

Structural controls on gold mineralisation, Reefton Goldfield, New Zealand

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Abstract

The Reefton Goldfield has had the largest hard-rock gold production (64 t Au) on the West Coast of the South Island of New Zealand, and is currently under renewed development by Oceana Gold. The gold predominantly occurs in variably sheared quartz veins that are associated with zones of tighter, shorter wavelength folds in the host Greenland Group metasediments. The quartz veins typically occur as a series of plunging shoots that align with specific fold limbs or fold hinge zones. Shear zones containing disseminated mineralisation and quartz veins have thickness variations that relate to the angular relationship between the shear and host-rock bedding. Exploration strategies and targeting can be developed around both types of structural control.

Keywords: *gold, structural controls, folding, faulting, quartz veins, Paleozoic, mesothermal, orogenic, Greenland Group, Reefton Goldfield*

Regional setting

Gold-bearing quartz veins of the Reefton Goldfield occur within the metasedimentary Ordovician Greenland Group of the Buller terrane (Cooper 1974, 1989). The terrane is widespread over the West Coast of the South Island of New Zealand and was originally contiguous with rocks in southeastern Australia and Antarctica as part of the Paleo-Pacific margin of Gondwanaland (Cooper & Tulloch 1992). The Greenland Group is indurated sedimentary rock, generally metamorphosed to sub-greenschist facies (Adams et al. 1975), although locally to amphibolite facies, and hornfelsed adjacent to intrusive plutons (Nathan et al. 2002). The basement to Greenland Group is not exposed in New Zealand but correlative metasediments of southeastern Australia are underlain by Cambrian metavolcanic rocks (Gray et al. 1991).

The Reefton Goldfield has historically been the largest hard-rock gold producer on the West Coast. The goldfield has produced over 64 tonnes of gold predominantly from quartz vein-hosted ore deposits (Barry 1993). The goldfield has been extensively explored and mined since the 1860s. The largest mine, Blackwater at Waiuta in the south of the area, produced over 22 tonnes of gold until its closure in 1952 and up until then had been New Zealand's third largest gold mine. Oceana Gold Ltd is currently developing an open-pit mine on the historic Globe-Progress deposit, with plans to mill and concentrate ore on site, and then rail it >450 km for processing at the Macraes gold plant in Otago. Their Reefton exploration is currently testing other opportunities at the former Crushington, Inkerman and Merrijigs groups of mines.

