From "Digital Mapping Techniques '10—Workshop Proceedings"
U.S. Geological Survey Open-File Report 2012–1171
http://pubs.usgs.gov/of/2012/1171/

Derivative Maps from Geologic Maps: Hazard Mitigation and Resource Planning

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Abstract

The California Geological Survey (CGS) uses digital mapping techniques to prepare products for a wide variety of users, who range from geologists to engineers to local government planners and the public. In California, almost all land-use planning and building decisions are made at the local level, and few local governments have the geologic expertise to interpret geologic maps and glean from them the information on geologic hazards and resources that are of interest to them. California law requires CGS to prepare several products specifically for use in hazard and resource evaluation by local government. Those maps are derivatives of geologic maps and contain only the information needed by land-use planners and decision-makers.

This paper briefly describes examples of digital mapping techniques in use at CGS to create maps for an audience that includes geologists, who want all the details of our geologic observations, and for other audiences who want only the information that directly affects their projects. It serves as an introduction to papers in this volume by Treiman and others, Perez and others, Rosinski, Lancaster and others, Clinkenbeard and others, and Harris and Roffers, who provide additional detail on specific CGS map products. Those descriptions and the additional examples below illustrate the range of digital map products developed by CGS and the range of users served.

Introduction

Pascal wrote, "I would have written a shorter letter, but I did not have the time." Actually what he wrote is closer to "I made this [letter] very long, because I did not have the leisure to make it shorter," but editors and translators have found it useful to have a quote from some famous person on the difficulty and time involved in being brief and to the point. Even famous quotes about brevity can be edited for brevity. In producing geologic hazard maps, brevity and clarity are vitally important so that the important message gets through. CGS has found that a simple hazard zone map requires the development of extensive and detailed geologic, geotechnical, and seismological data. All of those intermediate data can be shown on maps, but the "shorter letter" that delivers the message without all the potentially confusing detail requires much care and effort to produce.

This paper serves to introduce CGS's efforts to produce derivative maps, the "shorter letters" that deliver only a key message about geologic hazards or resources. First, of course, a detailed analysis of the geologic data is needed to prepare as complete a description of the hazard as possible. Then, we must take into account an even more basic rule for authors: "know your audience." In making hazard or resource maps for use by non-geologists, knowing the audience should lead us to produce derivative maps that have reduced the geologic content to simple, readily understandable concepts.

CGS has found that the geologic hazard format that leads to concrete changes in a community's resilience to geologic hazards is the "Zone of Required Investigation." Those zones are established based on extensive analysis of a hazard, but once they are drawn, any location is either inside the zone or outside it. California state law provides the authority for CGS to draw the zones, and it is the local government's duty to enforce the laws under which the zones are established. Where California law does not call for a "Zone of Required Investigation," derivative maps showing the level of a hazard may be effective in conveying the amount of information needed for land-use planning decisions.

Mapping of Active Faults and Other Geologic Hazards

Credible geologic hazard maps for planners and decision-makers require detailed mapping and analysis of those hazards. Treiman and others (this volume) describe some of the remote sensing techniques used to map active faults. Detailed remote sensing, particularly LiDAR, has become increasingly common for mapping of active faults, particularly in California where there has been a concerted effort to acquire LiDAR surveys along the major active faults. LiDAR is strictly a topographic tool, however, and although LiDAR surveys depict fault geomorphology in unprecedented detail, they do not show other features of active faults that are visible in other types of remote sensing. Recent studies by Treiman and others (2010, and this volume) have focused on determining which additional forms of remote sensing (aerial photographs, multi-spectral or thermal scanning) add the most additional detail.

Detailed mapping of landforms is also a key aspect of recognizing and mapping landslides. For many years, CGS has prepared maps of existing landslides based on interpretation of aerial photographs. More recently, this traditional approach has been supplemented with interpretation of LiDAR and interpretation of stereo digital imagery. CGS has found that landslide-related landforms are more quickly and accurately mapped from bare earth LiDAR DEM's than from aerial photographs, especially in heavily forested areas. In some areas, however, so many more landslide-related landforms are visible in the LiDAR topography that mapping them all requires more time per area than interpretation of aerial photographs of the same area. The resulting map is much more complete and accurate, but takes just as long to produce as using "traditional" methods (Falls and others, 2006).

Developing Derivative Maps

CGS is charged by the Alquist-Priolo Earthquake Fault Zoning Act of 1972 and the Seismic Hazards Mapping Act of 1990 with determining areas where further investigation of surface fault rupture, liquefaction, or seismically induced landslide hazards is required before construction of "structures for human occupancy." The maps that are produced by CGS show "Zones of Required Investigation" where additional studies by geologists are required. These zone maps incorporate all of the detail described by Perez and others (this volume) for seismically induced landslides and by Rosinski (this volume) for liquefaction. As described in those papers, the detailed geologic and seismic data are condensed to answer a single question: Are further geologic studies required? The final maps are given to local agencies, which are required to enforce the provisions of the acts.

