Genetic classification and prospectivity of gold-bearing veins in the Otago Schist, New Zealand

D Craw[1], RJ Norris[2], and DJ MacKenzie[3]

[1] *Geology Department, University of Otago, PO Box 56, Dunedin, Telephone 0064-3-479 7529, Email dave.craw@stonebow.otago.ac.nz*

[2] *Geology Department, University of Otago, PO Box 56, Dunedin, Telephone 0064-3-479 7520, Email richard.norris@stonebow.otago.ac.nz*

[3] *Geology Department, University of Otago, PO Box 56, Dunedin, Telephone 0064-3-479 9051, Email doug.mackenzie@stonebow.otago.ac.nz*

Abstract

Gold-bearing veins have formed at a wide range of depths throughout the uplift history of the Otago Schist. The earliest gold mineralisation occurred during the later stages of Mesozoic metamorphism. This mineralisation was characterised by diffuse wall rock alteration with greenschist facies metamorphic or retrograde metamorphic mineral assemblages, and gold occurs in this altered rock. Quartz veins formed in steeply dipping extensional fractures associated with this mineralisation type strike north to northeast. The Macraes mine exploits this deposit type. The present northwest strike of the mineralised zone at Macraes is a result of post-mineralisation deformation of the schistosity-parallel mineralised shear zone which hosts northeast striking extensional veins. This combination of schistosity-parallel shear zone and steeply dipping northeast striking veins may exist elsewhere in Otago, and this deposit type is most prospective.

Steeply dipping quartz veins formed during post-metamorphic unroofing of the Otago Schist strike northwest to west and occur as clusters of near-parallel structures in east and central Otago. These veins consist mainly of massive quartz, although some prismatic quartz occurs also. Breccia fragments in veins are common and these are generally silicified, with some gold. Wall rock alteration is negligible, and vein margins are sharp.

A set of middle Tertiary veins occurs in northwest Otago. Most of these also strike northwest and dip steeply, but some strike northeast. These veins contain abundant ankeritic carbonate as well as quartz. The carbonate pervades adjacent wall rock as veinlets, but gold mineralisation is confined to veins. Quartz is commonly prismatic and vuggy, and contains gold, which is commonly coarse grained especially in silicified breccia zones. Associated veins contain stibnite. This vein type formed close to the paleosurface (>2 km).

Mineralised veins in Marlborough currently strike northwest, but these have been rotated from northeast strike during Alpine Fault displacement of Marlborough from Otago. Some of these veins were formed under late-metamorphic conditions and are similar to the north to northeast striking veins in Otago. As in Otago, this type should be considered to be most prospective if they have associated schistosity-parallel shears.

Introduction

The Otago Schist has a long history of gold exploration and exploitation. Most of the 240 tonnes of historically extracted gold was alluvial, with only about 12 tonnes of hard-rock gold extracted. The currently active Macraes mine has changed this balance significantly by producing about three tonnes of hard rock gold per year over the last 10 years. Hence, further exploration for hard rock mineralisation is desirable.

Most hard rock exploration in Otago has focussed on historic sites, and many of these sites have been revisited several times. This approach was successful at Macraes, but none of the other known sites appear to be prospective. This paper aims to define exploration targets in Otago more clearly from a geological point of view (Table 1), in the context of mining success at Macraes and the known features of other sites. From this approach, we attempt to elucidate the types of structures which are most prospective.

Deposit type	Examples	Age	Strike	Host rock alteration	Metallic minerals	Carbonate minerals
Southern Alps	Ben Ohau Range Sealy Range Wilberforce valley	Pliocene-Recent	Northeast	none or minor	pyrite, Au arsenopyrite	ankerite, calcite
Moonlight-related	Skippers Macetown Carrick(?)	Miocene	Northwest northeast	none or minor	pyrite, Au arsenopyrite stibnite (locally)	ankerite
Post-metamorphic	Barewood, Nenthorn Bendigo, Rough Ridge Carrick, Nokomai Waipori	Cretaceous	Northwest	none or minor	pyrite, Au arsenopyrite stibnite (shallow) scheelite (deep)	calcite
Late metamorphic	Macraes, Rise & Shine Invincible, Glenorchy	Jurassic	northeast veins, flat-lying shears (?)	minor to major	pyrite, Au arsenopyrite scheelite	calcite

Table 1.

