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Coeval emplacement and orogen-parallel transport of gold in oblique convergent orogens

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ABSTRACT

Varying amounts of gold mineralisation is occurring in all young and active collisional mountain belts. Concurrently, these syn-orogenic hydrothermal deposits are being eroded and transported to form placer deposits. Local extension occurs in convergent orogens, especially oblique orogens, and facilitates emplacement of syn-orogenic gold-bearing deposits with or without associated magmatism. Numerical modelling has shown that extension results from directional variations in movement rates along the rock transport trajectory during convergence, and is most pronounced for highly oblique convergence with strong crustal rheology. On-going uplift during orogenesis exposes gold deposits to erosion, transport, and localised placer concentration. Drainage patterns in variably oblique convergent orogenic belts typically have an orogen-parallel or sub-parallel component; the details of which varies with convergence obliquity and the vagaries of underlying geological controls. This leads to lateral transport of eroded syn-orogenic gold on a range of scales, up to >100 km. The presence of inherited crustal blocks with contrasting rheology in oblique orogenic collision zones can cause perturbations in drainage patterns, but numerical modelling suggests that orogen-parallel drainage is still a persistent and robust feature. The presence of an inherited block of weak crust enhances the orogen-parallel drainage by imposition of localised subsidence zones elongated along a plate boundary. Evolution and reorientation of orogen-parallel drainage can sever links between gold placer deposits and their syn-orogenic sources. Many of these modelled features of syn-orogenic gold emplacement and varying amounts of orogen-parallel detrital gold transport can be recognised in the Miocene to Recent New Zealand oblique convergent orogen. These processes contribute little gold to major placer goldfields, which require more long-term recycling and placer gold concentration. Most eroded syn-orogenic gold becomes diluted by abundant lithic debris in rivers and sedimentary basins except where localised concentration occurs, especially on beaches.

1. Introduction

Most of the world's hydrothermal gold deposits were emplaced, with or without associated magmatism, into active convergent orogens (Bierlein and Crowe, 2000; Goldfarb et al., 1998, 2005; Hronsky et al., 2012; Kerrich et al., 2005). All young and active collisional orogens have evidence for at least some syn-orogenic gold mineralisation (Craw et al., 2002; Craw et al., 2010; Goldfarb et al., 2005; Kerrich et al., 2005). Collisional orogenesis inevitably causes differential rock uplift and generally leads to substantial mountain chains, so erosion and sediment transport are important syn-orogenic processes (Allen and Allen, 1990; DeCelles, 2011). This erosion and associated on-going uplift can therefore erode syn-orogenic hydrothermal gold deposits and mobilise the contained gold into sedimentary systems, leading to localised formation of gold placer deposits (Boyle, 1979; Henley and Adams, 1979; Kerrich et al., 2005).

Gold is a durable mineral and acts as a persistent tracer for long distance sediment transport. Detrital gold is a useful tracer for understanding the processes of erosion and sediment transport through and along the margins of orogens in which hydrothermal gold deposits are known to occur (Leckie and Craw, 1995). Conversely, occurrences of placer gold are commonly used as an exploration tool for finding hidden hydrothermal sources (Boyle, 1979; Chapman et al., 2010). Therefore, understanding the links between coeval syn-orogenic hydrothermal and placer gold mobility is significant for the gold exploration industry. However, the link between syn-orogenic hydrothermal gold deposits and downstream placer gold deposits can become obscured or severed by on-going tectonic uplift and drainage reorientation (Boyle, 1979; Chapman et al., 2010; Craw, 2013; Craw et al., 2006b; Garnett and Bassett, 2005).

