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Determining sources of placer minerals using U-Pb ages of detrital zircons: example of auriferous quartz pebble conglomerates in Otago and Southland, New Zealand

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Abstract

We have dated populations of detrital zircons in two Miocene gold-bearing quartz pebble conglomerates, one at St Bathans in Central Otago and one near Gore in Northern Southland. Both samples contain large numbers of Triassic-Permian zircon grains that indicate a source area dominated by Eastern Province Torlesse Composite Terrane protoliths. On the basis that the detrital quartz, zircon and gold are derived from the same source, we can thus confirm a textural zone IV Otago Schist source for the gold content of both Miocene deposits. Hypotheses invoking a Western Province Buller Terrane (e.g. Reefton) source for Central Otago gold are thus refuted. Our investigation highlights the power of the detrital zircon dating method to identify and/or confirm suspected sources of economic placer minerals.

Keywords: zircon, U-Pb dating, Miocene, placers, provenance.

Introduction

The paragenesis of gold is a topic of perennial interest to economic geologists. In the South Island of New Zealand (Fig. 1), gold occurs in two principal geological settings, in Paleozoic-Mesozoic metasedimentary basement, and as younger alluvial (placer) deposits reworked from the basement. The South Island placers mainly comprise unconsolidated Holocene gravels of modern rivers but also include paleoplacers of Late Cretaceous to Pleistocene age (e.g. Youngson et al., 2006).

About half of the quartz gravel occurrences in Central Otago contain detrital gold, which has been mined at many of these localities (Mackay 1894). It is generally assumed and/or accepted that the source of quartz in these deposits (and, by inference, the gold) was the local Otago Schist of the Eastern province, most of which is metamorphosed Rakaia Terrane (Williams, 1974; Turnbull, 2000; Forsyth, 2001). Repeated local sedimentary recycling has been invoked as an important process in gold concentration (Youngson and Craw, 1996).

However there are some aspects of the auriferous quartz gravels in the St Bathans area that mean a Reefton area, Buller Terrane, Western Province basement source may be feasible. These points have never been clearly made in the published literature but they include: (1) indications at St Bathans of paleocurrent directions from a northwest quarter (Wopereis, personal observation); (2) the schist adjacent to St Bathans is low grade and free from quartz veins (Forsyth, 2001) so would not be the source of large volumes of quartz pebbles observed in the local gravels; (3) some reported accessory minerals (e.g. K-feldspar, ilmenite) are not found in local schist sources (Youngson and Craw, 1996) but could ultimately be sourced from Western Province granites; (4) cobbles of well-rounded quartz called ‘goose eggs’ by the early St Bathans miners are always associated with high alluvial gold grades and therefore must come from wide quartz veins; arguably, wide quartz veins are more typical on the West Coast than in Otago; (5) paleogeographic reconstructions show that the Reefton and Central Otago areas were spatially much closer in the Miocene than they are today (Fig. 2); (6) Manuherikia Group alluvial gold particle size (mode = 300-400 µm) and well-rounded shape indicates it is consistent with extensive fluvial transport in a braided river environment (Youngson and Craw, 1993). None of these points on their own are strong enough to seriously underpin a Western Province source, but taken together, the possibility must at least be considered.

