

# Geological Society of New Zealand Inc 2003 Annual Conference



1 - 4 December  
University of Otago  
Dunedin

## Field Trip Guides

Compiled by  
Simon Cox & Belinda Smith Lyttle

### LEADERS & AUTHORS

David Barrell, Jennifer Bannister, Simon Cox,  
Ellen Cieraad, Dave Craw, Barry Douglas, Michael Findlay,  
Ewan Fordyce, Jane Forsyth, Daphne Lee, Jon Lindqvist,  
Nicola Litchfield, Phillip Maxwell, Nick Mortimer, Tony Reay,  
Rick Sibson, Michael Palin, Richard Price, GRD Macraes

### WITH SUPPORT FROM

Adrien Dever, Beverley Elliott, Phil Glassey, Elly Lang,  
Candace Martin, Richard Norris, Stephen Read, Janice Stenning,  
Lorraine Paterson, Damian Walls, John Williams.

**GEOLOGICAL SOCIETY OF NEW ZEALAND  
ANNUAL CONFERENCE 2003**

**FIELD TRIP 1A & 1B**

**EAST OTAGO GOLD**

**Simon Cox and Dave Crow**

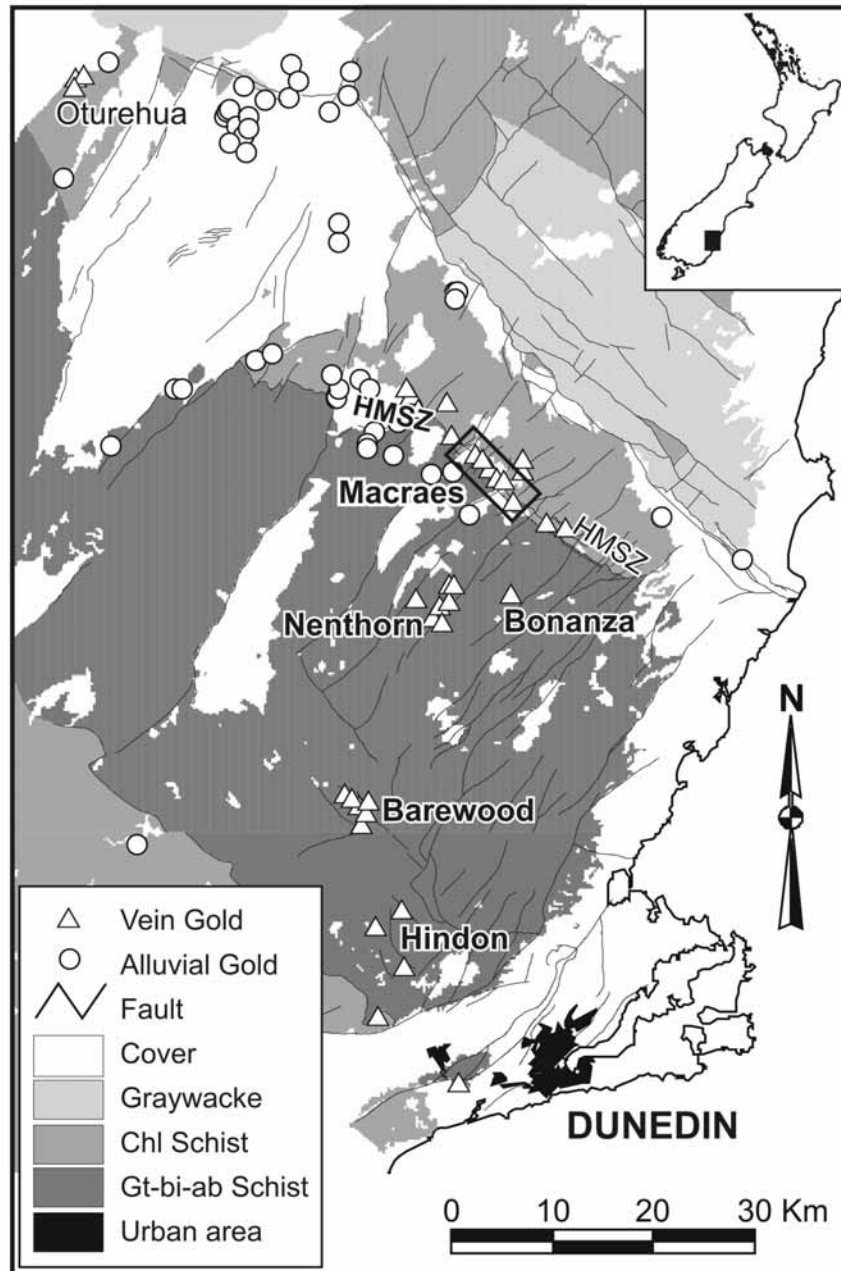
**INTRODUCTION**

Gold-bearing quartz vein deposits in Otago Schist have been worked since the 1860's. Prior to development in the 1980s the Macraes area was just one of numerous historic mining areas found throughout Otago. The history of early mining generally represents a wide diffusion of energy for little reward as nowhere has mineralisation found to be particularly strong. With new technology, however, the Macraes mine now plays a leading role in the local Otago economy. This field trip aims will outline the geology of gold mineralisation in Otago, historic and contemporary gold mining, and their effects on the local environment. Trip highlights include: Macraes Mine, Deepdell historic stamping battery, & Barewood. Topics for discussion: Issues of prospectivity for future exploration; development and promotion of NZ's mineral estate; alluvial gold; genetic models of mineralisation. Participants on Fieldtrip 1B will return by train, on Dunedin's award winning Taieri Gorge Railway. This train travels through the rugged and very spectacular Taieri River gorge.

These notes are intended to act as a brief record of some of the topics covered. They differ from field trip guides, in that they do not contain a complete record of exactly where and what was visited, nor are they a comprehensive list of references on the topics. However, it is hoped that they will serve as a prompt for detailed questions in any areas of your interest, and to aid in the labelling of your photographs and slides when you return home. Should you wish further reading material or want to follow up on any questions, please do not hesitate to contact the fieldtrip leaders Simon Cox ([s.cox at gns.cri.nz](mailto:s.cox@gns.cri.nz)) and Dave Crow ([dave.craw at stonebow.otago.ac.nz](mailto:dave.craw@stonebow.otago.ac.nz)).

## **ITINERARY**

- 9.00 am Depart St Margarets (look for vans marked Fieldtrip 1A & 1B).  
Travel to Macraes. Quick comfort stop at Palmerston.
- 10.30 am Split into three groups, spending about ½ hour at each location.
- 12.30 pm Lunch.
- 1.00 pm Depart for Barewood, comfort stop at Middlemarch.
- 2.30pm Arrive Barewood. Visit No.3 area & Bucklands workings.
- 4.30pm Fieldtrip 1B members depart on Taieri Gorge Railway.  
Fieldtrip 1A participants return to St Margarets via road.
- 5.45pm Van meets train and all participants return to St Margarets.
- 6.30pm Ice breaker function at Otago Museum.



**Figure 1:** Location of the Macraes and Barewood deposits, visited on this field trip, with respect to Dunedin city, Otago Schist northwest-trending structural arch, faults, and other alluvial and hard-rock gold deposits in East Otago, New Zealand. The Hyde-Macraes Shear Zone trends northwest, juxtaposing higher metamorphic grade schist (garnet-biotite-albite zone, greenschist facies) in the center of the arch against lower grade schist (chlorite zone, greenschist facies) and graywacke (prehnite-pumpellyite and pumpellyite-actinolite facies) on its flanks. Cover rocks include Quaternary alluvial deposits, a Cretaceous-Pliocene sedimentary sequence and Tertiary alkaline volcanics.

