New Hardware and Software Innovations (for Volumetric Modeling)

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NEW HARDWARE AND SOFTWARE INNOVATIONS

(For Volumetric Modeling)

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Uncovering the Hidden Resource: Ground-Water Law, Hydrology, and Policy in the 1990s

University of Colorado at Boulder
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Colorado Ground-Water Association
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INTRODUCTION

The applications of 3-D modeling technology to the geosciences are very diverse, and have the potential for making a huge impact on the way geologic investigations are conducted in the future. However these geologic applications pose some special problems to the designers of the computer software, mainly because of the the special characteristics of geologic data and the methods used in geologic investigations.

Before reviewing some typical examples of 3-D spatial representations, it is necessary to remember these special requirements of the geologic applications.

GOALS OF A GEOLOGIC MODELING SYSTEM

* Freedom of Interpretation
* Combination of Disparate Data Types
* Creation of ANY Geologically Realizable Model

What is Special about the Geosciences?

Unique problems include:

1) incomplete, conflicting information
2) natural subsurface is complex and heterogeneous
3) sufficient sampling to resolve all uncertainities is economicaly infeasible
4) scale effects on many rock properties are usually unknown

NOTE: **Concepts and methods of 3-D data management and display are independent of the geological scale; however, they are very dependent on the concept of "GEO-OBJECTS"**

"GEO-OBJECTS"

Distinctive geological features or conditions, located within the subsurface, and having measurable spatial limits or boundaries in three-dimensions, may be defined as "geological objects" or "Geo-objects".

Classes of Geo-objects

1) "Sampling Limited" Objects

- more samples may better define the geo-object
- may use "indicative data"
- (e.g. strata, fault trace, etc)

2) "Definition Limited" Objects

- definition may control object shape
- "fuzzy data" may confuse
- (e.g. ore zone, pollution plume)

Character of Geo-objects

* Multi-dimensional (at least 3-D)
* Hetergeneous
* may be
  - dynamic
  - hierarchical
* scale effects may change definition

GEOLOGIC vs MEDICAL VISUALIZATION

* both are 3-D
* sampling rates are very different
* geological features are variable and may be unfamiliar
* medical imaging is time dependent (necessary to track moving objects from image to image), while geoscience applications usually are not
* medical imaging is not designed for modeling, it does not require analytical tools for abstraction and interpretation as much as geoscience applications

* **GEOLOGISTS DON'T HAVE CADAVERS TO REVIEW!**

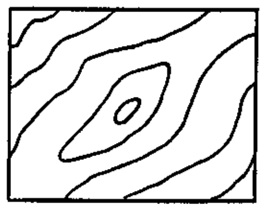
GIS DIMENSIONALITY

2-D traditional two dimensional (x,y) map and cross-section displays

2.5-D isometric or perspective displays of surfaces ("fish-net", "wire-frame, or "shaded")

3-D true three-dimensional (x,y,z) models of objects

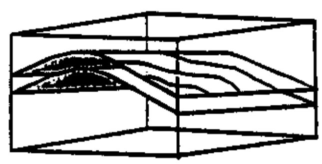
2-D GIS



2-Dimensional Traditional GIS: a Contour Map

- o 2-D representations include traditional graphics methods such as contour maps and cross-sections.

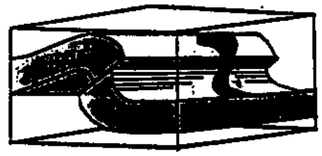
2.5-D GIS



2.5-Dimensional GIS: Stacked Surfaces

- o Z (elevation) is a function of X and Y
- o only 1 Z-value for any surface at any given X and Y
- o STACKED SURFACES MAY CREATE LAYERS AND VOLUMES
  - these volumes are "voids in the database"
  - cannot model property gradients within these volumes

3-D GIS



True 3-Dimensional GSIS Representation

- o independent X,Y,Z
- o Multiple Z-values are possible at any location
- o volumes may have variations in properties

3-D SPATIAL REPRESENTATIONS

1) Volume Representations
   - Voxels (including octrees)
   - 3-D grid/isosurfaces

2) Surface Representations
   - Constructive Solid Geometry (CSG)
   - Non-Uniform Rational B-Splines (NURBS)
   - Boundary Representations/Polygon Meshes

