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Transport-related mylonitic ductile deformation and shape change of alluvial gold, southern New Zealand

Gemma Kerr [a], Donna Falconer [a], Frank Reith [b,c], Dave Craw [a,*]

[a] Department of Geology, University of Otago, Dunedin 9054, New Zealand
[b] The University of Adelaide, School of Biological Sciences, Department of Molecular and Cellular Biology, Adelaide, South Australia 5005, Australia
[c] CSIRO Land and Water, Environmental Contaminant Mitigation and Technologies, PMB2, Glen Osmond, South Australia 5064, Australia

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ABSTRACT

Gold is a malleable metal, and detrital gold particles deform via internal distortion. The shapes of gold particles are commonly used to estimate transport distances from sources, but the mechanisms of internal gold deformation leading to shape changes are poorly understood because of subsequent recrystallisation of the gold in situ in placer deposits, which creates a rim zone around the particles, with undeformed >10 μm grains. This paper describes samples from southern New Zealand in which grain size reduction (to submicrometer scale) and mylonitic textures have resulted from internal ductile deformation. These textures have been preserved without subsequent recrystallisation after deposition in late Pleistocene-Holocene alluvial fan placers. These mylonitic textures were imposed by transport-related deformation on recrystallised rims that were derived from previous stages of fluvial transportation and deposition. This latest stage of fluvial transport and deformation has produced numerous elongated gold smears that are typically 100 μm long and 10–20 μm wide. These smears are the principal agents for transport-induced changes in particle shape in the studied placers. Focused ion beam (FIB) sectioning through these deformed zones combined with scanning electron microscopic (SEM) imaging show that the interior of the gold particles has undergone grain size reduction (to ~500 nm) and extensive folding with development of a ductile deformation fabric that resembles textures typical of mylonites in silicate rocks. Relict pods of the pre-existing recrystallised rim zone are floating in this ductile deformation zone and these pods are irregular in shape and discontinuous in three dimensions. Micrometer scale biologically-mediated deposition from groundwater of overgrowth gold on particle surfaces occurs at all stages of placer formation, and some of this overgrowth gold has been incorporated into deformation zones. These examples provide a rare view into the nature of the physical processes that accommodate gold particle shape change during sedimentary transport.

1. Introduction

Most detrital minerals undergo shape change by physical abrasion during transport and redeposition, resulting in variably rounded exterior surfaces (Schumm and Stevens, 1973; Mills, 1979; Dill, 2007; Boggs, 2009). The degree of rounding and sphericity that results from this abrasion is affected by the hardness of the minerals and their crystal structures (Dill, 2007; Morton, 2012; Garzanti et al., 2015; Zoleikhaei et al., 2016). Common metallic detrital minerals such as gold (Au–Ag alloy), isoferroplatinum (Pt_3Fe), and awaruite (Ni_2Fe) are more malleable, and undergo internal deformation during transport in addition to external abrasion, leading to flattening (Yeend, 1975; Nutting and Nuttall, 1977; Eyles, 1995; Knight et al., 1999; Townley et al., 2003; McClenaghan and Cabri, 2011; Craw et al., 2013). In particular, gold readily deforms during transport to form thin detrital flakes that can have width to thickness ratios >10 (Yeend, 1975; Eyles, 1995; Knight et al., 1999; Youngson and Craw, 1999; Townley et al., 2003; McClenaghan and Cabri, 2011).

Despite the common occurrences of flakes of metallic minerals in sedimentary environments, the actual transformation mechanisms of these flakes by internal deformation are little understood. Detrital metals become increasingly flattened with transport distance, and edges of flakes are folded and refolded as the particles are hammered by larger and harder detritus, especially gravel, in the accompanying sediments (Yeend, 1975; Eyles, 1995; Knight et al., 1999; McClenaghan and Cabri, 2011). These processes are the external manifestations of internal ductile deformation, but the nature of this internal ductile deformation has not been studied. This lack of information, particularly in relation to gold, largely arises because gold flakes develop a secondary rim during and after transport (Desborough, 1970; Groen et al., 1990; Eyles, 1995; Chapman

* Corresponding author.
E-mail address: dave.craw@otago.ac.nz (D. Craw).

