California

Geologic Maps Identify Landslide Hazards

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Example

Defining the Problem

The geologic history of the Oakland, California, area has produced **steep** hillsides and **unstable** rock and soil that generate damaging landslides during severe storms and wet winters (Fig. 1). During the 1997-98 rainy-season, the two-county area surrounding Oakland experienced more than **200 landslides** leading to **losses** estimated in excess of **$47 million**. The landslide hazard is exacerbated by the presence of the highly active Hayward Fault, which runs through Oakland and surrounding cities, and is considered to be the most likely source of a large earthquake in the area. Such an earthquake would likely trigger many landslides in the surrounding hills. The challenge is to predict what areas are more likely to suffer future landslides so that proper engineering can be applied for hazard mitigation or appropriate zoning restrictions applied to the most susceptible undeveloped areas.

The Geologic Map

The geologic map of the Oakland metropolitan area (Fig. 2) shows the **complex** geologic **structure** and distribution of rock units that are typical of the region where the active Hayward Fault Zone (HFZ) separates metamorphic rocks of the Franciscan Complex (fss, fs, fm) from sedimentary and volcanic rocks. The same natural forces responsible for the complicated geology are still at work, deforming the rocks and raising the hills that occupy the eastern portion of the mapped area. A complementary map (Fig. 3) shows the large landslide deposits (red) that have accumulated in the landscape since the uplift of the hills.

Applying the Geologic Map

Statistical analysis of the relations between the accumulated **large landslides** in the area and the underlying rock units and slope reveals which slope/rock-unit combinations are more likely to experience future landslides (Fig. 4). By calculating the expected ground-shaking from an earthquake and using additional data from the geologic map, we can also assess the susceptibility to earthquake-induced landslides in the area. The resulting **susceptibility** maps (Fig. 5) show which areas are most susceptible. The analysis also revealed that intermediate slopes are more likely to have landslide deposits than the steepest areas. The steepest slopes may truly be less susceptible, or landslides may have occurred at steep slopes but the deposits are resting on steep slopes down the hillside.

1958

1998

Fig.1. Homes in Oakland, CA, destroyed by landslides in 1958 and 1998.

Conclusion

The California Geological Survey is producing **zoning maps** for earthquake-induced landslides. The fundamental requirement for the analysis is availability of detailed, modern geologic maps, including an accurate map of landslides. With the advent of digital map technology, this approach to **evaluating** landslide **hazards** can be rapidly applied in any area.

geologic map

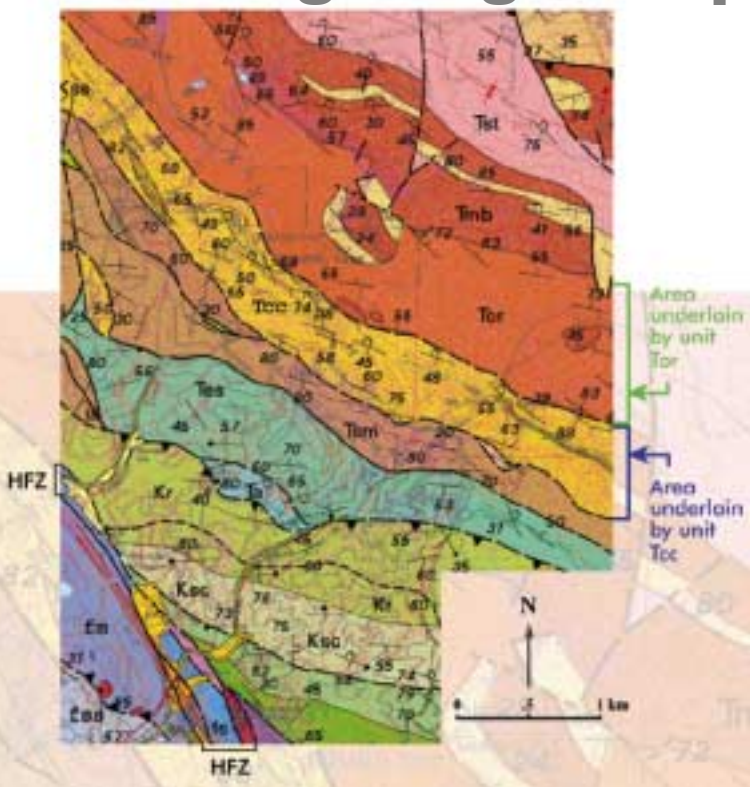


Fig.2. A portion of the geologic map of the Oakland, CA area, including part of the active Hayward Fault Zone (HFZ) separating metamorphic rocks of the Franciscan Complex (fss, fs, fm) from sedimentary and volcanic rocks.

