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Glacial tectonics: a deeper perspective

Robert M. Thorson*

Department of Geology and Geophysics, University of Connecticut, 345 Mansfield Road (U-45), Storrs, CT 06269, USA

Abstract

The upper 5–10 km of the lithosphere is sensitive to slight changes (< 0.1 MPa) in local stress caused by differential loading, fluid flow, the mechanical transfer of strain between faults, and viscoelastic relaxation in the aesthenosphere. Lithospheric stresses induced by mass and fluid transfers associated with Quaternary ice sheets affected the tectonic regimes of stable cratons and active plate margins. In the latter case, it is difficult to differentiate glacially induced fault displacements from nonglacial ones, particularly if residual glacial stresses are considered. Glaciotectonics, a sub-subdiscipline within Quaternary geology is historically focussed on reconstructing past glacier regimes and, by definition, does not include these effects. The term "glacial tectonics" is hereby suggested for investigations focussed on the past and continuing influences of ice sheets on contemporary tectonics. © 2000 Elsevier Science Ltd. All rights reserved.

1. Introduction

Presently, there is a conceptual shift in the geosciences away from increasing specialization, towards more integrative problems at global scales, a shift embodied by the phrase "Earth System Science" (Kump et al., 1999). Simultaneously, technologically driven advances in instrumental and computational techniques are permitting earth scientists to identify and explain synoptic variations in topography, seismicity, and ambient crustal stress that were not recognizable a decade ago. The recent paper by Peltzer et al. (1996) is a case in point; they used synthetic aperture radar (SAR) interferometry to explain the disappearance of transient topographic anomalies at the centimeter scale resulting from the 1992 Landers (California, USA) earthquake, anomalies erased by the in-migration of fluids to 4 km depth. As these conceptual and technical trends continue, the seismotectonic effects of past fluctuations of Quaternary ice sheets are becoming easier to notice and explain. As a result, the role of glaciers in earth deformation is being recognized at a range of spatial scales: from deformation within the ice itself to the reactivation of tectonic faults in response to crustal unloading and viscoelastic relaxation of isostatic anomalies. Broader recognition of the multiple effects of glacial mass transfers is blurring the distinction between the study of tectonics, per se, and the study of "glaciotectonics", which, historically, has been primarily concerned with deformed glacial deposits.

In this paper I show how the physical coupling between glaciation and crustal deformation extends far beyond the decollement between ice and its substrate (i.e. beyond the scope of glaciotectonics), and instead operates up to crustal scales. I begin by reviewing recent research illustrating the sensitivity of the earth's crust to stress differences far smaller than those associated with ice sheets. I then introduce examples of glacially induced, crustal scale deformation from a passive cratonic setting (Fennoscandia) and an active continental margin (Cascadian subduction zone). Next, I explore the basic mechanisms of glacially induced tectonics — effective vertical stress, membrane flexure, and traction at the base of the crust — and how each of these mechanisms is modified by the contrasting tectonic domains associated with compressive, extensional, and transform strain. Finally, I revisit the question of the scope of glaciotectonics.

2. Sensitivity of the Earth's crust

The ambient seismicity in many regions is extremely sensitive to small changes in stress, regardless of cause. For example: Rydelek and Sacks (1999) recently demonstrated that seemingly trivial changes in the confining

* Tel.: 860-486-1396; fax: 860-486-1383.
E-mail address: thorson@geol.uconn.edu (R.M. Thorson).

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