## **EN ROUTE TO MACRAES**

The city of Dunedin is nestled in the centre of an extinct volcano, which erupted during the Miocene through basement rocks and a Late Cretaceous-Tertiary sedimentary sequence. The volcano is a partly-eroded shield volcano which was intermittently active in late Middle Miocene time (13-10 Ma). Scattered smaller volcanic centres, some of which are significantly older (up to 21 Ma), form prominent hills en-route to Macraes. As we drive you may also notice the uneven road surface, which is due to slumping of the clay-rich marine sediments and regolith. Landslides are widespread throughout the coastal region of Otago, the most famous being Abbotsford where a suburb moved in 1979.

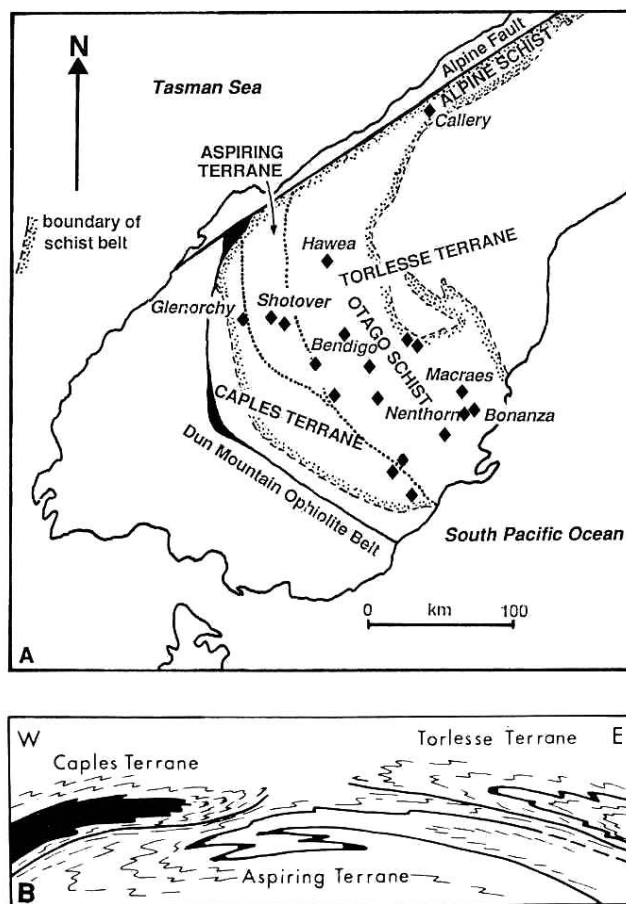
The basement rocks on the eastern side of the South Island are comprised of a series of terranes that were accreted to the margin of Gondwana during the Mesozoic. We will cross two of these, the Caples and Torlesse terranes, which were sutured during the Jurassic with resulting metamorphism forming the Otago Schist. The ductile terrane boundary, however, is now completely obscured amongst nappe-sheets and high strain zones within the Otago schist, and locating it in east Otago requires the aid of geochemical and isotope data.

## **MESOTHERMAL GOLD VEINS IN OTAGO**

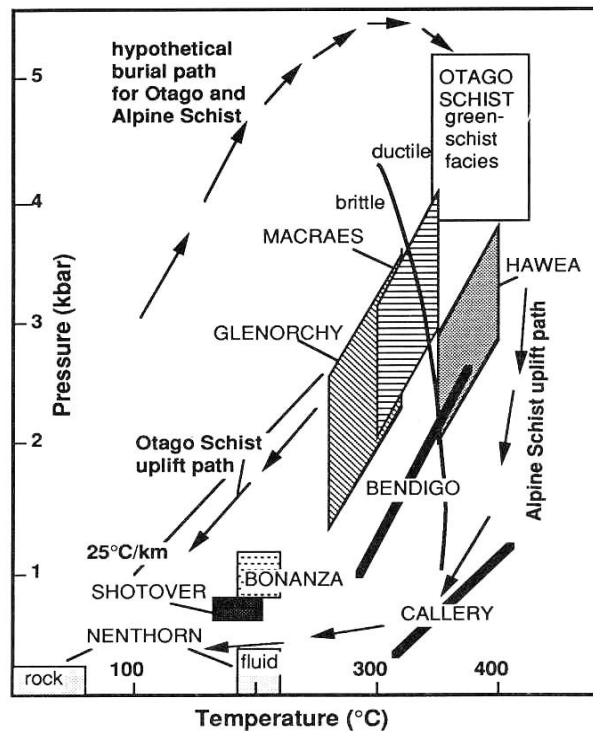
Hard rock gold-quartz deposits are found within the Otago Schist and appear to be almost entirely restricted to rocks of TZIII and IV (greenschist facies and above – Mortimer 2000, 2003, Turnbull et al. 2001). The known occurrences are either isolated veins in fault/fractures with limited wall-rock deformation, or more complicated multiple vein-systems in highly deformed shear zones. Veins typically have steep dip, cutting across schistosity that formed during the Early-Mid Jurassic regional metamorphism. The veins precipitated from hydrothermal fluids that circulated through the faults, fractures and shear zones. Structures hosting the vein deposits nearly all have a NW-SE strike, generally parallel either to local lineation in schist wall rocks or the strike of schistosity. Hard-rock deposits were worked historically from 1868-1920, but only Macraes is currently mined.

Differences in the style, texture, mineralogy, alteration geochemistry and fluid-inclusion thermobarometry of deposits are thought to reflect formation over a wide range of pressure and temperature conditions during waning metamorphism (Craw & Norris 1991, Craw 1992). Isotopic studies indicate Late Jurassic to Early Cretaceous cooling of Otago Schist (Adams & Graham 1997 - and references therein) that was probably episodic, rather than continuous. Preliminary dating suggests mineralisation may have been episodic with at least two phases during 40-50 Ma of cooling. Late Jurassic-Early Cretaceous ages have been returned from micaceous selvages and veins at Macraes and Otarehua deposits, whereas Barewood and Nenthorn samples have returned Middle Cretaceous ages (Angus et al. 1997, Adams & Graham 2000).

Early hypotheses invoked metamorphic dehydration of the schist as the genesis of ore-bearing fluids, with percolation through the volcano-sedimentary pile leaching metals as fluids became focused into shear zones and faults, (see Craw & Norris 1991 and refs therein). Recent microanalytical research on fluid inclusions, however, proposes that mineralisation at Macraes was a result of mixing between equilibrated meteoric water and a magmatic fluid (de Ronde et al. 2000). Although no obvious Late Jurassic-Early Cretaceous magmatic source is currently exposed in the vicinity of Macraes, arc-related igneous activity was widespread elsewhere throughout New Zealand at this time. Projects are currently attempting to evaluate the regional importance of magmatic fluid input and improve age constraints of other deposits (de Ronde/GNS in progress).



**Figure 2:** A regional geological map and schematic cross section (from Craw & Norris 1991) showing the extent of terranes in the Otago Schist. Principal Au-W deposits are indicated with diamonds.



**Figure 3:** Pressure-temperature-time paths deduced for the Otago and Alpine Schist from vein P-T data. (from Craw & Norris 1991)

## MACRAES GOLD PROJECT

The Macraes Gold Project is situated in East Otago, 60 km north of Dunedin. It is the largest gold mine in New Zealand, owned and operated by GRD Macraes Ltd. Over 40,000 kg (>1.4 Moz) of gold have been produced since renewed development in 1990. A series of linked open pits are currently focussed on pods in a small 7 x 3 km portion of the shear zone to depths of c. 200 m. This small segment of land has resulted in a significant economic impact – at least \$463 million has been paid to suppliers and \$47.2 million to employees, with ~75% of supplies sourced either in or through Otago based companies.

