Acquisition of 3D Subsurface Well Data and 3D GIS for the Ventura Basin, California

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Abstract

In the Ventura basin, faults and folds accommodate high rates of oblique crustal strain and uplift rates exceed 10 mm/yr. To improve our understanding of how faults and folds develop in oblique convergence and to test the reliability of 2D models to predict 3D subsurface structure, we acquired a unique 3D dataset for the Ventura Basin provided by the Ventura Basin Study Group (VBSG). The VBSG study consists of 17 structure contour maps and 84 interlocking cross section data panels based on nearly 1200 correlated deep-penetration wells. The wells vary in depth from 1 to 5 km. Many of these wells drill active fault and fold structures associated with major fault systems, including the San Cayetano, Oak Ridge, and Santa Susana faults. This integrated 3D study is based on wire-line logs, mud logs, paleontological reports, core analyses, and surface maps. Each data panel typically ties in 4 directions to define the sides of a 3D data volume or cell. The result is a 3D presentation of an enormous quantity of high-quality subsurface data that have been reconciled into a coherent geological interpretation. Any 2D or 3D kinematic model of the basin and its associated fault and fold geometry, as well as any valid estimate of the seismic hazard, must incorporate these data if it is to be successful. The VBSG structure contour maps and cross sections are now available to the entire NEHRP research community from our website at http://www.crustal.ucsb.edu/hopps.

Purpose of Project

There are two primary purposes of this project:

1) To acquire the Ventura Basin Study Group (VBSG) database of subsurface well information files consisting of nearly 1200 correlated deep-penetration wells, as well as the results of the VBSG study that includes 17 structure maps and 84 structure cross section data panels that were produced using these subsurface data.

2) Establish an on-line digital subsurface database of the Ventura basin, starting with the VBSG study and dataset. This evolving 3D database, which will eventually include maps, cross sections, well files, seismic reflection data and seismicity, will provide: (a) the framework for developing improved 3D models of how faults and folds develop in oblique convergence; (b) the ability to test and evaluate the reliability of 2D models to predict 3D subsurface structure; and (c) improve our understanding of the seismic hazards associated with these major fault and fold systems that comprise one of the most active tectonic areas in southern California.

Results

Funding for this project began April 17, 1997. No FY98 funds were received. This progress report thus covers the nominal 12-month period extending from about mid-April 1997 to mid-April 1998. Most of the available FY97 funds were expended in the first 6 months of the contract period.

The VBSG proprietary study and dataset were successfully acquired and are now available through a unique data license negotiated by ICS on behalf of NEHRP and the Southern California Earthquake Center (SCEC). The VBSG maps and cross sections have been scanned and are currently available as jpeg images from our ICS website. **Figure 1** shows a screen image of the VBSG website in operation. The website includes a clickable cross section index map that allows users to individually view selected cross section images, as well as a clickable thumbnail catalog of all the VBSG structure contour maps and cross sections. A preliminary Java map applet of the evolving 3D GIS database is also available, along with a VRML demonstration of the potential 3D capability of the dataset (**Figure 2**).

Preliminary analysis shows that the VBSG dataset provides significant subsurface information regarding the location, orientation, and geometry of active subsurface fault strands—several of which had not been previously identified. For example, this study, which was completed in 1992, clearly identifies active blind south-dipping faults in the footwall of the Santa Susana fault (e.g., **Figure 3**), well before the 1994 Northridge earthquake, which occurred on just such a south-dipping blind fault. Other features clearly evident in the VBSG dataset include non-planar faults, basin subsidence, evidence of earlier normal faulting, significant variation in pre-folding depositional thicknesses and material strengths of rocks, high-angle reverse-separation fault geometry, and significant changes in fold orientation with time and space. These observations are consistent with the reactivation of earlier normal-separation faults in transpression—causing in some places basin inversion—and the accommodation of regional strain through rotation and significant components of strike-slip or oblique-slip motion. These observations, based on actual subsurface structure as it has been drilled, are not consistent with previously published 2D balanced cross section models that presume moderate to low-angle fault dips, planar fault surfaces, homogeneous layers of uniform thickness, the absence of strike-slip or oblique-slip motion, and the absence of any pre-existing structure that would control initial fault and/or fold geometry.

