# Pluto's tectonic pattern predictions.

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**Introduction:** Despinning, orbital migration, contraction, and expansion are likely processes during Pluto's evolution that can produce surface tectonic patterns [1, 2]. We make global tectonic pattern predictions due to these processes that may be tested by the *New Horizons* mission [3]. Global tectonic patterns have been observed on Mercury, the Moon, and Enceladus [4, 5, 6]. Reorientation due to impacts is another likely process because Pluto is a slow rotator [7]. Although reorientation can produce global tectonic patterns [8], we ignore this process because no impact features are currently known. It is not possible to constrain the magnitude and geometry of reorientation, both of which determine the expected tectonic pattern, without an estimate for the impact size and location.

Following their formation, tidal dissipation brings the Pluto-Charon system to a minimum energy state of mutual synchronous rotation [9]. Pluto's initial rotation period is likely only a few hours [10, 11]; therefore, significant despinning is expected to explain the present rotation period of $\sim$ 6.4 days. Outward migration due to tidal dissipation in a state of synchronous rotation leads to further despinning accompanied by a reduction in the size of the tidal bulge. We will refer to this effect as migration to distinguish it from early despinning without significant migration.

In addition to despinning and migration, Pluto likely experienced volume changes [12]. The volume change is sensitive to the presence of an ocean. If no ocean forms, the volume can increase or decrease due to heating or cooling. On the other hand, ocean formation results in predominantly contraction due to the conversion of ice to water.

We calculate the stresses produced by despinning, migration, contraction and expansion, and the corresponding expected tectonic patterns using the method described in Matsuyama and Nimmo [13] and Matsuyama and Nimmo [14]. This method assumes a thin elastic lithosphere.

**Predictions:** Figure 1 shows Pluto's predicted tectonic patterns due to despinning from an initially non-synchronous rotational state, contraction, and expansion. Although we assume somewhat arbitrary despinning and volume change parameters (described in the figure caption), as described below, the predicted tectonic patterns are not sensitive to these parameters.

Rotational deformation is axisymmetric and therefore must produce stresses that are invariant with longitude. The longitudinal dependence apparent at the polar regions in Fig. 1 arises because we assume a final rotational state in synchronous rotation. The patterns become more axisymmetric as the amount of despinning increases, as expected.

Despinning alone (Fig. 1a) produces normal faults at high latitudes and strike-slip faults at low latitudes. This pattern, including the boundaries between tectonic regions at $\sim 50°$ N and S latitudes is independent of the amount of despinning. Despinning alone can produce an

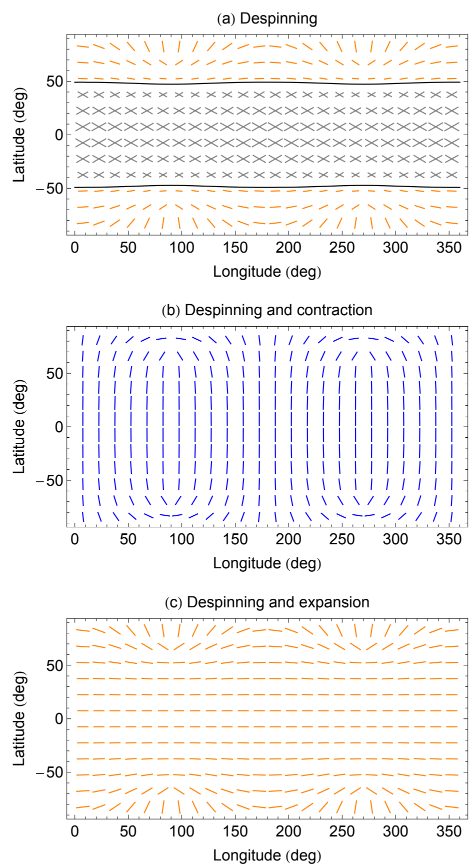


**Figure 1:** Predicted tectonic patterns due to (a) despinning, (b) despinning and contraction, and (c) despinning and expansion. We assume despinning from an initial non-synchronous rotation period of 2 days to a final synchronous rotation period of 3 days, and a 1 km global contraction or expansion. Orange, blue, and gray lines indicate the strike of the expected normal, thrust, and strike-strip faults. The length of the lines is proportional to the maximum shear stress. Continuous black lines mark the boundaries between different tectonic regions.

equatorial band of thrust faulting for thick elastic lithospheres [15]; however, we ignore this effect because it does not affect the tectonic pattern when additional contraction or expansion stresses are taken into account.

