North is up.

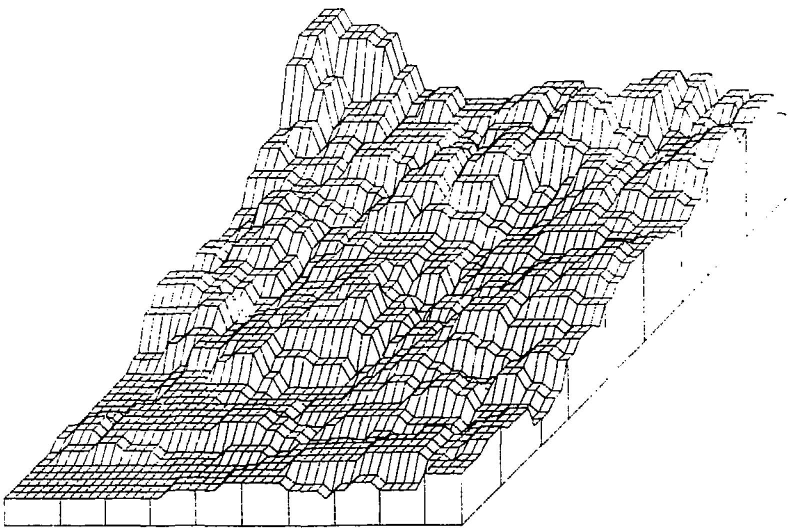

FIGURE 2.

Block diagram of the same area shown in the contour map of Figure 1. This view is looking from the southeast.

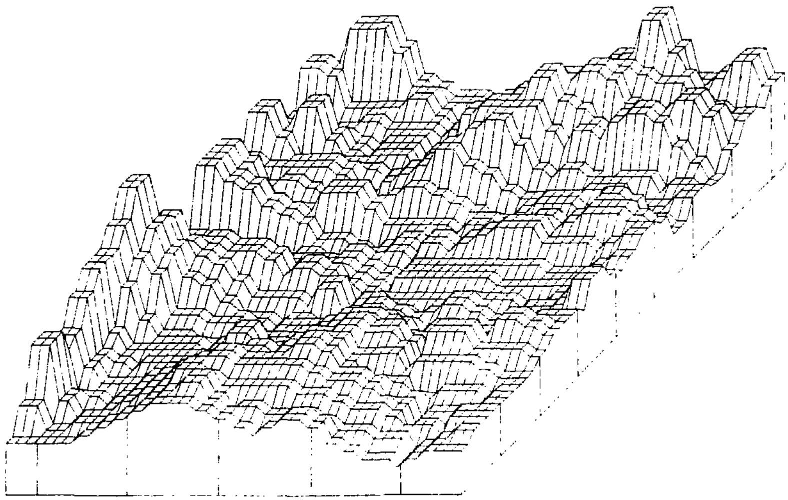

FIGURE 3.

Block diagram of the Three Mile Island area near Harrisburg, Pennsylvania. This view is looking from the southeast.

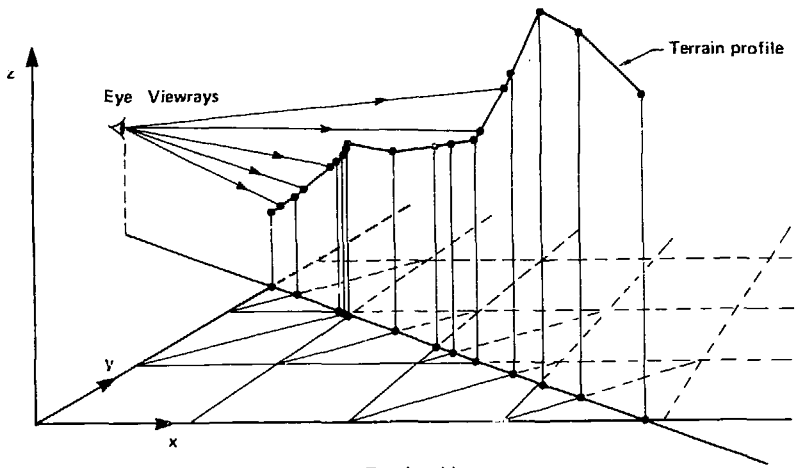

FIGURE 4.

Illustration of the first approach to generating perspective views of terrain indicating the orientation of the terrain grid, vertical scan plane and its associated view rays, and the resultant terrain profile.

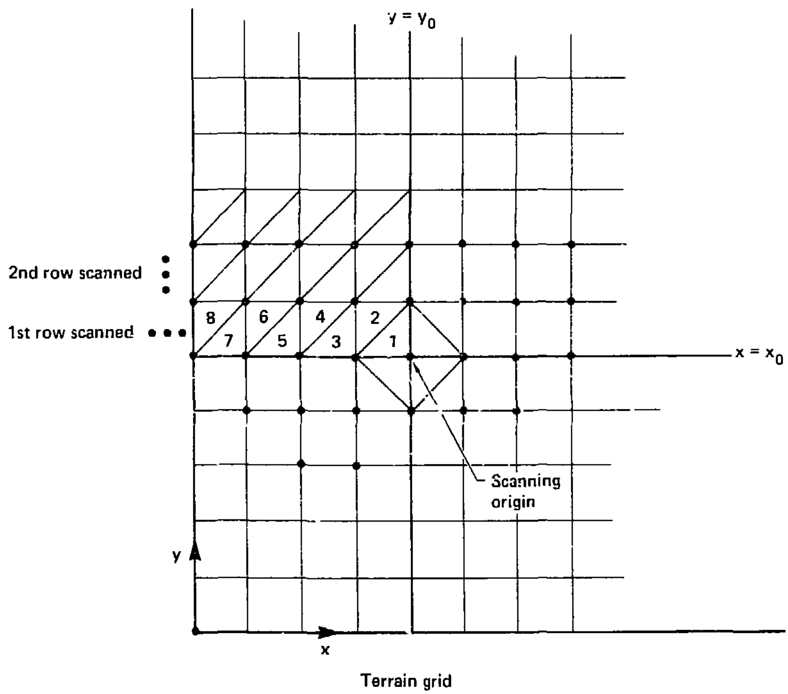

FIGURE 5.

