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Shaded-Relief Map of the San Francisco Bay Region, California

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The most detailed and accurate portrayal of the region's topography to date was created from 35,000,000 digital elevations spaced 30 meters apart

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Summary

Topography, the configuration of the land surface, plays a major role in the initiation of one type of landslide common to the San Francisco Bay region, the debris flow (Ellen and others, 1997), and in the recognition of such other modes of slope failure as slumping, translational sliding, and earthflow (Wentworth and others, 1997). Accordingly, a topographic portrayal at both local and regional scales is helpful in assessing the likelihood of slope failure and mapping the extent of its past activity. This report, one of six separate but related documents (San Francisco Bay Landslide Mapping Team, 1997), provides digital data and plottable map files that depict Bay region topography in detail by analytical hill-shading, a old technique at last made practicable by the digital computer.

Hill shading, or *chiaroscuro*, portrays the three-dimensional shape of the land in two dimensions by intensity of the Sun's shadows. At least as old as Leonardo da Vinci's 1502-3 sketches of the Tuscan landscape (Horn, 1981), manual (artistic) executions of the technique can economically show only small areas accurately and in detail. However, Lehmann (1799) and later Wiechel (1878) developed analytical treatments that would eventually lead to automation. Thus quantified, the technique was finally adapted to the computer by Yoeli (1967). Analytical hill-shading in its current, digital, form has unique advantages for the portrayal and analysis of surface features:

- it combines fine detail with large-area coverage;
- it shows terrain accurately and in its true complexity, two properties often lost in sketches and diagrams of large areas;
- the view is continuous—limited only by size of the digital data set—unlike relief models, aerial photos, and radar images;
- the map is free of distortion and the vegetation and cultural features that mask topographic form on satellite images;
- positions of Sun and viewer can be varied to obtain a different perspective on a landform or to enhance certain terrain features.

Most of these advantages are evident in the 11 digital shaded-relief images presented here, at 1:125,000 (county maps) and 275,000 (regional map) scale, the most detailed and accurate physiographic views to date of San Francisco Bay region and its ten constituent counties. Containing a vast amount of information, these computer portraits faithfully reflects the cumulative work of tectonism, fluvial activity,

marine erosion and deposition, and other geologic events and processes shaping the region's landscape (for example, Brown, 1990).

The 11 maps are numbered here, and in the other reports bearing the Open-file number 97-745, as follows:

1. San Francisco Bay Region
2. Alameda County
3. Contra Costa County
4. Marin County
5. Napa County
6. Santa Clara County
7. Santa Cruz County
8. San Francisco County
9. San Mateo County
10. Solano County
11. Sonoma County

The new maps supersede earlier mechanized portrayals of the region. Included are those parts of the California (Edwards and Batson, 1990) and U.S. (Thelin and Pike, 1991) shaded-relief maps covering the Bay area. A 1:125,000-scale slope map of the ten-county region (U.S. Geological Survey, 1972), derived photomechanically from a contour map (U.S. Geological Survey, 1970), had previously been the only medium-scale relief portrayal of Bay region topography. Prior to this report, a satisfactory shaded-relief map had been prepared only for San Mateo county (Mark and Aitken, 1990).

The data from which the new maps were computed consist of a digital elevation model (DEM), an (X,Y) array of terrain heights spaced 30 m apart. The data set was assembled from 204 separate DEM's derived from topographic maps in the USGS 7.5' series (see the quadrangle index map in Pike, 1997). Because all constituent DEM's were created by the recent and higher-accuracy "Level II" procedures that interpret elevations from digital line graphs of the map contours (U.S. Geological Survey, 1993), these maps are free from the striped artifacts that mar shaded-relief portrayals computed from older 7.5' DEM's.

At 1:275,000 scale, the full Bay Region map comprises some 35,000,000 rectangular picture elements (pixels), each about 0.11 mm across. The array measures 7743 cells in the east-west direction and 7423 cells in the north-south direction. Pixels of the ten 1:125,000-scale county maps, at about 0.24 mm across, are below the size at which the human eye begins to resolve individual elements.

