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Geochimica et Cosmochimica Acta 103 (2013) 276–294

Geochimica et Cosmochimica Acta

www.elsevier.com/locate/gca

The denudation of ocean islands by ground and surface waters: The effects of climate, soil thickness, and water contact times on Oahu, Hawaii

Stephen T. Nelson *, David G. Tingey, Brian Selck

Dept. of Geological Sciences, S-389 ESC, Brigham Young University, Provo, UT 84602, United States

Received 28 February 2011; accepted in revised form 26 September 2012; available online 12 October 2012

Abstract

Ease of access, size, and basalt as the dominant bedrock make Oahu an ideal locality for investigating chemical weathering-driven denudation rates as a function of climate (rainfall varies by an order of magnitude), water–rock contact time, and soil thickness. New and compiled surface and groundwater solute data permit calculation of mass balances for solute fluxes from Oahu, revealing that groundwater dominates surface water solute fluxes by a factor of 3–12.

Weathering reactions were written consistent with the mineralogy of Oahu soils, permitting denudation rates to be partitioned between dissolved and suspended loads. Total denudation rates, indexed to the leaching of SiO_2, vary from 0.016 to 0.063 m/ka, with about 70% of Si transport due to dissolved loads. Drier regions of Oahu have distinctly lower denudation rates, and areas with thick weathering profiles have suppressed surface-water solute loads.

Indexing denudation in basaltic terranes to dissolved SiO_2 rather than other solutes leads to improved estimates of weathering rates. Other approaches require correction for the atmospheric depositions of sea salts based on Cl^- abundances in waters that are assumed to derive solely from the ocean via atmospheric deposition.

Recent work indicates that Oahu is tectonically emerging at 0.060 m/ka. As long as this uplift continues, the net size of the island will slowly increase and the Koolau Range should persist as an orographic trap to precipitation, maintaining relative aridity in the Waianae Range. Comparing emergence and denudation rates suggests that growth of the island will be non-uniform, with arid regions experiencing the greatest emergence with wet regions in balance with denudation. More importantly, however, this work offers an increased appreciation of the controls on the rates and mechanisms of denudation in basaltic and intermediate composition terranes in the tropics.

1. INTRODUCTION

An enormous literature details the growth history of the Hawaiian and other ocean islands. Less is understood regarding the mechanisms and rates of erosion by which ocean islands are denuded and eventually converted to seamounts, although there is a growing interest in this topic. The purpose of this study is to clarify the processes of chemical weathering and associated mass fluxes from tropical ocean islands in order to develop a sense of how rapidly and by what mechanisms they disappear once their constructional and gravitational collapse phases have ended. In particular, we evaluate the relative importance of ground and surface water solute fluxes and associated soil development. Although other studies have recently addressed this (e.g., Rad et al., 2007, 2011; Schopka and Derry, 2012), we present a forward model that balances dissolved and suspended loads. In addition to estimating mass fluxes and denudation rates of ocean islands (and basaltic terranes in general), we evaluate the influence of local climate variation and other variables on these fluxes. Oahu is an ideal natural laboratory due to excellent access, the availability

* Corresponding author. Tel.: +1 801 422 8688.
E-mail address: stn@geology.byu.edu (S.T. Nelson).

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http://dx.doi.org/10.1016/j.gca.2012.09.046

of pre-existing data, bedrock is dominantly basalt, and precipitation rates and soil thicknesses vary greatly.

1.1. Background

1.1.1. Geology of Oahu

The remnants of two shield volcanoes comprise the island of Oahu (Fig. 1). Both the western side of the Waianae and eastern side of the Koolau Volcanoes have collapsed into the ocean, such that the island is constructed of their overlapping remnants (e.g., Sherrod et al., 2007). The Waianae volcano was active from ~4.0 to 2.6 Ma, whereas the Koolau shield developed between ~3.2 to 1.8 Ma. Beginning at about 1.0 Ma until as recently as 40 ka the mafic to ultramafic alkaline volcanic rocks known as the Honolulu Series were emplaced over the Koolau shield remnant in the southeastern portion of the island. By surface area, Oahu is dominated by the tholeiitic lavas of the Koolau shield (Sherrod et al., 2007).

