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The history of strike-slip formation on Europa as inferred from the shell tectonics model

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Abstract

The formation of strike-slip faults on Europa has been linked to tidal stresses, which change in magnitude and direction due to Europa's orbital eccentricity [2]. We have developed a linear elastic model that describes the response of a fault to such time-varying shear and normal stresses [5]. This mechanical model, called shell tectonics, predicts the net slip direction and rate of offset accumulation along preexisting faults. Using a tidal model that includes a small amount of obliquity, shell tectonics correctly predicts the slip directions of 75% of observed faults from a comprehensive survey by [6]. Further statistical analysis shows that approximately half of the observed faults were likely to have formed recently at their present locations. The remaining faults have either migrated in longitude (perhaps due to non-synchronous rotation of the icy shell), are old faults that have had enough time to accumulate significant offsets despite being "slow-slippers", or were formed by a process other than tidal shear stress. We apply additional statistical tests to examine the likelihood of each of these scenarios and construct a history of strike-slip formation on Europa.

1. Introduction

The shell tectonics model for strike-slip displacement on Europa utilizes general principles of stress and failure along faults and includes the influence of Europa's elastic shell [5]. We apply a Coulomb failure criterion to determine when and if failure will occur and adopt a linear elastic model for slip and stress release to determine the direction of net offsets along pre-existing faults. We approximate viscous relaxation in the shell by reducing stresses over a characteristic timescale.

Using tidal stresses due to eccentricity as inputs, the shell tectonics model reproduces the global-scale strike-slip fault pattern observed on Europa. Left-lateral faults dominate far north of the equator, right-lateral faults do so in the far south, and near-equatorial regions display a mixture of both types of faults depending on azimuth. Incorporating a small obliquity into calculations of tidal stresses can also explain regional differences in strike-slip populations. Comparable obliquity is theoretically supported [1] and indicated in fits to cycloidal features that are prevalent on Europa's surface [4].

In addition to slip direction, shell tectonics predicts the relative slip rates along faults of different azimuth and location on Europa. We hypothesize that faults with favorable orientations (i.e. azimuths that accumulate offsets relatively quickly) are more likely to be identified as strike-slip faults in the tectonic record. The apparent azimuth clustering observed in several regions of Europa may be a signal of this bias. We apply Bayesian statistical analysis using the predicted rates of offset accumulation to test fault histories with and without longitude migration.

2. Applying shell tectonics

2.1 Faults at observed longitudes

The most straightforward fracture history we could assume is one in which all faults formed at their present locations. To test this hypothesis, we calculate the probability of forming each observed strike-slip fault using the predicted slip rates from shell tectonics and the assumption that the fastest-slipping faults in a region are most likely to be observed. For comparison, we also calculate the probability of each fault being drawn from a random distribution. We make several assumption in this test: (1) faults formed at the locations at which they are observed, (2) faults are the same age, and (3) all observed offsets are generated by tidal shear stress according to the shell tectonics formation model.

We find that 50% of faults in the survey have a high probability of forming at their present locations compared to the random model. An additional 25% of faults have a low probability of forming; these are faults whose slip direction we predict correctly but with a probability worse than random. Our model cannot reproduce the last 25% of observed faults at their present locations (zero probability).

Fully 1/3 of all low or zero probability faults are near longitude ~240° between 0° and 20°S. This region is dominated by features formed through extension and compression [3][6]. Reconstructions show that at least one of the low-probability faults was formed when part of its length experienced extension. Hence, it was not created directly by tidal shear stress through a process like shell tectonics. Further reconstructions will help distinguish additional strike-slip faults in the survey that were formed through these other processes.

2.2 Faults with longitude migration

The distribution of fault slip directions differs slightly between the leading and trailing hemispheres. A small obliquity accounts for these regional differences [5] and has implications for Europa's rotation history. Several lines of evidence suggest that Europa's ice shell may rotate non-synchronously [see 1]. In order for the signal of obliquity to be maintained, the timescale of formation and removal of strike-slip faults must be fast with respect to the period of shell rotation. However, the tectonic record may still contain some faults that formed at other longitudes and migrated to their present locations. Using the predictions of shell tectonics, we can determine the most likely formation longitudes for each observed fault. Our preliminary analysis indicates, at best, a weak signal of longitude migration, but additional work must be done to determine the significance of these results. We plan to create synthetic data sets based on the shell tectonics predictions that contain populations with and without longitude migration and faults with random azimuths.

3. Conclusions

We present a linear elastic model for tidally-controlled strike-slip fault formation on Europa. This model provides a prediction of the slip direction along preexisting faults. It is very successful at reproducing the observed fault patterns on Europa especially when a small obliquity is included in calculations of tidal stresses. The shell tectonics model also provides relative offset accumulation rates based on fault location and azimuth, which lends itself to statistical techniques. Our analysis has identified a complex tectonic region in which strike-slip faults may not form directly from tidal shear stress. We are also investigating longitude migration to reproduce faults whose formation the shell tectonics model would not otherwise predict.

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