We have also begun initial analysis of the VBSG structure map and cross section interpretations using various kinematic and compatibility constraints, and have begun

the incorporation of other independent data into the Ventura basin dataset. The VBSG study and dataset only includes information from wells and surface geologic maps. It does not incorporate seismic reflection, gravity, or earthquake data, which provide important independent information on the geometry of major subsurface reflectors, the depth to basement, and the location, orientation, and sense of slip of active seismogenic faults. These preliminary kinematic and compatibility analyses have already identified several places were the VBSG interpretations can be improved, including the identification of two previously unsuspected faults that may act to segment the greater north-dipping Red Mountain-Santa Cayetano–Santa Susana fault system. These results have also been used to define preliminary finite strain fields and estimates of fault slip rates using 3D map restoration techniques. Combining the VBSG dataset with seismicity has proved particularly effective in developing improved understanding of how active fault and fold structures in the shallow and near-surface crust connect with—and are related to—deeper faults at seismogenic depths.

Future Work

Assuming that continued funding for this project becomes available, we hope to:

- Provide internet access to the VBSG database of well information files. This requires converting current well descriptions into useful GIS coordinates.
- Link the VBSG 3D dataset of maps, cross sections, and well information files to an on-line mapping application, and to other GIS relational databases.
- Continue to evaluate and improve VBSG subsurface interpretations of maps and cross sections using various kinematic and compatibility constraints.
- Integrate the VBSG dataset with other subsurface information, such as seismicity, gravity, and available seismic reflection data.
- Construct isopach maps of various formation intervals to help identify possible piercing points, lines or planes, and thus evaluate the magnitude of both the horizontal and vertical cumulative fault motion.
- Evaluate finite displacement fields using 3D map restoration techniques.
- Develop improved 3D models for the evolution of faults and folds in oblique convergence. Describe the variation in structural style along strike of major fault and fold systems and what the controlling elements for this variation might be.
- Tie the observed onshore 3D subsurface structure and geology in the Ventura basin to equivalent features observed offshore in the Santa Barbara Channel.
- Provide improved estimates of the seismic hazard based on this integrated 3D database of subsurface fault, fold, and basin geometry and related slip rates.

Currently, the continuation of this project remains unfunded. No FY98 funds were received because the review panel felt there was a supposed "lack of progress and direction for future work", even though our renewal proposal clearly stated that:

- no funding for this project had been received by the time the renewal proposal was due (April 4)—so there was no FY97 progress to report or expect;
- FY97 funding only covered acquisition costs of the VBSG dataset, and the initial establishment of the on-line database—not extensive data analysis; and
- the purpose of the continuation would be to conduct the goals stated above—each of which would make effective use of the VBSG data acquired in FY97.

Data Availability

The entire VBSG study of 17 maps and 84 cross sections is now available from our website at http://www.crustal.ucsb.edu/hopps. This website has already proven useful to a number of people working in southern California. In its first 4 months of operation (September 1997 to January 1998), it sustained 12,000 hits from 500 external (i.e., non-UCSB) users. Preliminary results of our on-going 3D map restoration project and analysis of fault displacements and finite strain fields are available at http://www.crustal.ucsb.edu/vbmrp. Specific information regarding the VBSG study and dataset is available by contacting Craig Nicholson at ICS.

Reports Published

Nicholson, C., D. Valentine, M.J. Kamerling, and T.E. Hopps (1997), 3D subsurface structure of the Ventura Basin: Analysis of active fault and fold development in oblique convergence, *SCEC 1997 Annual Meeting Report*, Costa Mesa, p.78-79.

