Geomorphology 105 (2009) 291–302

Contents lists available at ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph

Structural, tectonic and glaciological controls on the evolution of fjord landscapes

Neil F. Glasser [a,*], Matías C. Ghiglione [b]

[a] Centre for Glaciology, Institute of Geography and Earth Sciences, Aberystwyth University, SY23 3DB, Wales, UK
[b] CONICET and Laboratorio de Tectónica Andina, FCEyN, Universidad de Buenos Aires, Ciudad Universitaria C1428EHA, Argentina

ARTICLE INFO

Article history:
Received 8 May 2008
Received in revised form 3 October 2008
Accepted 12 October 2008
Available online 26 October 2008

Keywords:
Fjords
South America
Patagonia
Structural geology
Tectonics
Glacial geomorphology

ABSTRACT

The fjord landscape of South America, stretching ~1500 km between Golfo Corcovado (~43°S) and Tierra del Fuego (~56°S), is the largest continuous fjord landscape on Earth. This paper presents the results of new structural geological and geomorphological mapping of this landscape using optical satellite images and digital elevation models. First-order geological structures are represented by strike-slip faults forming lineaments up to hundreds of kilometres long. The strike-slip faulting has been active since Late Cretaceous times and is responsible for the presence of a conspicuous structural cleavage visible as lineaments up to ~10 km long. A detailed analysis of these second-order lineaments from digital image data was carried out in three sectors. In Sector 1, located northwest of the North Patagonian Icefield, there are three distinct mean orientations, characterized by a main nearly orogen-parallel orientation (az. ~145°) and two orogen-oblique secondary orientations (az. ~20° and az. ~65°). In Sector 2, located west of the South Patagonian Icefield, there are also three separate mean orientations, with most of the lineaments concentrated between azimuths 0° and 80° (mean at ~36°); and two other orogen-oblique means at azimuth ~122° and ~163°. In Sector 3, around the Cordillera Darwin, there is a single main orogen-parallel mean at ~100–115°. In all three sectors, mapped fjord orientations bear a striking similarity to the structural data, with fjords orientated preferentially in the same direction as structural lineaments. We infer that successive glaciations followed the same ice-discharge routes, widening and deepening pre-existing geological structures at the expense of the surrounding terrain to create the fjord landscape. This study has broader implications for ice sheet reconstructions and landscape evolution beneath ice sheets because we demonstrate that the primary control on fjord development in glaciated areas is geological and not glaciological.

1. Introduction

Fjords are drowned glacial troughs. These deep, often-linear features carved into bedrock represent the effects of glacial erosion in situations where ice flow is confined by topography and channelled along a trough or valley (Glasser and Bennett, 2004). Fjord landscapes are common in the Arctic and Antarctic, as well as along the maritime fringes of southern South America, NW Europe and Norway, Canada, Alaska and New Zealand. Troughs and fjords also underlie the contemporary Greenland and Antarctic ice sheets (Sugden, 1974; Jamieson et al., 2005). Individual fjords are generally recognized to be palimpsest features, developed over successive glaciations (Nesje and Whillans, 1994; Bronge, 1996). Fjords erode rapidly under glacial conditions and their considerable dimensions indicate that they represent significant volumes of rock removal by glacial erosion. Mean Quaternary glacial erosion rates of between 1 and 2 mm a^{-1} have been calculated for glacial troughs in western Norway (Nesje et al., 1992) and Scotland (Glasser and Hall, 1997).

The cross-sectional form of individual glacial troughs has traditionally been described as 'U-shaped', but their true cross-sectional morphology is more accurately described by empirical power-law functions (Hirano and Aniya, 1988; Harbor and Wheeler, 1992; Yingkui et al., 2001) and by second-order polynomials (James, 1996). Trough cross-sectional morphology is highly variable since it varies with lithology (Harbor, 1995), rock mass strength (Augustinus, 1992a, 1995; Brook and Tippett, 2002) and the degree of alluvial modification (James, 1996). Modelling studies demonstrate that the cross-sectional morphology of glacial troughs tends towards an equilibrium form (Harbor et al., 1988; Harbor, 1992a,b). Valley patterns in fjord landscapes have been used to quantify the effects of glacial erosion (Haynes, 1977; Roberts and Rood, 1984; Haynes, 1995). Haynes (1972) and Augustinus (1992b) have suggested that the dimensions of outlet troughs in glaciated regions are adjusted to the discharge of ice through the trough and MacGregor et al. (2000) reached similar conclusions regarding trough longitudinal profiles.

The role of geological structure in fjord formation has previously been noted by a number of authors, although never investigated at a regional scale or in systematic detail. Gregory (1913), for example,

* Corresponding author.
E-mail address: nfg@aber.ac.uk (N.F. Glasser).

