

# THE ROLE OF GEOLOGICAL MODELING IN A WEB-BASED COLLABORATIVE ENVIRONMENT

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## INTRODUCTION

Over the past two decades, a series of sophisticated three-dimensional modeling technologies have been developed to address the need for a precise definition of subsurface conditions (Turner, 1991). Because geological modeling requires the extension of traditional GIS methods (Turner, 2000; 2006), the modeling process remains technically challenging. In 2001, during a conference sponsored by the European Science Foundation, four major impediments to the greater use of subsurface geological modeling by a broad spectrum of users were identified (Rosenbaum & Turner, 2003). These constraints were: (1) a lack of 3D/4D mathematical, cognitive, and statistical spatial tools, (2) a lack of cheap modeling tools designed for the shallow subsurface that can be operated without specialist personnel, (3) the inability of models to depict natural variability of geological systems, and (4) a shortage of case histories. By 2008, these constraints had been largely overcome with the use of new modeling software and techniques and, importantly, with an understanding of the needs of the client (Kessler, *et al.*, 2008).

Unlike the older resource-industry-based user-community, many of today's potential users of geological models and visualizations cannot interpret basic geoscience data or evaluate the merits of alternative interpretations. They may be unable to distinguish between theories and facts. In short, these new users clearly desire "solutions, not data" and "information in understandable form" (Turner, 2006). Society increasingly demands that earth- and environmental-resource issues be evaluated and addressed by interdisciplinary investigators from the scientific, engineering, planning, and regulatory communities. Often these investigators are required to interact with a larger community of public stakeholders. These investigators, also, by necessity, develop databases and models derived from disparate data sets that are often large, complex, and vary dramatically in scale and quality.

Two critical technological innovations can assist participants engaged in these societal decision-making exercises: (1) second-generation internet, or Web 2.0, technologies and hosted services facilitate communication among online groups belonging to Web-based communities, and (2) client- and Web-based 2-D and 3-D visualization systems (including Google Earth and Google Maps).

## THE GEOLOGICAL MODEL-BUILDING PROCESS

Figure 1 illustrates the steps in a typical geological modeling process. Raw data collected from various sources can be considered as two types – spatial data and properties data. The spatial data are used to create a 3-D geometry model, shown on the left-hand side of Figure 1. Geometry modeling involves two steps – first the development of a suitable geometric representation of the fundamental "geological framework," and subsequently the subdivision, or "discretization," of this framework to allow for the attribution of spatially varying properties. Discretization also supports analytical computations within the numerical models used in predictive modeling. The horizontal arrow linking the discretization and analytical modeling operations in Figure 1 defines this linkage.

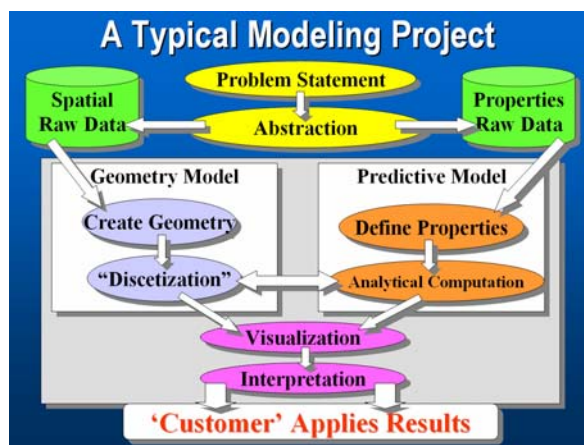


Figure 1. Overview of the geological modeling process.

An accurate representation of the geological framework allows for 3-D visualization, but even more importantly defines and controls the spatial distribution and propagation of rock-properties required by modeling. Sedimentary environments are usually modeled by creating surfaces defining the strata interfaces, stacking the surfaces in stratigraphic order, and subsequently defining the zones between surfaces as geologic units. Construction of individual surfaces generally proceeds by one of three methods: (1) using the borehole observations to create

triangles defining a surface, (2) applying surface generation and contouring procedures to borehole observations, or (3) developing a series of interpretive cross-sections between boreholes. Regardless of the method used, several problems remain. Surfaces created independently may intersect each other in geologically impossible situations, thus careful review and editing of all surfaces is usually required to allow for areas of erosion or non-deposition (Turner, 2006; Turner & Gable, 2007). Figure 2 is an example of a 3-D geologic framework model of a layered sedimentary environment – a part of the Edwards Aquifer in Texas.

