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Progress Report

MODELS FOR RUPTURE MECHANICS OF PLATE BOUNDARIES AND CRUSTAL DEFORMATION

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(1) INTRODUCTION

Four aspects of plate boundary tectonics are being investigated in this project:

(1). The role of pull aparts and pushup in transcurrent systems.

(2). The rotation of faults and blocks within transcurrent fault systems.

(3). The role of accretion tectonics in plate boundary deformation.

(4). Power law creep behavior and the yielding at plate boundaries.

(2) EVOLUTION OF PULL-APART BASINS AND PUSH-UP RANGES

Strike-slip faults operate at divergent and convergent plate boundaries as well as in broad belts of transform plate boundaries. Many geological and geophysical features of these tectonic regimes can be understood in terms of interaction among numerous faults or fault strands which make up these regimes. For example, pull-apart basins and push-up ranges are produced at regions of extension and compression, respectively, associated with strike-slip systems.

The correlation between the width and length of pull-apart basins and ranges associated with strike-slip systems suggests that smaller basins coalesce into bigger ones as slip continues to take place (Figure 1). This conclusion has important implications for our understanding of (1) fault systems and (2) the formation of basins. The two mechanisms suggested for the growth of basins and ranges provide a view of strike-slip faulting as an evolutionary process. This view offers an explanation for the various sizes of basins and ranges along a given strike-slip fault system. This variety is expected if the interaction and coalescence processes leading to the formation of the basins and ridges occur over long time span.

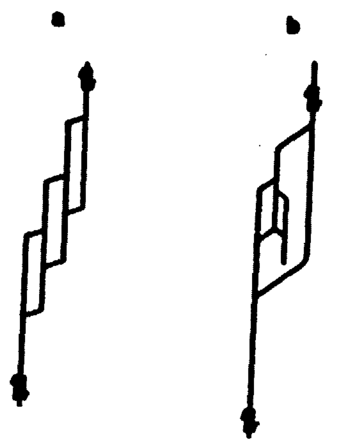

Fig. 1. Coalescing basins and slivers.

