EXPLANATION

Table 1.—*Terms of slope measurement, description, and occurrence*
[Modified from Witkind and others, 1979; and Brabb and others, 1972]

Slope description of map unit	Slope angle: Percent	Slope angle: Approximate angle (degrees)	Slope angle: Grade rise (feet) per horizontal distance (feet)	Occurrence
Flat to very gentle	0–5	0°–3°	1 in 20 or less	[illegible]
Gentle	>5–15	>3°–9°	>1 in 20 to 1 in 6.6	[illegible]
Moderate	>15–30	>9°–17°	>1 in 6.6 to 1 in 3	[illegible]
Moderately steep	>30–50	>17°–27°	>1 in 3 to 1 in 2	[illegible]
Steep	>50–70	>27°–35°	>1 in 2 to 1.4 in 1	[illegible]
Very steep	>70	>35°	>1.4 in 1	[illegible]

INTRODUCTION

Accurate, detailed information about topographic slope, the steepness of terrain, has many applications including land-use decisions where engineering design and cost analysis are critical, comprehensive planning and land-use regulation, and scientific investigations of the relation between slope angle and the processes that modify hillslopes, such as landsliding, stream erosion, and earthquakes (Chorley and others, 1984, p. 255–277). For example, in part of San Mateo County "that portion of a parcel which has a slope in excess of 50% shall have density accumulation limited to one dwelling unit per 40 acres; that portion of a parcel having a slope in excess of 30% but not exceeding 50% shall have density accumulation limited to one dwelling unit per 20 acres; that portion of a parcel having a slope in excess of 15% but not exceeding 30% shall have density accumulation limited to one dwelling unit per 10 acres" (San Mateo County Board of Supervisors, 1973). Elsewhere in California, the degree or percentage of slope is commonly written into grading regulations, such as those in Santa Clara and Los Angeles Counties (Santa Clara County Board of Supervisors, 1978; Los Angeles County Board of Supervisors, 1984).

Slope is an important factor in determining land stability. In general, steeper slopes have more serious landslide problems than gentle slopes, and the kinds of landslide processes that prevail are likely to change with increasing slope (Ellen and others, 1982). For example, soil slips in the Santa Monica Mountains of southern California are most common on slopes from 26° to 45°, whereas rockfalls are the major hazard on slopes steeper than 45° (Campbell, 1975).

MAPPING SLOPE

Slope maps have a long history of manual compilation (for example, Raisz and Henry, 1937; Demek and others, 1972) and a much shorter one of automated derivation (for example, Evans, 1980). Until recently, information about slope was derived primarily by measuring the distance between contour lines on topographic maps. Measurements were made either by hand (for example, Witkind and others, 1979) or by photomechanical means (for example, U.S. Geological Survey, 1975; 1979). Neither of these methods has proved to be satisfactory. The manual method is laborious and has a high potential for error. The photomechanical method is faster but generates false data along ridge tops, in valleys, and in other areas where contours fold back on themselves and thereby double the contour density.

Two recent developments permit a new approach to the automated construction of detailed slope maps. They are (1) mass production of digital elevation models (DEM's) by the U.S. Geological Survey (Elassal and Caruso, 1983), and (2) the adaption of laser plotters for producing high-resolution color-separated images of digital data. The DEM's of 7.5-minute quadrangles are generated by manually scanning quadrangle-centered aerial photographs on a stereoplotter or by digitizing contour-line images from which topographic maps are made. The x, y, and z coordinates of grid intersections, spaced at 30 m of horizontal ground distance, are derived by computer processing. The resulting elevation grids are then converted into slope-category grids, which in turn are converted into color-separated images by the laser plotter. This map is one of the first to use this new procedure.

DEFINITION OF SLOPE

A general definition of slope is the amount or degree of deviation from the horizontal. More precisely, slope at any point is the change in elevation per unit horizontal distance in the direction of greatest elevation change. Thus, slope is the tangent of the angle between the line of steepest descent and the horizontal (fig. 1). Slope is commonly expressed as a percent, as on this map, or as an angle measured in degrees of arc. The relations between slope expressed as percent, angle, and grade rise are shown in table 1.

EXPLANATION

$$\text{Slope} = \frac{\Delta Z}{\Delta X}$$

Slope angle = arc tangent of slope
Percent slope = 100 times slope

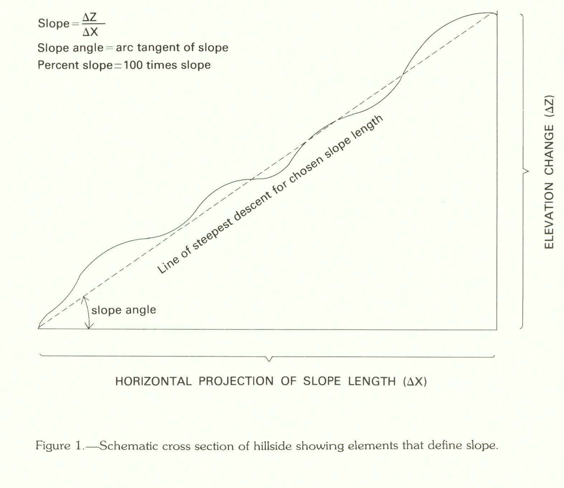

Figure 1.—Schematic cross section of hillside showing elements that define slope.