Northwest striking veins

One of the most outstanding structural features of historic hard rock mine sites in Otago is the general northwest strike of the host structures (Figure 1). This feature has been remarked on by generations of prospectors and researchers, and has become a part of the Otago exploration folklore. There are over two hundred historically mined veins and the vast majority of them have this northwest strike (Paterson 1986). Many of the veins which deviate from this general strike are minor structures connecting well-defined northwest striking systems. The vast majority of these northwest striking veins dip steeply (45 to 70 degrees), mainly to the northeast. The veins occur in swarms separated by 10-100 m of unmineralised schist. Hydrothermal alteration on vein margins is restricted to extremely narrow zones, less than 10 cm wide and commonly less than 1 cm wide. Veins commonly contain breccia fragments which are variably silicified and locally replaced by sulphide minerals. Gold is closely associated with breccias where present, and is almost invariably found with sulphide minerals. Some free gold occurs in clean white quartz, but this is relatively rare.

Most of the northwest striking veins formed in faults and fractures in the latter stages of uplift of the Otago Schist, and some veins had more than one stage of mineralisation during that uplift history. An additional set of northwest striking veins formed in the middle Tertiary in northwest Otago near Macetown and Shotover River (Figure 2; Craw 1989) in extensional structures associated with the Moonlight Fault (Figure 2). Mineralised veins related to this latter set of structures have a northeast strike, but farther north these are relatively recent discoveries and have not been mined.

Macraes

The Macraes mine is developed in the Hyde-Macraes Shear Zone, a late-metamorphic structure which lies parallel to the regional schistosity in the Macraes area and juxtaposes lower greenschist facies rocks on upper greenschist facies rocks. The schistosity strikes generally northwest at Macraes, and dips about 10-15 degrees northeast. Locally the schistosity, and the mineralised shear zone, strike west and dip to the north. The strike and dip of the shear zone and schistosity is a function of post-mineralisation deformation of what was originally an essentially flat-lying set of metamorphic structures. Some of this post-mineralisation deformation is

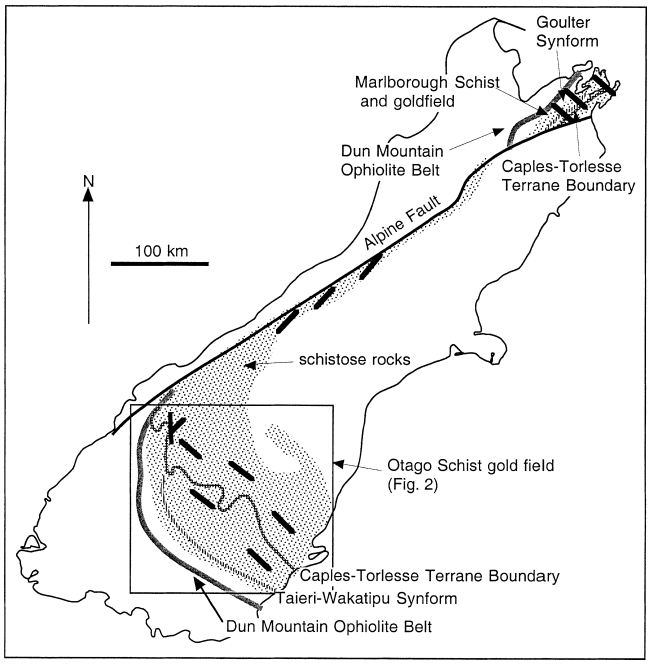

Figure 1. Sketch geological map of the South Island of New Zeland showing general orientations of gold-bearing quartz veins and principal geological features associated with Mesozoic development of the basement for those veins (after Williams 1974; Mortimer and Johnston 1990; Mortimer 1993). Features rotated during Cenozoic Alpine Fault movement are also indicated.