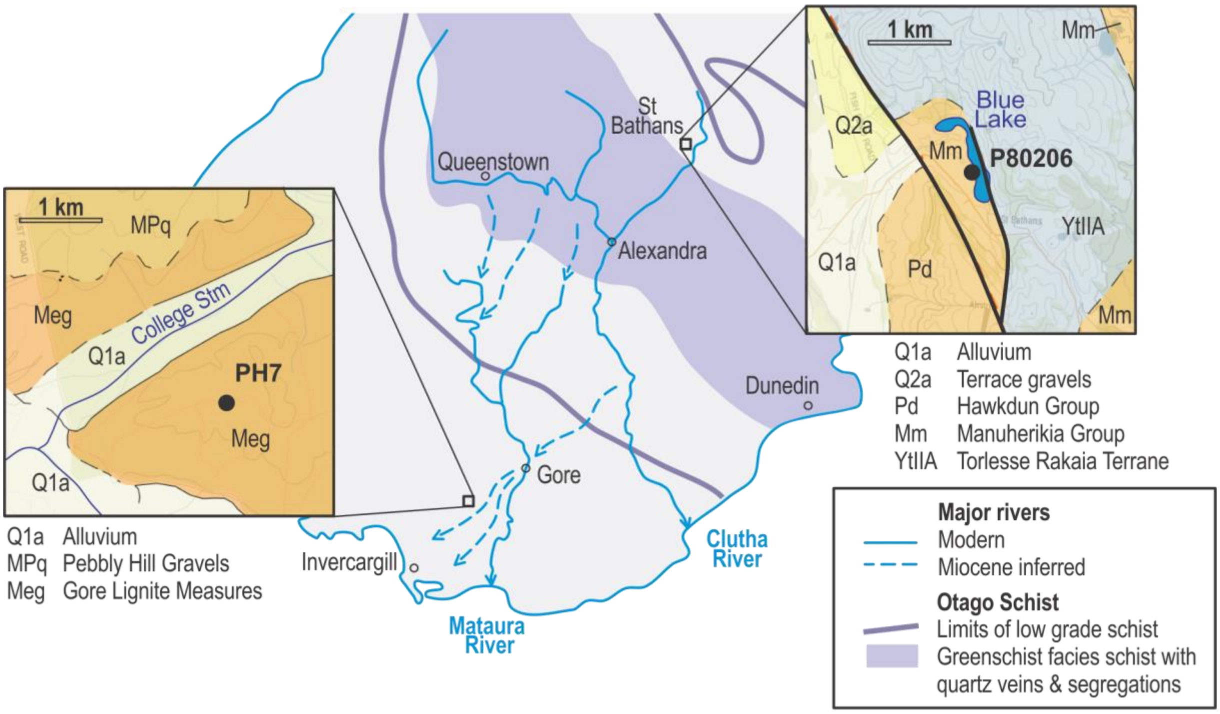

Figure 1. Location map of the southern South Island, New Zealand, showing selected geological and geographic features. Inset geology from Forsyth (2001) and Turnbull & Allibone (2003) via http://gns.cri.nz/geology; see these references for more detailed rock descriptions.

A Western Province vs. Eastern Province source for clastic detritus (quartz and gold) in South Island quartz pebble conglomerates is, in principle, capable of being tested by U-Pb dating of detrital zircons for the following three reasons: (1) zircon is intermediate in density and hydraulic equivalence between quartz and gold (Tourtelot, 1968) thus zircon might reasonably be expected to travel with those minerals; (2) the two potential source areas, Western and Eastern provinces, are of quite different basement geology and would supply zircon of different age ranges; (3) research work in the last few years has built up substantial reference datasets of zircon ages that characterise Zealandia’s basement terranes, batholiths and provinces.

In this paper we present a small case study in which U-Pb dating of detrital zircons from an auriferous non-marine quartz pebble conglomerate of Miocene age from St Bathans, Central Otago is used to inform on its detrital source area. For comparison, we also report results from a broadly coeval non-marine to deltaic quartz pebble conglomerate from near Gore in Northern Southland, also associated with detrital gold.

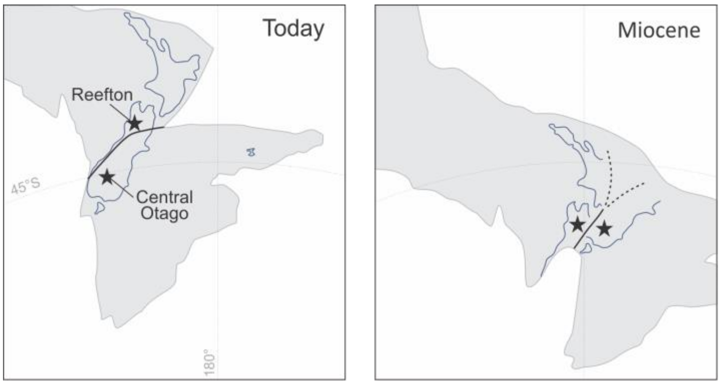

Figure 2. Present day and Miocene shape of the Zealandia continent (grey). Modern coastlines shown for reference. From Mortimer & Campbell (2014).

Methods

Bulk samples were cleaned of weathered material, washed, dried and weighed. They were then crushed and sieved and the <250 µm sieve fractions passed through sodium polytungstate (relative density 2.85) to remove quartz and feldspar. The dense mineral fraction for each sample was dried and weighed. Further concentration of zircon was made using a magnetic separator, followed by final handpicking. Zircon crystals were dated by excimer laser ablation inductively couple plasma mass spectrometry (ELA-ICP-MS) in the Otago Community Trust Centre for Trace Element Analysis, University of Otago. Analytical procedures followed Ballard et al. (2001) with data reduction as described by Sagar and Palin (2011). Zircon cores were avoided during analysis and our data can be considered to comprise rim ages. We acknowledge that the numbers of grains analysed in this reconnaissance study (c. 70 for each sample) are fewer than would be ideal for a statistically defendable detrital population, and therefore care was taken to avoid over-interpretation of the data.