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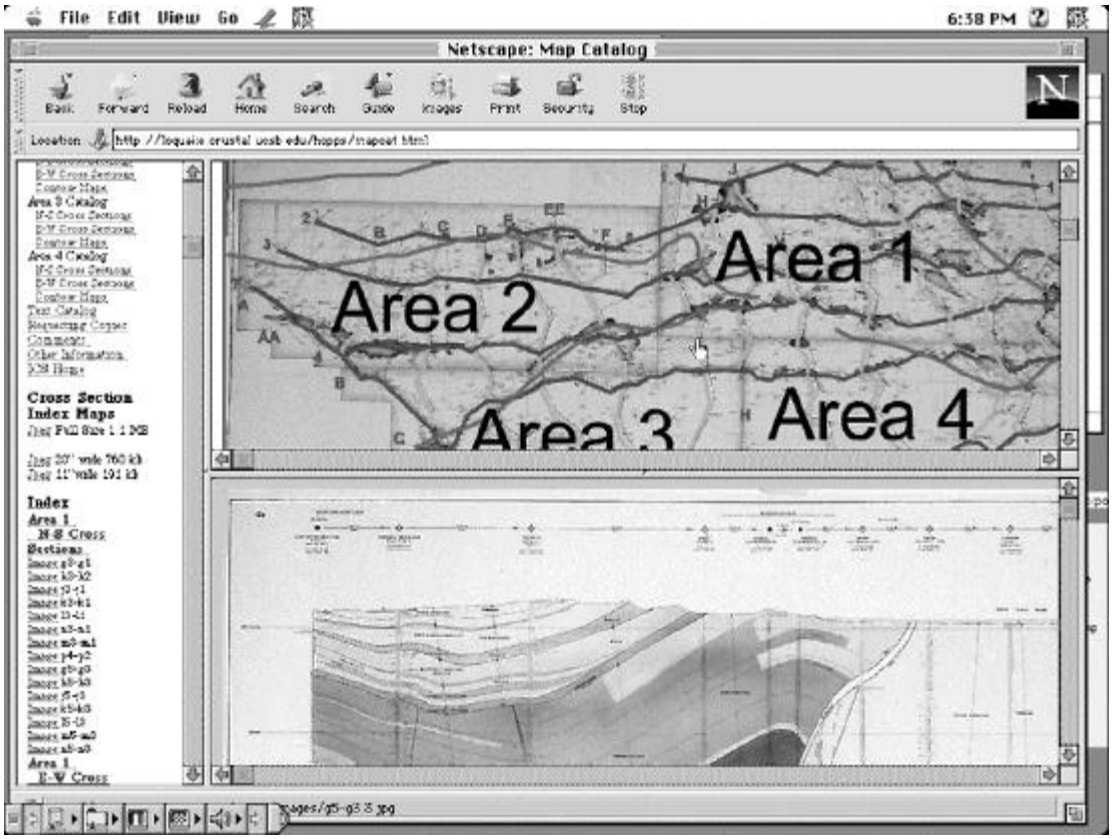

Figure 1. Screen image of the Ventura Basin Study Group website. The VBSG website includes a clickable cross section index map (top right), a simple text catalog (left), and a thumbnail image catalog (not shown), that allows users to access individual images of VBSG structure maps and cross sections (e.g., lower right).