The operation has progressively increased in milling capacity from the original 1.5 Mtpa in 1990 to 4.5Mtpa as a result of major plant upgrades in 1994, 1999 and 2002. The successful introduction of Pressure Oxidation technology at the Macraes Gold Project in 1999 resulted in a significant increase in gold recovery. The concentrate is now passed through a pressured autoclave heated to 225°C, through which oxygen is passed. The difficult sulphide ore containing finer grained refractory gold is in effect oxidised, lifting the yield of gold from from around 70 to 84%. This achievement coupled with ongoing reductions in operating cost and mine planning enhancement has resulted in the lowering of the economies cut-off grade.

A change to owner mining in July 2002 provided a major shift in focus for the GRD Macraes Ltd. The mining operation is now managed for overall efficiency instead of

managing to total material movement targets. This allows for additional cost savings to be realised. For example, the performance of haul roads has become one focus of attention, and how the road and fleet performance can be improved. GRD are currently developing the Frasers pit to expose a deep section mineralisation, and will shortly develop the Golden Bar satellite orebody about 7 km further southeast. The possibility of an underground mining operation is currently under investigation, targeting orebodies that extend considerably beyond the economic limits of open pit mining.

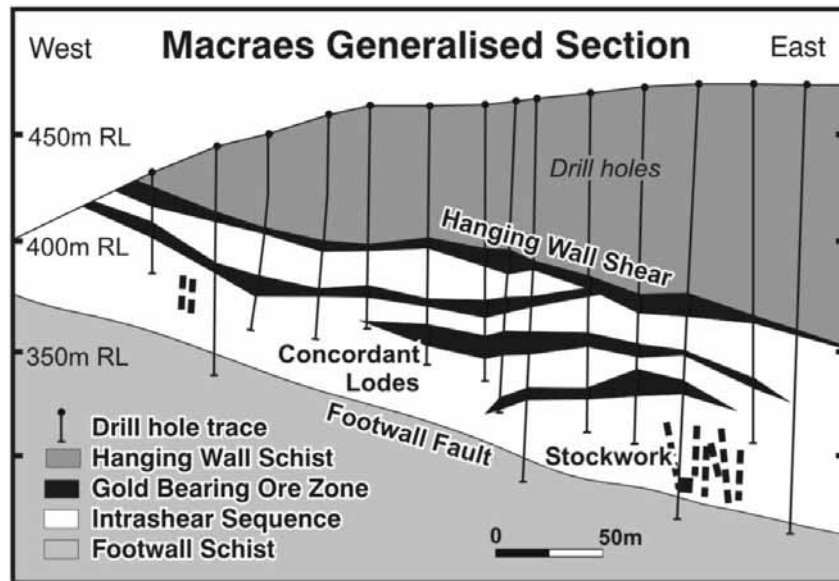
Macraes gold mine produced 162,405 ounces of gold at a cash cost of A\$357 per ounce during 2002. The average gold price received was A\$593 per ounce, resulting in an average cash margin of A\$236 per ounce, or \$38.3 million gross cash operating margin. GRD have just posted record quarterly gold sales of 50,219 ounces (Quarterly Report Sept 2003). Ore reserves have been maintained in excess of 65,000 kg (2.1 Moz) contained gold since 1996, with the current resource (December 2001 estimate of 94.27 Mt at 1.27 g/t for 119,746 kg (3.85 Moz)) expected to supply gold for another decade (GRD Macraes, 2001). Chances are strong that the mine life will be extended further as GRD invests further money on its exploration, and there is significant potential for similar low-grade gold mineralisation elsewhere along the 30 km strike length of the HMSZ.

## **MACRAES DEPOSIT GEOLOGY AND MINERALISATION**

Gold-quartz mineralisation at Macraes is hosted in a shallow NE-dipping, regional-scale shear zone within the Otago Schist - the Hyde-Macraes Shear Zone (HMSZ). The shear zone is relatively planar, striking 025-045 and dipping 15-20°NE, with only minor ramps and flats and changes in orientation due to offset at late-stage faults. Resource drilling has identified numerous pods of relatively concentrated gold, where the total of g/t gold assays of 1 m drilling interval is >60 gm. Apart from Round Hill, all of the Macraes pods discovered to date are sub-surface and have not been detectable by mapping, trenching or soil sampling. Pod discovery and definition has been achieved by pattern drilling along the shear zone.

The first area to be mined at Macraes by modern methods was Round Hill, which exposed a mineralised, pelite-rich intrashear sequence lying between relatively unmineralised, massive psammitic schists in the hangingwall and footwall. The mined resource at Round Hill was associated with moderately dipping concordant shears and steeply dipping stockwork veins, but elsewhere in the Hyde-Macraes Shear Zone a discrete shear at the base of the hangingwall psammite is a significant target for mining. Replacement of metamorphic titanite to rutile, and epidote to siderite, chlorite, muscovite and calcite, has occurred within the intrashear sequence (Craw et al. 1999). Early hydrothermal alteration, accompanied by addition of pyrite, arsenopyrite, hydrothermal graphite and fine-grained gold, preceded formation of a series of mesothermal quartz veins and shears containing gold, scheelite, rutile, pyrite and arsenopyrite (Craw et al. 1999, de Ronde et al. 2000). Graphite in the intrashear sequence may have played an important chemical role in the deposition of gold (McKeag et al. 1989, Craw et al. 1999).