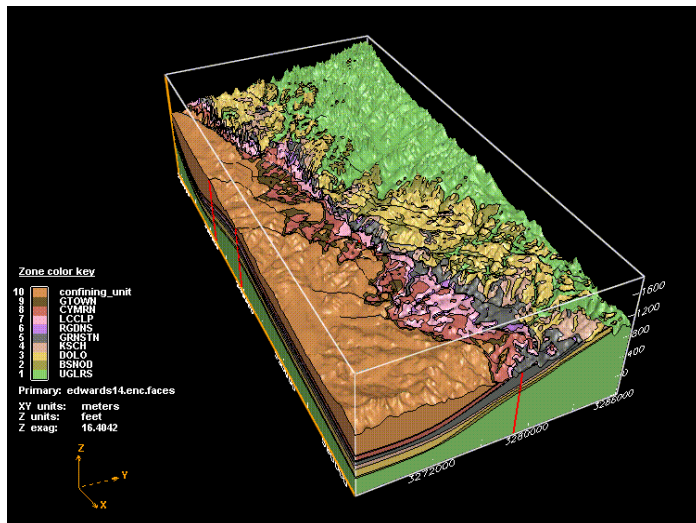


Figure 2. Overview of the Edwards Aquifer stratigraphic model (Pantea & Cole, 2004),

Other techniques are used to model regions with complex geological structures, or without layered sequences. One approach is to develop a series of complex shapes enclosing volumes derived from a series of interpreted cross-sections. The individual volumes must share common bounding surfaces so that there are no voids or overlapped volumes. Several 3-D modeling products used by the mining industry provide such model building capabilities (Houlding, 1994). An alternative approach begins with an entire regional volume and then progressively subdivides it into regions with a series of intersecting surfaces that represent major discontinuities such as shear zones or faults. The various regions may have distinct material properties with oriented anisotropies or gradients, while the discontinuity surfaces may also be assigned widths and unique properties (Turner, 2006; Turner & Gable 2007).

A number of modeling tools have been proposed to assist the accurate representation of faults. Rock strata on opposite sides of a fault may have similar or different thicknesses and characteristics depending on the type of fault and the temporal relationships between the depositional processes and the faulting. Faults may provide preferential conduits for fluid flow, or they may act as barriers to flow. They typically add anisotropy to property distributions required by the numerical models. Vertical, or nearly vertical, faults and nearly horizontal thrust zones can be defined by adding additional surfaces to the existing stratigraphic models (Figure 3). This increases the complexity of model creation, but otherwise is relatively straightforward. Moderately inclined faults present greater modeling difficulties.

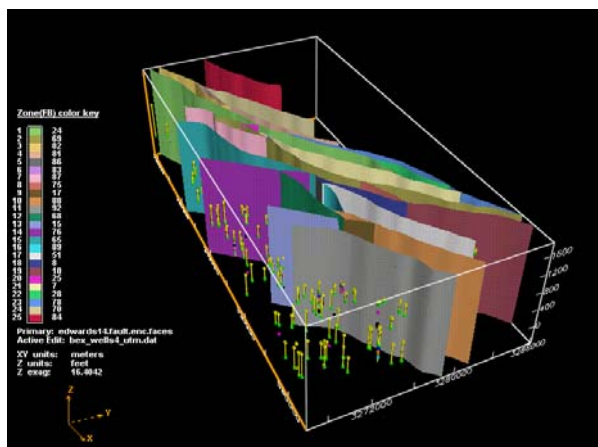
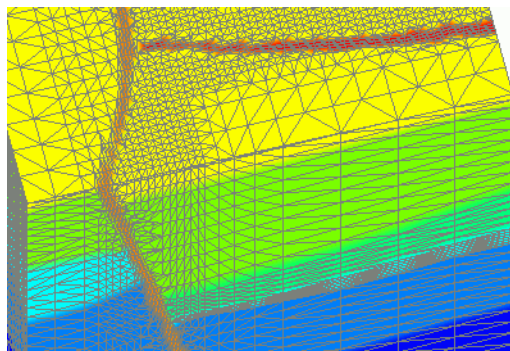


Figure 3. Overview of faults and wells contained within the Edwards Aquifer model (Pantea & Cole, 2004).