A notable feature of all orogenic belts is that parts of their river drainage systems flow parallel or sub-parallel to the orogens (Fig. 1; Burbank and Anderson, 2001; Koons, 1994, 1995; Roy et al., 2015a). Despite abundant orogen-perpendicular drainage, many of the largest rivers flow parallel to mountain belts for much of their lengths (Fig. 1). Consequently, abundant sediment transport and associated gold placer

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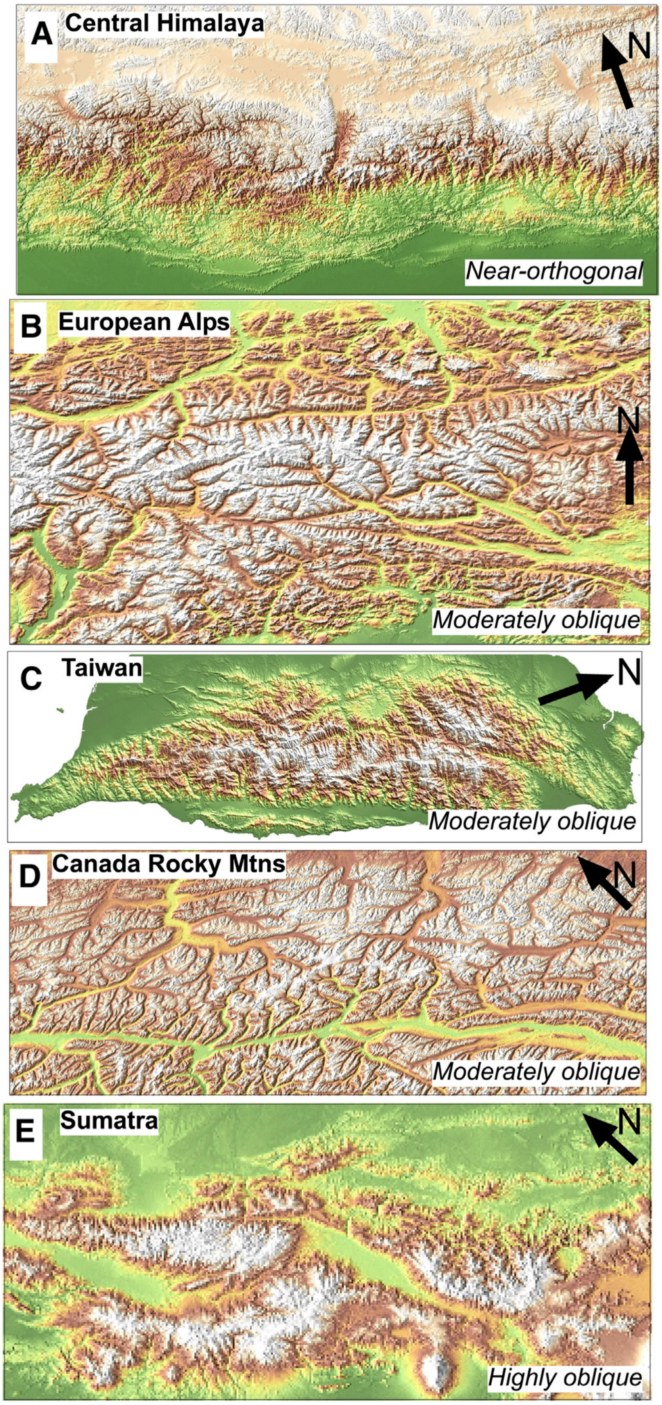

Fig. 1. Topographic images (derived from SRTM data; Kobrick, 2006) of portions of young and active convergent orogens, with long axis of each orogen rotated approximately horizontal, and orogens arranged in order of increasing obliquity. Note that numerous parts of the drainage patterns for each orogen are parallel, sub-parallel, or distinctly oblique to the orogen axis. Small syn-orogenic hydrothermal gold deposits are exposed in each orogen and contribute detrital gold to some orogen parallel rivers (Bowles et al., 1984; Craw et al., 2002; Jaffe, 1989).

formation occurs laterally, parallel to the orogens, rather than directly into syn-orogenic sedimentary basins (Burbank and Anderson, 2001; Craw, 2013). As collisional orogens develop, early-formed topography can be overprinted by later topographic features associated with ongoing uplift and erosion (Craw, 2013; Craw et al., 2013a).