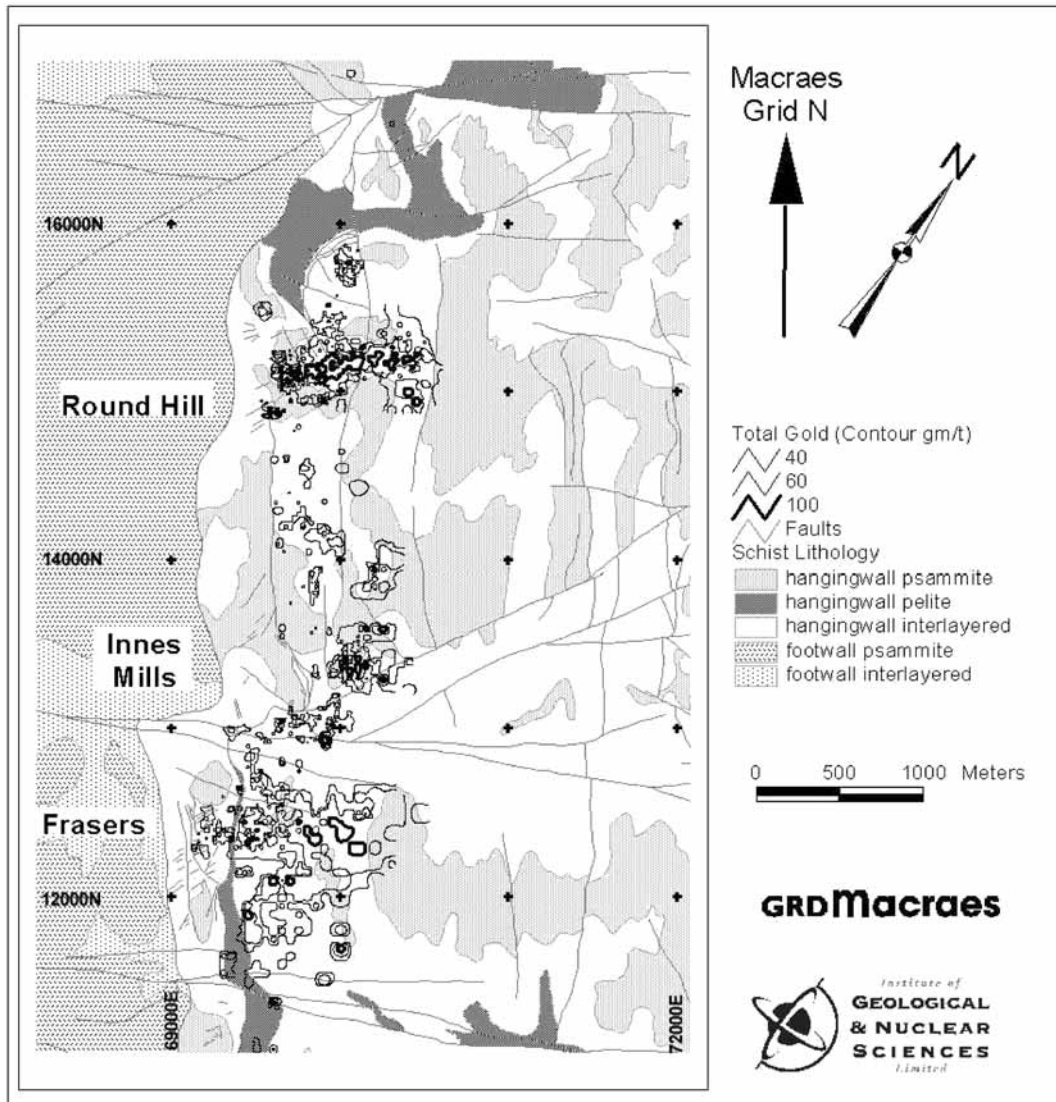


**Figure 4:** Generalized cross-section of the Hyde-Macraes Shear Zone, outlining terminology and location of major mineralized structures within the shear zone. Drill hole traces are shown (solid vertical lines) to exemplify the location, spacing and distribution of drill holes.

The gold occurs primarily in quartz veins that lie sub-parallel to the schist foliation or cut across the foliation at a low angle. The veins are typically less than 1 m thick and rarely continuous for more than 10 meters. Some of the best-developed veins are along the upper fault of the shear zone, the Hanging Wall Shear. Associated fault rocks in this zone also contain gold. Steeply dipping gold-bearing veins formed synchronously with the shallow-dipping veins, as lateral ramp structures (Angus 1993). The low angle quartz veins are commonly polyphase, and some have been deformed and locally recrystallised. White quartz is cut by dark stylolites of micas, sulphides and gold. Sheared schist has been silicified and mineralised with sulphides and gold. Steeply-dipping quartz veins are polyphase, are commonly banded on the millimetre scale, and locally contain angular breccia fragments.

Pyrite is the most common sulphide, generally accompanied by arsenopyrite with minor chalcopyrite and sphalerite. Scheelite occurs in most of the gold-bearing veins as creamy white masses up to 2 cm across, and in steep late-stage veins without gold. Gold occurs as free grains rarely up to 0.5 mm in quartz and associated with sulphides. Finer grained gold occurs intergrown with sulphides or in fractures cross-cutting sulphides. Micron-scale gold is dispersed through pyrite and arsenopyrite grains. The gold contains only about 5% silver. The ore is refractory and contains “preg-robbing” carbonaceous material (Windle et al. 1999), but profitable gold recoveries have been achieved with pressure oxidation and a carbon-in-leach circuit. Approximately 1000t of

tungsten was produced from 1875-1936, but is not worthwhile recovering at current prices.



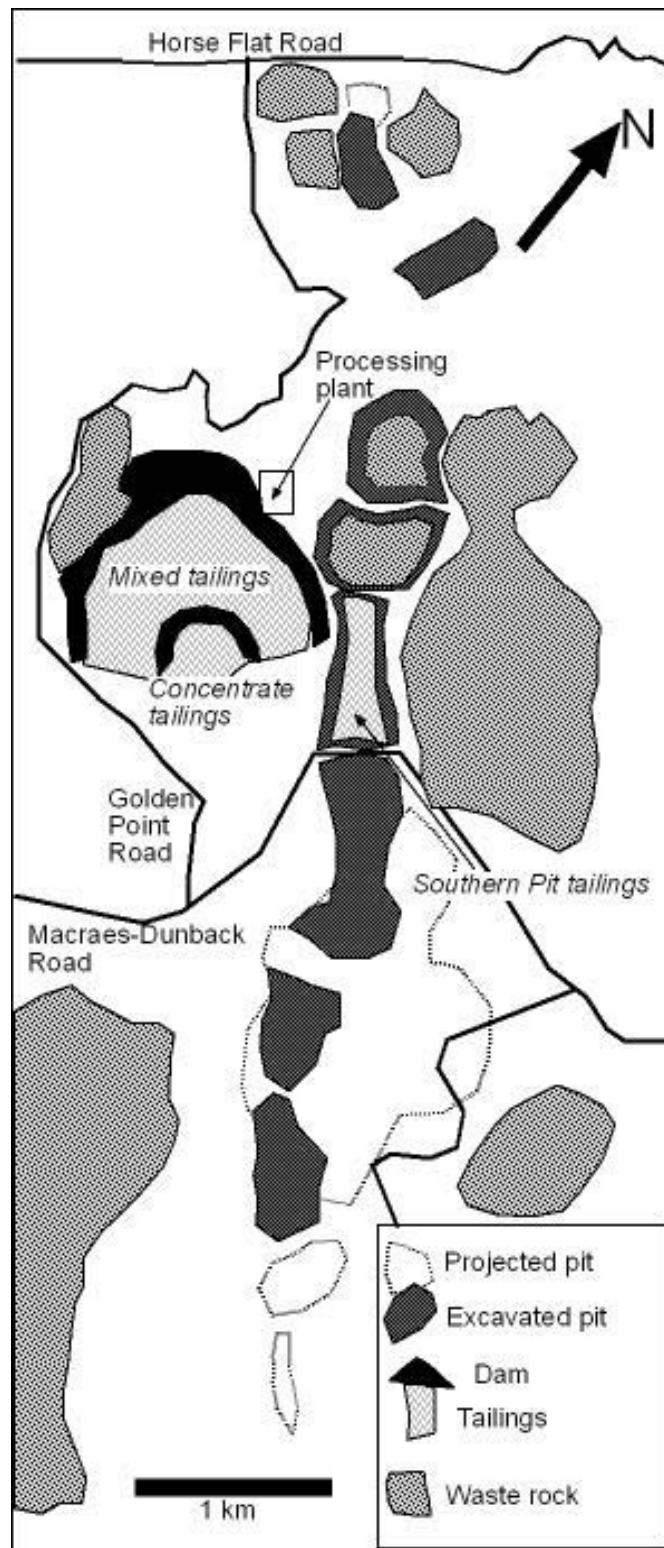
**Figure 5:** Map of the Hyde-Macraes Shear Zone between Round Hill and Frasers. Map shows the distribution of different lithologies in the schist (interpreted from field mapping and geophysics) and contours of total downhole gold (from resource drill holes, typically spaced either 50 or 25m apart). Early primary lithological variations, now folded and deformed, are oblique to the shear zone and form an important control on the distribution of relatively high-grade pods of mineralisation >60gm/t. Note the map is oriented with respect to the Macraes Gold Project Grid North (from Cox 2001).