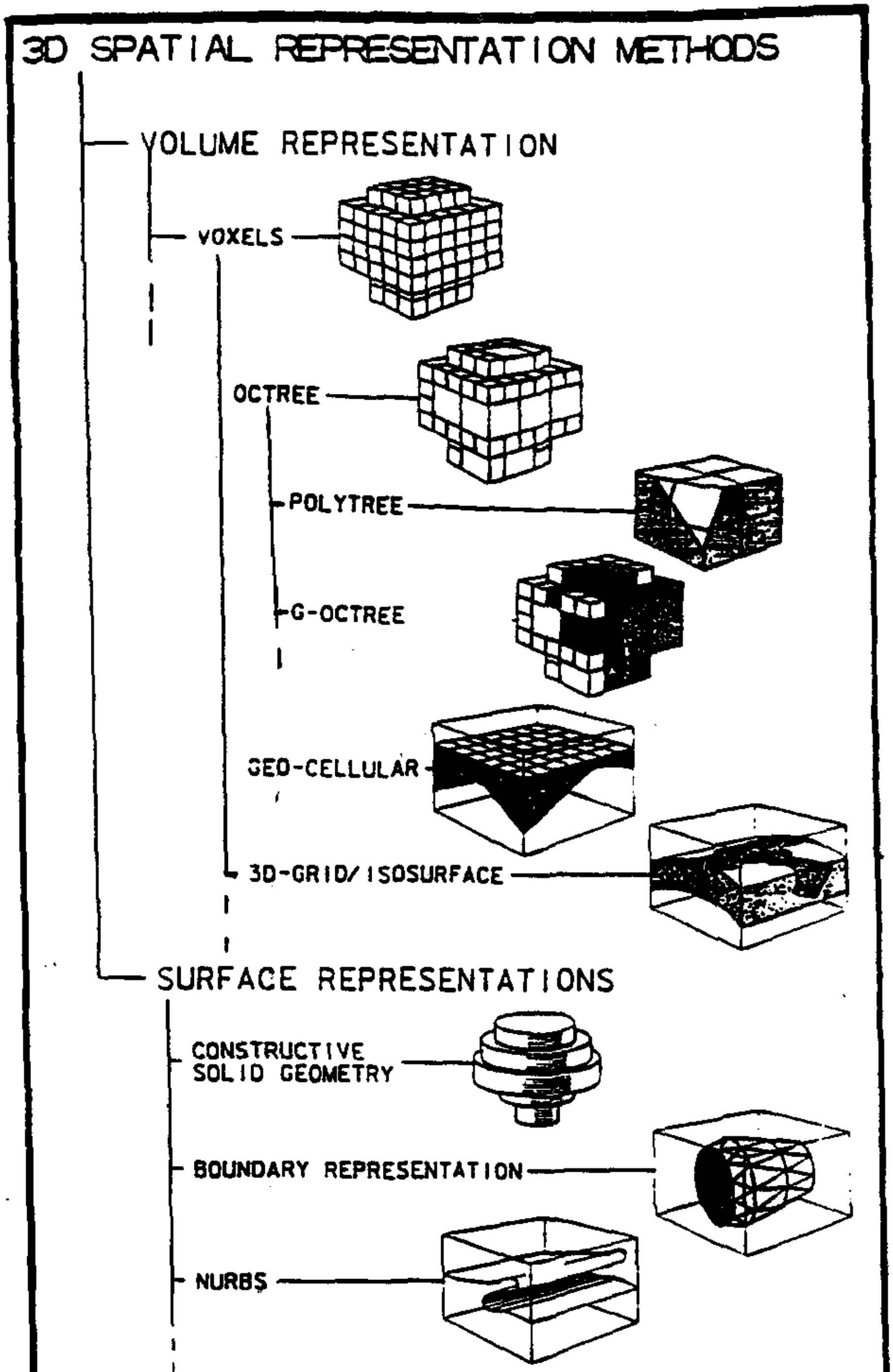


Figure 2: Three-dimensional spatial representation methods.

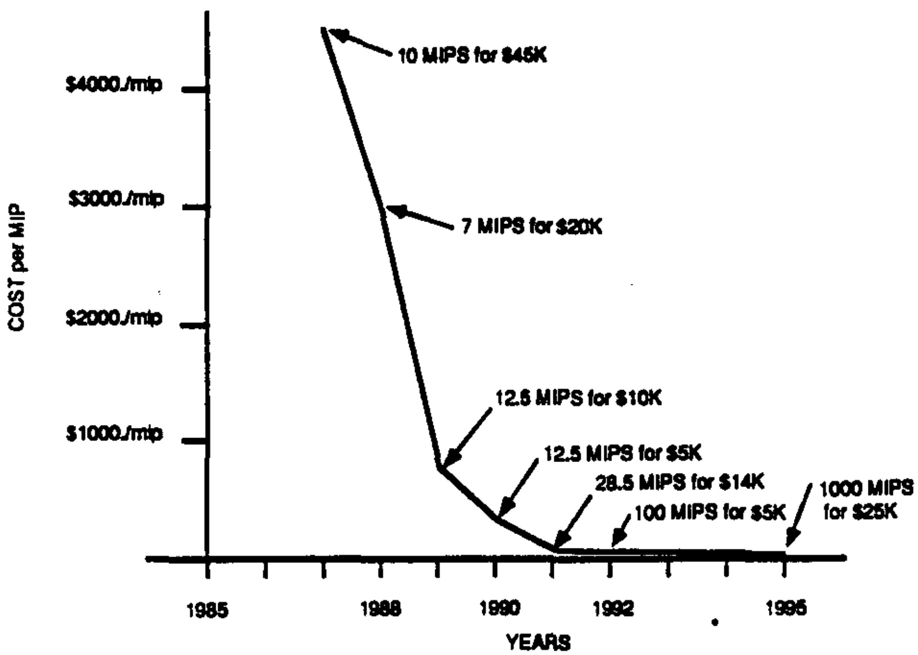
TWO FACTORS HAVE AFFECTED 3-D GIS DEVELOPMENT

1) Dramatic drop in cost of computer memory
2) Dramatic rise in computation speeds, at fixed or lowered costs.