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et al., 2000; Stewart et al., 2017). Recrystallisation of the rims has been driven by internal strain energy induced during transport (Stewart et al., 2017). Consequently, details of the processes of the ductile deformation of gold have typically been obscured by the later recrystallisation. The present study fills this knowledge gap by reporting on internal ductile deformation textures in detrital gold that has not yet undergone post-depositional recrystallisation.

In this study, we draw the distinction between a gold ***particle***, which is the whole detrital mineral entity, and gold ***grains***, which are the crystallographic components of a detrital particle. We present observations, down to the submicrometer scale, of the external particle textures and internal grain textures of gold particles that have been deformed in a ductile manner during transport, yielding mylonitic textures. Hence, these examples provide a rare view into the nature of the physical processes that accommodate gold particle shape change during sedimentary transport. We have examined these textures using scanning electron microscopy (SEM), including electron backscatter diffraction (EBSD) and focused ion beam (FIB) sectioning at the micrometer scale to document the changes to the internal grain structure of gold immediately at and beneath the exterior surfaces of deformed particles. This study extends the work of Stewart et al. (2017) on gold from the same placers by identifying the mechanisms of grain deformation at the submicrometer scale that lead to internal ductile deformation and particle shape change. These processes occurred before the >10 μm scale post-depositional recrystallisation processes investigated by Stewart et al. (2017) that generally overprint and obscure the ductile deformation features.

2. Gold sample sites and analytical methods

2.1. Geological setting of gold sampling sites

Detrital gold for this study was obtained from placer concentrations in Pleistocene-Holocene fluvial sediments in the Otago placer goldfield of southern New Zealand (Figs. 1a–d; 2a–d; 3a–e). The basement for the goldfield is the Otago Schist belt, which hosts Cretaceous orogenic (hydrothermal) gold deposits including the world-class Macraes mine in the Hyde-Macraes Shear Zone (Fig. 1a, c; Williams, 1974; Mortensen et al., 2010). This shear zone is dominated by sulphidised sheared rock in which the gold is encapsulated in pyrite and arsenopyrite (Mortensen et al., 2010). The shear zone also contains sulphidic quartz veins, and some other small orogenic vein deposits occur in the area as well (Mortensen et al., 2010; Craw et al., 2015).

Gold placers have developed progressively on the schist basement by fluvial concentration and sedimentary recycling since the Cretaceous (Williams, 1974; Henley and Adams, 1979; Craw, 2010). Most of the hydrothermal gold has micrometer-scale particle size, but particle size has been enhanced in this area by supergene enrichment processes in the near-surface groundwater zone (Craw, 2010; Craw et al., 2015). The gold placers that contributed samples for this study from the Patearoa area in the eastern portion of the goldfield, are all relatively proximal to a basement source (primary and/or supergene), which is thought to be an extension of the Hyde-Macraes Shear Zone (Fig. 1a–d). However, specific outcrops of such mineralised rocks have not been found in the