A difference of metamorphic grade between the biotite-zone hangingwall (textural zone 3) and garnet-zone schists (textural zone 4) in the footwall in the Hyde-Macraes Shear Zone suggest the shear zone was a major crustal structure (Mortimer 2003). Fluid inclusion analysis suggests mineralisation occurred at ~300-350°C, equating to formation at ~10-15km depths (McKeag & Craw 1989, de Ronde et al. 2000). Slickensides and duplex structures within the shear zone indicate mineralisation accompanied compressive motion, with reverse southwest-directed motion of the hangingwall relative to the footwall (Teagle et al. 1990, Angus 1993, Angus et al. 1997, J. Scott unpublished company reports). Significant post-mineralisation extensional deformation has deformed the intrashear sequence internally and extensional slip occurred on a discrete fault between the intrashear sequence and the footwall (Angus et al. 1997). Potential for significant dip-slip displacement indicated by differences in metamorphic grade, possibly > 5 km, are supported by significant differences in the cooling ages and deformation history of hangingwall and footwall schist sequences (Angus et al. 1997, Adams & Graham 2000).

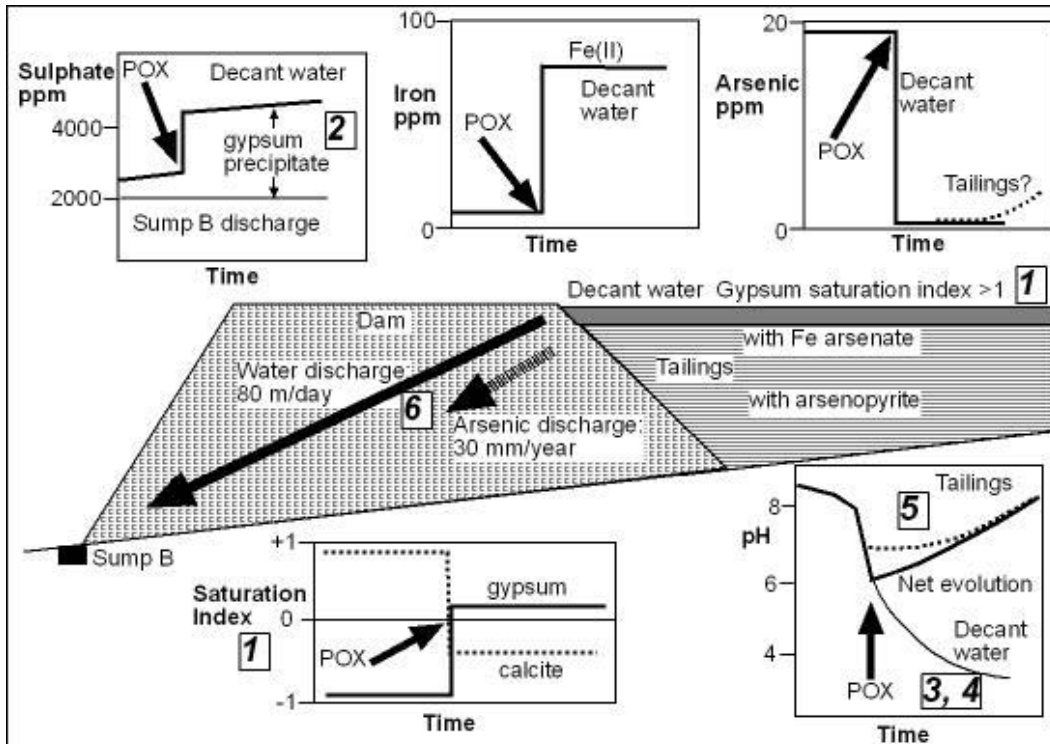
## **MACRAES ENVIRONMENTAL ISSUES**

Excavation of the Macraes mine pits involves extraction of large volumes of waste rock from above the ore, and this has been dumped as nearby piles, some of which are over 2 km long and 1 km wide (Fig. 6). Some infilling of disused pits with waste rock has also occurred (Fig. 6). The waste rock contains pyrite and minor arsenopyrite locally. The schist that dominates the waste rock contains natural calcite that ensures that any acid from oxidation of pyrite is neutralised and any discharge waters have near-neutral pH (Craw 2000; Craw and Nelson 2000). Discharging circum-neutral pH waters commonly deposit iron oxyhydroxides through the flow path (Craw 2000; 2003).

Gold is closely associated with the sulphide minerals pyrite and arsenopyrite (FeAsS) in the ore, so initial processing involves crushing and separation of a sulphide mineral rich concentrate. This concentrate is then crushed more finely and gold is extracted from ore by cyanidation. The residue is discharged as tailings behind purpose-built dams and into a disused mine pit (Southern Pit, Fig. 6). The tailings are a mixture of sand and silt, and are discharged as a wet slurry. Water from the slurry accumulates on the top of the tailings, from where it is recycled through the processing plant. A separate concentrate tailings dam was used until 1993, after which all tailings were mixed during discharge behind the main mixed tailings dam (Fig. 7; Craw et al. 1999; Craw et al. 2002). The concentrate tailings have since been reprocessed (2003). Pressure-oxidation was incorporated into the process stream in 1999 to release gold from sulphide minerals. The concentrate is oxidised under high oxygen pressure at 225°C. Resultant tailings contain iron and arsenic oxide material, rather than sulphide minerals (Craw 2003). Chemical changes associated with the change to pressure oxidation are summarised in Fig. 7. The initial pH was distinctly lower than before pressure-oxidation, but pH has since risen slowly due to dissolution of calcite. There is widespread precipitation of various calcium sulphate minerals (gypsum, anhydrite and bassanite).



**Figure 6:** Map summarising the movement and storage of material at Macraes.



**Figure 7:** Chemical change of Macraes ore, tailings and decant water over time, showing the marked change associated with pressure oxidation (POX).

The tailings have built up to a pile nearly 100 m thick behind the mixed tailings dam (Fig. 7). Tailings have essentially the same chemical composition as the ore, less the gold. Hence, tailings have up to 1% arsenic (Craw and Pacheco 2002). The tailings contain natural calcite from the schist, and additional calcite is added in the processing plant, so acidification cannot occur in the tailings. Dissolved cyanide residues in the tailings waters are readily decomposed by ultraviolet light in the shallow pond on top of the tailings before the water is recycled. Arsenic is readily mobilised in alkaline solutions in the process stream (Craw and Pacheco 2002), but dissolved arsenic becomes adsorbed on to iron oxyhydroxide precipitates within the dams (Roddick-Lanzilotta et al. 2002). Water discharging from the main mixed tailings dam (which is recycled) has arsenic concentrations below drinking water limits.

## **MACRAES HISTORY**

Like many Central Otago towns, Macraes owes its origins to gold. The area was originally settled by farmers in the 1850s. Alluvial gold was discovered at Macraes Flat in the 1862, and within six years a new town had sprung up – its prosperity marked by the presence of four hotels. The Macraes village, situated about 520 metres (1700ft) above sea level, became home to about 350 people. The flat was dredged, sluiced and gravel pumped until the turn of the century. There is no record of the amount of gold recovered here during that period. Alluvial mining by individual prospectors finished in 1875, and hard rock mining at Golden Point, Round Hill, Innes-Mills and Deepdell followed.

The Golden Point Quartz mining company began underground mining operations on 24 December 1889, exactly 100 years before the Macraes Gold Project began its operations. Between 1890 and 1930, 15,000 ounces of gold were recovered from the four mines in the area. In addition, 1000 tons of scheelite (tungsten) were mined during both World Wars and the Korean War. The old workings were almost entirely underground, and followed particular quartz veins or sets of quartz veins into the hillsides of Deep Dell, the main stream which flows through the area. Ore was taken to batteries in the valley; one such battery still survives in working order and is maintained by the Department of Conservation as part of the Otago Goldfields Park.