NET RESULT = huge rise in effective performance/cost ratio.

WORKSTATION COST/PERFORMANCE RATIOS

(SOURCE: GISDEX'91, Washington DC)



COMPUTATIONAL REQUIREMENTS

Functionality	Total	Increment
2-D static	1x	
2-D dynamic	10x	10x
3-D wireframe dynamic	40x	4x
3-D shaded surf. dynamic	2000x	50x
3-D solids modeling	20,000x	10x
3-D maximum realism	200,000x	10x

NOTE: "Dynamic" = motion at 10 frames/second

OVERVIEW OF EXISTING 3-D GIS PRODUCTS

* until recently, no true 3-D commercial systems
* true 3-D GIS supports 3 independent coordinate axes (X,Y,Z) plus observational values
* isometric surface representations are "2.5-D"
* CAD/CAM have 3-D capabilities, but do not handle objects with uncertain shapes

Some Commercial 3-D GIS Products

Interactive Volume Modeling (IVM)

* a 3-D contouring system that develops nested iso-surfaces ("onion skins")
* borehole picks develop bounding surfaces which control 3-D contouring within geologic units
* fault-handling and geologic process modeling are under development

Geotechnical Modeling System (GMS)

* a true 3-D system originally developed for mine design and management
* converts borehole, map, and cross-section data into 3-D objects
* supports geostatistical operations

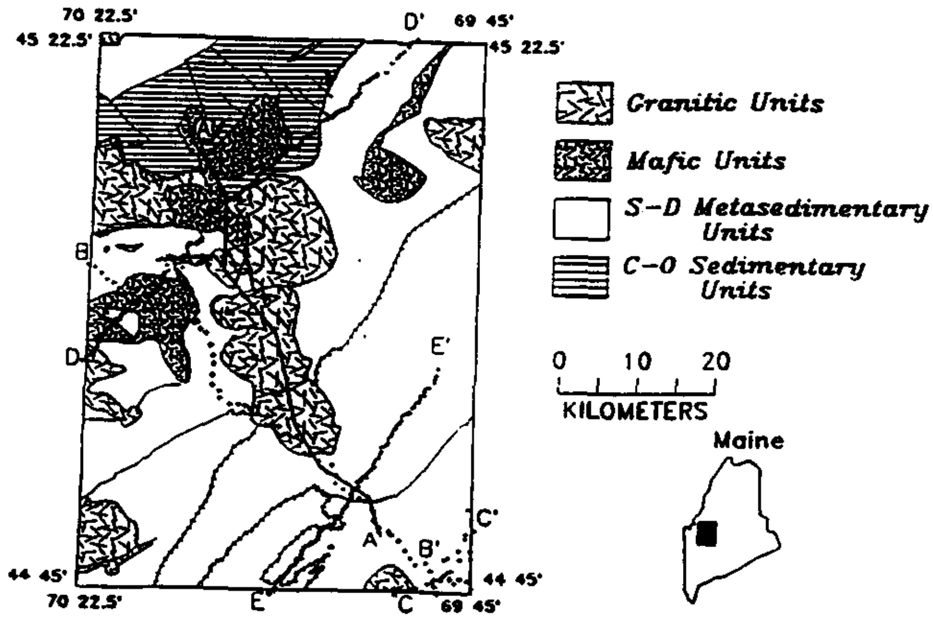
Intergraph Corporation Approach

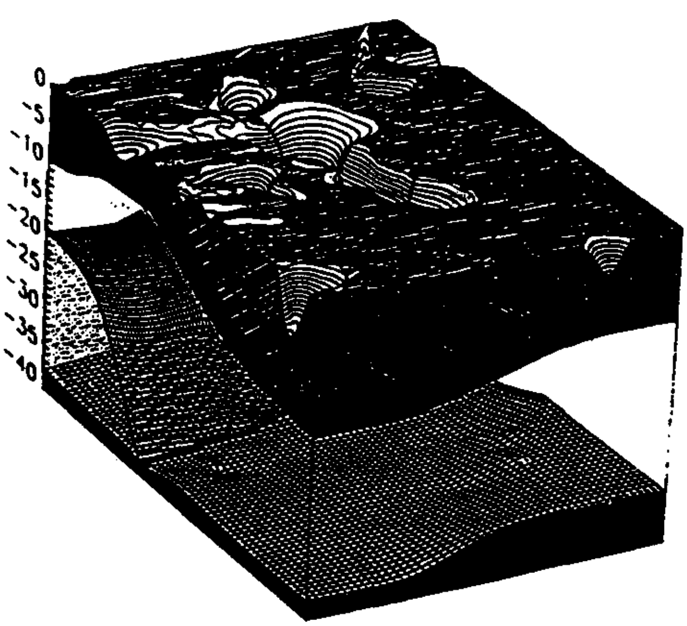
* 2-D and 2.5-D geological products under MicroStationGIS Environment (MGE)
* borehole/geophysics from petroleum applications
* MGE supports queries to RDBMS
* new ground-water flow and contaminant modeling applications in Beta-test
* future 3-D geologic applications may involve NURBS to model complex lines, surfaces, and volumes