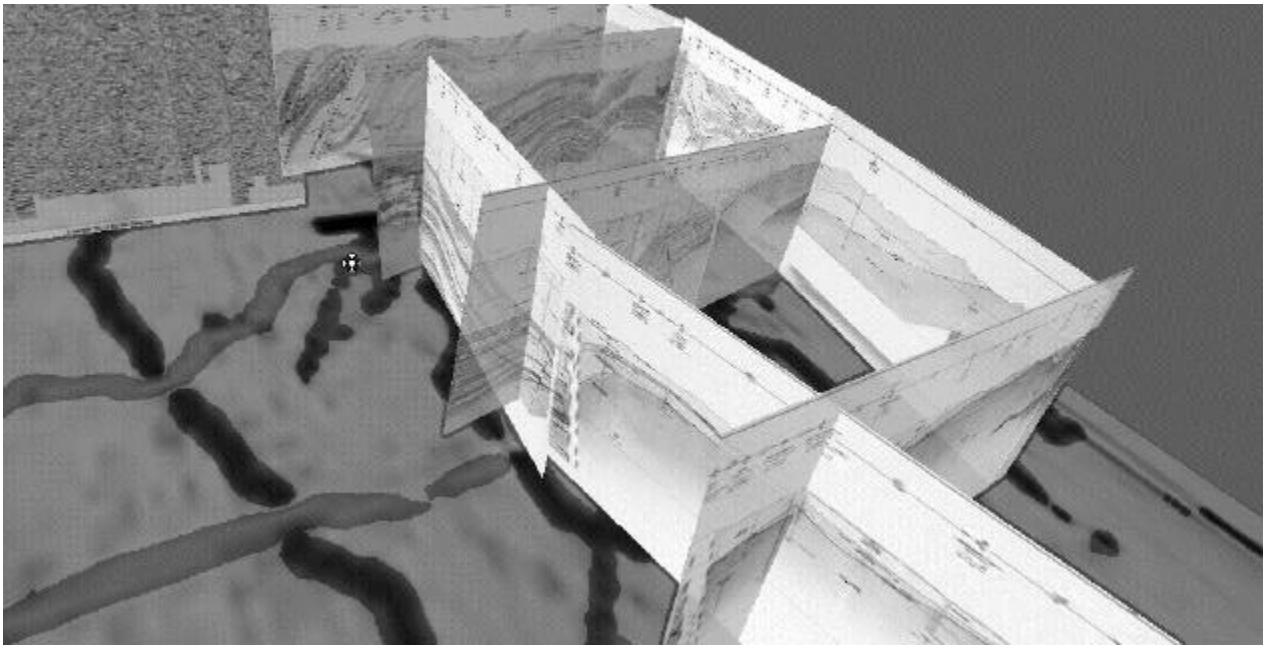

Figure 2. Prototype 3D VRML image of VBSG cross sections viewable from our ICS VBSG website (requires Navigator 4.0, Netscape plug-in, or SGI computer to access).

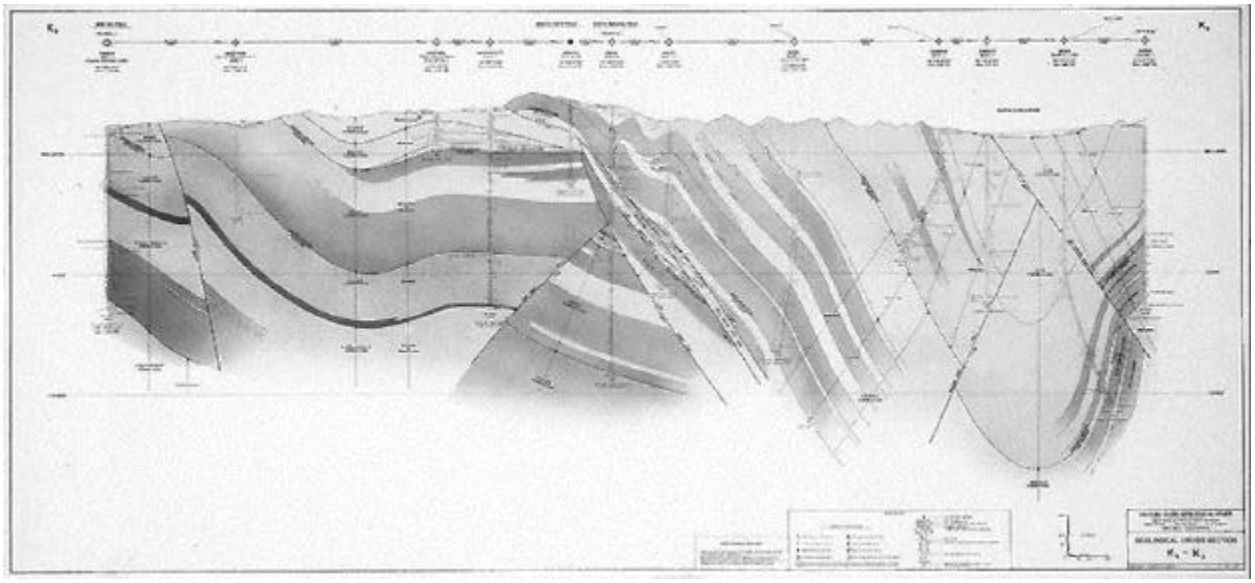

Figure 3. North-South VBSG cross section data panel across the Santa Susana fault showing the presence of a significant south-dipping blind fault in the footwall block, similar to the fault responsible for the 1994 Northridge earthquake.