The Golden Point Battery was constructed in 1902 but has undergone many changes. It was originally run with a waterwheel, but during the 1930's most of the machinery was replaced and a kerosene engine installed drive five heavier stamps (each weighing 225kg). There are a number of buildings in the vicinity of the battery that date from the 1930's and all were at one time lived in by the various operators. During the 1940's and 1950's ownership of the battery changed regularly and the battery worked intermittently. Small-scale mining remained until operations ceased in 1954, leaving sheep and cattle to graze the tussock land. Life in the Macraes community was once again dominated by farming.

Exploration for the current mine began in 1983 with core sample drilling. The arrival of geologist and drill crews came at a good time for the local community – with the downturn in farming, the number of people residing and working in the area had been steadily reducing. Major economic benefits began to flow when construction of the mine began in February 1990.

## **ALLUVIAL GOLD**

Alluvial gold has been won from terrestrial sediments in Otago over the past c.150 years. Prolonged and deep weathering of the schists, exposed on the Cretaceous peneplain surface, resulted in the formation of an extensive alluvial blanket comprising residual concentrates of chemically resistant minerals including quartz, kaolinitic clays, gold, rutile, zircon, and monazite. Heavy mineral constituents within this surficial auriferous deposit were then further concentrated during several cycles of erosion,

transportation and deposition, to produce a complex pattern of gold distribution. The gold occurs in (a) Tertiary deposits that are preserved in fault-angle depressions or beneath resistant caps of sub-horizontal basalt (e.g. Mt Highlay-Hyde area), (b) the Pliocene Maniototo Conglomerate (previously referred to as Maori Bottom Formation), (c) Pleistocene terrace gravels, and (d) Recent alluvium and elluvium.

The richest concentrations of gold were generally at the base of the Tertiary sequence, in "basal" quartz conglomerates or bottom-wash immediately overlying the schist basement (true bottom). Therefore, most of the worked deposits are located in gullies on the margins of the basins where the conglomerate - schist contact is exposed. The basal beds are characterised by "chinaman" or "sarsen" stones that were formed by siliceous bonding of basal gravels, grits, and sands in the water-table fluctuation zone. Workable concentrations of gold were also found higher in the sedimentary sequence, at the base of former stream channels overlying clay bands (false bottoms) that separate different conglomerate units. Rich bottom-wash may be present above each false bottom. At many localities, the miners were able to follow the former stream channels and their leads of gold-rich gravel. Early operations mostly used hydraulic sluicing and hydraulic elevating. Some of the rich basal leads were mined via tunnels and shafts, although, in many instances, loose running sand defeated the underground operations. Problems of getting water to the operations limited the hydraulic methods, so that some operations were abandoned before the ore was exhausted.

Gold dredges were an invention of the resourceful miners of Otago. Prospectors working the banks of the Clutha, Kawarau and Shotover Rivers soon found that the rich leads of gold followed crevices into deep water. When the rivers were low the diggers waded out in search of gold. The hardier miners ventured into deep water, each with a rope tied around his waist and held by a partner on the shore. The "spoon" dredge was the first development - a simple system in which a spoon-shaped container was thrown into the river, dragged along the bottom until full, then hauled ashore by hand. Running the spoon from boats and pontoons with winches was the next logical step, followed by paddle-wheels & continuous bucket lines, and steam power. In 1894 the invention of the Cuttance elevator, fitted to the stern to receive the waste tailings and stack them on the worked ground, allowed deeper as well as higher ground to be worked, and paved the way for the modern dredge. The dredging was so successful that by 1900 a major dredging boom had begun in Otago which reached a fleet of 187 dredges. However, many dredges were placed on ground inadequately prospected and in other cases the machinery was too low-powered to operate in hard ground or had insufficient bucket length and by 1908 the boom was over.

The Macraes Flat area is a broad shallow depression in the schist unconformity due to Cenozoic warping of the late Cretaceous erosion surface. The depression contains some remnants of early Tertiary nonmarine sediments which are locally auriferous (alluvial). However, most of the thin sediments that infill in the depression are late Cenozoic alluvium and colluvium, which is auriferous. The latter deposits were dredged earlier this century, and the dredge ponds are still present.

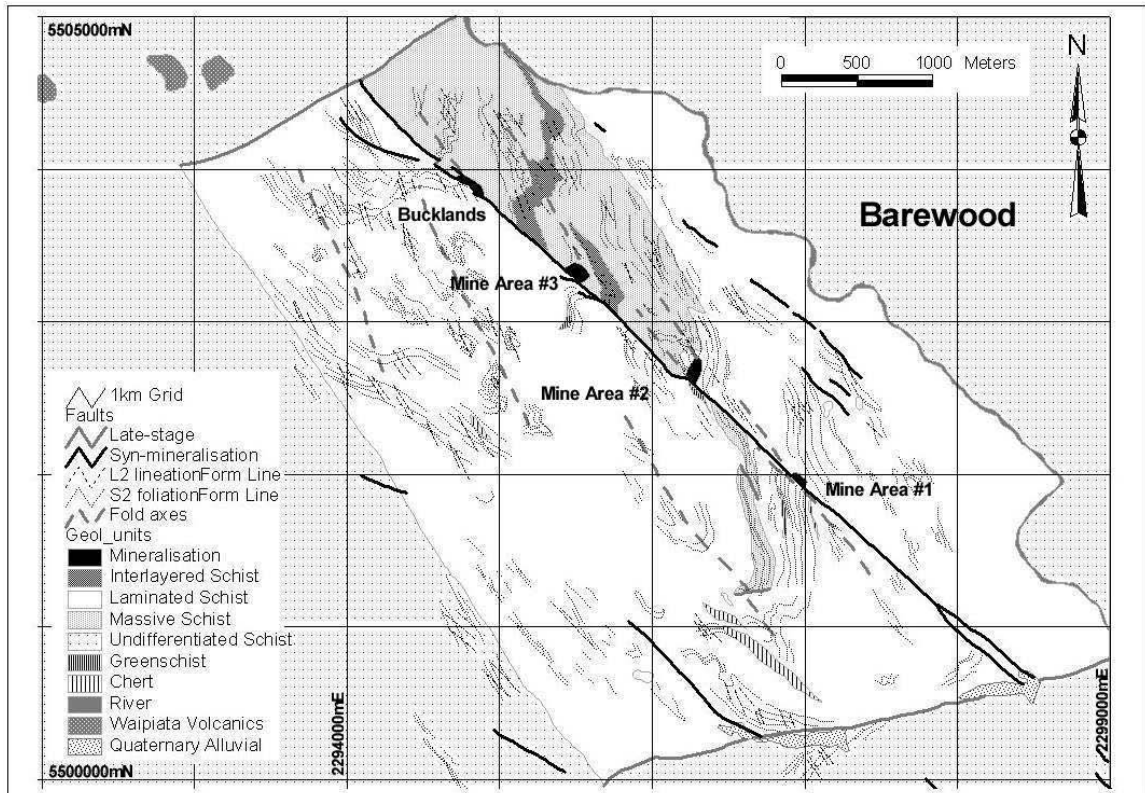
## BAREWOOD

Barewood is located 30 km northwest of Dunedin and was settled and mined for gold and scheelite from 1888-1919. A northwest-trending normal fault, the “Barewood Reefs Fault”, dips 55°NE and hosts two styles of mesothermal quartz veins. Massive, white, tabular quartz pods (1-10 m), with sparse gold and scheelite, occur sporadically in left-stepping dilational jogs associated with a normal+sinistral fault movement (MacKenzie & Craw, 1993). Younger translucent prismatic quartz veins and silicified cataclasite, richer in both scheelite and gold, developed during a younger, pure dip-slip normal movement. Both styles of veins are thought to have developed at relatively shallow, brittle crustal levels ( $P \sim 2\text{kbar}$ ,  $T \sim 300^\circ\text{C}$ ) (MacKenzie & Craw, 1993) about 125 Ma (Adams & Graham, 2000), which was shallower and 7-19 Ma younger than gold mineralisation at Macraes. Mineralised rock averages 1.3-1.6 m wide, but reaches 5 m where the fault splays locally into the hangingwall. Changes in dip of wall-rock schistosity, reflecting “fault drag”, occur in a restricted zone within 5 m of the fault.