EXAMPLES OF 3-D APPLICATIONS

2.5-D APPLICATION

* 2.5-D is not true 3-D, but does allow for isometric and perspective views.
* The ***Gulf of Maine Transect*** (USGS) utilized Interactive Surface Modeling (ISM) to produce a perspective view of the map area shown.





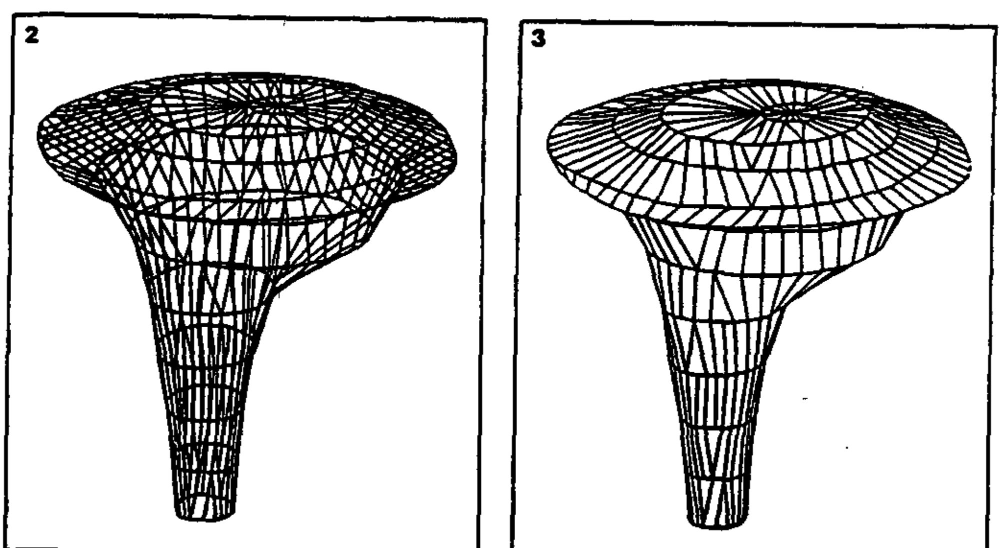
3-D MESH GENERATION

- a commonly used ***Boundary Representation*** method involves the creation of a 3-D triangulated mesh -- the mesh can be generated in several ways, but one method seems particularly attractive to geoscientists. This method, called ***Surface Triangulation*** involves the linking of a series of approximately parallel boundary loops (which may be contour lines, or cross-sections) with a series of shortest span linking triangulated facets (see next page)

- The method generally requires some intervention by the user to produce an optimal mesh. Problems occur when two boundary loops are not coincident, or one is very different in size/shape from the other (see next page). These can be solved by allowing definition of relationships between parts of the boundaries, and some manual over-ride of the automatic process.

- The salt dome, shown below, was generated by joining a series of horizontal boundary loops to create the polygonal mesh. On the left, all mesh elements are shown, and a ***Wireframe*** display is created.

- On the right, the triangular facets, or panels, are considered opaque, and so hidden lines are removed. This requires some additional computing time, but more clearly represents the "solid" model. Additional aids to visualization can be applied by applying **color and light sources** to produce a ***fully rendered shaded volume model.***



Small Thrust Belt in Spanish Pyrenees

* An example of a fully rendered shaded volume model based on 3-D mesh techniques (REF: Klein, H., Pflug, R., and Ramshorn Ch., 1989, Shaded Perspective Views by Computer: A New Tool for Geologists, *GEOBYTE*,Aug. 1989, pp.16-24).

* The area contains a small thrust belt within the southwest Pyreneen foreland basin. Upper Cretaceous units are quite complexly deformed due to flowage within Triassic evaporites. Six parallel cross-sections (A through F) were published.

* A 3-D mesh model was constructed using these sections. In order to produce a satisfactory mesh, 5 additional cross-sections were developed, one between each pair of the six published sections. The triangulation and display required:
  - 4 hours to create the five new cross-sections.
  - 2 hours to digitize two surfaces from all 11 cross-sections.
  - 1 hour to perform the interactive triangulation and create the model.