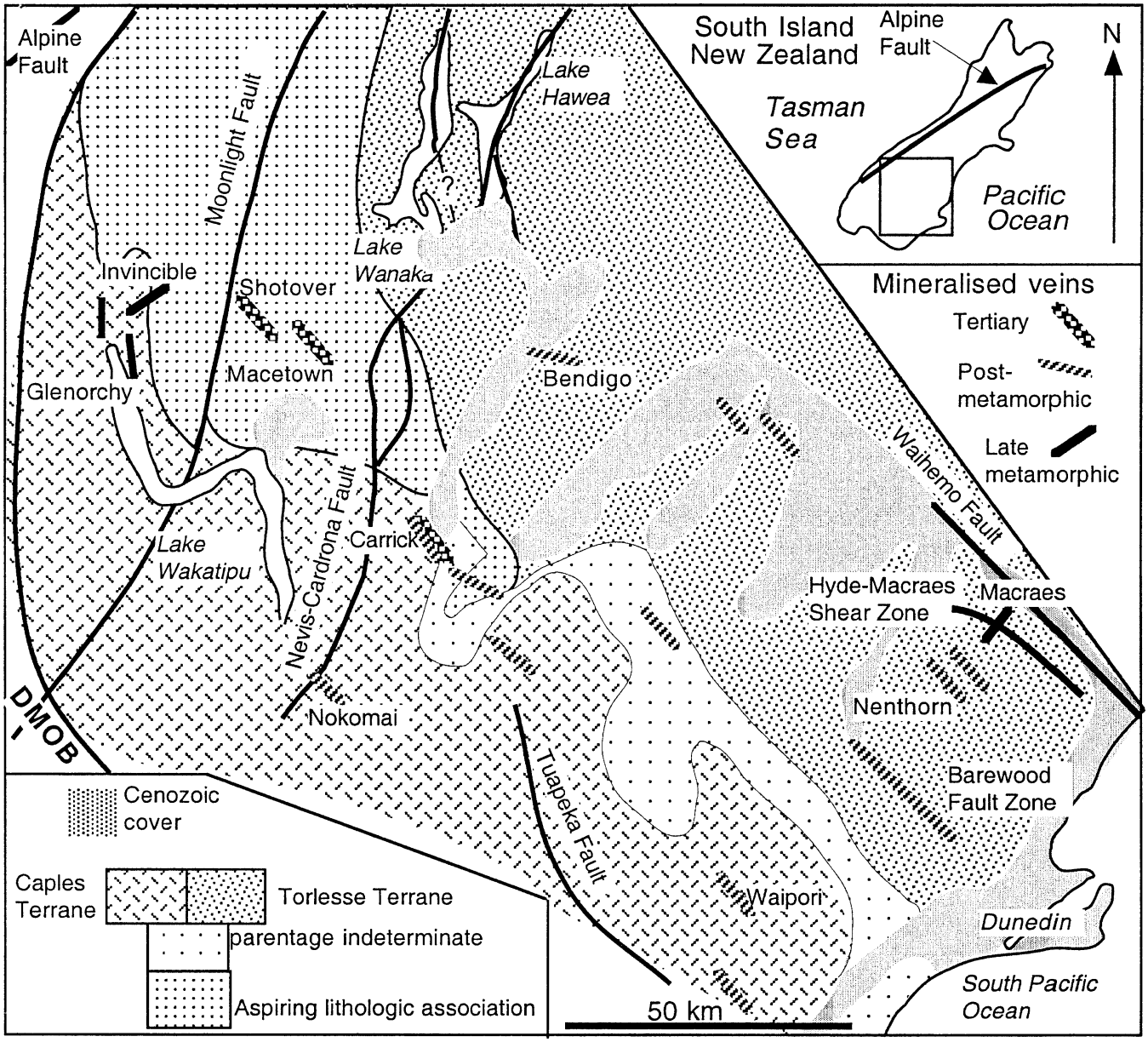

Figure 2. Geological map of the Otago Schist, modified from Mortimer (1993), showing the principal terranes amalgamated during metamorphism. Locations, orientations and inferred age of the main gold-bearing vein systems are indicated.

Cenozoic in age, associated with the active northwest-striking Waihemo Fault system immediately to the northeast of Macraes (Figure 2). Hence, the parallelism of strike of the Hyde-Macraes Shear Zone with the numerous other mineralised veins in Otago is largely a geological accident.

The mineralised portions of the Hyde-Macraes Shear Zone are made up of three principal styles of mineralisation: hydrothermally altered schist, gently dipping quartz veins, and steeply dipping quartz veins. The hydrothermally altered schist has elevated graphite contents and has been partially replaced by sulphide minerals with associated gold (Craw et al. 1999). Gently dipping quartz veins formed in the shear zone during thrust movement and many of these veins have been deformed into parallelism with the host schistosity. The steeply dipping quartz veins fill localised swarms of extensional fractures which strike north to northeast (Angus 1993).

Exploration target

The mined zones at Macraes contain all three mineralisation types mentioned above to varying extents, and the economics of the operation depend on the resulting widely dispersed gold in large volumes of rock. No one type of mineralisation would, by itself, constitute an economic deposit. Hence, as a first approximation, future exploration targets in the Otago Schist should have the Macraes styles of mineralisation built into them. This concept is summarised in a general way in Figure 3. This shows a late metamorphic shear zone, which has schistosity-parallel quartz veins and rock-replacement mineralisation, sandwiched between different slabs of unmineralised schist. Steeply dipping quartz veins are rooted in the shear zone, representing near-vertical fluid escape pathways from an otherwise near-horizontal fluid flow and mineralisation zone associated with late metamorphic focussed shear.