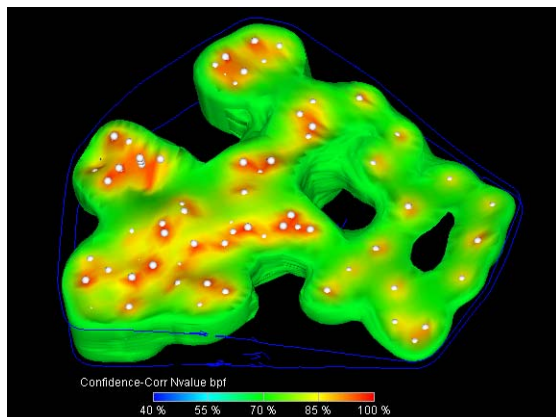
Property distributions are generally modeled by applying discretization methods to subdivide the framework objects into a series of small elements. There are two broad classes of meshes – structured and unstructured (Turner, 2006;

Turner & Gable, 2007). Available commercial geological modeling products mostly use basic structured meshes – a 3-D volume is divided into discrete cubical “volume elements”, or “voxels.” Unless the cell dimensions are very small, important geometric details may be lost, but small cells produce extremely large model files. Hierarchical cells provide greater flexibility in adapting grid resolution to where it is needed – in 3-D, the “octree” representation provides this functionality. Unstructured meshes are not constrained by having to have a constant node and face structure, and can link with finite element models. Three-dimensional unstructured meshes, based on tetrahedrons, hexahedrons, are particularly useful in modeling faults and fracture discontinuities (Figure 4). This provides added flexibility during model development, but this flexibility comes at a price: added computational demands and more effort in model construction that requires use of sophisticated mesh generation software (Gable, et al., 1996).



**Figure 4. A 3-D unstructured mesh model of a faulted layered sequence (Source: Carl Gable, Los Alamos National Laboratory)**

As shown on the right-hand side of Figure 1, the primary objective of subsurface geometry modeling is to provide geometric controls and property distributions for some type of analytical modeling, and the purpose of this analytical modeling is prediction. Prediction has an extrapolative rather than interpolative character; thus it involves risk and uncertainty. Prediction leads to decision-making. Predicted results often require supporting visualizations and interpretations that can be presented to and used by the “customer” of the modeling results (Figure 5).



**Figure 5. A 3-D predictive model showing confidence levels of the density of till underlying the Boston financial district (Source: Laurie Baise, Tufts University).**

## THE ROLE OF 3-D MODELS IN A WEB-BASED COLLABORATION ENVIRONMENT

The entire 3-D geological modeling process is but a single component of a much larger, modular “Internet-based Earth-Systems Monitoring, Analysis, and Management Tool” (Figure 6) that provides the essential earth-science business and data-management processes required for Web-based collaboration in an “Earth-Systems Investigation Enterprise”. The “Knowledge Portal” and the “Collaboration Environment” are key additional components required to function successfully within a Web-based collaborative enterprise. These components provide users with the capability of searching, discovering, posting, mapping, visualizing, and archiving data, information, news, and commentary. They also provide essential enterprise security and control functions, including user interaction and access, group management, and content management (Figure 6).

Visualizing 2-D maps and 3-D models is a critical function of the tool’s “Knowledge Portal” that also should allow users the ability to query, explore, comment on, and potentially contribute additional data and information to, these models. Utilization of tools such as Google Maps and Google Earth permits a richer fusion of these models with

information that previously has not been viewed in the context of 3-D models, including scientist or other user-contributed photos, video, audio, wikis, Web-logs, and online news.

In contrast to Web-based data management and analysis systems designed to serve the scientific community, a platform that employs “off-the-shelf” and consumer-oriented, hosted Web-services better reflects the information needs and Web-interface usage behavior of the general public. An early form of these tools and services is being used to facilitate the investigations and conversations of scientists, resource managers, and citizen stakeholders addressing water-resource sustainability issues in the Great Basin region of the desert southwestern United States (Figure 7).