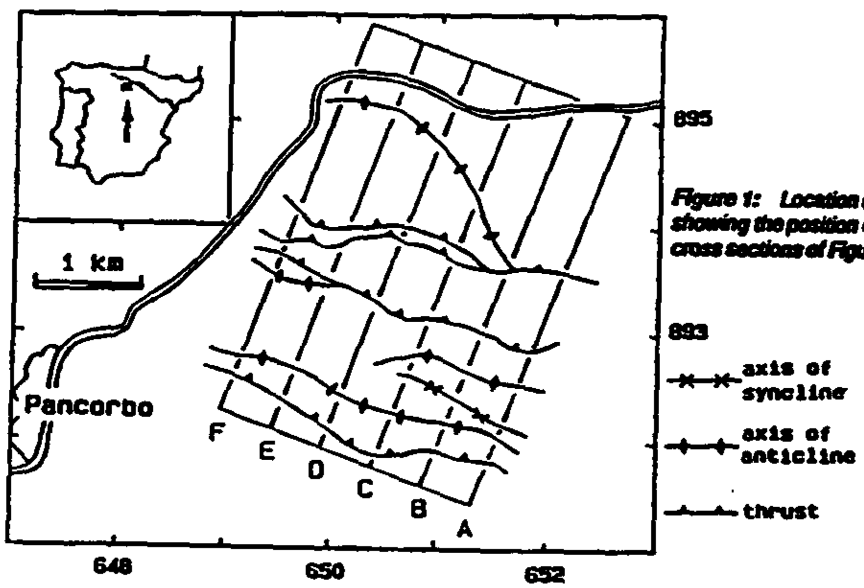


Figure 1: Location map showing the position of six cross sections of Figure 2.

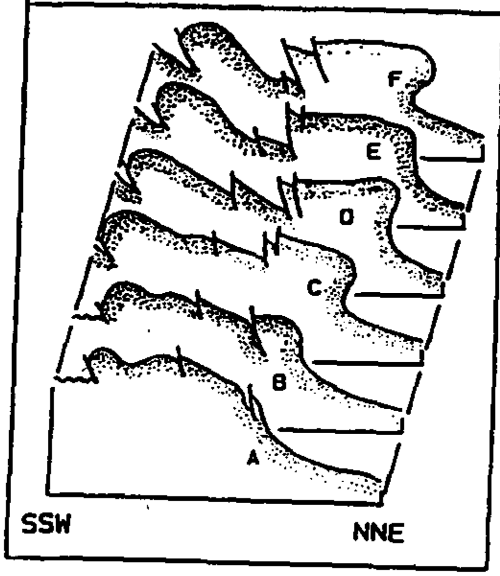


Figure 2: Serial sections through the upper surface of Figure 6, isometric projection, not to scale.

TRUE 3-DIMENSIONAL CONTOURING (PRODUCING ISO-SURFACES)

* Interactive Volume Modeling (IVM) is the foremost commercial product using this method. It contours using a ***Minimum Tension Algorithm*** from a 3-D grid mesh. The mesh values are handled by ISM. IVM has very good rendering capabilities.
* Geological units can be defined by surfaces, and the contouring of properties can be restricted **within** such a unit.
* IVM allows the selective display of iso-surfaces, and the cutting (or slicing) of the model along all major axes to display interior conditions.
* IVM has been widely used in petroleum and environmental applications.

Porosity and Permeability of a Limestone Block(J. Raper)

A block of limestone, which measured 35cm long, 15cm wide, and 15cm thick was cored in 5cm cubes from which the porosity and permeability were measured. The measured porosity distributions reveal the 3-D morphology of high porosity zones which form discrete 'pipes' through the limestone block. Similar features can be seen in the permeability model.

Agricultural Chemical Monitoring

Data from an area at the Rosholt Research Farm in Minnesota have been examined. Levels of nitrate were measured in about 40 wells at multiple intervals between July 1988 and May 1990, and levels of atrazine were similarly monitored during the summer of 1989. The site is located on sandy glacial outwash which forms a shallow unconfined aquifer.

Since the application volumes of these chemicals are known, the 3-D modeling is being used to perform volumetric modeling of the plumes to demonstrate:

1) the value of being able to visualize these concentration distributions, and
2) a method for computing the mass of agricultural chemicals remaining in aqueous solutions in ground water.

The visualizations have shown that the original experimental plots were too close to each other to allow for determination of the effects of different application rates, there was a significant "cross-over" between plots. The visualizations clearly demonstrate the seasonal variations in the plumes. Additional methods of determining plume volumes will be used, including geostatical approaches, and these results will be compared to the IVM volumes.

Recent IVM Extensions - Fault Handling and Geologic Process Modeling

Recent IVM developments include a fault modeling capability, illustrated with examples of off-shore oil-field data, and geologic process models which allow the user to define cross-cutting relationships among geo-objects. This latter capability is illustrated with a model of intersecting channel deposits.

USE OF NURBS FOR GEO-OBJECT DEFINITION

Alluvial Facies Definition, South Platte River Alluvium

* The selected area involves a 5-mile stretch of the South Platte alluvial valley-fill near Platteville, about 30 miles north of Denver.

