Earth and Planetary Science Letters 410 (2015) 174–185

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

www.elsevier.com/locate/epsl

# Constraints on the role of tectonic and climate on erosion revealed by two time series analysis of marine cores around New Zealand

Antoine Cogez[a,b,*], Laure Meynadier[a], Claude Allègre[a], Delphine Limmois[a], Frédéric Herman[b], Jérôme Gaillardet[a]

[a] Equipe de Géochimie et Cosmochimie, Institut de Physique du Globe de Paris – Sorbonne Paris Cité, UMR 7154, Université Paris Diderot, Paris, France

[b] Institut de la Dynamique des Surfaces Terrestres, Faculté des Géosciences et de l'Environnement, Université de Lausanne, Lausanne, Switzerland

ARTICLE INFO

*Article history:*
Received 21 July 2014
Received in revised form 4 November 2014
Accepted 19 November 2014
Available online 11 December 2014
Editor: A. Yin

*Keywords:*
glacial erosion
Southern Alps
tectonics and climate controls
neodymium isotopes
glacial–interglacial cycles

ABSTRACT

Physical and chemical weathering govern rocks and chemical elements cycles at the Earth surface. The importance of climate and tectonic forcings has been identified but their relative influence still needs to be investigated. We address this question by studying neodymium (Nd) isotopic composition time series in two ocean sediment cores located on the eastern and western sides of New Zealand. We measured both detrital and authigenic phases of the sediment to decouple the oceanic from the continental contributions. The current and past climatic and oceanographic settings of this region have already been well studied, providing the underlying framework.

The results show glacial–interglacial variations of the authigenic signal, with larger amplitudes for the eastern core. We argue that oceanic influences can be discarded and propose that continental erosion on the South Island controls the Nd isotopes records in both cores. Mixing calculations show that Nd discharge was 2 to 10 times higher during glacial times than during interglacials on the eastern side, whereas these variations are almost negligible on the western side. We suggest that, on the East, larger ice volumes and fluxes during glacials generate higher physical erosion and thus an increase of easily weathered fine grains. In contrast, we observe steady rates on the western side. This implies that where both rock uplift and precipitation are extreme, topography and thus erosion rates are less sensitive to switches from glacial to fluvial erosion. Furthermore, the temporal relationship between climatic indicators like oxygen isotopes and the Nd isotopic composition reveals a nonlinear response of erosion to climate forcing. Those results contrast with previous studies using the same tracer that indicated stronger erosion over the Himalaya during interglacial periods and point out the complexity of erosion and weathering responses to climatic and tectonic forcings.

## 1. Introduction

Physical and chemical weathering are two main agents governing the terrestrial surface cycles of rocks and chemical elements. Chemical weathering has an incidence on climate over million years timescales through $CO_2$ consumption (Walker et al., 1981; Berner et al., 1983; Raymo and Ruddiman, 1992). Various parameters contribute to erosion and weathering, among which those related to or resulting from climate (e.g. temperature, precipitations, glaciers, runoff, vegetation) and those related to tectonics (e.g. sediment transport, exhumation, landscape surface age). Physical erosion has been recognized as a first order control on chemical weathering (Gaillardet et al., 1999; Millot et al., 2002; West et al., 2005; Calmels et al., 2007). Therefore, the quantification of the respective influence of climatic and/or tectonic parameters on erosion and weathering rates is essential to understand the long-term evolution of the Earth climate (West et al., 2005; von Blanckenburg, 2005; Willenbring and von Blanckenburg, 2010). This coupled system is nonlinear and threshold effects can make it even more delicate to decipher the role of each parameter (West et al., 2005; Dixon and von Blanckenburg, 2012). This objective can be reached by comparing present catchment areas and/or by studying the time evolution within a specific area.