Results are shown graphically in Fig. 3. Raw analytical data have been lodged in the Petlab geoanalytical database (http://pet.gns.cri.nz) and are also available from the authors on request.

Dunstan Formation, Manuherikia Group

Placer gold mining took place in the St Bathans area from 1864 to 1933 (Everett, 1982). The largest workings were at St Bathans itself, now flooded to form the Blue Lake from where sample P80206 was taken (NZMG E2258017, N5588253) (Fig. 1). P80206 is a loosely consolidated, poorly-sorted, subrounded non-marine quartz pebble conglomerate from the Dunstan Formation of the Manuherikia Group. Bedding dips c. 45° southwest. Further descriptions of the Dunstan Formation are given by Youngson and Craw (1996) and Forsyth (2001).

The maximum size of pebbles in P80206 is c. 10 mm and a silty matrix is present. The heavy mineral 'crop' was 0.0008 wt% of the bulk sample crushed and mainly comprised zircon, ilmenite and oxidised ilmenite ('leucoxene') with lesser amounts of biotite, monazite, garnet, clinozoisite and tourmaline. This corresponds with heavy mineral data reported in Everett (1982).

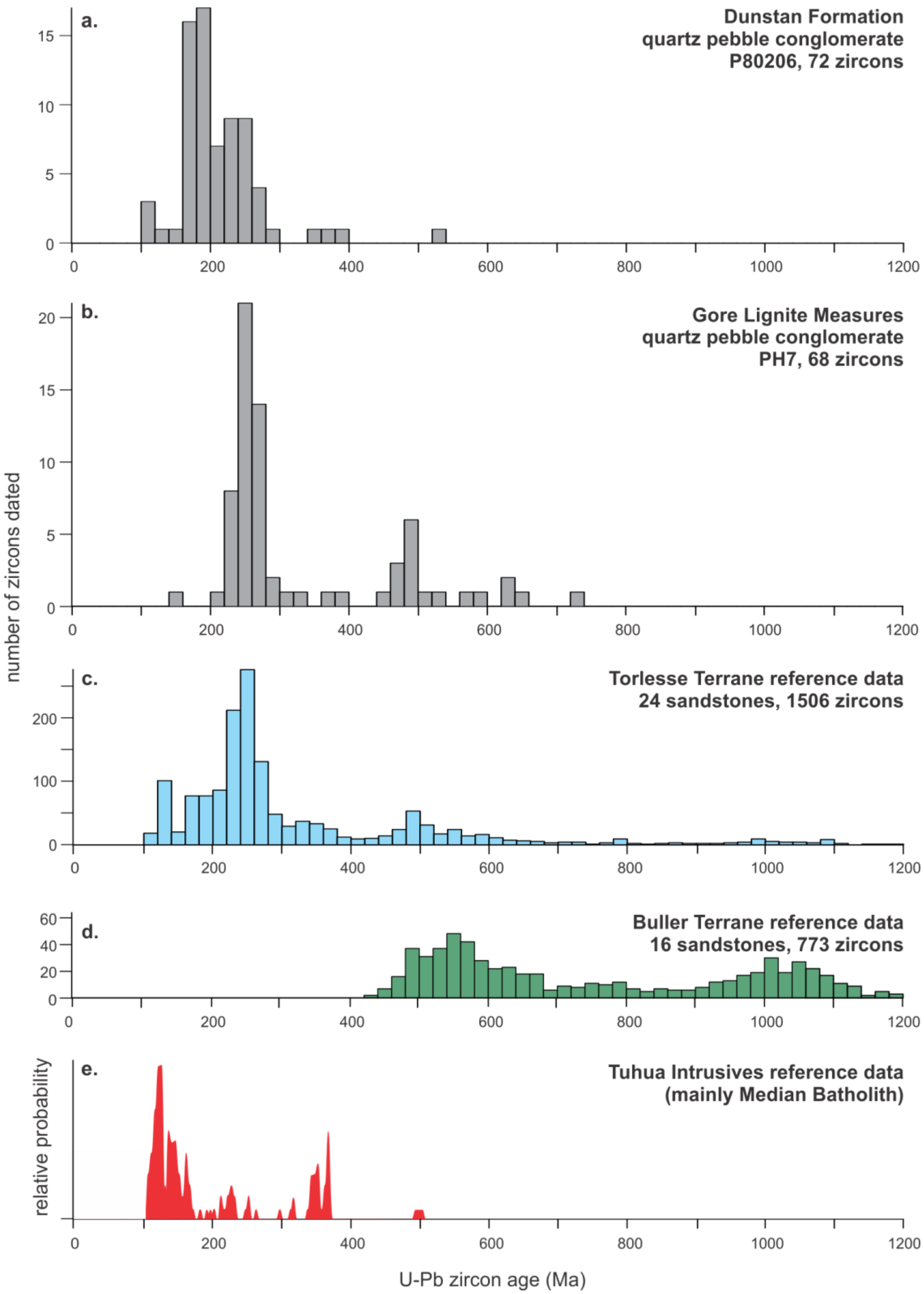

Figure 3. U-Pb zircon age plots. **a-b** histograms of new detrital zircon data from the two quartz pebble conglomerate samples; **c-d** histograms of Torlesse Composite and Buller terrane detrital zircon reference data from Adams et al. (2007, 2009, 2011, 2013, in revision); **e** relative probability plot of plutonic record of New Zealand after Mortimer & Campbell (2014) based on Kimbrough et al. (1994), Tulloch and Kimbrough (2003), and Tulloch et al. (2009). The four histograms have been height-adjusted so that the area of the bars is the same in each.

Seventy two out of 74 analysed zircons in P80206 gave analytically concordant ages (were <10% discordant on $^{235}U/^{207}Pb$-$^{238}U/^{206}Pb$ plots) and form the dataset on which our interpretations are based (Fig. 3a). Most of the detrital zircon grains in P80206 are Early Jurassic to Middle Permian (160-270 Ma) in age; the median age of the entire dataset is 196 Ma. There are five Early Cretaceous zircons (115, 116, 118, 133 and 142 Ma) and five Early Permian to Early Cambrian zircons (284, 355, 378, 381 and 536 Ma).

Gore Lignite Measures, East Southland Group