PROCEDURES

We have experimented with several methods of generating slope maps from the DEM's at grid spacings of both 30 and 100 m. These methods include: (1) choosing the maximum of the slopes calculated from each grid point to its 8 neighbor points (fig. 2), (2) fitting a plane to each 3-by-3-point neighborhood (subgrid), and (3) fitting a least-squares quadratic surface to each 3-by-3 subgrid (for example, Evans, 1980).

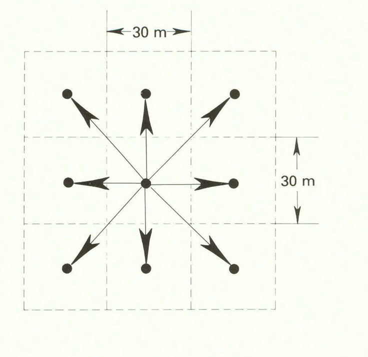

Figure 2.—Three-by-three subgrid used for calculating slopes. Arrows indicate eight slope calculations from which the maximum slope value was assigned to the central point of the central grid cell. This method was not used to produce this map; rather, a quadratic surface was fit to the subgrid and the slope of the central point calculated.

Results were checked by visual inspection of color-coded slope-category images (much like this map), and by statistical comparison with 4.2 km of profile lines surveyed over a variety of terrains near La Honda in San Mateo County. These studies indicate that the 100-m grid spacing is too coarse for a 1:125,000-scale map, and that the least-squares quadratic surface algorithm using the 30-m data produces the best results. The computations for all of San Mateo County require about 15 minutes on a VAX−11/785 computer[1].

Our slope map was prepared for publication by dividing the observed range of slope values, from 0° to 62°, into the six percentage categories shown in the explanation. These classes were selected for their relevance to local land-use planning and landslide research, but resemble those in general use elsewhere (for example, Demek and others, 1972, table 4). The color-separated images for printing were generated on the Scitex Response 280 System laser drum plotter.

USES OF THE MAP AND RELATED DIGITAL DATA

We anticipate that, in addition to the traditional use of the printed map, there will be many applications that depend on availability of the mapped information in digital form. These slope data, for example, can be combined in a computer with the information on bedding dip (Brabb, 1983) to locate surfaces in San Mateo County where the dip of the rock strata is less than the angle of slope. These localities are likely to be more susceptible to certain types of landsliding. Similarly, slope data were incorporated with other data by Wieczorek and others (1985) to prepare a map showing areas in the county that are likely to fail by landsliding during an earthquake. Digital slope data also constitute one of several input factors in statistical modeling of debris-flow probability in San Mateo County (Mark and others, 1985).

The area of the county within each slope category can be calculated by computer and graphically portrayed in histograms, such as that accompanying this map. When the slope data are combined with the geologic data of Brabb and Pampeyan (1983), the derivative compilation may provide clues about the resistance of each geologic unit to weathering and the development of distinctive landforms, such as cliffs and hogbacks. County-wide analyses can be performed to determine the relation between slope and other variables (Evans, 1980) such as elevation, direction of slope exposure (slope aspect), slope curvature, vegetation types, rainfall distribution, and fault traces. Moreover, average slope and its variation can be calculated to describe smaller areas of interest, such as a municipality or large park. Digital slope data can also be organized by drainage basins, an effective tool for analytic hydrology. When additional digital slope data from neighboring counties becomes available, county-to-county digital analysis will be possible. With digital slope information many derivative applications are now possible.

LIMITATIONS OF THE MAP

Users should be aware of the limitations of the map. The slope map has been prepared from interpolated data points 30 m (about 100 ft) apart, and the resulting effective resolution (greater than 60 m) of the subgrid is not satisfactory for indicating the slope of small areas such as an average residential lot. Rather, the data shown here are applicable to problems requiring more general slope information over broader areas such as large development parcels, highway rights-of-way, argricultural fields, parklands, and municipal watersheds.

SUMMARY

Recent developments in digital elevation models and laser plotters and the availability of computer software to manipulate and output data efficiently have led to the production of a digital-image slope map for San Mateo County. Techniques used in creating this map provide an automated and relatively inexpensive way to generate detailed slope information that is as accurate as the raw elevation data and can be made available rapidly in either map or digital form. The combination of these technological resources has enormous potential for future research and derivative mapping projects.