The Southern Alps of New Zealand are particularly appropriate to address these issues. First, it is an active orogenic belt, with exhumation rates as high as 6–9 km/Ma (Herman et al., 2009; Little et al., 2005; Batt et al., 2000; Hovius et al., 1997), which have been shown to be the most important parameters controlling

---

[*] Corresponding author at: Institut de la Dynamique des Surfaces Terrestres, Faculté des Géosciences et de l'Environnement, Université de Lausanne, Lausanne, Switzerland.

*E-mail address:* antoine.cogez@unil.ch (A. Cogez).

http://dx.doi.org/10.1016/j.epsl.2014.11.029

modern erosion rates in this area (Whitehouse, 1986; Hovius et al., 1997; Herman et al., 2010). Second, the highest reliefs are covered by glaciers, which are suspected to have a strong influence on erosion and weathering (Anderson, 2005; Hallet et al., 1996; Herman et al., 2013). Moreover, there is an asymmetry of the precipitation rates (Tait et al., 2006) and rock uplift (Beavan et al., 2007) between the eastern and the western side of the chain. As a result, this area provides an ideal natural laboratory to constrain the respective roles of climate and tectonics. Fluctuations in temperature and precipitation led glaciers to come and go over the last glacial and interglacial cycles (Suggate, 1990; Barrell, 2011), while tectonic activity was most likely constant on the 100 ka timescale.

Here we studied two marine sediment cores on both sides of New Zealand over the last 300 ka to reconstruct the past erosion processes. We measured neodymium (Nd) isotopes, lead (Pb) isotopes, and Rare Earth Elements (REE) concentrations in both detrital and authigenic fractions of the sediments. Nd isotope abundance in marine sediment cores is a robust source and mixing tracer in the oceans for three main reasons: i) the wide heterogeneity of isotopic compositions of the different continental rocks, ii) the short mean residence of Nd in the oceans ($\simeq$500 yr) compared to the ocean mixing time ($\simeq$1500 yr) and iii) Nd isotopes are not significantly fractionated during erosion, dissolution, transport or sedimentation. Nd has been widely used for two decades as a tracer of both continental inputs in the ocean and ocean water masses mixing through time (Frank, 2002; Goldstein and Hemming, 2003). As mentioned by von Blanckenburg (1999) an issue is to decouple them in the same oceanic record. When the oceanic influences can be isolated, one may reconstruct the relative evolution of continental derived materials to the oceans (i.e. total denudation, including erosion and weathering) with a fine temporal resolution. Nd has a rather complex chemical behavior, as it can be dissolved in river waters as well as in seawater from particulate matter, associated with colloids, adsorbed onto oxides minerals (e.g. Elderfield et al., 1988; Gaillardet et al., 2003). Consequently the $\epsilon_{\mathrm{Nd}}$ record of the authigenic phase in marine sediments can reflect patterns in physical erosion as well as in chemical weathering over the continents. For this reason we assume that Nd data can record both processes. Lead isotopes can be used similarly, with the advantage that it has a much lower residence time in the oceans (some decades), hence is less influenced by water masses mixing, but its drawback is that it can be significantly fractionated during erosion and weathering.

Denudation rates reconstructions with resolution of tens of thousands years are lacking because the quantification of denudation rates through time (e.g., thermochronology) are often integrated over several tens to hundred of thousands years, or million years. The interest of Nd isotopes is to study with a 10 ka resolution the relative variations in total erosion, in the context of a temporally and spatially changing climate and spatially contrasted tectonics. Burton and Vance (2000) and Gourlan et al. (2010) studied Nd isotopes in a core located in the Bay of Bengal. They found that erosion and/or weathering was higher over Himalaya during interglacial periods, probably due to higher precipitations, in agreement with other studies using different proxies (e.g. Lupker et al., 2013; Colin et al., 1999). Hidy et al. (2014) also measured higher denudation rates in Texas during interglacial than during glacial periods. By contrast we show here using two Nd isotopes records on both sides of New Zealand that erosion was higher during glacial times over New Zealand. Our results reveal a contrast of erosion between the eastern and the western side of New Zealand. The topography and erosion rates are less sensitive to climate variations on the West than on the East. This study raises some important perspectives regarding erosion and weathering controls.

