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Accumulation of permanent deformation and formation of topography on timescales of decades to millions of years at the Cascadia Subduction Zone (USA).

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The formation and maintenance of mountain topography (surface uplift) requires the accumulation of permanent deformation (via rock uplift) at a rate faster or equal than surface processes can remove it (via denudation). Geodetic methods or thermochronometry and cosmogenic nuclide dating allow to constrain either rock uplift or denudation, respectively. Previous attempts to compare where and how fast permanent deformation occurs with rates of denudation and topographic development have been limited for several reasons: Difficulties in separating geodetic signals of elastic vs. permanent deformation, sparse observations of denudation or inconsistent observations between methods integrating over short or long timescales. For the Olympic Mountains, located at the Cascadia Subduction Zone (USA), various published datasets of denudation or rock uplift are available. Here, we capitalize on the plethora of datasets and compare them with the long-wavelength topography in order to refine the understanding of permanent deformation in active mountain ranges over different timescales.

Topography as well as denudation rates based on cosmogenic nuclide and thermochronometry data (integrating over 10^3–10^4 and 10^6 years, respectively) all yield similar patterns, suggesting that on long timescales most permanent deformation is accumulated in the center of the mountain range. Contrary to the long-term pattern of deformation, the velocities from GPS stations (integrating over 10^1 years) display a disparate pattern, and locate the highest velocities to the west of the mountain range's center, close to the coast. This suggests that the GPS signal mostly records elastic deformation due to the loading of the thrust fault of the Cascadia Subduction Zone. An attempt to get an independent estimate of the elastic component of deformation by forward modeling it using an elastic dislocation model is not ambiguous. After subtraction of the elastic component, the residual GPS velocities should yield an estimate of permanent rock uplift on timescales of 10^1 years. However, the resulting pattern only partly overlaps with the long-term patterns of deformation from topography and denudation rates. On the other hand, a GPS-derived pattern of deformation associated with episodic tremor and slip (ETS) events, which integrates over 10^1 years, most closely resembles the wavelength and magnitude of deformation indicated by longer timescale datasets. Our observations suggest that methods integrating both over short and long timescales yield information on the deformation within the Olympic Mountains. The GPS signal contains a large elastic component, which is likely recovered coseismically during a megathrust earthquake. Additionally, the presence of elevated topography within the Olympic Mountains requires some of the deformation to be accumulated on long timescales (i.e., 10^6 years). Based on the agreement between the patterns of deformation related to ETS, topography, and denudation, ETS events could be a mechanism involved in permanent deformation, ultimately leading to the formation of the topography of the Olympic Mountains.