Our previous work has studied the processes that lead to hydrothermal gold emplacement in orogenic belts, and this work involved 3D numerical modelling (Upton et al., 2011; Upton and Craw, 2014a, 2014b). In separate studies, we and others have investigated the topographic development of oblique orogens and the implications for mountain drainage geometry, also using 3D numerical modelling (Craw et al., 2013b; Craw, 2013; Koons, 1994, 1995; Koons et al., 2012; Roy et al., 2015b; Upton et al., 2009, 2014). Some of these models have specifically predicted orogen-parallel drainage geometry (Koons, 1994, 1995; Koons et al., 2012; Upton et al., 2014). In this study we combine the results of these two disparate themes to provide an integrated account of coeval gold emplacement and dispersal. These themes and associated models are applicable, to some extent, to all collisional orogens (e.g., Fig. 1). Our previously developed models were specifically targeted at the active New Zealand obliquely convergent plate boundary and in this study we link these two sets of model results in the framework of the Southern Alps (Fig. 2). We then place our models into a more global context and relate them to syn-orogenic gold emplacement, erosion, and detrital transport in other young orogens of varying obliquity.

2. Coeval orogenic and detrital gold in southern New Zealand

The New Zealand example of syn-orogenic gold emplacement and its coeval erosion and detrital transport is useful because it contains a wide range of hydrothermal and placer gold deposits, and the structural and drainage evolution of the orogen is well understood (Fig. 2). We go on to use previously published 3D geodynamic models which were developed for southern New Zealand, and herein we apply them to gold mobility in that oblique orogen (Upton and Craw, 2014a, 2014b; Upton et al., 2009). These geodynamic models provide insight into the topographic development of southern New Zealand and we use them to explain the current distribution of placer gold deposits (Fig. 2), including some that are now far removed and topographically separated from the portion of the orogen in which the hydrothermal gold was emplaced.

2.1. Tectonic setting and evolution

New Zealand lies astride the Pacific–Australian plate boundary, which is defined by subduction zones to the north and south, and a transcurrent fault, the Alpine Fault, which runs through the South Island (Fig. 2A; Norris et al., 1990; Walcott, 1986). Highly oblique convergence results in deformation of Paleozoic–Mesozoic basement rocks to form a range of high mountains, the Southern Alps, on the southeastern side of the Alpine Fault (Fig. 2A; Norris et al., 1990; Walcott, 1986). The plate boundary in the South Island was initiated in the early Miocene as a primarily strike-slip structure, with relatively minor mountain uplift, and has progressively evolved to the current configuration, with the most pronounced mountain uplift occurring over the past 5 million years (Cooper et al., 1987; Craw, 1995; Norris et al., 1990).

The Paleozoic–Mesozoic basement rocks in the Southern Alps are turbiditic greywackes and argillites, with minor mafic metavolcanic intercalations (Cox and Barrell, 2007). Mesozoic metamorphism resulted in partial to complete recrystallisation between pumpellyite–actinolite facies and amphibolite facies, with pervasive foliation in the higher grade rocks. High grade rocks are now being exposed by rapid uplift (up to 8 mm/year) immediately to the southeast of the Alpine Fault but to the northwest of the high mountains (Cox and Barrell, 2007). Farther southeast, the mountains are dominated by low-grade greywacke, with minor argillite. A large Mesozoic greenschist facies schist belt, the Otago Schist, occurs at the southern end of the mountains (Fig. 2A; Mortimer, 2003).

The distinction between inherited greywacke-dominated and schist-dominated basement has been important for relative crustal strength in the young orogen (Upton et al., 2009). In particular, the Otago Schist crustal block (Fig. 2A), which is some of the thickest crust in the orogen (~30 km), has behaved as a relatively weak zone as the

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