A notable feature of this exploration target is the absence of northwest striking, steeply dipping, quartz veins. None of the later-stage northwest striking vein systems known in Otago resemble this exploration target in any way. A key factor in discounting the northwest striking veins is the lack of dispersed mineralisation in the schist host rock. The northwest striking veins were economic only when small scale underground mining was viable, and these systems are unlikely to prove economic for modern bulk mining methods.

Northeast-striking structures

Quartz veins have traditionally been the primary target for the first stages of hard rock gold exploration in Otago, mainly because they form prominent outcrops. Future exploration programmes will also rely to some extent on quartz extensional veins as indicators of hydrothermal systems. A notable feature of the exploration target described above (Figure 3) is that the quartz veins strike northeast, not northwest. In order to be more specific about possible application of this model, some potential target areas are discussed below.

Glenorchy-Invincible area

This area, near the head of Lake Wakatipu (Figure 2) is notable for the numerous gold-scheelite veins which strike north to northeast. This north to northeast strike is an original feature, not an effect of post-mineralisation rotation, as distinctive schist structural features such as prominent synmetamorphic lineations have not been rotated. The Invincible Vein formed under greenschist facies metamorphic conditions in the latter stages of schist metamorphism (Hay and Craw 1993). The Glenorchy vein system formed in the early stages of post-metamorphic uplift (Paterson 1982). The veins themselves have been abandoned as mining prospects and are unlikely to be viable in the future. However, they may be indicators of nearby schistosity-parallel late metamorphic fluid flow, as suggested in the model above (Figure 3). The vein system structurally overlies the syn- to late-metamorphic tectonic boundary between Caples Terrane and the Aspiring Lithologic Association (Figure 2). This tectonic boundary is one of the most prominent shear zones in the Otago Schist and is allied with the regionally extensive Caples-Torlesse terrane boundary (Figure 1; Mortimer 1993).

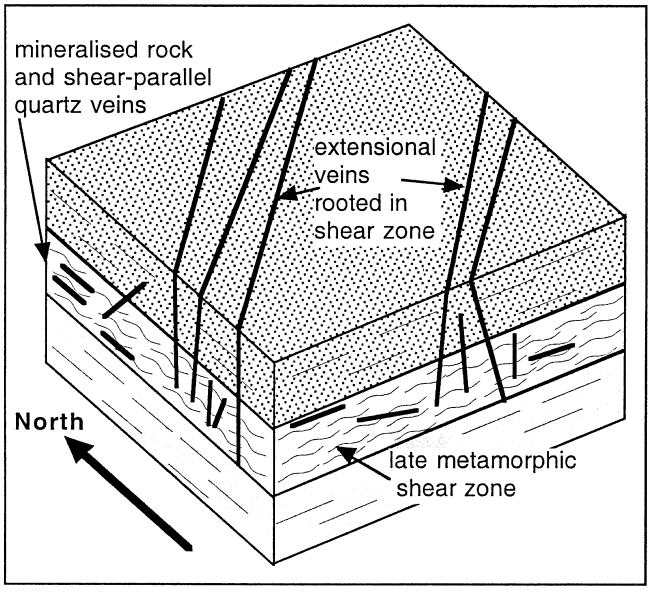

Figure 3. Block model of an idealised combination of shallow-dipping shear zone and associated steeply dipping extensional veins. This hypothetical target is the most prospective in Otago and Marlborough Schist belts.

Rise and Shine Shear, Bendigo

This shear is shallow-dipping, lies essentially parallel to the regional schistosity, and juxtaposes rocks of differing metamorphic grade, similar to the Hyde-Macraes Shear Zone (above). The shear zone hosts northeast striking extensional quartz veins which are mineralised and have been worked historically. The shear has been prospected several times in the immediate vicinity of the quartz veins and some shear-parallel veins. Thus far, there is no evidence for foliation-parallel replacement mineralisation. However, the overall geometry of the shear zone system is similar to that in the above model (Figure 3).

Alexandra-Ophir area

This area is notable for a remarkably continuous zone of northeast-striking quartz veins and silicification zones, locally very weakly mineralised, cutting generally flat-lying schistosity (MacKenzie et al. 1998). The zone strikes into a region near Ophir where foliation-parallel mineralised veins were reported during historic mining (MacKay 1894). The structure of the area is as yet poorly known due to poor outcrop. However, the area appears to have many of the features of the model in Figure 3.