## 2. Materials and methods

### 2.1. Geographic setting

#### 2.1.1. Oceanic setting

New Zealand is located at the Southern Oceanic Front between surface to intermediate subtropical water masses coming from the Pacific Ocean and subantarctic water masses coming from the Southern Ocean (Fig. 1). Both water masses have very distinct isotopic compositions. The Pacific waters have the most radiogenic $\epsilon_{\mathrm{Nd}}$ ($\epsilon_{\mathrm{Nd}} \simeq -3$) and the Antarctic waters have more negative $\epsilon_{\mathrm{Nd}}$ ($\epsilon_{\mathrm{Nd}} \simeq -8$) (Lacan et al., 2012). The surface and intermediate currents have a North–South direction and are deviated eastward at the subtropical front (Tomczak and Godfrey, 2003). Deep Antarctic water masses flow toward the Pacific Ocean along the continental plateau (Tomczak and Godfrey, 2003). Deep waters farther away from New Zealand have lower $\epsilon_{\mathrm{Nd}}$ than the surface waters, $\epsilon_{\mathrm{Nd}} \simeq -6/-7$ (Elderfield et al., 2012). Weak intensity upwellings are present along the southern edge of the plateau, but they could have been stronger during glacial times (Lorrey et al., 2011; Nelson et al., 1993, 2000). The surface oceanic hydrologic characteristics are rather similar on both sides of New Zealand.

#### 2.1.2. Terrestrial setting

The Southern Alps are located in the South Island of New Zealand. Relief is asymmetric, with steeper slopes on the western side, and larger plains on the eastern side. This relief results from the collision between the Pacific Plate and the Australian Plate (Walcott, 1978). The Alpine Fault separates both plates and is located 20 to 30 km west of the Main Divide (Fig. 1). The western side, i.e. between the Alpine Fault and the Main Divide, is characterized by very high erosion rates (among the highest in the world, up to 5–10 km/Ma), which decrease rapidly to the east (Wellman, 1979) (Fig. 1). Strong precipitations occur on the western side (up to 12 m/yr), whereas the eastern side is drier (1 m/yr) (Tait et al., 2006). Present day erosion is characterized by landslides and rivers incisions on the western side, while U-shape glacial valleys dominate in the eastern side (Whitehouse, 1986; Hovius et al., 1997; Korup et al., 2004; Herman and Braun, 2006). A metamorphic gradient is observed from the Alpine Fault toward the East, schists lithology is mostly present on the western side of the Main Divide whereas sedimentary rocks like greywackes are exposed on the eastern side (Cox and Barrel, 2007). Along this gradient the protolith remains uniform, and low grade metamorphism is supposed to fractionate unsignificantly the Sm/Nd ratio and consequently the $\epsilon_{\mathrm{Nd}}$. Consequently little variations in $\epsilon_{\mathrm{Nd}}$ are expected along an east–west profile through the Main Divide. Some plutonic and intrusive magmatism is observed sparsely, mainly in the Northern Island and on the southern edge of the Southern Island. However, there is no particular east to west pattern, which would cause the average $\epsilon_{\mathrm{Nd}}$ to differ from the eastern to the western basins. Delmonte et al. (2004) measured $\epsilon_{\mathrm{Nd}}$ in different continental sedimentary deposits like fluvioglacial deposits, loess, sands, moraines. Interestingly these sediments provide an integrated value at a basin scale. The average value of their data (collected on both eastern and western sides) is $-3.8$, with no apparent differences between the east and the west of the Main Divide. An additional potential source of detrital material to the both sites is the Australian aeolian particles that travel along the Tasman Sea. Hesse and McTainsh (2003) showed that these dusts mostly originate from the Murray–Darling basins.

#### 2.1.3. Past climatic setting

Paleoceanographic studies have shown that Antarctic water masses have migrated northward during glacial periods with