Gold is recorded from gravels near Gore but production history does not rival that of Central Otago. Sample PH7 is a bulk channel sample from a 4.5 m thick section of quartz pebble conglomerate south of College Creek (NZMG E2171417 N5430745; NZTM E1261639, N4868812) (Fig. 1). Bedding dips 2° west. PH7 is a loosely consolidated, poorly-sorted rounded quartz pebble conglomerate. The sample location is mapped within an area of poorly exposed Miocene Gore Lignite Measures of East Southland Group that underlie Miocene-Pliocene Pebbly Hill Gravels (Turnbull and Allibone, 2003). The stratigraphic correlation of PH7 is confirmed by its SiO2 content of 98.77 wt % (normalised anhydrous), distinctly less than the 99.37wt% average of Pebbly Hill Gravels (Mine Design Systems, 2003). The clastic content of the Miocene Gore Lignite Measures changes from lithic, local Murihiku Terrane-derived, at the base to quartz pebble-dominated near the top (Isaac and Lindqvist, 1990; Stein et al., 2011). These authors as well as Clough and Craw (1989) state that the quartz pebbles were derived from Otago Schist.

The maximum pebble size of PH7 is 16 mm. The heavy mineral 'crop' was 0.0064wt% of the bulk sample crushed and mainly comprised ilmenite and oxidised ilmenite with lesser amounts of zircon, tourmaline, epidote and gold.

Sixty eight out of 69 analysed zircon grains in PH7 gave analytically concordant ages and form the dataset on which our interpretations are based (Fig 3b). The pattern is somewhat different from P80206. Most of the detrital zircons in PH7 are Late Triassic to Early Permian (219-290 Ma) in age (Fig. 3a); the median age of the entire dataset is 261 Ma. There is also a distinct group of 12 Ordovician-Cambrian zircons (443-534 Ma). The remaining zircons comprise one Early Cretaceous grain (143 Ma), four Carboniferous-Devonian grains (309, 330, 369, 383 Ma) and six Proterozoic grains (575, 600, 625, 632, 645, 736 Ma).

Reference datasets

Due to a programme of geological research work at GNS Science in the last few years, there are substantial reference datasets of basement zircon ages that can be used in the interpretation of our two 'unknown' samples (e.g. Adams et al., 2007, 2009, 2011, 2013, in revision; Kimbrough et al., 1994; Tulloch and Kimbrough, 2003; Tulloch et al., 2009).