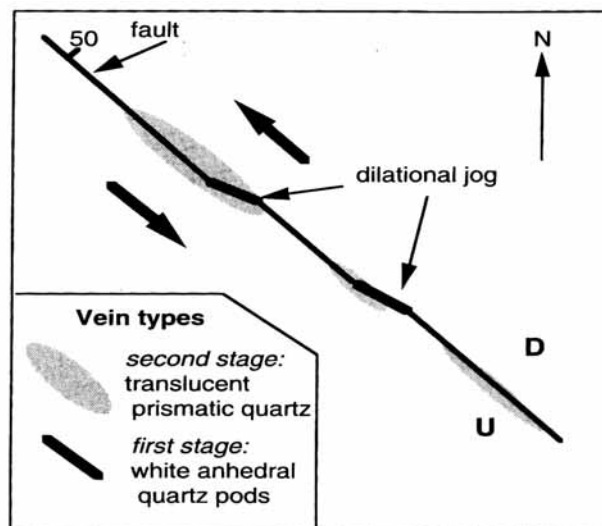
The Barewood Reefs Fault is significant for its known 5 km strike length (possibly 10 km) which is of similar scale to the area of mining at Macraes, and for the extensional sense of movement that accompanied mineralisation. Despite widespread evidence for historic exploration all along the fault (e.g. exploration pits and holes), the old mine workings are spaced at regular intervals c.900 m apart, suggestive of periodic spaced northeasterly trending ore shoots. Production figures indicate at least 379 kg (12,183 oz) of gold were won from 32,374 tons (11.5 g/t recovery grade) and 600 tons of scheelite produced, but early mining efforts were seriously hampered by a shallow water table that necessitated pumping of water (Ingram, 1982; Jeffery, 1987). Secondary mobility has resulted in coarser, more easily won gold near the surface, compared with more refractory gold at depth below historic workings (MacKenzie & Craw, 1993).

Recent exploration at Barewood includes geochemical chip sampling, stream sediment and soil surveys, ground-based geophysics, trenching and channel sampling, plus 2024 m of diamond and reverse circulation drilling. Exploration has confirmed the presence of gold in significant concentrations within the fault and a number of other smaller, parallel structures (chip samples up to 32.2 g/t Au, trench channel with 6m @ 5.23 g/t, and drilling of 5.8 m @ 1.94 g/t). However drilling was widely spaced and focused on areas of historic production, leaving unanswered questions as to the continuity of mineralisation, potential for ore-shoot development, and size of resource that may be present. The area has great potential to act as a satellite deposit for the Macraes Mine, due to the presence of the Taieri Gorge Railway, and is currently under licence to GRD Macraes and HPD New Zealand.

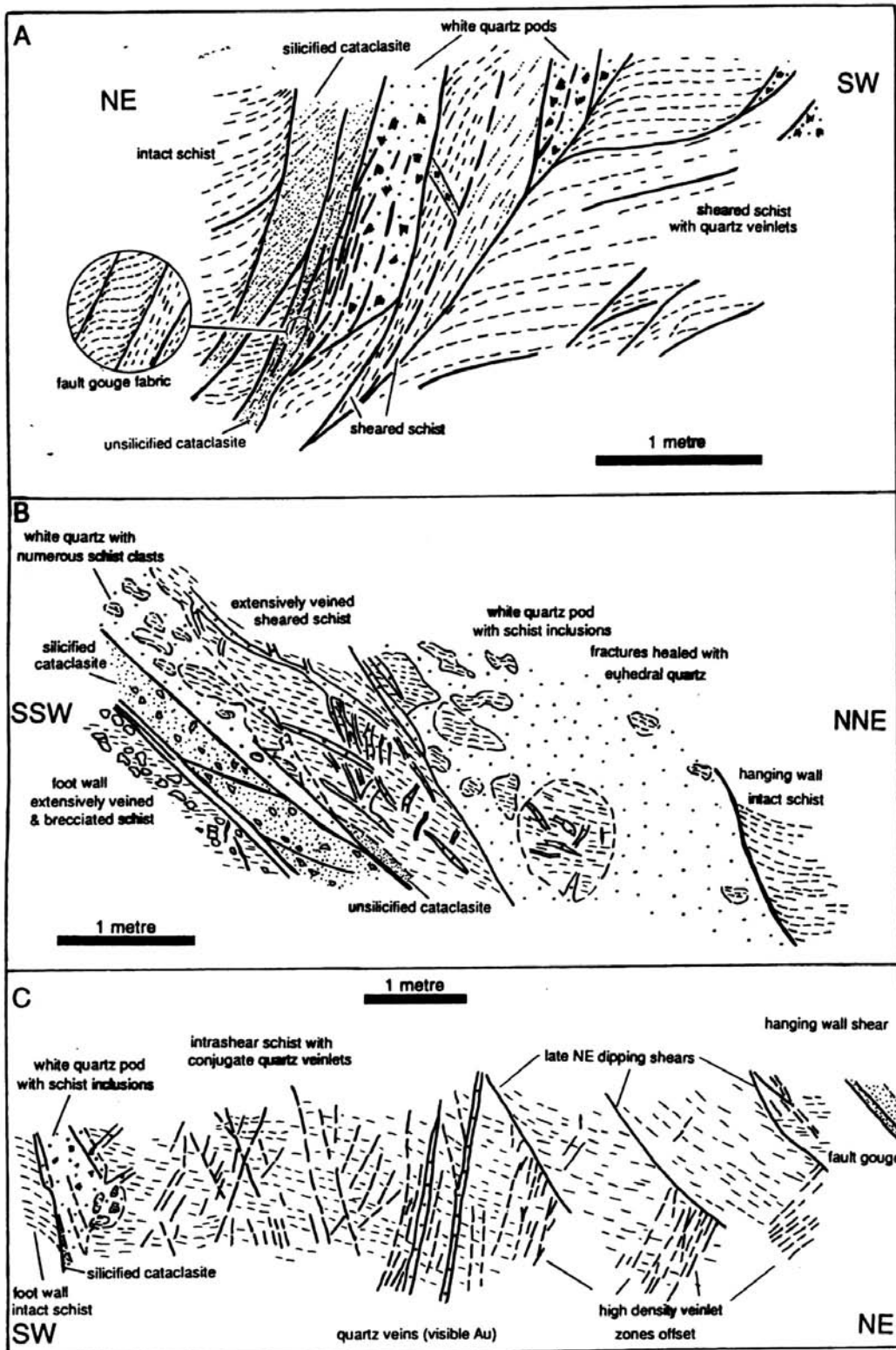




**Figure 8:** Map of Barewood showing the distribution of different lithologies in host-rock schists defined by field mapping (from Cox 2001).