Alquist-Priolo Earthquake Fault Zone Maps ("AP maps") show faults that are "sufficiently active and well-defined as to constitute a potential hazard to structures from surface faulting or fault creep" (Public Resources Code Chapter 7.5, section 2622) (fig. 1). Determining which faults meet those criteria involves detailed mapping and evaluation of the neotectonic geomorphology along faults. The evaluation of which faults are "sufficiently active and well defined" is of interest to geologists, but the basic product of the program is the AP map, which only shows the faults that meet the criteria and the regulatory zones around them. A local planner only needs to be able to read a map to determine if a property is inside or outside the "AP zone." If a property is within a zone, a CGS publication (Bryant and Hart, 2007) describes in detail the responsibilities of the property owner, the permitting agency (usually local), and the state.

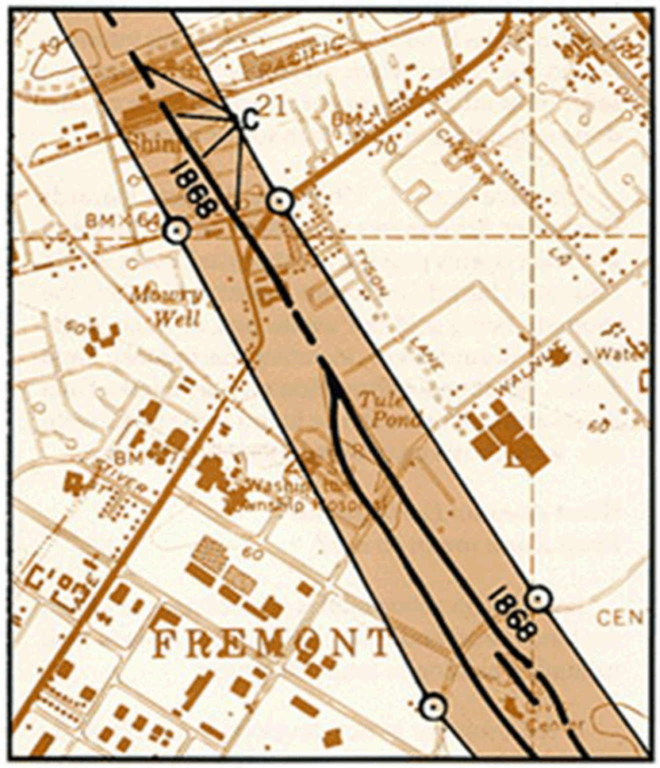

Figure 1. Part of Alquist-Priolo Earthquake fault zone in Fremont, California, showing faults, dates of surface rupturing earthquakes, and zone boundaries.

The process of making AP maps began in 1974, long before digital mapping techniques were available. As more sophisticated remote sensing data have become available, CGS has incorporated those into our analysis. Currently, designation of a fault as "sufficiently active and well defined" requires clear evidence of Holocene surface rupture along with a fault trace that can be accurately mapped at the surface. As described by Treiman and others (this volume), a wide variety of remote sensing techniques provide some information about the location of faults.

The Seismic Hazards Mapping Act of 1990 was modeled after the Alquist-Priolo Earthquake Fault Zoning Act. Like the AP Act, it requires the California Geological Survey to prepare maps showing “zones of required investigation” for particular seismic hazards, and it requires other agencies to ensure that additional studies are done to determine the severity of the hazard before development is allowed within those zones. Rosinski (this volume) and Perez (this volume) describe the process of assembling the geologic and geotechnical data required to define the zones of required investigation. Once the seismic hazard zones maps are prepared, agencies that oversee land use and construction use them to ensure that the potential hazards are evaluated and, if necessary, mitigated before construction. Detailed guidelines for the evaluation of these hazards and review of these reports are provided in a CGS publication (CGS, 2008).

Other geologic hazards that should be considered in making land-use decisions include flood potential and dangers due to naturally occurring hazardous materials. In contrast to Seismic Hazard Zones, there are no statutory requirements for CGS to prepare maps or for permitting agencies to use maps showing areas that may be subject to these hazards. Information is needed by agencies with regulatory authority over these types of hazards, however, and derivative products based on geologic maps can help focus effort on areas where they may occur. CGS prepares derivative maps using digital mapping techniques for these hazards, but these derivative maps do not result in “zones of required investigation.” In southern California, CGS is preparing maps of relative flood potential on alluvial fans, from information found on geologic maps. Traditional floodplain models may not accurately portray flood potential on alluvial fans, and usually do not account for the changing location of alluvial fan flooding with time. As described by Lancaster and others (this volume) geologic maps that emphasize the different ages of alluvial fan deposits can greatly assist users who are planning development projects by showing areas where alluvial fan flooding has occurred in the past. These maps can use the same polygons as on a geologic map, simply by including additional attributes related to alluvial fan flooding potential.