0169-555X/$ – see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.geomorph.2008.10.007

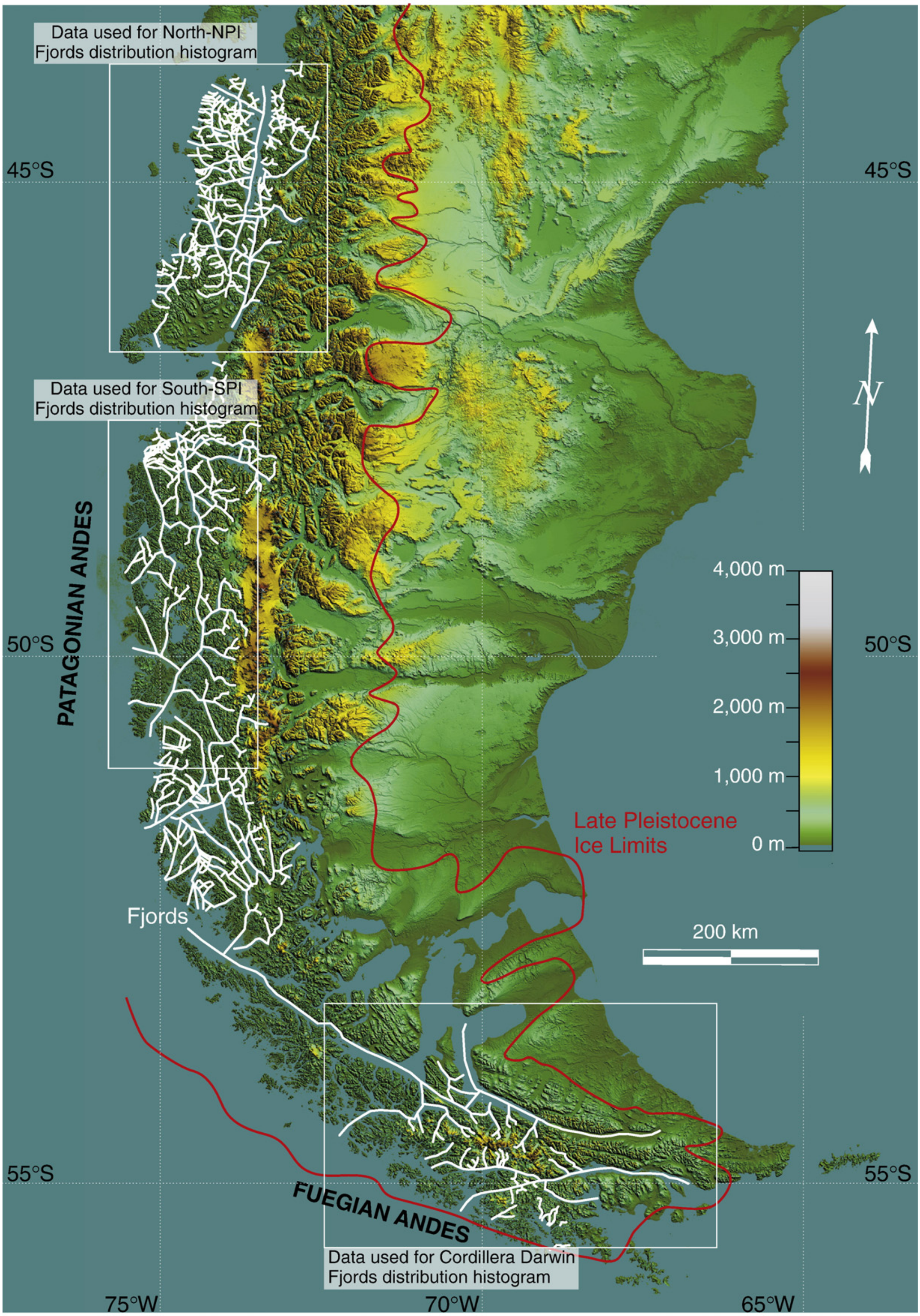

Fig. 1. High-resolution digital elevation model (Mercator projection) from processed National Aeronautics and Space Administration (NASA) Shuttle Radar Topography Mission data (SRTM; Farr et al., 2007) of the southernmost Andes (~38°–56°S). Superimposed on the map are the centre-lines of mapped fjords and other large coastal valleys, indicated by the white lines, and the Late Pleistocene ice limit from Sugden et al. (2005) marked with a red line. The white boxes indicate the extent of the three sectors used in orientation analysis: (1) around the North Patagonian Icefield, (2) around the South Patagonian Icefield and (3) in the Cordillera Darwin.