The Torlesse Composite Terrane pattern in Fig. 3c is based on detrital data from all three constituent terranes: Rakaia, Kaweka and Pahau which have Permian-Triassic, Jurassic and Early Cretaceous depositional ages respectively. Although traditionally, the protolith of the Otago Schist has been interpreted as just being Rakaia Terrane (Turnbull, 2000; Forsyth, 2001), Jurassic U-Pb zircon ages have been reported by Jugum et al. (2013) and (albeit further north in the Alpine Schist), Cretaceous U-Pb zircon protolith ages by Cooper and Ireland (2013). It is not yet possible to map out the extent of these younger Torlesse units within the Otago Schist but, even in younger Torlesse rocks, the Triassic-Permian peak is present and distinctive of Torlesse Composite Terrane.

Source areas of Miocene quartz pebble conglomerates

If Buller Terrane (Western Province) had been a major or even a partial contributor, then substantial proportions of Precambrian zircons (Fig. 3d) would be present in our two Miocene samples: they are not. Insterad, both samples have a distinctive major Triassic-Permian peak and a hint of a weaker Cambro-Ordovician peak (Fig. 3a, b). We therefore interpret both the Manuherikia Group sample, P80206 and the Gore Lignite Measures sample PH7, to have been derived predominantly from the Torlesse Composite Terrane. P80206 has a large number of Early Jurassic zircons (Fig. 3a) suggestive of Kaweka Terrane (Adams et al., 2009) and certain Otago Schist samples (Jugum et al., 2013). A Median Batholith source for the Early Jurassic zircons can be ruled out because there was a lull in batholith plutonism in the Early Jurassic (Fig. 3e). The youngest, Cretaceous, zircons in both P80206 and PH7 may, too, ultimately have schist protolith origins or may have been derived from the Median Batholith and ended up in the Miocene rocks via one or more sedimentary recycling episodes (cf. Youngson and Craw, 1996).

Based on the >95% abundance of quartz in the samples we, like workers before us, interpret the quartz pebble conglomerates to have come from a greenschist facies or higher grade metamorphic region where quartz veins and segregations are both thick (>10 mm) and abundant. Because the new zircon data indicate a Torlesse Composite Terrane, not a Buller Terrane protolith, the interpreted source region is greenschist facies Torlesse Composite Terrane, the shaded region between Dunedin and Queenstown in Fig. 1. The St Bathans quartz pebble conglomerates rest against low grade (unveined and unsegregated) Torlesse Schist (Fig. 1) so although some fluvial transport is necessary and indicated (Youngson and Craw, 1993), the quartz pebble conglomerates can still be regarded as relatively proximal to source. In contrast the Gore area quartz pebble conglomerates are well isolated from source and a number of potential paleo-fluvial pathways can be identified (Fig. 1; Craw, 2013).

The differences between the P80206 and PH7 samples are interesting. They suggest that, (1) despite the shared greenschist facies Torlesse Composite Terrane provenance, local intra-schist source differences persist through into Miocene sediments and (2) there was not complete mixing, or even necessarily a detrital connection, between our two sample sites. Additional detrital zircon dating thus shows promise to further inform on Miocene drainage patterns and paleogeography.

Conclusions

We interpret the detrital source of the zircon grainss (and, by association, quartz pebbles and gold grains) in a sample of Miocene Dunstan Formation, Manuherikia Group quartz pebble conglomerate at St Bathans to be proximal Torlesse Composite Terrane greenschist facies Otago Schist. This may not seem an especially surprising result, given the immediate presence of the underlying and surrounding Otago Schist with its known auriferous quartz lodes and shear zones. However it authoritatively puts to rest any notions that the source of the Central Otago Miocene placers could have been the Reefton area of New Zealand’s Western Province.

A sample of Miocene Gore Lignite Measures, East Southland Group quartz pebble conglomerate near Gore gives a slightly different detrital zircon age spectrum but we also interpret it to be sourced from Torlesse Composite Terrane greenschist facies Otago Schist. The area of Gore Lignite Measures outcrop is now isolated geographically from any obvious gold source although, as with the Manuherikia Group conglomerates, an Otago Schist source has previously been inferred. Gore Lignite Measures were deposited along and near a Miocene coastline and our zircon data rule out any substantial sediment contribution from New Zealand's Western Province, including from the Median Batholith.

The main result of this small study is to demonstrate the value that detrital zircon dating studies can add in understanding the origin and context of economically significant placer deposits. In New Zealand, such studies could be applied to other placer gold deposits and also to ironsands.

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