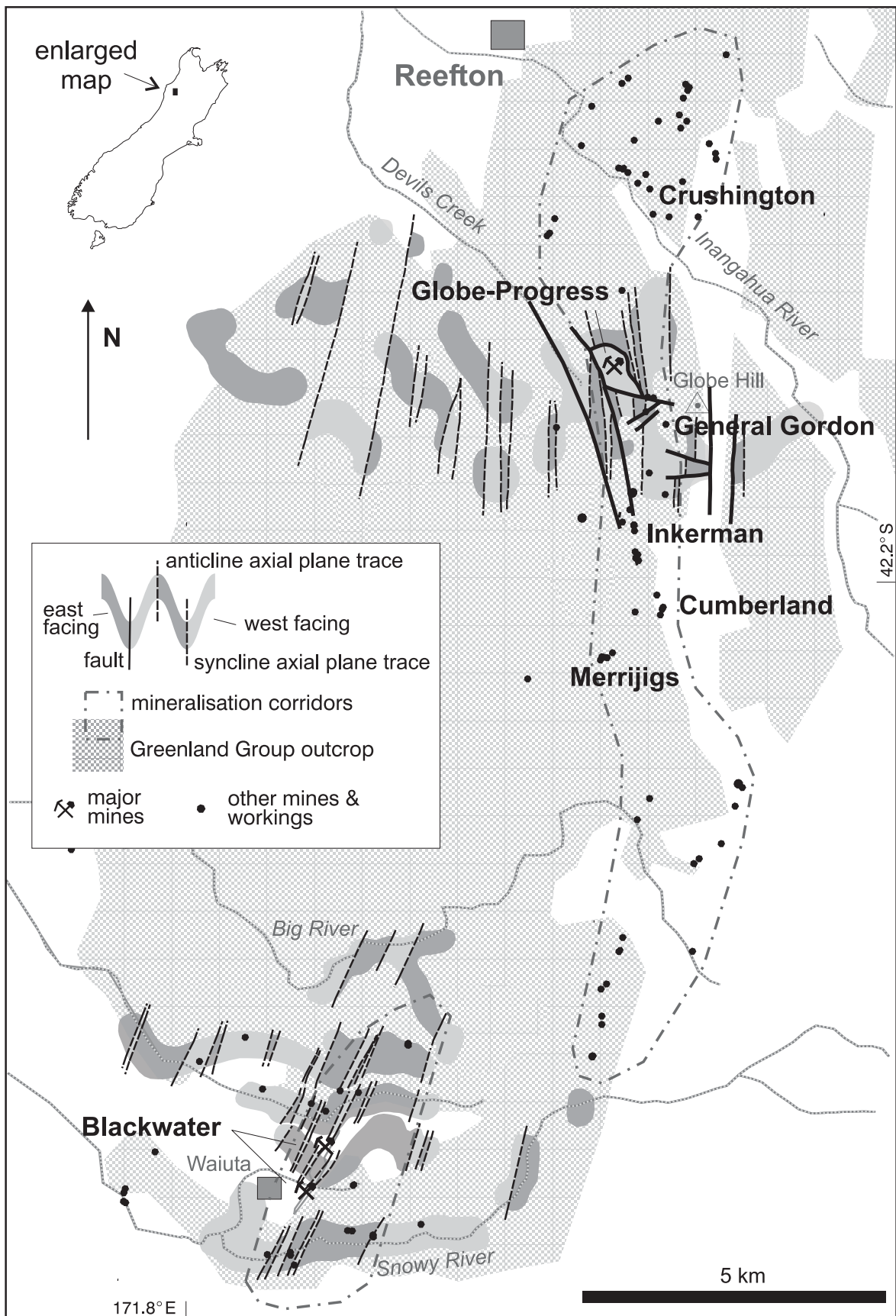


Fig. 1 Structural geology of the Reefton Goldfield showing Greenland Group outcrop and areas of common fold limb facing bounded by folds and faults. The northern part of the goldfield is not shown and includes the Caplestone group of mines 5 km north of Reefton. Modified after Rattenbury & Stewart (2000).

Reefton Goldfield setting

The Reefton Goldfield occurs in low-mid elevation hills, east of the Grey-Inangahua valleys and west of the more elevated Victoria Range. The host Greenland Group rocks are characteristically monotonous quartzose sandstone and mudstone turbidites lacking identifiable fossils apart from one instance of graptolites (Cooper 1974). Late Devonian – Carboniferous and Early Cretaceous granitic rocks intrude the Greenland Group (Nathan et al. 2002). Covering strata include Early Devonian, Permian, Late Cretaceous to Eocene, and Miocene sedimentary rock, typically in-faulted as grabens or half-grabens. These are capped by locally thick Quaternary glacial outwash deposits.

The structure of the Reefton Goldfield is dominated by moderate to steeply dipping, north-striking strata (Gage 1948). The strata are commonly tightly folded about gently plunging to subhorizontal axes, accompanied by a pervasive axial plane cleavage (Rattenbury & Stewart 2000). Most of the mined gold occurrences in the Reefton Goldfield occur within a north trending zone approximately 1-2 km wide (Fig. 1). The zone is characterised by tighter and shorter wavelength folding than the sparsely mineralised rocks either side.

Undisrupted fold hinges are uncommon and show significant hinge thickening. In general, the fold hinges are cut by shears parallel to one bedding limb or the axial. Identification of fold hinge location is possible from sedimentological younging criteria in some places but elsewhere can be determined from bedding-cleavage vergence (Rattenbury & Stewart 2000). Delineation of zones of common fold limb facing is an essential structural mapping tool where outcrops can be limited to river and road cuttings. Identification of west- versus east-facing zones allows the inference of cross-cutting faults and highlights areas of increasing fold complexity, a potential mineralisation indicator.