The second approach to perspective viewing. In this case, the view point lies above a point within the grid boundaries, so the grid is divided into four sections. Detail is given to indicate the scanning method of the section to the upper-left of the scanning origin. Numbers show the scanning order for a given row of triangles in that section. Diagonals in the remaining sections indicate the method of subdividing quadrilaterals in those sections.

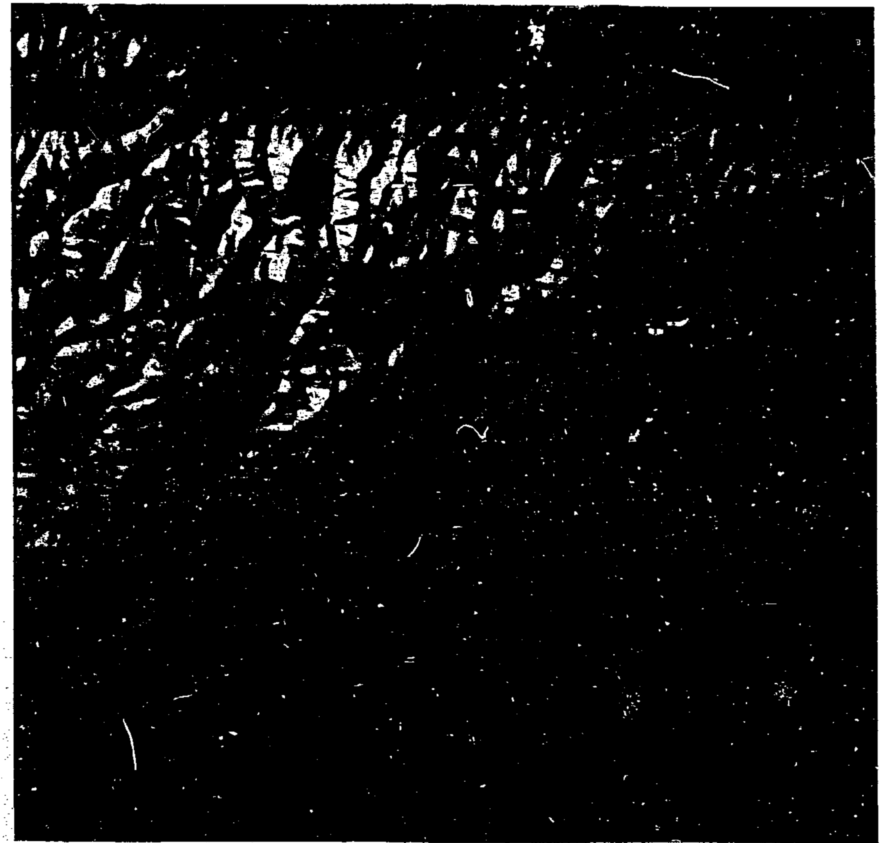

FIGURE 6.

Overhead view of a 200 km area on the southeastern coast of France. North is up.

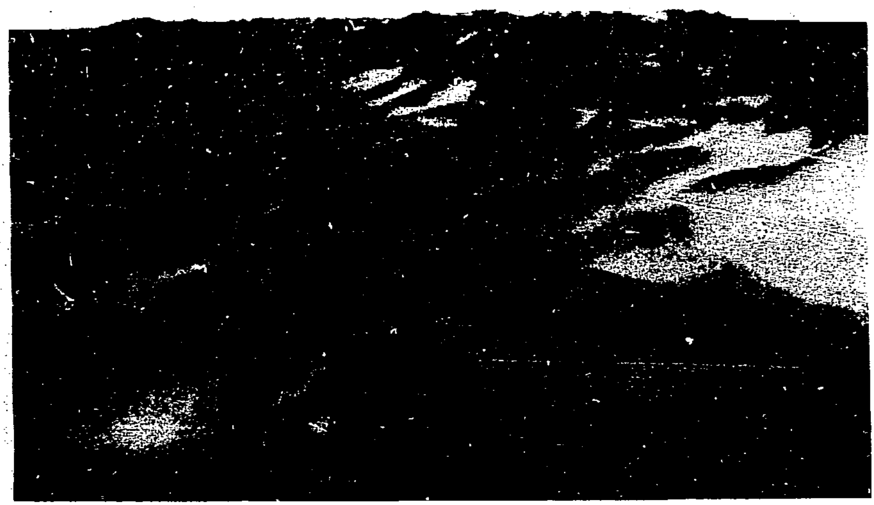

FIGURE 7.

Perspective view of simple terrain in the San Francisco Bay area viewed from the southeast.

FIGURE 8.

Perspective view of complex terrain. View is from the south rim of the Grand Canyon in Colorado, looking north.

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