Marlborough Schist

The Marlborough Schist is a portion of the Otago Schist which has been moved nearly 500 km northeast along the Alpine Fault since the Tertiary (Figure 1). Fault offset was accompanied by approximately 90 degrees rotation of the principal regional structural features (Figure 1). Mineralised veins now strike northwest (Williams 1974), and were therefore originally formed with a northeast strike. Some of these veins formed in the latter stages of metamorphism, such as that described by Skinner and Brathwaite (1999) at Wakamarina. The main Wakamarina vein has many similarities to the Invincible Vein in Otago (above; Hay and Craw 1993). Hence, the model in Figure 3 may be a useful starting point in re-prospecting these veins, with emphasis on associated flat-lying shear zones rather than the veins themselves.

Conclusions

A wide variety of gold mineralisation styles are apparent in Otago, and most of these have been mined historically. Steeply dipping, northwest striking veins with little or no host rock alteration and gold mineralisation are unlikely to be of economic significance for bulk mining. The most prospective

geological situation involves schistosity-parallel shear zones with deformation-related mineralisation, and associated steeply dipping, northeast-striking extensional quartz veins. This mineralisation style occurred in the waning stages of Mesozoic metamorphism, before the more brittle northwest-striking veins formed during post-metamorphic uplift.

References

Angus, P.V. 1993: Structural controls on gold deposition in the Hyde-Macraes Shear Zone at Round Hill, Otago, New Zealand. Proc., 27th Ann. Conference, N.Z. Branch Aust. Inst. Min. Metall., 11 pp

Craw, D. 1989: Shallow-level, late-stage gold mineralisation in Sawyers Creek, Shotover valley, North West Otago, New Zealand. *New Zealand journal of geology and geophysics 32*: 375-384.

Craw, D; Windle, S.J.; Angus, P.V. 1999. Gold mineralisation without quartz veins in a ductile-brittle shear zone, Macraes Mine, Otago Schist, New Zealand. *Mineralium Deposita* 34: 382-394.

Hay, R.; Craw, D. 1993: Syn-metamorphic gold mineralisation, Invincible Vein, NW Otago Schist, New Zealand. *Mineralium Deposita 28* : 90-98.

McKay, A. 1894: Geological reports on older auriferous drifts of Central Otago. Journal of the House of Representatives, Appendix C4, p. 1-48.

MacKenzie, D.J.; Becker, J.; Craw, D. 1998. Hydrothermal mineralisation in northeast striking fault zones, Otago Schist. Proceedings, Australasian Institute of Mining and Metallurgy NZ Branch 31st Annual Conference: pp.121-134.

Mortimer, N., 1993. *Geological map of the Otago Schist and adjacent rocks*, 1: 500 000. Institute of Geological and Nuclear Sciences Map 7, Wellington, N.Z.

Mortimer, N.; Johnston, M.R. 1990. Discovery of a new Rangitata structure offset by the Alpine Fault: enigmatic 350 km long synform within Caples-Pelorus Terrane. Geological Society of New Zealand Miscellaneous Publication 50A: 99.

Paterson, C. J. 1982: Oxygen isotopic evidence for the origin and evolution of a scheelite ore-forming fluid, Glenorchy, New Zealand. *Economic geology 77*: 1672-1687.

Paterson, C. J. 1986: Controls on gold and tungsten mineralisation in metamorphic-hydrothermal systems, Otago, New Zealand. *Geological Association of Canada special paper 32:* 25-39.

Skinner, D.N.B.; Brathwaite, R.L. 1999. Mesozoic mesothermal quartz-gold-scheelite lodes, Wakamarina, Marlborough, New Zealand. *New Zealand journal of geology and geophysics* 42: 335-348.

Williams, G. J. 1974: Economic geology of New Zealand. *Australasian Institute of Mining and Metallurgy monograph 4*.

Authors

DAVE CRAW has a PhD in geology from University of Otago and an MSc from University of Calgary. He is currently Associate Professor in the Geology Department at University of Otago, with teaching responsibilities in various aspects of applied and economic geology, and also in the multidisciplinary Environmental Science Programme. He has research interests in all aspects of gold mineralisation including associated environmental effects.

RICHARD NORRIS has a PhD from Oxford University and is currently a Professor in the Geology Department at University of Otago. He specialises in structural geology and its applications to tectonic processes. He has a long history of research activity in the Otago Schist including inter-relationships between metamorphism, deformation and gold mineralisation.

DOUG MACKENZIE obtained an MSc from University of Otago working on vein gold mineralisation. He has worked extensively in mineral exploration and mining in Canada and Indonesia. He is currently a research fellow in the University of Otago Geology Department, investigating relationships between deformation, fluid flow, and gold mineralisation in the Otago Schist.