REFERENCES

Brabb, E.E., 1983, Map showing direction and amount of bedding dip of sedimentary rocks in San Mateo County, California: U.S. Geological Survey Miscellaneous Investigations Series Map I–1257–C, scale 1:62,500.

Brabb, E.E., and Pampeyan, E.H., compilers, 1983, Geologic map of San Mateo County, California: U.S. Geological Survey Miscellaneous Investigations Series Map I–1257–A, scale 1:62,500.

Brabb, E.E., Pampeyan, E.H., and Bonilla, M.G., 1972, Landslide susceptibility in San Mateo County, California: U.S. Geological Survey Miscellaneous Field Studies Map MF–360, scale 1:62,500.

Campbell, R.H., 1975, Soil slips, debris flows, and rainstorms in the Santa Monica Mountains and vicinity, southern California: U.S. Geological Survey Professional Paper 851, 51 p.

Chorley, R.J., Schumm, S.A., and Sugden, D.E., 1984, Geomorphology: Methuen Co., London and New York, 605 p.

Elassal, A.A., and Caruso, V.M., 1983, Digital elevation models: U.S. Geological Survey Circular 895–B, 40 p.

Ellen, S.D., Peterson, D.M., and Reid, G.O., 1982, Map showing areas susceptible to different hazards from shallow landsliding, Marin County and adjacent parts of Sonoma County, California: U.S. Geological Survey Miscellaneous Field Studies Map MF–1406, scale 1:62,500.

Evans, I.S., 1980, An integrated system of terrain analysis and slope mapping: Zeitschrift fur Geomorphologie, Series NF, Suppl. Bd. 36, p. 274–295.

Los Angeles County Board of Supervisors, 1984, Ordinance no. 2225 relative to excavation and fill (as amended): Los Angeles County Excavation and Grading Code, Title 26, ch. 70, secs. 7015 and 7016.

Mark, R.K., Wieczorek, G.F., Newman, E.B., and Brabb, E.E., 1985, Digital cartographic and statistical modeling of debris flow distribution, San Mateo County, California: Geological Society of America, Abstracts with Programs, v. 17, p. 653.

Raisz, E.J., and Henry, Joyce, 1937, An average slope map of southern New England: Geographical Review, v. 27, p. 467–472.

Santa Clara County Board of Supervisors, 1978, Ordinance no. NS–1203.35 relative to Land Development Regulation: Santa Clara County Grading Ordinance, ch. 3, C12–400 through C12–599.

San Mateo County Board of Supervisors, 1973, Resource management zoning district: Chapters 20A and 23 of the San Mateo County Zoning Ordinance, adopted December 20, 1973, 44 p.

U.S. Geological Survey, 1975, Slope map of part of west-central King County, Washington: U.S. Geological Survey Miscellaneous Investigations Series Map I–852–E, scale 1:48,000.

——— 1979, Slope Map, Connecticut valley urban area, central New England: U.S. Geological Survey Miscellaneous Investigations Series Map I–1074–F, scale 1:125,000, 2 sheets.

Verstappen, H.T., editor, 1972, Manual of detailed geomorphological mapping: International Geographical Union Commission on Geomorphological Survey and Mapping, Academia, Prague, p. 50–73.

Wentworth, C.M., Ellen, S.D., Frizzell, V.A., Jr., and Schlocker, Julius, 1985, Map of hillside materials and description of their engineering character, San Mateo County, California: U.S. Geological Survey Miscellaneous Investigations Series Map I–1257–D, scale 1:62,500.

Wieczorek, G.F., Wilson, R.C., and Harp, E.L., 1985, Map showing slope stability during earthquakes in San Mateo County, California: U.S. Geological Survey Miscellaneous Investigations Series Map I–1257–E, scale 1:62,500.

Witkind, I.J., Boyles, J.M., and Patteson, P.E., 1979, Generalized slope map of the Big Fork-Avon Environment Study area, Flathead, Lake Missoula, and Powell Counties, Montana: U.S. Geological Survey Miscellaneous Investigations Series Map I–1130, scale 1:125,000.

[1]Any trade names and trademarks found in this publication are used for descriptive purposes only and do not constitute endorsement by the U.S. Geological Survey.

Base from U.S. Geological Survey San Francisco Bay Region, sheet 3, 1:125,000, 1970
Park boundaries revised 1981
5000–meter Universal Transverse Mercator grid ticks, zone 10

SCALE 1:62 500
CONTOUR INTERVAL 200 FEET
DOTTED LINES REPRESENT 40-FOOT CONTOURS
NATIONAL GEODETIC VERTICAL DATUM OF 1929
DEPTH CURVES IN FEET—DATUM IS MEAN LOWER LOW WATER

SLOPE MAP OF SAN MATEO COUNTY, CALIFORNIA

By

Robert K. Mark, Evelyn B. Newman, and Earl E. Brabb

1988