* Stratigraphic and sedimentological analysis of 130 water well logs, supplemented by shalow geophysical soundings, were used to develop 6 transverse and two longitudinal cross-sections.

* Published geological and hydrological data were used to generate water table and bedrock surface contour maps.

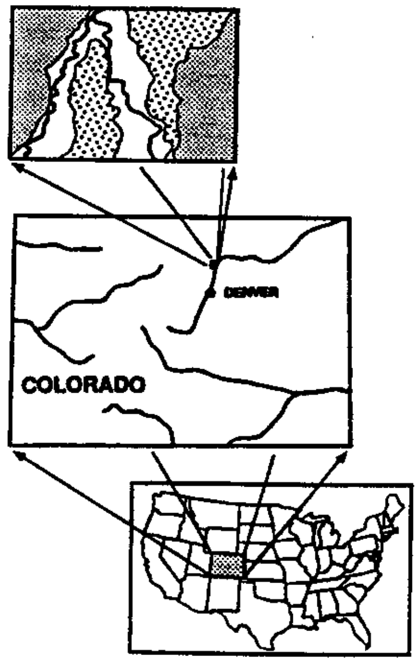
* *Stratal Architecture* and *facies modeling* techniques were used to convert the observations into a more complete 3-D correlated spatial model.

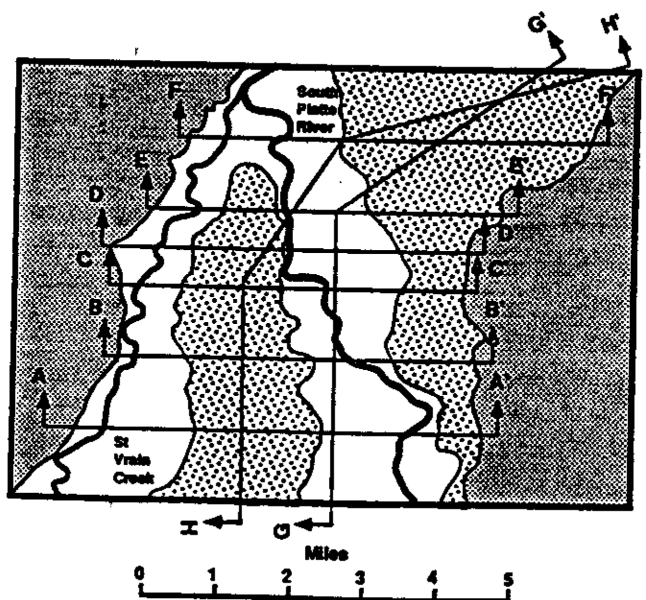
* Well log records and geophysical interpretations were used to create a 3-D digital spatial framework model with the Intergraph I/EMS CAD system.

* Individual cross-sections were scanned and these digital bit-map images were registered to the well-log and geophysical data.

* Selected identified channel boundaries in the cross-sections were digitized.

* These were used to define 3-D solid "channel-sand geo-objects" with NURBS methods.





LEGEND

A — A' Location of Section A-A'

NOTE: Sections A-A' through F-F' are transverse to the valley.

Sections G-G' and H-H' are longitudinal sections along approximate paleo-channel axes.

MINING APPLICATIONS WITH 3-D COMPONENT MODELING

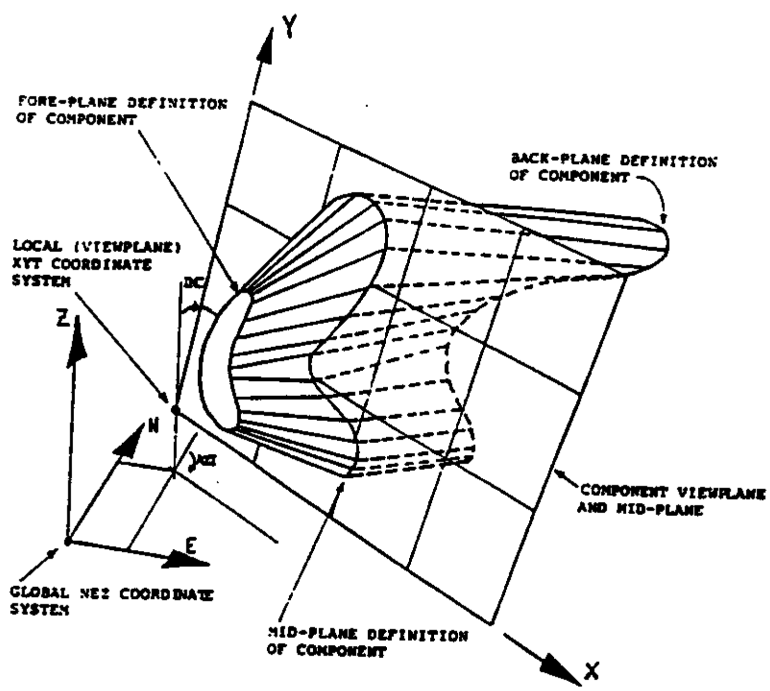
* Mining applications have specific needs:
  - accurate volume calculations
  - model *sampling-limited* (geological) features
  - model *definition-limited* (ore grade) feature
  - model mining elements with simple elements
  - allow continuous updating of the model as new data acquired
  - interface with statistical, production, and engineering modules

