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Invited review

Review of erosion dynamics along the major N-S climatic gradient in Chile and perspectives

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ABSTRACT

Chile is an elongated country, running in a north-south direction for more than 30° along a subduction zone. Its climate is progressively wetter and colder from north to south. This particular geography has been used positively by a growing number of studies to better understand the relationships between erosion processes and climate, land use, slope, tectonics, volcanism, etc. Here we review the erosion rates, factors, and dynamics over millennial to daily periods reported in the literature. In addition, 21 new catchment mean erosion rates (suspended sediment and ^{10}Be) are provided, and previous suspended sediment-derived erosion rates are updated. A total of 485 local and catchment mean erosion rates are reported. Erosion rates vary between some of the smallest values on earth (10^{-5} mm/a) to moderate values ≤0.5 mm/a compared to other active ranges. This review highlights strong limitations concerning the quantification of local erosion factors because of uncertainties in sampling point location, slope and rainfall data. For the mean erosion rates E for the millennial and decennial catchments, a model of the form $E \propto S/[1-(S/0.6)^2]R^{\alpha}$ with $\alpha = [0.3, 0.8]$ accounts for 40 to 70% of the erosion variance, confirming a primary role of slope S compared to precipitation rate R over this time scale. Over the long-term, this review points to the long (5 to >10 Ma) response time of rivers to surface uplift in north-central arid Chile. Over millennia, data provide evidence for the progressive contribution of extreme erosion events to millennial averages for drier climates, as well as the link between glacier erosion and glacier sliding velocity. In this period of time, a discrepancy exists between the long-term offshore sedimentological record and continental decennial or millennial erosion data, for which no single explanation appears. Still, little information is available concerning the magnitude of variation of millennial erosion rates. Over centuries, data show the variable role of groundwater in the dynamics of suspended load and document a decrease in erosion over hundreds of years, probably associated with historical harvesting.

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1. Introduction

Chile, a country that runs from north to south, is 4000 km long and <150 km wide (excluding Antarctica), bordering part of the western side of the Andes. To the north in the Atacama Desert, the climate is one of the driest on earth, while the southern third of the country is probably the wettest extratropical region of the world (Garreaud et al., 2009). Along this exceptional climatic gradient, drainage is roughly perpendicular to the range, resulting in a string of catchments (Fig. 1). These elementary portions of the landscape encompass a wide range of slopes, lithologies, seismicity, vegetation, glacier cover, volcanism, precipitation rates and tectonic histories. This diversity in Chilean catchments leads to the potential to study a diversity of surface processes and to become a reference natural laboratory.

At the heart of these surface processes, erosion may link tectonics and climate over geological time scales by redistributing masses, promoting silicate weathering and CO_2 consumption or affecting the mechanical coupling between tectonic plates (Molnar and England, 1990; Raymo and Ruddiman, 1992; Lamb and Davis, 2003; Whipple, 2009). Erosion is also associated with landslide and debris flow hazards (Korup, 2002), as well as with the evolution of river patterns and the coast line. Over human time scales, erosion is closely related to land management with respect to crops, industrial forestry and mining (Hooke, 2000; Vanacker et al., 2007), and fluvial management in hydroelectric plants (Syvitski and Kettner, 2011). Therefore, quantifying erosion rates is crucial in order to determine its relationship with climate, tectonics or other environmental and anthropogenic variables.

The diversity of the environmental situations found in Chile has motivated a growing number of erosion rate studies in the last decade. These erosion rates are mostly based on cosmogenic nuclides or suspended sediment in rivers, and some of them are based on soil erosion models. Cosmogenic nuclides provided either local (soil) or catchment-averaged mean erosion rates. Riverine suspended sediment discharges at gauging stations were used to estimate catchment mean erosion rates over the last decades. The reconstruction of reference geological surfaces and thermochronology have yielded erosion rates over millions of years. The sediment budget in lakes and the sea were also used to estimate the erosion rates of the surrounding reliefs.

The purpose of this paper is to review the different erosion patterns and dynamics evidenced in Chile to date. Two main questions underscore this review: How much does erosion vary when erosion factors, slope, and rainfall in particular vary spatially, and how much does erosion vary through time?

We begin with a brief description of the geodynamical and climatic context. Then we explain the selection of the data and methods used to update catchment-scale erosion rates. In a first part, we compile and compare available local and catchment mean annual erosion rates ($n = 485$). From north to south, we review the interpretations of previous authors regarding the control of erosion rates. We then review the dynamics of erosion rates over time, first during the Neogene and Pleistocene and then for the Holocene. We review studies about the effect of harvesting on erosion rates over the last centuries. In addition to published data, mean annual water and suspended sediment discharges from 76 hydrological gauging stations were updated including previously unpublished data between 2010 and 2016. We provide 21 new catchment mean erosion rates (12 from suspended sediment and 9 using [^{10}Be] from the PhD thesis of the second author). We compare four mean annual precipitation rate (MAP) data sets. We recalculate the local and catchment mean slopes using the SRTM 1 Arc-Second digital elevation model. We use these data to evaluate the relative control of different erosion factors. Finally, we discuss the difference between erosion rates in Chile and other tectonically active regions, and then we list open questions that may be addressed in the Andes of Chile, identifying missing data.

2. Geodynamical and climatic context

The Andes show remarkable latitudinal variations in their maximum mean elevation, width, and morphological features (Fig. 2). Central Andes are >1000 km wide and include a 200 km large