Southern California Areal Mapping Project (SCAMP) and Multidimensional Databases

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INTRODUCTION

The digital world has created a number of developments and opportunities for geologists, albeit allowing opportunities for abuses. Probably the most important impact to date is the routine production of publication-quality digital geologic maps. These maps can be produced and released relatively quickly, easily revised, and made inexpensively available on the web, thus keeping the maps current and serving map-using customers most effectively. However, for most geologists the greatest appeal of 'going digital' is the opportunity to solve complex geologic problems, because concomitant with the development and production of digital geologic maps has come the increasing ability to address geologic problems through quantitative spatial analysis. This type of analysis has evolved from simple intuitive overlays having two variables, to more sophisticated, nonintuitive multi-component analyses, such as factor analysis. With the advent of distributive parallel processing, it is now also possible to engage relatively inexpensively in uncompromised dynamic (numerical) modeling.

Two of the goals of the Southern California Areal Mapping Project (SCAMP) are to unravel the geologic history of southwestern California and to predict geologic events that may affect people and infrastructure in the region. Due to hazards resulting from the large number of major active faults, particular emphasis is placed upon the origin and evolution of the San Andreas Fault System and attendant structural and geomorphic changes such as mountain and sedimentary basin formation. Other goals include landslide (especially debris flow) hazards analyses, and unraveling Cretaceous orogenesis and magmatism. Common to these divergent geologic goals is the requirement for high quality multidimensional areal and temporal databases. The most fundamental database is the two-dimensional digital geologic map with temporal and other attributes.

SOME EXAMPLES

The following briefly summarizes examples of the current status of (1) searchable geologic maps, (2) unraveling past processes; and (3) predicting events.

Searchable Geologic Maps

Development of a prototype searchable geologic map for southwestern California is currently underway, and is being coordinated with the National Geologic Map Database Project. The prototype area is a revision of a 60'x60' geologic map coverage of the recently released Santa Ana (Morton, 1999) and San Bernardino (Morton and Miller, 2003) 30'x60' quadrangles. This map covers a rapidly growing area that currently has a population of over 5 million, greater than the populations of 30 states. To produce the map, most of the polygon data are being input at 1:24,000 scale, about 15 percent at 1:12,000, and 5 percent at 1:62,500. Detailed geologic maps of selected areas at scales as large 1:600 and 1:1,200 will augment the 1:100,000-scale map. The geology within the area is complex, and includes over 675 map units, parts of 3 major geologic provinces of California (Mojave Desert, Transverse Ranges, and Peninsular Ranges), and several major active faults, including the San Andreas, San Jacinto, Elsinore, Whittier, and Cucamonga Faults. Due to a combination of steep slopes, the fractured nature of much of the bedrock, and the character of many Tertiary and Quaternary units, the area abounds with landslides. We are attempting to construct the map to the quality of USGS Geologic Quadrangle maps and Professional Papers, and will include interactive and searchable databases. Publication will have a standard Correlation of Map Units and Description of Map Units as well as extensive illustrated text describing the geologic history and features of the area.

SCAMP has closely interacted with the very extensive southern California map user community to determine what map attributes are needed to answer the most important and anticipated questions. Most user needs and queries to the database require combination of polygon and line attributes or polygon and point attributes. Also, users expressed considerable interest in relating recency of fault displacement to map units, especially Holocene deposits cut by faults. Currently only 20-25 attributes are being entered into spreadsheets for each map unit; these include age, name, and basic descriptions (mineral composition, texture, etc). Future revisions will contain additional attributes, but because there are 675 map units, this initial effort in itself is not trivial. It is anticipated that when a legend parser is completed in the near future by the National Geologic Map Database Project, data entry will be greatly facilitated.

To impart as concise a picture as possible of the geology, the map content builds on the adage that ‘a picture is worth a thousand words.’ The map will be augmented with digital images for most of the major map units at scales ranging from landscape to microscopic, as well as images of structural and physiographic features, particularly faults and landslides. The recently released San Bernardino 30’x 60’ quadrangle includes 149 color photographs, less than 10% of what is planned for the Santa Ana-San Bernardino map. The exhaustive retinue of images will permit virtual geologic field trips through the area. In addition to digital images, analytical data such as major and trace element chemistry, isotope geochemistry, specific gravity, and magnetic susceptibility will be accessible by map unit, individual map polygons, and individual points within polygons.

Unraveling the past – Cretaceous orogenesis and magmatism

Digital geologic maps showing rock type distribution and structure are fundamental to understanding the Cretaceous history. About 60 million years(Ma) of geologic history of the Peninsular Ranges Province is recorded only in Mesozoic and older basement rocks. For the northern part of the province a number of databases were developed to help unravel the geologic setting and history for this interval of time. Analyses of the collective databases indicate that during the Cretaceous this part of the Peninsular Ranges Province was the site of a major and prolonged period of orogenesis that produced a wide and complex assemblage of volcanic, plutonic, and metamorphic rocks. Digital geologic maps showing rock type distribution and structure are fundamental to understanding the Cretaceous history. Extensive density, magnetic susceptibility, and major and trace element databases were developed using approximately 330 samples collected by the late A.K. Baird and his coworkers (Baird and others, 1979; Baird and Miesch, 1984) augmented by 200 new samples. In addition, Sr and Rb isotopic values were obtained for these samples and initial Sr values, (Sri) were calculated. The Sri values were used to characterize the source of the magma (Kistler and Morton, 1994; Morton and Kistler, 1997). For selected samples whole rock ^{18}O and common Pb isotopic values were determined (Kistler and others, 2003) to further understand the nature of magma source materials. Samples from a geochemical traverse across the northern part of the Peninsular Ranges batholith were analyzed for whole rock elemental and isotopic chemistry including Nd/Sm (Premo and others, 1994). Emplacement ages of plutonic rocks are based on zircon and sphene U/Pb ages, and cooling temperature ages are based on Ar/Ar ages from hornblende, biotite, and K-feldspar (Premo and others, 1994). Pressure of crystallization for hornblende was determined for some samples. Structural analysis, metamorphic age, temperature and pressure, and provenance of detrital zircons were determined for selected metamorphic rocks (Johnson and others, 2000; Premo and others, 2002). All of these data are integrated in the geologic map database, and are queryable.