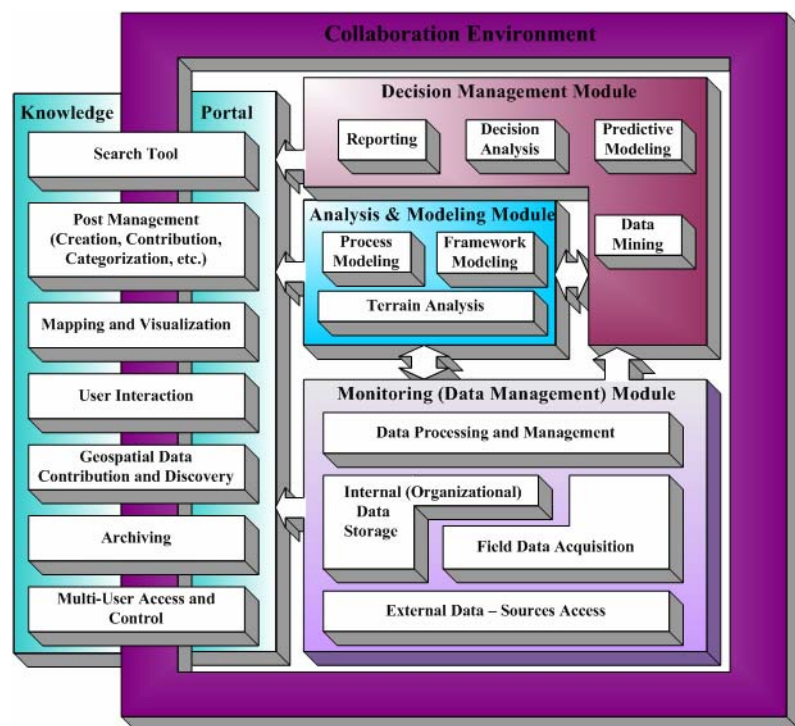


Figure 6. The modular components of the Internet-based Earth-Systems Monitoring, Analysis, and Management Tool.

The Knowledge Portal and Collaboration Environment are the essential information-technology building blocks of the larger platform.

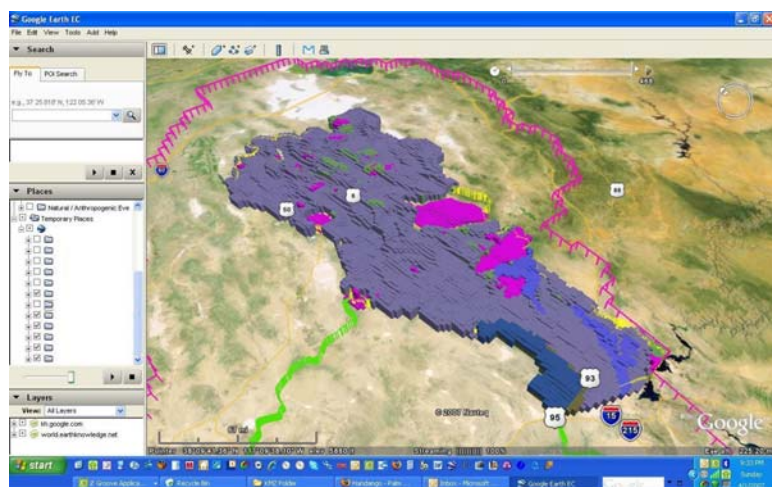


Figure 7. A volumetric model of a portion of the aquifer systems in the Great Basin, southwestern United States visualized in Google Earth.

During the past decade, several European, Canadian, and American geological surveys have gained considerable experience with applying existing commercial technologies to create 3-D geological framework models. These models have been developed for a variety of geological situations at various scales and levels of geologic complexity. Large advantages have been demonstrated when such models have been linked to numerical models of physical processes, specifically ground-water flow models, to provide specific and quantifiable answers to decision makers. Yet, these experiences clearly demonstrate that computer technology alone cannot enable geoscience knowledge integration. Rather, they emphasize that human-computer interaction must be supported by a 'geoinfrastructure' that contains integrated, formalized, and fully documented protocols. O'Brien, et al. (2002) define such a 'protocol' as equivalent to a 'business process' and specify that appropriate protocols contain the rules that define the data flow, sequencing of events, techniques, and standards that integrate various inputs to create a measurable output. Thus, widespread future use of geological models will require adoption of Web-based tools that are familiar to, and accessible by, the general public, making geological modeling and visualization accessible to a broader user base. This will support increased collaboration, which will, in turn, result in better models and greater applicability to societal needs.

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