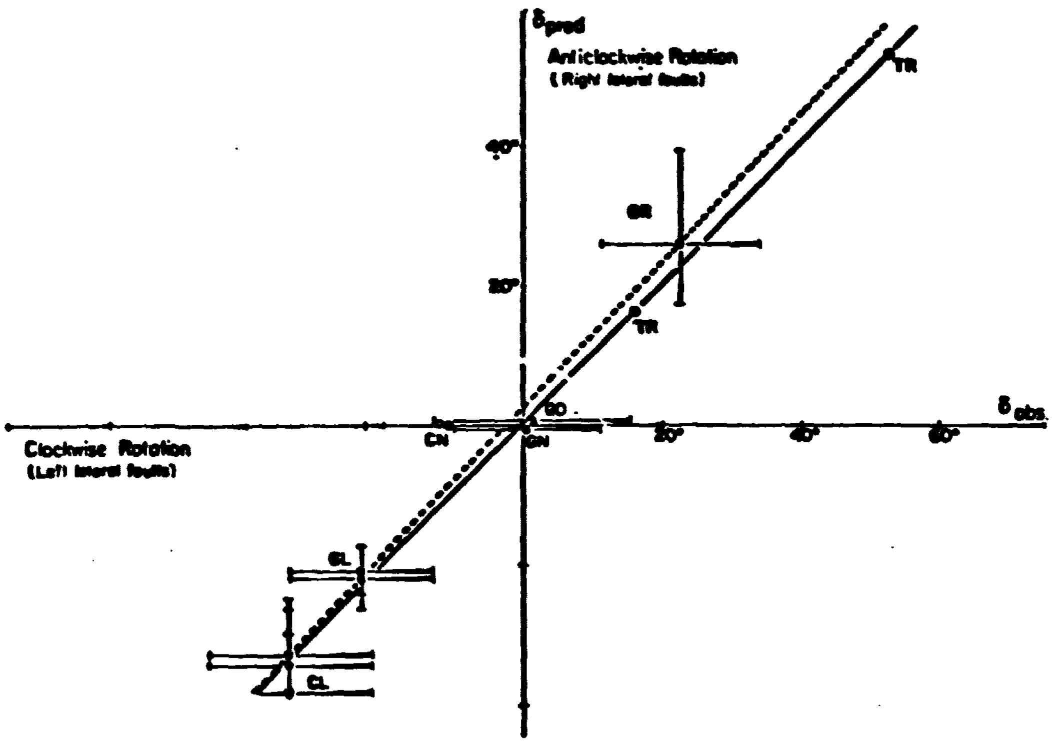

Fig. 2. Comparison between structurally observed and paleomagnetically predicted block rotations.

Faults that are traditionally classified into different groups such as strike-slip, dip-slip normal, and reverse or thrust, and which are believed to have distinct environments, can occur next to each other in the same tectonic environment under the same remote stress condition. Normal and thrust faults associated with active strike-slip faults should be recognized as potential active faults.

The processes of coalescence and interaction imply that the width of the fault system itself must also grow with time, incorporating old and new fault strands as well as a complex arrangement of basins and ranges. These broad zones, which are broken by faults, are likely to be mechanically weaker than normal crust. The presence of a weak, brittle upper crust around major faults limits the shear stress level that can be supported by such faults. This limitation may account for the low stresses inferred, for example, from in situ stress measurement around the San Andreas fault system.

The dimensional and geometric features of the basins and ranges, together with the nature of deformation in these tectonic domains, can be used to interpret ancient basins and ranges in terms of strike-slip tectonics. The fact that pull-apart basins become wider as they grow longer may provide a mechanism for the initiation and the enlargement of sedimentary basins. Sedimentary basins and back arc basins probably develop as a result of crustal stretching followed by the rise of hot and light mantle material. As this material cools, the surface above it subsides, creating a basin that is usually filled with sediments. The most viable process for crustal stretching is a pull-apart basin, which must be large enough (tens of kilometers in width) to interact with the upper mantle. Our observations suggest that a large pull-apart basin can develop from small ones if the associated fault displacements are large enough and the fault strands are numerous enough.

(3) THE ROTATION OF FAULTS AND BLOCKS WITHIN AND NEAR TRANSCURRENT FAULT SYSTEMS

Geometric analysis shows that fault slip on fault sets must cause block rotation which is related to the amount of slip, spacing, and orientation of the faults. The sense of rotation is the opposite to the sense of fault slip. Thus structural data can be used to predict the sense and magnitude of the rotations. These can be tested by paleomagnetic measurements that are completely independent of the structural data (Figure 2).

The block rotation model was tested by a combination of structural and paleomagnetic studies in several domains of conjugate right and left lateral faults along the Dead Sea transform. The paleomagnetic measurements show that *NNW* left lateral faults rotated $23.3^0 \pm 10.5^0$ clockwise, and *NE* right lateral faults rotated $22.4^0 \pm 11.6^0$ anticlockwise, as predicted. The combined deformation resembles pure shear and allows $N-S$ extension of ~25%. In nearby domains rotations of ~35° ± 12° and ~53° ± 15° were found. In all cases the original angle between conjugate fault sets, which enclosed the principal axis of shortening, was about 60° - 70°, in accordance with brittle failure theories. Now, however, this angle is much larger, reaching 110°, as a result of the fault rotation.

The results, combining data obtained by two independent methods demonstrate that large block rotations occur in domains of strike slip faulting. Block rotation may thus be an efficient mechanism of plate boundary deformation in general.