For the adopted despinning parameters, a 1 km global contraction (Fig. 1b) or expansion (Fig. 1c) produces compressive or extensional stresses respectively that are large enough to dominate the global tectonic pattern. In this case, the global tectonic pattern is dominated by N-S oriented thrust faults due to contraction, or E-W oriented normal faults due to expansion.

Figure 2 shows Pluto's predicted tectonic patterns due to outward migration in synchronous rotation, contraction, and expansion. Once again, although we assume somewhat arbitrary migration and volume change parameters (described in the figure caption), the predicted tectonic patterns are not sensitive to these parameters. Unlike the case discussed above for despinning, the patterns are no longer predominantly axisymmetric because we assume an initial rotational state in synchronous rotation.

Migration alone (Fig. 2) produces normal faulting around the rotation poles, thrust faulting around the sub- and anti-Charon points, and strike-slip faulting on the remainder of the surface. This pattern, including the location and size of each tectonic region, is independent of the amount of migration. For the assumed amount of migration, a 1 km global contraction (Fig. 2b) or expansion (Fig. 2c) produces compressive or extensional stresses respectively that are large enough to dominate the global tectonic pattern.

**Discussion:** The predicted tectonic patterns due to despinning and migration are independent of the parameters adopted above if the stresses generated by contraction or expansion are large enough to dominate the stresses generated by despinning or migration. In this case, although contraction or expansion is responsible for the style of faulting, the orientation of the faults is determined by despinning or migration.

Our predictions are subject to some simplifications and approximations. First, we ignore other possible sources of local and global stress such as impacts and reorientation. Second, if tidal heating is important, shell thickness variations may also have played a role in where stresses are maximized [16]. Despite these caveats, the global orientation and style of faulting may reveal the history of Pluto, in particular whether an ocean formed or not. If an ocean formed, cross-cutting relationships may constrain the transition from contraction to more recent extension due to re-freezing of the ocean [12].

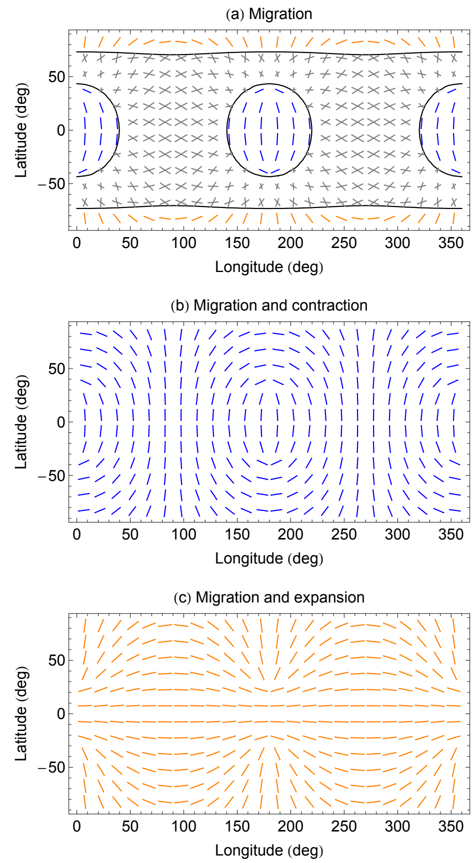


**Figure 2:** Predicted tectonic patterns due to (a) migration (b) migration and contraction, and (c) migration and expansion. We assume that Pluto remains in synchronous during migration from an initial semimajor axis 20% smaller than the present value, and a 1 km global contraction or expansion. Conventions for predicted tectonic patterns and stress field follow Fig. 1.

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