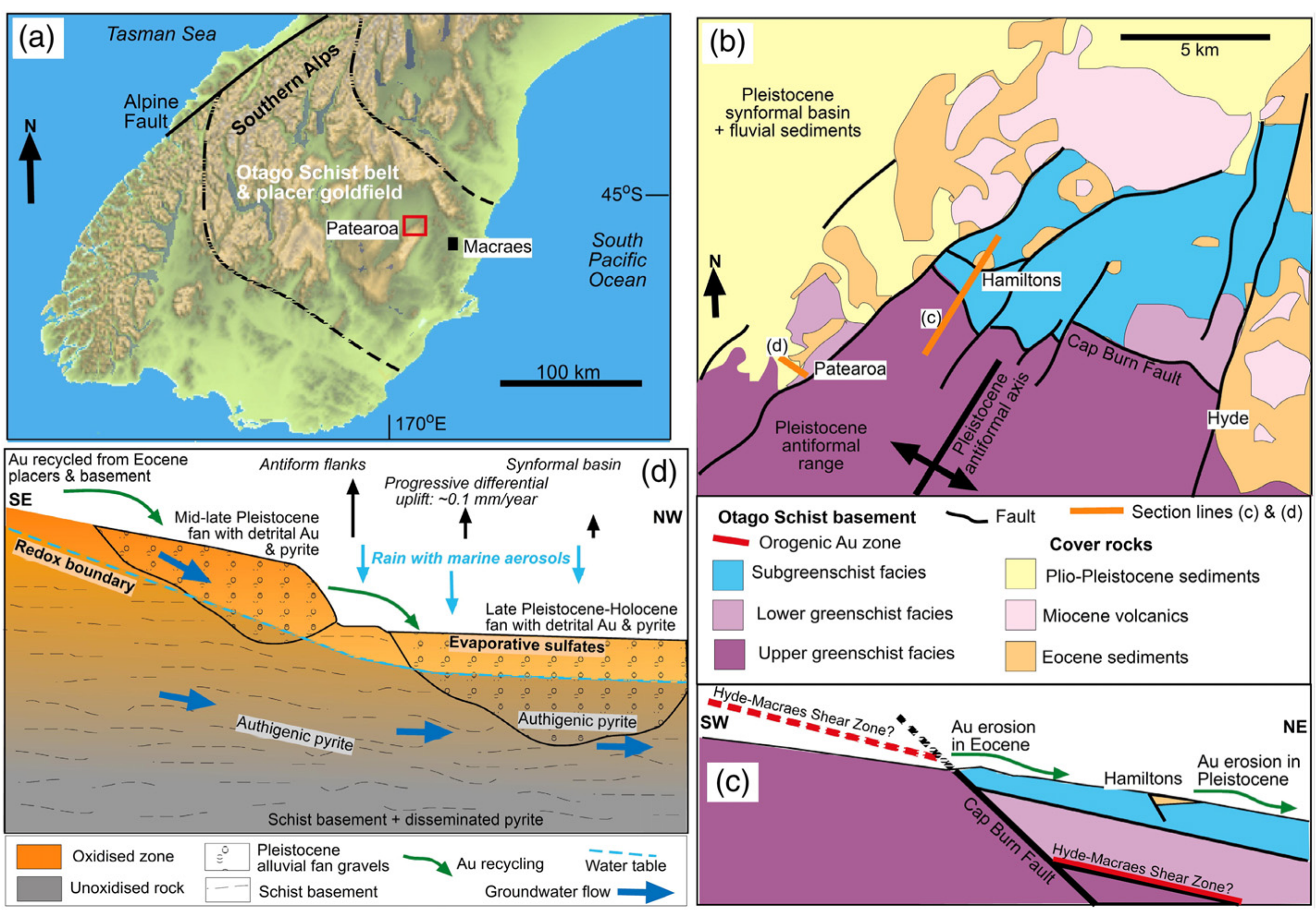

Fig. 1. Location and geological setting of gold samples from the Patearoa area in the Otago placer goldfield. (a) Regional topography and tectonic setting. (b) Geology of the Patearoa area (modified from Forsyth, 2001). Gold samples were obtained from alluvial fans at Patearoa and downslope of the Hamiltons Eocene paleoplacer. (c) Cross section through the Hamiltons paleoplacer showing inferred initial derivation of gold from orogenic sources (now eroded) and subsequent recycling. (d) Composite sketch cross section through Pleistocene-Holocene alluvial fans at Patearoa, showing the setting of gold placers.