On all 11 maps the gray tone of each pixel is a brightness value computed from a mathematical relation between ground-surface slope and azimuth and elevation of the observer and a simulated Sun (see, for example, Yoeli, 1967; Thelin and Pike, 1991). All images are illuminated from the north-northwest, halfway between the zenith and the horizon. Light and dark tones show steep areas, facing the Sun and in shadow, respectively; intermediate tones are gentle terrain. To enhance fine detail in low-relief terrain, we applied a modest vertical exaggeration. As a result, ridges appear about twice as high as they actually are, and valleys twice as deep. Details on the processing follow below. For references to the vast literature on relief shading see Horn (1981) and Thelin and Pike (1991).

Drainage lines and nearshore bathymetry from an existing digital base (Aitken, 1997) enhance the relief-shaded portrayal on all 11 maps. To facilitate rapid location of specific areas of interest, particularly for emergency-response applications, the ten 1:125,000-scale county maps carry a detailed road network and major place names (Aitken, 1997). Similarly, we added a two-km buffer zone, mapped by a white-bounded black line, around each county to provide context for any slope failures and response activities near the county limits.

Data Processing

The digital compilation was performed in ARC/INFO, a commercial Geographic Information System (Environmental Research Institute [ESRI], Redlands, California). The database for shaded-relief maps consists of ARC/INFO GRID coverages for the region as a whole and for each of the ten counties (two versions of each set, the light-toned edition to be used as a base map for plotting other data), postscript map-image files for each of those 11 areas, and a postscript version of this text. See San Francisco Bay Landslide Mapping Team (1997) for information about filenames and how to obtain the data and plotfiles.

The 7.5-minute DEM's were compiled into a single data set by the LATTICEMERGE command in ARC/INFO. Inconsistencies and edge-match problems between adjacent quadrangles were resolved using the FOCALMEAN function in ARC/INFO GRID. The hillshade grid (sfbr-sr) was prepared by the HILLSHADE command in ARC/INFO, using a Sun azimuth of 315 degrees, a Sun-elevation angle of 45 degrees, and a z-factor (vertical exaggeration) of 2.0.

The light-toned hillshade grid was prepared by the HILLSHADE command in ARC/INFO, again using a Sun azimuth of 315 degrees and a Sun angle of 45 degrees, but a z-factor (vertical exaggeration) of 1.0. This grid was then recalculated from 255 brightness values to 100 values using the SLICE function in ARC/INFO GRID. The resulting grid was run through two additional grid algorithms (see below), which moved the hillshading towards the lighter end of the gray-scale spectrum yet still preserved the details of topographic features.

Step 1:

```
temp_grid = (ltgrid - [value GRD$MEAN]) * 15 / [value GRD$STDV] + 90
```

where ltgrid is the grid produced by the SLICE function

Step 2:

```
sfbr-srlt = con(isnull(temp_grid), 99, temp_grid <= 60, 60,temp_grid <= 99,
   int(temp_grid),99)
```

where temp_grid is the grid produced by Step 1

Hillshade grids for the ten counties were prepared with the LATTICECLIP command in ARC/INFO, using a buffered county boundary-line (2 Km buffer) as the clip cover.

The Digital Database

No paper maps accompany this document or the other five reports in the San Francisco Bay Region Landslide Folio. Rather, the Folio is released as a digital database that can be obtained by either (1) connecting with a USGS Web page, (2) through anonymous ftp (file transfer protocol) over the Internet, or (3) sending a request, accompanied by a blank magnetic tape, to USGS. Available in two data formats (ARC/INFO Export-compatible or PostScript), the map files described here can be plotted on the user's equipment or that of a commercial vendor.