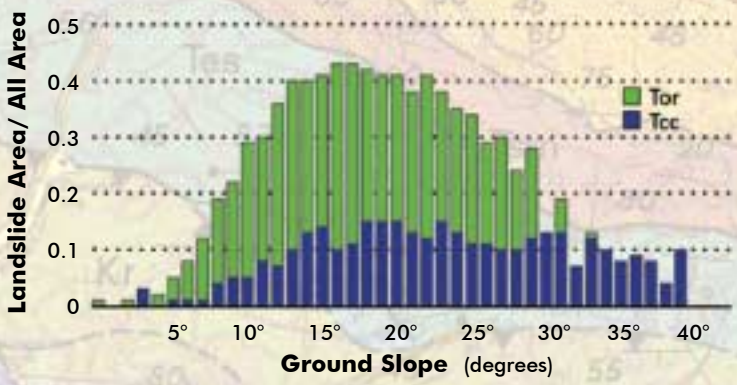
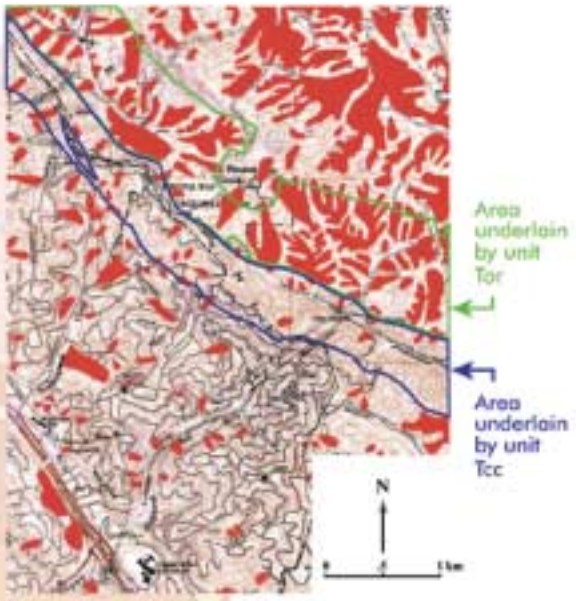


Fig. 4. Comparison of large landslide distribution at different slopes in two rock units in the Oakland metropolitan area. The unit Tor is more than doubly covered by large landslide deposits at most slope angles, and so is mapped as twice as susceptible. Note that susceptibility is lower at near-flat and very steep slopes, which is also reflected in the mapped susceptibility.

Fig.3. Red areas are large landslide deposits in the Oakland area. Note that many more landslide deposits cover the area underlain by unit Tor than the area underlain by unit Tcc.

landslide deposits



landslide susceptibility

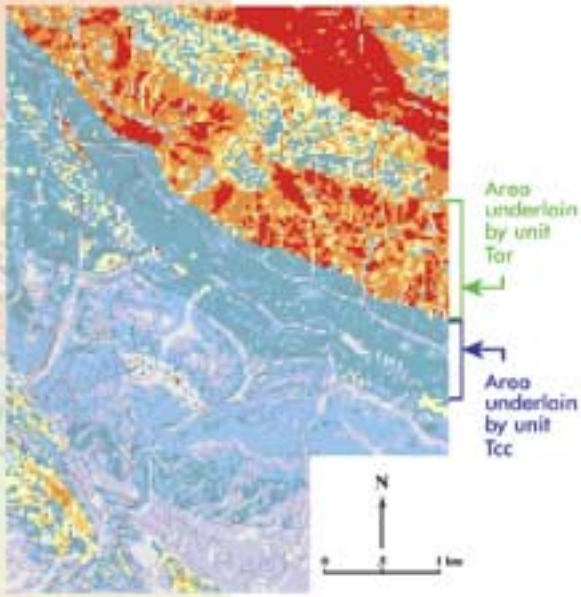


Fig.5. Large-landslide susceptibility map in the Oakland area. Orange and red areas have the highest relative susceptibility to landslides.