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Development of transform faults at mid-ocean ridges: plate fragmentation vs. plate growth origin

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A fundamental problem of plate tectonics is how the orthogonal ridge transform fault pattern typical of spreading oceanic ridges has evolved and why it is maintained. One common view is that the oceanic transform faults result from plate fragmentation processes often controlled by pre-existing structures. This view is, in particular, based on geometric correspondence between passive margins and mid-ocean ridges, which is especially prominent for South Atlantic Ridge and West African coast. It is, therefore, often suggested that transform faults develop in regions adjacent to originally offset ridge segments and that these offsets remain constant through time. However, several lines of evidence from both analogue models and nature contradict this common view, namely: (i) single straight ridges can develop into an orthogonal ridge-transform pattern, e.g. after changes in plate motion, (ii) zero offset fracture zones exist, (iii) there is a correlation between ridge segment length and spreading rate, and (iv) often transform faults are not inherited from transverse rift structures and nucleate while or after spreading starts. Important problem also concerns orientation of transform faults that is commonly parallel to the direction of spreading and thus deviates strongly from typical orientation of shear bands formed during plate fragmentation under extension. To explain this peculiar pattern thermal stresses in cooling oceanic plates are often referred to as modifying stress distribution at mid-ocean ridges and thus changing fault orientation during plate fragmentation.

Our high-resolution 3D numerical models suggest, however, that transform faults are formed during millions of years of plate growth from rotated, stretched and sheared mid-ocean ridge sections. Their orientation is changing with time and may initially deviate from the spreading direction. Transform faults are thus actively developing and result from specific type of thermomechanical dynamical instability of constructive plate boundaries. This instability is most efficient at low to intermediate spreading rates of 4 to 6 cm/yr (i.e. at 2 to 3 cm/yr half rates). Boundary instability from asymmetric plate growth can spontaneously start in alternate directions along successive ridge sections; the resultant curved ridges become transform faults within a few million years. Offsets along the transform faults may change continuously with time by asymmetric plate growth and discontinuously by ridge jumps. Transform faults obtained in our numerical experiments share similarities with natural observations. They are characterized by up to several km deep and wide topographic lows. Ridge offsets along the faults vary from tens to hundred km. Development of the faults occurs on the timescale of plate separation and should react nearly instantaneously to changes in spreading direction. Curved ridges generated in numerical experiments are similar to some of the natural ridge structures. They have a pronounced, often asymmetric axial valley characteristic of slow to intermediate spreading ridges (spreading rates below 7.5-8.0 cm/yr). Intra-transform spreading centers and hooked ridge tips found in numerical models are also common in nature. Nucleation and growth of transform faults in numerical models are associated with detachment faults and asymmetric accretion which are well documented in nature based on seismic and bathymetric data. Computed asymmetric patterns of plate age distribution and changes of ridge offsets with time are also indicated in nature by magnetic data.

This new mid ocean ridge concept thus suggests that transform faults are originally plate growth and not plate fragmentation structures. Similarly snowflakes differs from broken glass fragments.