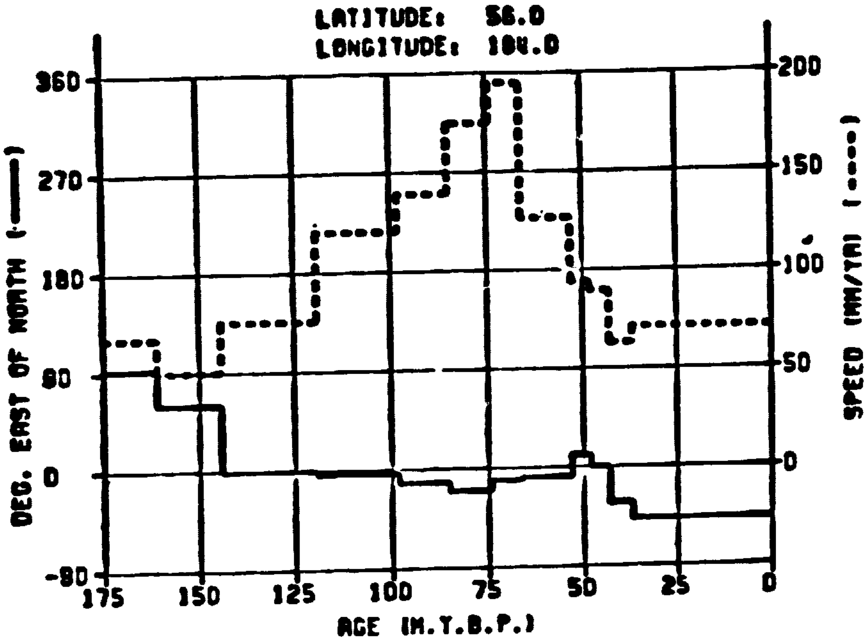

Fig. 3. Direction and speed of the Kula plate relative to the North American plate between 175 M.Y.B.P. and present.

(4) PLATE RECONSTRUCTION AND MIGRATION PATHS OF TERRANES IN WESTERN NORTH AMERICA AND SOUTH AMERICA

The relative motion between the Kula and North America plates and the Pacific and North America plates have often been assumed to be constant over the last 100 m.y. with stable trenches and arcs existing for long periods of time.

However, recent studies of the relative motion between the Pacific Basin plates and North America indicate that there were considerable changes in their relative velocities through the Mesozoic and Cenozoic. In recent work at Stanford the relative motions between the Farallon and Kula oceanic plates and North America have been calculated for various points along the North American margin. The analysis is based on magnetic isochons and fracture zones within the Pacific Plate and a plate circuit through the North Atlantic assuming that the hot spots in the Atlantic and Pacific regions are fixed relative to each other.

In the Bering Sea region at latitude and longitude shown (Figure 3), significant changes can be seen in both speed and direction for the Kula and Farallon plates, changes which should leave a record in the structure of the Bering Shelf. Also, the Kula-Farallon-North America triple junction was probably located near the region for portions of the Mesozoic and Cenozoic. The effects of this tectonic feature should also be found in the resulting geology.

(5) THE YIELDING AT PLATE BOUNDARIES

The problem is to solve for the velocity field $\dot{v}$ given that the viscosity $\nu = A^{-1/n}(v_{,i}v_{,i})^{1-n/2n}$ where the velocity components and the stresses are power law functions of position $v = v(x_1, x_2)$, with (1) displacement and (2) stress boundary conditions and appropriate initial conditions.

To solve the problem we use the finite element method. The problem is formulated in the form of the integral equation as follows:

$$\int_{\Gamma} p\,\nu v_{,i} n_i \, d\Gamma - \int_{\Omega} [p_{,i} \nu v_{,i} + p p \dot{v}] \, d\Omega = 0$$

where p is pressure and n_i are the components of the normal to the surface Γ. Since $p = 0$ on part of Γ and $v_{,i} = 0$ on the remainder of Γ we have

$$\int_{\Omega} [p_{,i} \nu v_{,i} + p p \dot{v}] \, d\Omega = 0$$

The Finite Element program used is based on *LEARN - A Linear Static Finite Element Analysis Program* by Thomas J.R. Hughes, written in 1977 at Cal Tech. The power low creep program was developed from LEARN, involving changes which were made to modify the static program to make it into a time dependent computational routine.