Mine and prospect setting

Individual mined ore deposits appear to have contrasting structural styles and the two largest gold mines in the goldfield represent two end members in style. The Blackwater mine at Waiuta is a single, remarkably planar, and uniformly wide (0.5-1 m) quartz vein that lacks significant shearing (apart from discrete cross-faulting) and has a thin alteration halo. In contrast, the Globe-Progress mine worked a series of quartz veins with an overall curvilinear shape of variable thickness, with significant shearing, brecciation, disseminated mineralisation and a wide alteration halo (Christie & Brathwaite 2003). This wider envelope of shear-related mineralisation is the focus of Oceana Gold's renewed Globe-Progress development. Despite the differences between deposit styles, there are common features that link these deposits.

Plunging shoots of gold-quartz mineralisation are a feature throughout the Reefton Goldfield. Shoots are tabular, commonly with regular parallel-edged geometry. Plunge direction varies systematically along the goldfield, plunging northeast where bedding strikes N-NE, and southwest where bedding strikes WNW-N. Based on detailed analyses of three mined areas, an apparent relationship between plunge and the overall trend of bedding and fold axes points to some form of host-rock structural control on quartz vein formation (Lew & Corner 1988, Cox 2000).

Blackwater

Evaluation of the geometry of mineralisation and host rocks within 2 km of the Blackwater mine indicates the sheet-like gold-bearing quartz vein obliquely truncates host rock folding by c.10° (Fig. 2). The shape and scale of the vein is very similar to the expected pattern of intersected fold limbs projected onto the walls of the vein. The trace of 200-400 m wavelength folds on the vein walls have an apparent wavelength of between 1.3-2.5 km. The 1050 m strike-length of historic mining is equivalent to the half-wavelength spacing of fold hinges in the wall rock, suggesting that the vein may be related to the intersection with folds.

The vein also stops abruptly along lines with the same plunge as the trace of the fold axial planes on the vein margin, although faults with this orientation are also known to exist (Barry 1993). While there is clear evidence for small-scale offset on these faults, larger-scale formation of the Blackwater vein appears to have preferentially developed in one limb of a fold. A corollary of this model is that exploration targets with excellent potential may exist as parallel shoots one fold wavelength (c. 1350-2500m) further along strike from the Blackwater mine, with relatively barren rock expected between the mine and target area.

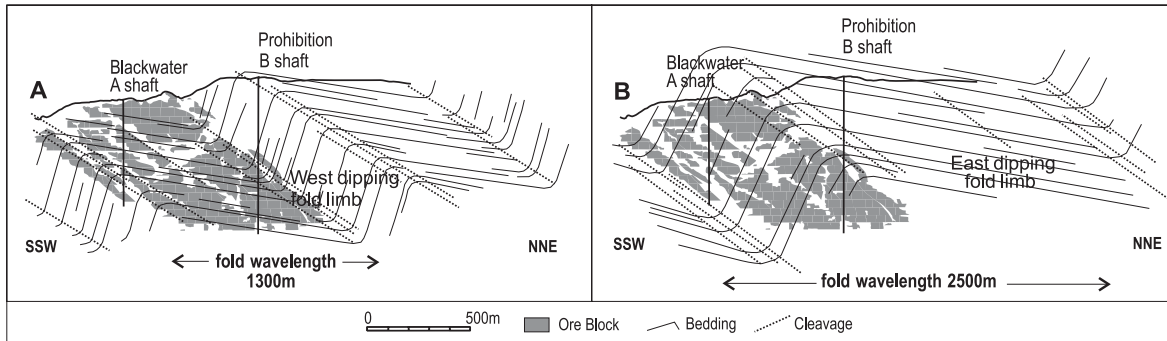


Fig. 2 Inferred long sections of the Blackwater mine at Waiutu. The mine worked a north-plunging quartz vein that obliquely intersects cleavage and bedding. The vein is probably constrained by fold limbs although this can only be narrowed down to two possibilities (A or B) until more data becomes available. Modified after Cox (2000).