Interpretations derived from the collective databases have unraveled parts of the Cretaceous history of this part of southern California. Emplacement ages of plutons indicate the batholith was developed over a 45 Ma interval. Magmatism, preceded by tectonism, began in the western part of the Peninsular Ranges at 125 Ma before present(BP), accompanied by volcanism and emplacement of plutons into Mesozoic marine sedimentary rocks that are probably part of a back-arc basin assemblage. Magmatism progressively extended eastward where plutons were emplaced into Paleozoic and Proterozoic (?) continental nonmarine rocks; magmatism continued to about 80 Ma(BP).

Based on extensive Sri and limited Nd/Sm data, magma that formed the plutons in the western part of the batholith was derived from oceanic crust. These plutons have relatively uniform Sri values, mostly between 0.703-0.704, have an extensive compositional range from gabbro to granite, and cover a remarkably broad area. The central part of the magmatism had a source from a mixed oceanic and continental crust; the eastern part has Sri values ranging from 0.707-0.708+, indicating a continental crust source. Plutons in the western part were passively emplaced, crystallized at pressures of 2-4 Kb, and are relatively small to intermediate in size and exposed at shallow levels. Similar sized plutons in the central part of the batholith were emplaced at intermediate to deep levels, and are relatively high-strain. They were in part forcefully emplaced and crystallized at pressures of 5-6.5 Kb. Further east, large plutons were emplaced about 100 Ma(BP), crystallized at lower pressures of about 4-4.5 Kb, and were accompanied by development of a major dislocation zone, producing a broad zone of Buchan thermal metamorphism and repeated deformation of the metamorphic rocks (Johnson and others, 2000; Morton and others, 2000; Bern and others, 2002). East of the large plutons is a regional mylonite zone, the Eastern Peninsular Ranges Mylonite Zone. Plutons east of the mylonite zone crystallized at high pressures of 6-6.5 Kb at 80-85 Ma(BP).

Prediction – El Nino soil slips-debris flows

Landslides of a wide variety abound in southern California. They constitute one of the most serious geologic hazards in the region and are of major interest to a large segment of our geologic map users. Debris flows are a common and widespread landslide type that occur by the tens of thousands during unusually wet "El Nino" winters. These landslides occur during periods of intense rainfall, beginning as soil slips - small slab-like failures that disintegrate to form debris flows that move various distances down slope. Although most are small in size, these flows can do considerable damage and result in loss of life. To mitigate damage and loss of life, it is important to be able to predict the size and the dynamics of future debris flows and when and where they will occur.

Over 100,000 debris flows have been mapped and systematically digitized, producing an essential database that can be used to help develop predictive tools for the occurrence of soil slips and debris flows. Debris flows that were generated under different rainfall conditions were mapped in 15 different geologic-physiographic settings in southwestern California. Debris flow maps were produced for a number of winters over the period of 1927 to 2001, with most of the debris flow data obtained for the years 1969 and 1998.

Based on analyses of selected variables, geology, slope, and aspect were the most useful for the production of predictive maps showing the locations having the highest likelihood to generate soil slips (Hauser, 2000; Koukladas, 1999). Over 700 geologic map units were assigned a numerical value based on the number of soil slips in the mapped units, per unit area. Similarly, numerical values were assigned to slope and aspect categories, again based upon the frequency of soil slips by slope and aspect. An algorithm for predicting the point of origin of soil slips was then developed from the geology, slope, and aspect values. For map presentation, soil slip susceptibility values were calculated from 5-meter cells of geologic map units; slope and aspect were calculated from 10-meter digital elevation models(DEMs). The resultant soil slip susceptibility values were divided into four categories, ranging from no susceptibility to low, medium, and high susceptibility. A susceptibility category was assigned to individual 10-meter cells. Soil slip susceptibility values were calculated for over 2,000,000 10-meter cells covering 128 7.5' quadrangles in southwestern California (Morton, Alvarez, and Campbell, 2003).

To test the accuracy of the soil slip susceptibility values three test areas, one coastal, one inland, and one semi-arid, were selected to compare actual mapped soil slip-debris flows with the soil slip susceptibility maps. The test showed that 85% to 95% of the soil slips occurred in high susceptibility value areas. Without digital maps these types of analyses are not possible. Work is continuing to refine the susceptibility maps and provide answers to timing, size, and dynamics of the debris flows.

FUTURE – DYNAMIC MODELING

The principal long range goal of SCAMP is to produce a dynamic model for the complex geologic history of southern California, and to predict future geologic events ranging from tectonism to landsliding. Included in the dynamic model will be interaction of tectonism, denudation, mass wasting, erosion, and sedimentation. There are now more comprehensive, faster, and less expensive computational means, utilizing widespread distributive computing such as Beowulf clusters, available to solve extremely complex problems. In order to utilize the staggering increases in computational ability the geosciences community faces vast challenges. At no time in the past was there ever the demand for 4-dimensional data that there is today, and that demand will be ever greater in the near future. Concomitant with development of new analytical techniques to further our insights on composition, temperature, pressure, and age of earth materials there will be greater demands than ever before on the field geologist to collect, in digital form, more detailed and comprehensive field data. The challenges of the future work load are staggering, but the prospects of fundamental new geologic insights unraveling the past and predicting the future are boundless.

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