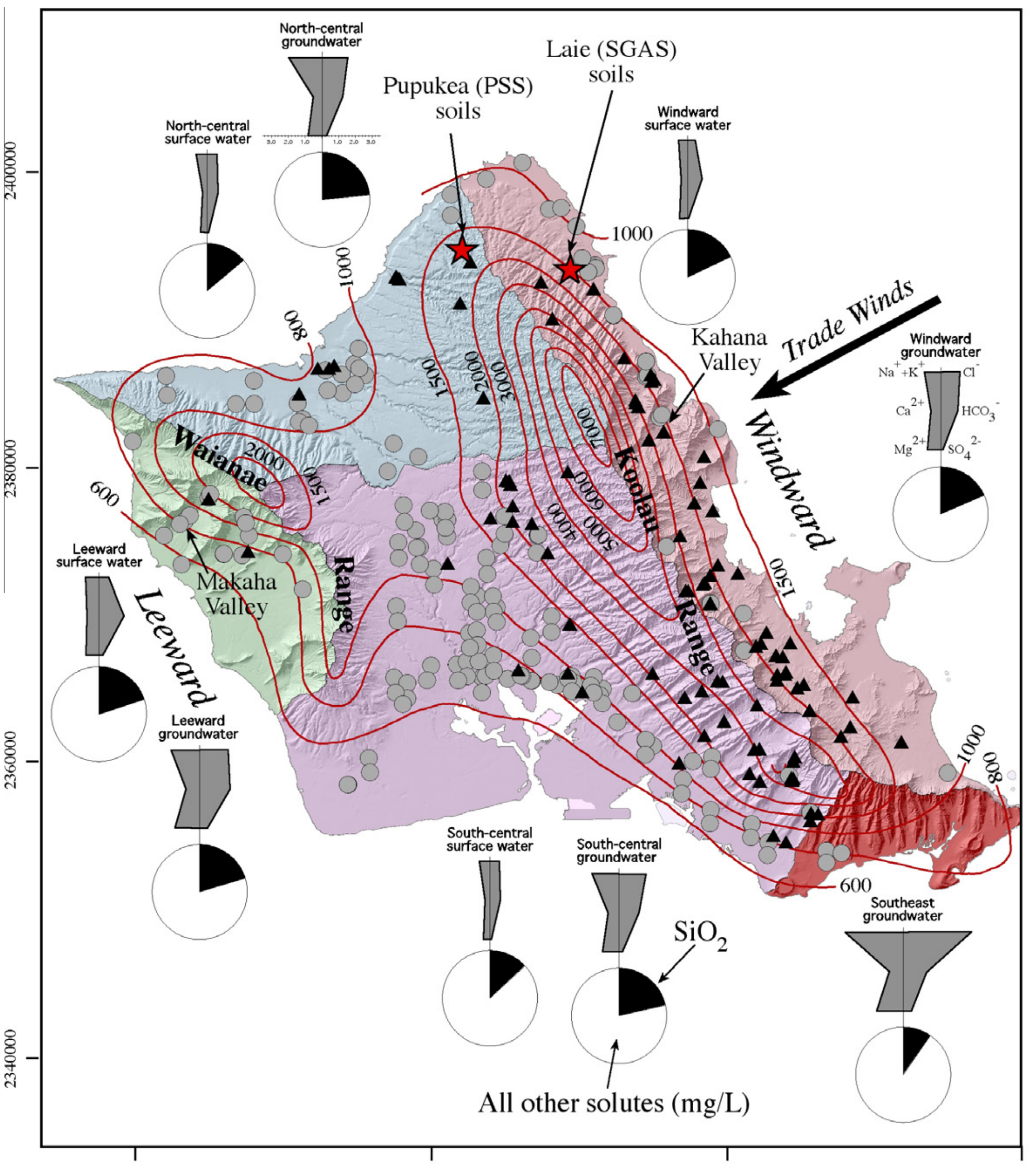

Fig. 1. Index map of Oahu illustrating the 5 hydrologic zones (Shade and Nichols, 1996) used in this study. Triangles represent water samples and shaded circles represent wells. Stiff diagrams (all at the same scale) of average ground and surface waters are presented, along with pie diagrams indicating the proportion of SiO_2 in the solute load (black) on a mass basis. Red contours represent mean annual rainfall in mm.