Capleston

The scale of mineralised shoots forming the Capleston group of mines is much smaller than at Blackwater. At Capleston four of the five shoots are regularly spaced along a single planar shear, and a model is envisaged where ore shoots are located on a syn-mineralisation shear where it has propagated through fold limbs in the host rocks (Fig. 3). Minor offset on post-mineralisation faults separates the Specimen Hill shoot from the rest of the Capleston Group, and truncates the other shoots at depth.

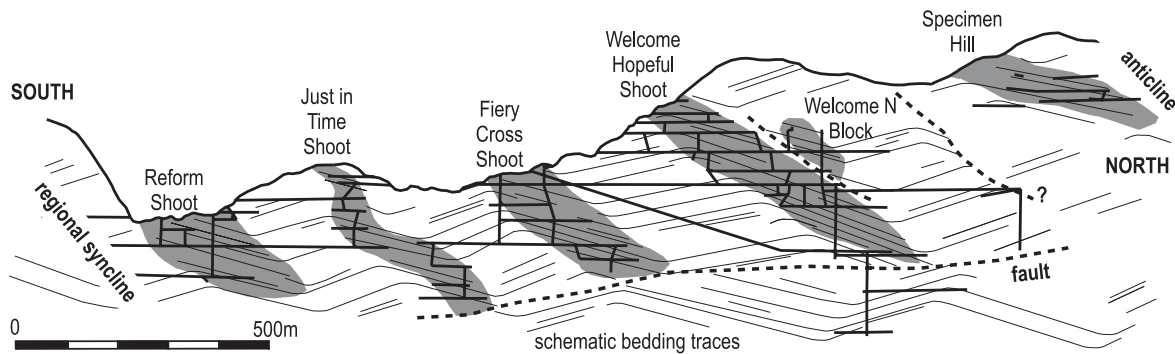


Fig. 3 The Capleston group of mines follows quartz veins that appear to be constrained by one set of limbs of plunging folds. Shown here are bedding traces on a north-trending shear plane that contains the quartz shoots. Modified after Cox (2000).

Globe-Progress

The Globe-Progress mine has worked reef quartz occurring in a series of plunging shoots contained within a shallowing curvilinear shear surface, the Globe-Progress Shear (Fig. 4). In the west the shear strikes east and dips 60° S, but swings to a SSE strike farther east. The shear shallows from 60° at the surface to dips of 10-20° at depth, and appears to be semi-continuous southward at least as far as General Gordon. The overall shape of the Globe-Progress shear resembles a quarter bowl. A NNW trending structure, the Oriental Shear, occurs along the eastern side of the Globe-

Progress Shear, dipping 65°W. In the deepest part of the mine, mineralisation is truncated at the Chemist Shop Fault but recent work suggests this fault may be less influential than previously believed. The continuation of the mined Progress and Callaghans quartz shoots indicates that mineralisation extends farther west and deeper without significant fault displacement (Fig. 4).

Gold is concentrated in historically mined quartz-rich shoots, and in larger high-grade pods defined by resource drilling and modelling. The quartz-shoots and high-grade pods differ in location and orientation (Fig. 4). The correlation of quartz-shoots with fold hinges was first noted by Lew & Corner (1988). Recent interpretation indicates a stronger correlation with hanging wall folding. The steeply west-dipping axial planes of these anticlines, synclines and monoclinial flexures intersect the Globe-Progress Shear at the position of many of the main SSW-plunging quartz shoots, unlike the subvertical axial planes of the footwall folds. The shoots also appear to have developed preferentially where the Globe-Progress shear intersects west-facing, west-dipping beds.