* Lynx Geosystems have developed a system to satisfy these needs which utilizes a data management scheme defined as *3-D component modeling*. This involves:
  1) Development of a borehole data base
  2) Interactive creation of interpretative cross-sections between boreholes
  3) Development of *3-D modeling elements* for each component on each cross-section by creating a "thickness" around each cross-section with *"fore-plane"* and *"back-plane"* definitions
  4) The individual elements can then be interpolated to form component volumes.
  5) Intersections of components can be readily determined and accurate volumes computed with these techniques.

* The method can be used equally well for complex and strataform deposits.

* Bounding surfaces (such as the terrain) can be defined with triangulated meshes and used to limit the extent of modelled components.

* Engineered mining and civil engineering elements can be combined with natural objects.



The Definition and Geometric Characterization of a 3D Component (Modelling Element) Representing an Irregular Volume.

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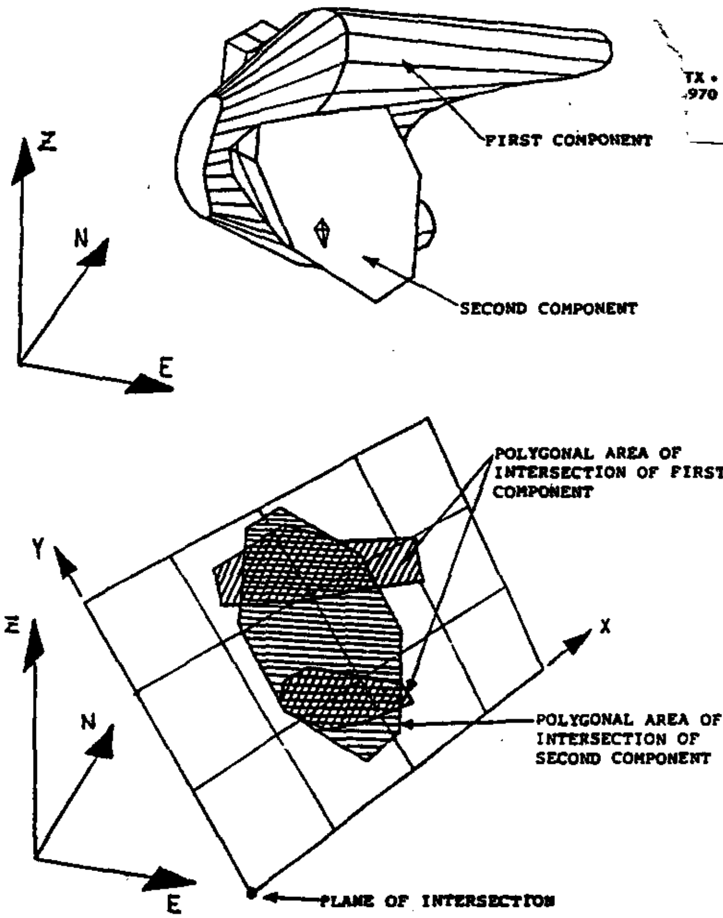


Top: Two Components Which Intersect.
Bottom: A Common Intersection Plane showing the Polygonal Areas of Intersection.

