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Title: Mechanisms of Crustal Deformation in the Western United States

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The basic purpose of the research carried out under this grant was to obtain a better understanding of deformation processes in the western United States. The research considered both deterministic models and random or statistical models. One important aspect of deformation is the rheology of the lithosphere. We have been one of the leading proponents of an intracrustal asthenosphere. This is a soft zone at mid-crustal depths that has an important effect on a variety of tectonic phenomena. We examined the influence on faulting and showed that it was essential to the understanding of the earthquake cycle (1). We have also examined the role of the intracrustal asthenosphere on crustal delamination and on mechanisms of crustal thinning. The latter was reported at the XVIII General Assembly of the International Union of Geodesy and Geophysics in Hamburg, Germany, August 15-27, 1983, (12).

Our work on lithospheric extension with application to the western United States included a simple approach to the problem of lithospheric boudinage (2). We showed that for a fluid with a power law rheology, $E \sim \sigma^n$, boudinage is only found for $n > 1$. Large scale boudinage is one explanation for the systems of parallel basins and ranges that cover much of Utah, Nevada, and Arizona.

Our work on the implications of lithospheric rheology was reviewed in an invited paper presented at the 27th International Geological Congress, Moscow, August 4-14, 1984 (16). This review was subsequently written up and published (11). A paper on how space based techniques can be used to deduce the properties of the lithosphere and asthenosphere was presented at the Geopotential Research Science Conference, College Park, Maryland October 29-31, 1984 (NASA Conference Publication 2390, pp. 44-45).

The other principal line of research carried out under this grant was to apply fractal techniques in order to understand how the crust is deforming in complex regions such as the western United States. The basic approach to the understanding of fractal processes is the renormalization group method. Our first study applied the renormalization group method to the problem of the stick-slip behavior of faults. It was hypothesized that the distribution of asperitites on a fault is a fractal. The interaction of failed asperitites was modeled as a fractal tree. The resulting model showed that the failure of only a few asperitites would lead to a propagating failure on a fault. This explains why there is very little seismic activity on major faults prior to a large earthquake and why stress levels on active faults are generally low. This work was written up and published (3 & 4) and was presented at several meetings (13, 14, 15, 17, & 18).

Work continued on the development of a fractal based model for deformation in the western United States. The initial results were presented at the Texas A & M conference on Intraplate Deformation, College Station, Texas, April 10-12, 1985. Regional deformation was hypothesized to occur on a scale invariant matrix of faults. Deformation occurs on all scales of faults. The fractal dimension determines the fraction of the total regional displacement that occurs on faults of a particular scale. The value of the fractal dimension can be obtained from the frequency-magnitude relation for earthquakes. The results were applied to the San Andreas fault in central California. The model predicts that the relative velocity across the main strand of the fault is 2.93 cm/year while the remainder of the relative velocity of 5.5 cm/year between the Pacific and North American plates occurs on other faults in the system. The predicted value is in quite good agreement with the value 3.39 ± 0.29 cm/year inferred from geological studies. The concept that only a fraction of the relative velocity occurs on the primary strand of the fault has important implications regarding the occurrence of great earthquakes in California. Our model also predicts recurrence rates on smaller faults in southern California. This work was written up and published in the proceedings of the conference (6). This work was also presented at the Centre National d' Etudes Spatiales (CNRS) Summer School held in Toulouse, France in July 1984 and was published as part of the lecture notes of the summer school (5). Aspects of this work were presented at several meetings (19, 20, & 21). This work also formed a substantial part of an invited paper given at the 1986 National Meeting of the Society of Industrial and Applied Mathematitions (SIAM) held in Boston, Massachusetts, July 21-25, 1986 (24).

Our fractal studies have also been extended to the study of topography and the geoid. If the spectral energy density has a power law dependence on wave number a fractal is defined. In order to better understand deformation in the western United States, the fractal dimension in several regions has been obtained. The fractal dimension was obtained from a one dimensional spectral analysis of the topography. In general the fractal dimension was near the value 1.5 that corresponds to Brown noise with the amplitude proportional to wave length. Thus the topography is truly self similar. The fractal dimension was also obtained using the dependence of path length on step size following a topographic contour. In this case fractal dimension was in the range 1.15 - 1.25. The difference is attributed to the difference between a self similar fractal defined by the path length method and the self affine fractal defined by spectral techniques. This work was published (7).

We also applied fractal techniques to fragmentation (8 & 10) and to the relationship between ore grade and tonnage (9). In order to model the distribution of seismicity in a region we developed a fractal analog. The analog consisted of a third order parallel and series network of elements with a fractal distribution of sizes; each element was given a random strength. The system effectively modelled the occurrence of foreshocks and aftershocks. The distribution of failures of elements of various sizes was effectively modelled by the empirical Richter frequency magnitude relation and a reasonable b-value was obtained. This work was presented at the Spring Annual Meeting of the American Geophysical Union, Baltimore, Maryland, May 19-22, 1986, (22).

The fractal concept also provides a means of testing whether clustering in time or space is a scale-invariant process. We have analyzed a catalog of earthquakes from the New Hebrides for the occurrence of temporal clusters that exhibited fractal behavior. In all cases significant deviations from random or Poisson behavior were found. This method introduces a new method for qualifying the clustering of earthquakes. This work was presented at the Spring Annual Meeting of the American Geophysical Union, Baltimore, Maryland, May 19-22, 1986, (23).

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