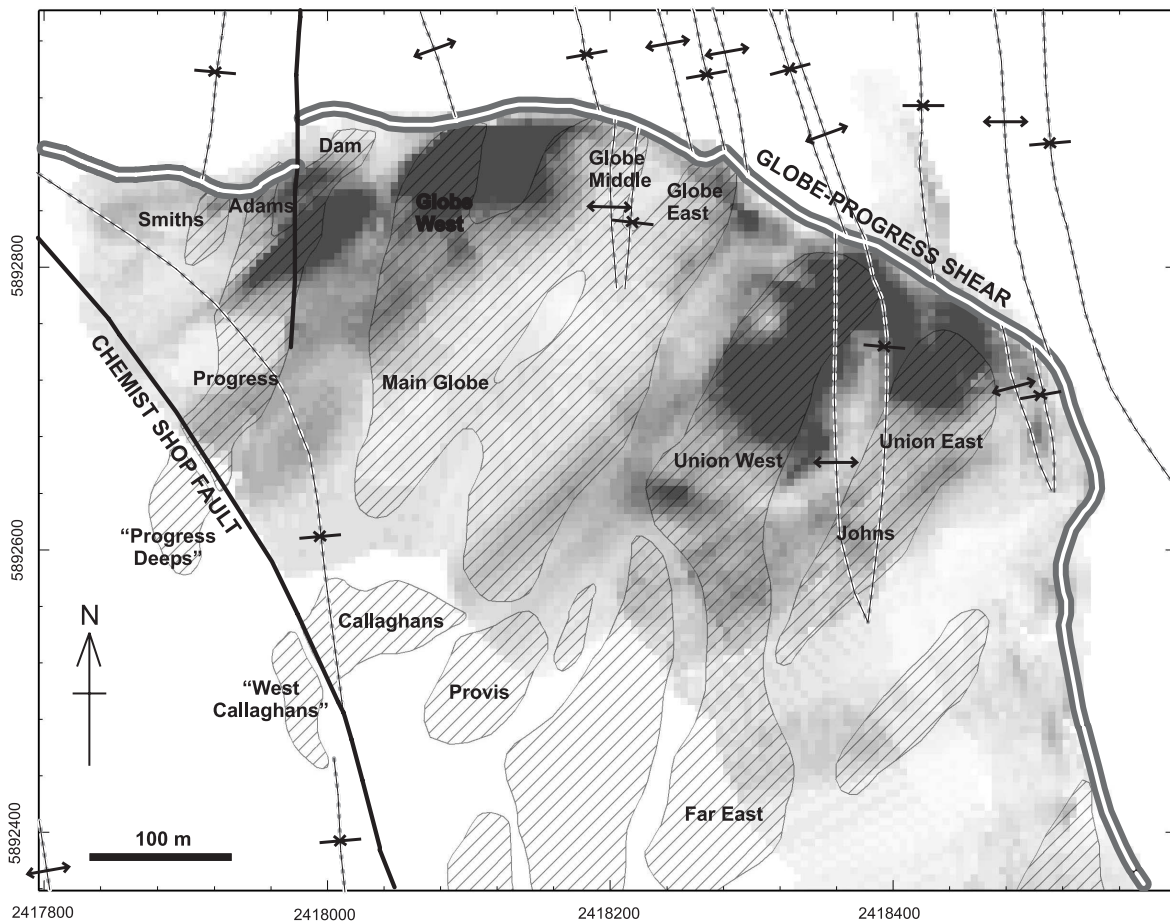


Fig. 4 Historic mining at Globe-Progress focused on a number of S-SW plunging gold-quartz shoots (hachured overlays) which correlate with the position of fold hinges and monoclinial flexures where they intersect the Globe-Progress shear. Oceana Gold's open-pit mining will extract a larger resource, including disseminated gold and quartz shoots. The resource thickens into high-grade pods (darker shading) where the shear zone cross-cuts host-rock bedding at a high angle, and is thinner where it is near-parallel to bedding.

Thickening of the shear and of the high-grade pods may also be controlled by the position of folds in the hanging wall. The angle between bedding (predominantly varying dip between and within fold limbs) and the undulating shear surface has been calculated over the shear surface. Areas where bedding-shear angle is $>70^\circ$ correspond closely to the first-order distribution of >50 g/t resource model gold. The shear zone thickens and is more-strongly mineralised where it cross-cuts bedding at a high-angle, and is thinner and more discrete where it is parallel to

bedding. The localisation of high-grade pods in areas of larger bedding-shear angles may have occurred during mineralisation. For example, bedding-plane slip or hydro-fracturing may have occurred preferentially across rather than along bedding surfaces resulting in more favourable, dilational sites for mineralisation. Alternatively, post-mineralisation shearing and fault reactivation may have accentuated brecciation in areas of large bedding-shear angle due to mechanical or competency contrasts. The late brecciation could have caused the ore thickness variation, and wider disseminated gold and alteration halos.