As described by Clinkenbeard and others (this volume), CGS has prepared maps showing areas that may contain naturally occurring asbestos, radon, or other potentially hazardous geological materials. These maps are designed to show local planning departments and other agencies the extent and severity of these hazards. Harris and Roffers (this volume) provide a similar analysis for a different hazard: the potential for spores of a pathogenic fungus in Tertiary sedimentary rocks and soils derived from those rocks. Like AP or Seismic Hazard Zones Maps, maps showing potential for naturally occurring asbestos, radon, or *Coccidioides immitis* spores must be based on detailed geologic mapping and analysis. Like alluvial fan flood potential maps, the polygons from a geologic map, with additional attribution, can form the basis for these maps.

Mineral resources can be shown on maps derived from geologic maps in much the same way as geologic hazards. In California, the Surface Mining and Reclamation Act requires CGS to prepare maps showing areas of potentially valuable mineral resources. Although California is known for gold production, the most valuable resources in recent years are construction materials, particularly sand and gravel. Maps showing where regionally important natural resources are most likely to occur are provided to local agencies so that they can consider them in making land use decisions. The maps show areas where construction aggregate exists in the region, and accompanying reports provide estimates of the volume of these resources (fig. 2). The potential resources are compared with the current permitted resources (reserves), and projected demand is estimated for the region, thereby allowing local agencies to consider future resource availability when they make a land use decision.

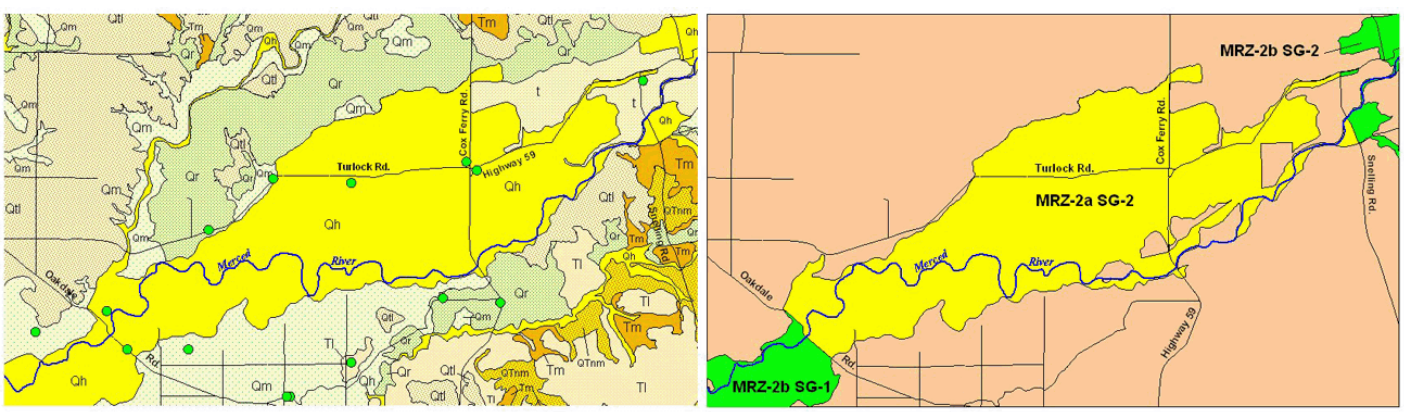

Figure 2. Geologic map (left) and mineral resource zones map (right) of part of Merced County, California. Mineral resource zones correspond to Holocene alluvial deposits (Qh); MRZ-2a in yellow shows where the material is well characterized, and MRZ-2b in green where similar geologic material is less well tested. Note that areas where existing surface mines have removed the resources are not included in MRZ-2a.

Conclusions

Most potential users of geologic information do not have the training to interpret geologic maps. Therefore, it is vital to produce derivative maps that are based on thorough geologic mapping and analysis but focus on the critical factors that might constrain land use or other societal decision-making. The California Geological Survey has developed several types of derivative maps for different purposes. The concept of a "zone of required investigation" is the most effective at focusing on an area where a more detailed site-specific study must be completed so that geologic hazards can be considered before structures are built. Derivative maps showing other geologic hazards or resources maps can be developed from geologic maps. All derivative maps are intended to convey geologic information to an audience of non-geologists. To keep these maps simple, they should show a limited number of categories (such as high, moderate, or low) describing the range of a hazard and not try to show too much information on the same map.

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