

LONG-TERM CONTINENTAL AREAL REDUCTION PRODUCED BY TECTONIC PROCESSES. B. C. Hahn¹, W. E. Holt¹, C. Kreemer² and P. G. Silver³, ¹Stony Brook University, Department of Geosciences, Stony Brook, NY 11794-2100, USA (bhahn@mantle.geo.sunysb.edu), ²Collège de France, Eurôpe de l'Arbois, Aix en Provence 13545, France, ³Carnegie Institution of Washington, Department of Terrestrial Magnetism, Washington D.C., 20015, USA.

Introduction: Continental area is reduced during continental collision events and increased during rifting and extension. But what is the net effect: reduction, expansion, or neither? We use a global strain-rate model and a finite-element approach with over 24,000 grid elements to define the velocity gradient tensor field within all plate boundary zones. Using GPS velocity vectors and Quaternary fault-slip rates, we define the deformation field within the deforming plate boundary zones and define spherical cap motions. After corrections for elastic strain near subduction zones we determined a present-day areal rate of change in continental area as well as the spreading rates of oceanic ridges and back-arc basins. We found a negative change rate indicating a loss of continental area due to tectonic processes. This reduction holds long term if current plate velocities are similar to velocities of the geologic past. If past velocities were higher than they were today, we expect a greater rate of reduction.

Method: Using the global strain-rate model developed by Kreemer et al., 2003 [2, 3], we calculate areal change. Continental regions were defined based on geographic location and average topography. Subduction zones were assumed mostly to experience elastic strain where conservatively, only ~5% of the total areal reduction would remain permanent [4, 5].

The global RMS plate velocity inferred from space geodesy is in good agreement with RMS inferred plate velocity estimates from a three million year average of sea floor spreading rates [1]. Over 3,800 GPS velocity vectors and Quaternary fault-slip rates were used for this study. Site locations are shown in **Fig. 1**.

Global Areal Change: We determined that the net change in continental area from tectonic processes to be a reduction of -0.17 ± 0.02 km²/yr. This indicates that tectonic processes preferentially reduce continental area and increase continental thicknesses. There is a net reduction of area from continental collisions equal to -0.298 km²/yr and a net increase of area from continental extension equal to 0.128 km²/yr (**Fig. 2**). Without any additional process for areal recovery, long-term, this rate implies a 10% reduction in continental area every 100 Ma.

We calculate that of all new oceanic area produced, either through back-arc extension or plate-creation, approximately 94% is eventually destroyed through areal removal at subduction zones. The remaining 6% is taken up through deformation of continental crust.

We found the total area produced at oceanic ridges and extending back-arc basins to be approximately 2.7 km²/yr (of which, ~0.1 km²/yr is produced at small basins and ~2.6 km²/yr is produced at mid-ocean ridges). These values are in good agreement with previous studies determining present-day ocean spreading rates which also suggest that spreading rates have not varied significantly over at least the past 180 Ma [6].

Reduction in continental area by tectonic processes is mitigated by deposition of sediment at continental margins. These sediment deposits will be incorporated as new continental crust during the next continental collision. Also, a new volume of continental crust is created by volcanism at a rate of approximately 1 km³/yr [7]. However, these sedimentary and volcanic additions may be insufficient to balance the tectonic reduction.

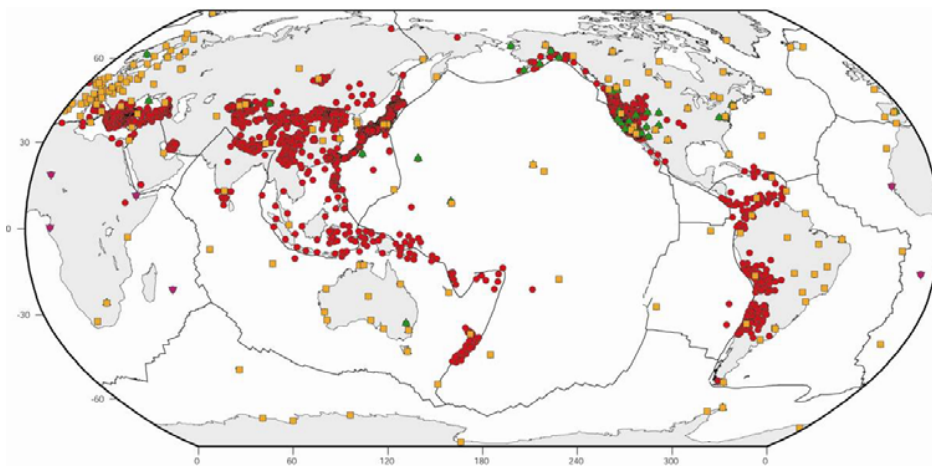


Fig. 1: Geodetic site locations used in this study. Circles are regional data; Squares are International GPS Service stations; Triangles are Very Long Baseline Interferometry (VLBI) stations; and Inverted Triangles are DORIS Stations. [3]