Conclusions

The Reefton Goldfield has a number of significant gold deposits that exhibit strong structural controls. The gold-bearing quartz veins occur in zones of tighter and shorter wavelength folds and formed where a controlling shear surface intersected appropriately oriented strata in specific fold limbs. The vein extent can be constrained by the thickness of the fold limb and the wavelength of the folding. This opens up the exploration potential of repeat structures along the trend of the veins, one or more fold wavelength distances apart. Shear-hosted resources with disseminated mineralisation and quartz-veins also vary in thickness, with high-grade pods that are similar in scale and magnitude to quartz-related shoots. The geometry and location of high-grade pods correlates strongly with the local orientation of bedding and its angular relationship to the controlling shear. Cross-faulting is also a significant factor in the goldfield and mineralisation is offset locally. Mapping areas of common fold limb facing is a key technique for identifying cross-faults in the absence of good continuous outcrop.

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References

- Adams, C.J.D., Harper, C.T. and Laird, M.G. 1975. K-Ar ages of low grade metasediments of the Greenland and Waiuta Groups in Westland and Buller, New Zealand. *New Zealand Journal of Geology & Geophysics* 18: 39-48.
- Barry, J.M. 1993. The history and mineral resources of the Reefton Goldfield. Resource Information Report 15, Ministry of Commerce. 59 pp.
- Christie, A.B. and Brathwaite, R.L. 2003. Hydrothermal alteration in metasedimentary rock-hosted orogenic gold deposits, Reefton goldfield, South Island, New Zealand. *Mineralium deposita*, 38(1): 87-107.
- Cooper, R.A. 1974. Age of the Greenland and Waiuta Groups, South Island, New Zealand. *New Zealand Journal of Geology & Geophysics* 17: 955-962.
- Cooper, R.A. 1989. Lower Paleozoic terranes of New Zealand. *Journal of the Royal Society of New Zealand* 19: 73-112.
- Cooper, R.A. and Tulloch, A.J. 1992. Early Paleozoic terranes in New Zealand and their relationship to the Lachlan Fold Belt. *Tectonophysics* 214: 129-144.
- Cox, S.C. 2000. The geometry of mineralisation and exploration models for the Blackwater mine in the Reefton Goldfield. *New Zealand Minerals and Mining Proceedings 2000*: 125-136.
- Gage, M. 1948. The geology of the Reefton quartz lodes. Geological Bulletin 42, Department of Scientific and Industrial Research.
- Gray, D.R., Wilson, C.J.L. and Barton, T.J. 1991. Intracrustal detachments and implications for crustal evolution within the Lachlan fold belt, southeastern Australia. *Geology* 19: 574-577.
- Lew, J.H. and Corner, N.G. 1988. The Globe-Progress Prospect, Reefton, New Zealand. *Bicentennial Gold 88*, Melbourne, May 1988, Posters 1: 271-273.

Nathan, S., Rattenbury, M.S. and Suggate, R.P. (Compilers) 2002. 1:250,000 Geology of Greymouth area. Institute of Geological & Nuclear Sciences 1:250,000 geological map 12. 1 sheet + 58 pages. Lower Hutt, New Zealand. Institute of Geological & Nuclear Sciences Ltd.

Rattenbury, M.S. and Stewart, M. 2000. Structural setting of the Globe-Progress and Blackwater gold mines, Reefton Goldfield, New Zealand. New Zealand Journal of Geology & Geophysics 43: 435-445.

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Mark who is presenting this paper is a graduate of Auckland and Otago universities and has 6 years experience in Australian structural geology research and geological mapping in the Eastern Goldfields, Northern Territory and western Tasmania. Since 1993 Mark has worked for GNS, principally mapping around the mountains of the South Island for the QMAP 1:250 000 geological mapping project. He is currently the QMAP programme leader but still gets his hands dirty in the field and tinkers with GIS data management. Mark has also been involved in continuing research and consulting work on the structural geology of the Reefton Goldfield.