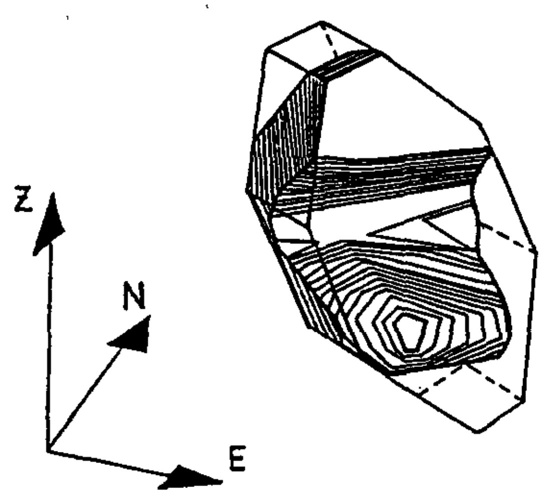
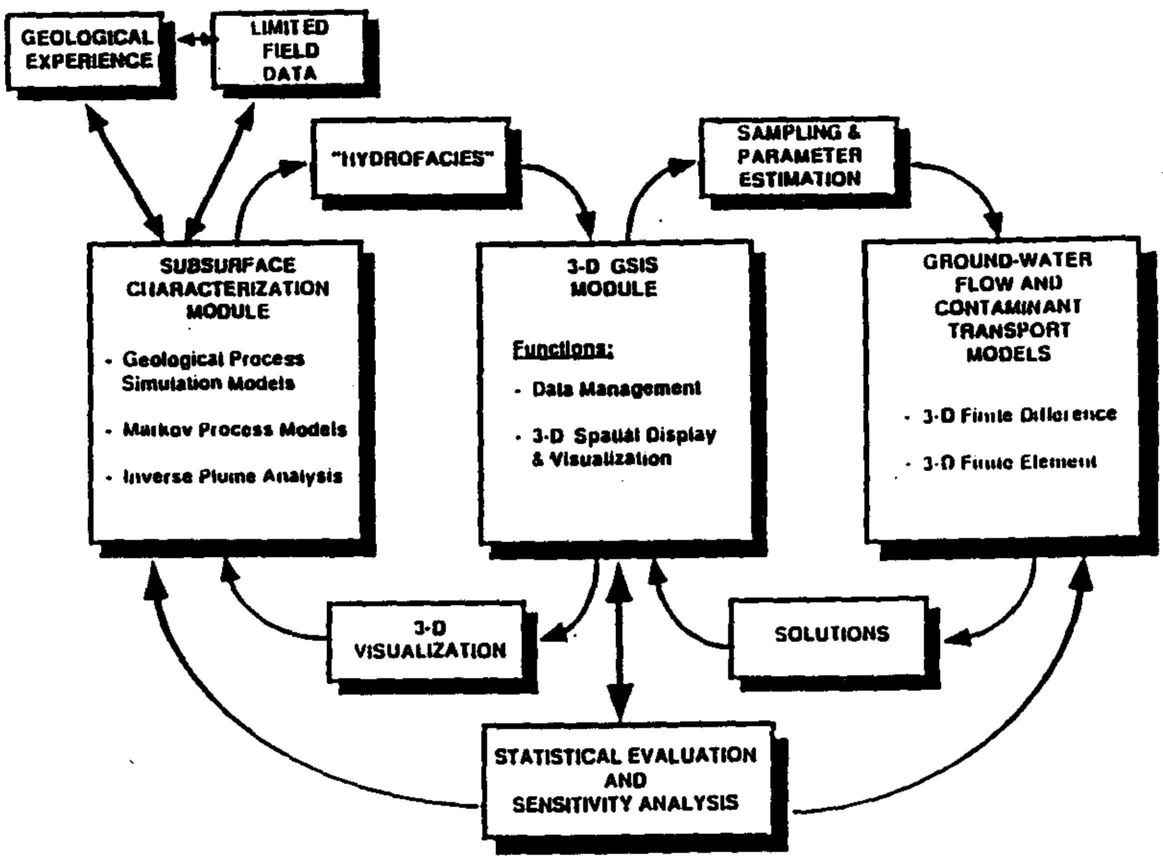


Figure 8. Parallel Intersection Planes through the Volume of Intersection of Two Components – Used for Volumetric Integration

Geologic Process Simulation Modeling

* many methods and approaches
  - process simulation
    - deterministic models
    - stochastic models
    - combined methods
  - inverse solutions
  - Markov Process models
  - Geostatistical Models
  - Fractals

* when linked with GSIS procedures, the techniques become very powerful



Information Flow and the Role of Three-dimensional GSIS for Hydrogeology.

A LOOK TO THE FUTURE

What Are Outstanding the Issues?

* How do we handle volumetric properties?
* Do volumetric modeling methods (based on Octree's) give satisfactory display?
* How do we handle faults?
* What are User Interface requirements?
* What about data availability and standards?
* How will GSIS interface with other applications?

PROBLEMS IN GEOLOGICAL MODELING

1) data base integration
2) complex data structures
3) inadequate relational retrieval logic
4) difficult Ad Hoc query language
5) lack of DBMS transportability
6) lack of standard geologic unit codes
7) lack of data and format standards
8) maintenance costs increase with time
9) difficult quality control:
   - multiple sources for some data
   - names change with time
10) interface with graphics
11) interface to applications software
12) rate of change of information technology
13) inaccurate base maps
14) raster/vector conversion methods

SOLUTIONS TO GEOLOGICAL MODELING PROBLEMS

1) database standards and exchange formats

2) raster/vector translations in GIS

3) new geodetic survey stations (GPS)

4) UNIX Workstations

5) SQL

6) extensions to UNIX and SQL to handle graphical objects

7) object oriented databases

8) new mass storage/distribution systems

9) hypermedia concepts

CONCLUSIONS

3-D VOLUMETRIC MODELING ENHANCES THE INTERPRETIVE PROCESS:

It allows the geoscientist to:

* See and Understand Spatial Relationships and Variations
* Test Alternative Hypotheses
* Enhances Creative Process

3-D VOLUMETRIC MODELS HAVE CENTRAL ROLE BECAUSE:

They provide the geoscientist with:

* strong links with:
  - data bases
  - statistical methods

* three main functions:
  - data management
  - analytical modeling
  - visualization and display

* support for QA/QC requirements