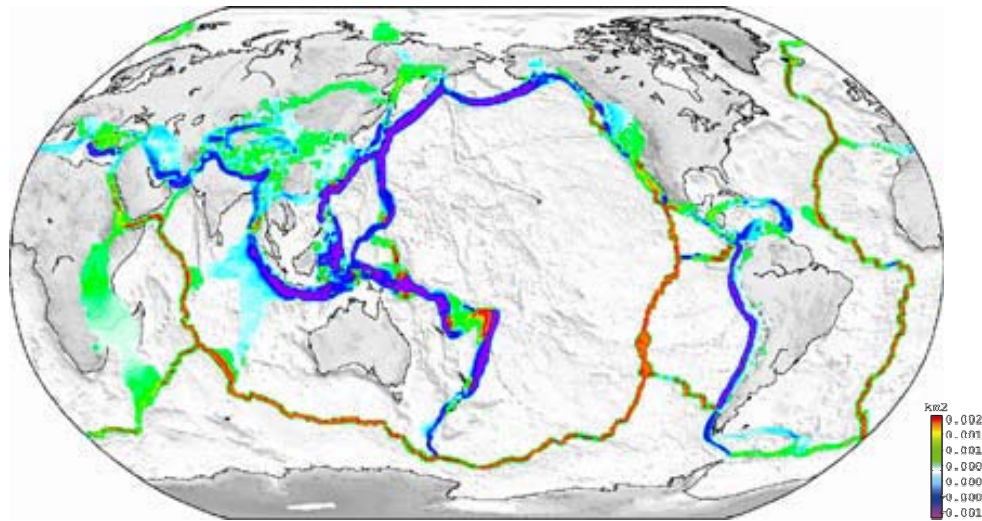


Fig. 2: Annual global areal change field for deforming regions. Blues and purples indicate compression along collision zones. Greens and reds indicate extension and rifting. Regions near subduction zones have been corrected for elastic strain recovered during major seismic events.

Uplift And Sedimentation: Assuming an incompressible continental mass, areal reduction will be accompanied by an increase in continental thickness

Assuming an average crustal thickness near collision zones of 45 km and an isostatic ratio of uplift volume to root volume for continental crust equal to 0.2; an areal reduction of $-0.17 \text{ km}^2/\text{yr}$ corresponds to an uplift volume of $1.275 \text{ km}^3/\text{yr}$.

As uplifted regions erode, isostasy will cause additional uplift. In a long-term, steady-state system, we can expect all thickened portions of the crust eventually to be entirely uplifted and eroded as sediment. Thus, if area is to stay constant, for steady-state, we estimate the yearly sediment discharge rate resulting from denudation of tectonic uplift to be $\sim 7.65 \text{ km}^3/\text{yr}$. However, current estimates of global sediment flux are, on average, lower by a factor of 2, indicating a long-term, net-loss of continental area [7-9]. Several previous models have suggested a slight growth of or constant continental area, indicating an additional process may be in play for areal creation to balance the tectonic reduction.

Conclusions: We have used a variety of datasets, both geologic and geodetic to describe the deformation field for the earth's surface, specifically for determining long-term alterations in continental area. Although terrestrial studies obviously benefit from dense GPS coverage, detailed structural study and well-constrained geological timescales; similar, less-complete datasets do or will exist for similar studies of surface deformation fields on other terrestrial bodies.

For earth, we have found a worldwide, yearly change of continental crustal area equal to $-0.17 \pm 0.02 \text{ km}^2/\text{yr}$ caused by tectonic processes alone. Some continental area is recovered through sedimentation at continental margins and through rifting and extension.

Although the value of this rate can be expected to change over time with changes in individual plate velocities and different regimes in the Wilson cycle, a reduction is expected long-term due to the different timescales involved in rifting and collision events. Although both continental rifting and collisions potentially last millions of years, rifting events only cause extension in continental crust for a relatively short period of time. Shortly after the onset of rifting, the continental crust is split apart and the gap is filled by new oceanic lithosphere. Conversely, areal reduction of continental crust continues throughout the entire lifespan of the collision event.

Sediment wedges deposited at continental margins will be incorporated into the continental mass as new crust during the next collision event. While much of the sedimentary wedge overlies extended and thinned continental crust, a significant portion overlies oceanic crust. Oceanic crust buried in this manner is unlikely to completely subduct and therefore may be incorporated into the continental mass during collision. This additional material would, in turn, increase the continental volume (and therefore continental area) and alter the bulk geochemistry of the system.

References: [1] DeMets C. et al. (1994) *GRL*, 21, 2191-2194. [2] Kreemer C. et al. (2002) *Geodynamics Series*, 30, 173-190. [3] Kreemer C. et al. (2003) *Geophys. J. Intl.*, 154, 8-34. [4] Liu M. et al. (2000) *GRL*, 27, 3005-3008. [5] Shen-Tu B. et al. (1995) *JGR*, 100, 24275-24293. [6] Rowley D. B. (2002) *GSA Bulletin*, 114, 927-933. [7] Taylor S. R. and McLennan S. M. *The Continental Crust: Its Composition and Evolution* (Blackwell, Oxford, 1985). [8] Milliman J. D. and Syvitski P. M. (1992) *The J. of Geo.*, 100, 525-544. [9] McLennan S. M. and Taylor S. R. (1983) *Nature*, 309, 169-172.