The data files are as follows. (See San Francisco Bay Landslide Mapping Team (1997) for information on how to obtain the data.)

sfbr-sr-dbsesc.ps	-Postscript version of this text
sfbr-sr.dbdesc.txt	-ASCII version of this text

ARC/INFO GRIDS

sfbr-sr.tar	-Tar file containing Bay Region hillshade grid
al-sr.tar	-Tar file containing Alameda County hillshade grid
cc-sr.tar	-Tar file containing Contra Costa County hillshade grid
ma-sr.tar	-Tar file containing Marin County hillshade grid
na-sr.tar	-Tar file containing Napa County hillshade grid
scl-sr.tar	-Tar file containing Santa Clara County hillshade grid
scr-sr.tar	-Tar file containing Santa Cruz County hillshade grid
sf-sr.tar	-Tar file containing San Francisco County hillshade grid
sm-sr.tar	-Tar file containing San Mateo County hillshade grid
sol-sr.tar	-Tar file containing Solano County hillshade grid
son-sr.tar	-Tar file containing Sonoma County hillshade grid
sfbr-srlt.tar	-Tar file containing Bay Region light hillshade grid
al-srlt.tar	-Tar file containing Alameda County light hillshade grid
cc-srlt.tar	-Tar file containing Contra Costa County light hillshade grid
ma-srlt.tar	-Tar file containing Marin County light hillshade grid
na-srlt.tar	-Tar file containing Napa County light hillshade grid
scl-srlt.tar	-Tar file containing Santa Clara County light hillshade grid
scr-srlt.tar	-Tar file containing Santa Cruz County light hillshade grid
sf-srlt.tar	-Tar file containing San Francisco County light hillshade grid
sm-srlt.tar	-Tar file containing San Mateo County light hillshade grid
sol-srlt.tar	-Tar file containing Solano County light hillshade grid
son-srlt.tar	-Tar file containing Sonoma County light hillshade grid

POSTSCRIPT MAP-IMAGE FILES

sfbr-sr.ps	-Shaded relief map of the San Francisco Bay Region

al-sr.ps	-Shaded relief map of Alameda County
cc-sr.ps	-Contra Costa County
ma-sr.ps	-Marin County
na-sr.ps	-Napa County
scl-sr.ps	-Santa Clara County
scr-sr.ps	-Santa Cruz County
sf-sr.ps	-San Francisco County
sm-sr.ps	-San Mateo County
sol-sr.ps	-Solano County
son-sr.ps	-Sonoma County

The map database itself is rather simple, consisting of attributed GRID cells stored in Universal Transverse Mercator (UTM) projection (Table 1).

Table 1 - Map Projection

PROJECTION	UTM
UNITS	meters
ZONE	10
DATUM	NAD27
PARAMETERS	none

Content of the map database can be described in terms of the grid cells comprising the map. Descriptions of the database fields use the terms explained in Table 2.

Table 2 - Field Definition Terms

ITEM NAME	name of the database field (item)
WIDTH	maximum number of digits or characters stored
OUTPUT	output width
TYPE	B-binary integer, F-binary floating-point number, I-ASCII integer, C-ASCII character string
N.DEC	number of decimal places maintained for floating-point numbers

The gray-shaded picture elements (pixels) comprising the maps are rectangular cells shown on each map by a GRID coverage, consisting of 30-m cells derived from values of terrain steepness and azimuth as described briefly in the Introduction.

The database format of the grid is described in Tables 3 and 4, which show the format of the GRID attribute and statistics tables.

Table 3 - Contents of GRID Value Attribute Table (<GRIDNAME>.VAT)

ITEM NAME	WIDTH	OUTPUT	TYPE	N.DEC
AREA	4	10	B	--
COUNT	4	10	B	--

Table 4 - Contents of GRID Statistics Table (<GRIDNAME>.STA)

ITEM NAME	WIDTH	OUTPUT	TYPE	N.DEC
MIN	8	15	F	3
MAX	8	15	F	3
MEAN	8	15	F	3
STDV	8	15	F	3

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