**Figure 9:** Map view of a Barewood normal fault (schematic) showing localisation of early quartz pods in dilational jogs formed by a sinistral strike-slip component of motion. Later quartz veinlets are superimposed on quartz pods and previously unmineralised portions of the fault. Similar geometry may have occurred down-dip due to normal motion (from MacKenzie & Craw 1993).

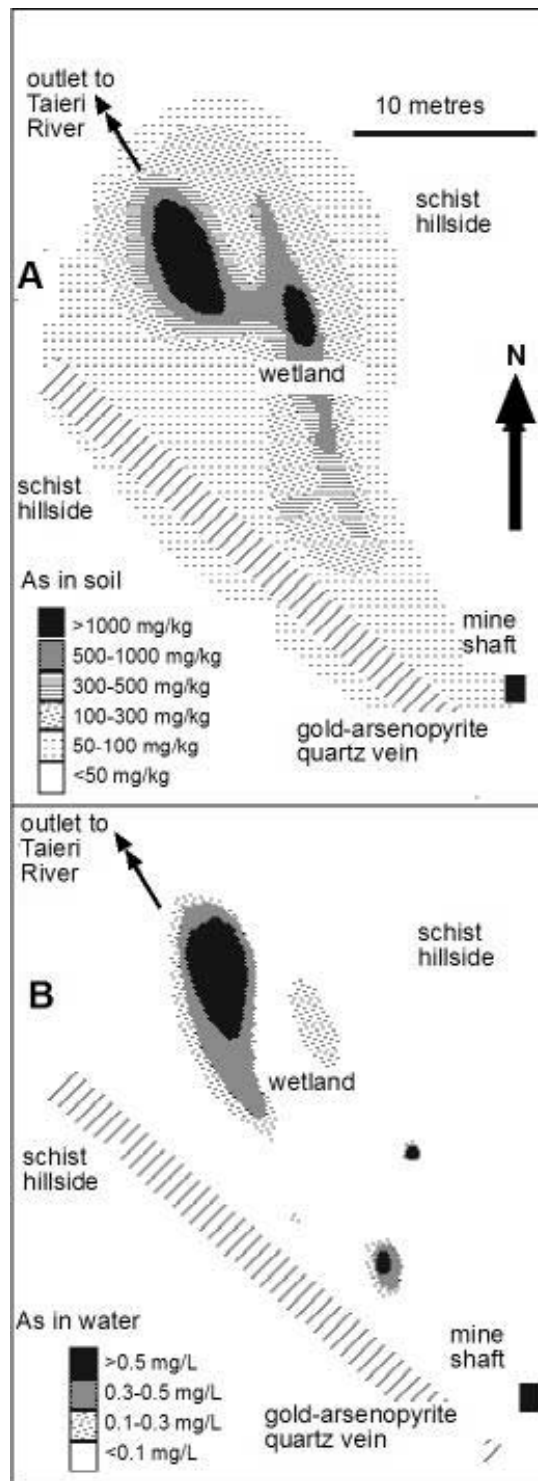


**Figure 10:** Field sketches of mineralised portions of the Bucklands Fault, showing the internal structure of the fault zone. **A.** Bucklands workings, **B.** Mining area No.3 **C.** Mining area No.1. The direction of dip is the same in all sections (from MacKenzie & Craw 1993).

## ENVIRONMENTAL BAREWOOD

The quartz veins at Barewood contain pyrite and arsenopyrite as well as gold and some scheelite. Natural erosion of the quartz vein has resulted in elevated arsenic concentrations in soils, up to 300 mg/kg (Fig. 11), about 20 times higher than normal Otago schist background soil arsenic concentrations. Dissolved arsenic concentrations in waters associated with small mine tunnels can reach 1 mg/kg (Craw et al. 2000). The area has a cool temperate to semi-arid climate, with evaporation exceeding precipitation. Hence, streams and wetlands commonly dry up in summer, and dissolved arsenic concentrations may increase in times of drought. Several cows died from reputed arsenic poisoning in the area in the 1980s, although the specific arsenic source has not been identified with certainty.

The principal mine at Mining Area 3 was developed underground in one of the quartz veins, with mine access via a vertical shaft and horizontal tunnels. The ore was crushed and gold extracted by cyanidation in one of the earliest uses of cyanide in New Zealand. Tailings from the processing plant were dumped into the adjacent creek, following the standard practice of the time. This creek flows into the Taieri River, which is now an important recreational waterway and source of domestic water supply for the city of Dunedin. The creek has developed a wetland where tailings were dumped, and some tailings are still present. These tailings have been largely oxidised, and they consist mainly of brown iron oxyhydroxide-rich slurry. High arsenic concentrations persist (locally over 30 000 mg/kg) in these tailings residues in the centre of the wetland (Fig. 11A; Craw et al. 2000). Dissolved arsenic is up to 1 mg/L in this area of the wetland (Fig. 11B). The dissolved arsenic is readily attenuated by adsorption to iron oxyhydroxides downstream of the wetland (Craw et al. 2000).



**Figure 11:** Geochemical maps of Barewood showing As concentrations in water and soil.

## REFERENCES

- Adams, C. J. and Graham, I. J. (2000) K-Ar and Rb-Sr age determinations relating to gold and tungsten mineralisation in the Otago Schist. Institute of Geological & Nuclear Sciences Science Report 2000/5, 16p.
- Angus, P.V.M., (1993). Structural controls on gold deposition in the Hyde-Macraes Shear Zone at Round Hill, Otago, New Zealand. Proceedings of the 27th Annual Conference of the New Zealand Branch of the Australian Institute of Mining and Metallurgy.
- Angus, P.V.M., de Ronde, C.E.J, Scott, J.G. (1997). Exploration along the Hyde Macraes Shear Zone. Proceedings of the 1997 New Zealand Minerals and Mining Conference, Ministry of Commerce, p151-157.
- Craw, D. (2000) Water-rock interaction and acid neutralization in a large schist debris dam, Otago, New Zealand. *Chemical Geology* 171: 17-32.
- Craw, D. (2003) Geochemical changes in mine tailings during a transition to pressure-oxidation process discharge, Macraes Mine, New Zealand. *Journal of Geochemical Exploration* 80:81-94.
- Craw D., Norris R.J. (1991) Metamorphogenic Au-W veins and regional tectonics: mineralisation throughout the uplift history of the Haast Schist, New Zealand. *New Zealand Journal of Geology and Geophysics* 34: 373-383.
- Craw, D.; Chappell, D.; Nelson, M.; Walrond, M. (1999) Consolidation and incipient oxidation of alkaline arsenopyrite-bearing mine tailings, Macraes Mine, New Zealand. *Applied Geochemistry* 14: 485-498.
- Craw, D., Windle, S.J., Angus, P.V.M. (1999). Gold mineralisation without quartz veins in a brittle-ductile shear zone, Macraes Mine, Otago Schist, New Zealand. *Mineralium Deposita* 34: 382-394.
- Craw, D.; Chappell, D.; Reay, A.; Walls, D. (2000). Mobilisation and attenuation of arsenic around gold mines, east Otago, New Zealand. *New Zealand Journal of Geology and Geophysics* 43: 373-383.
- Craw, D.; Nelson, M. (2000) Geochemical signatures of discharge waters, Macraes mine flotation tailings, east Otago, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 34: 597-613.
- Craw, D., Koons, P.O., Chappell, D.A. (2002) Arsenic distribution during formation and capping of an oxidized sulphidic minesoil, Macraes mine, New Zealand. *Journal of Geochemical Exploration* 76: 13-29.
- Craw, D.; Pacheco, L. (2002) Mobilisation and bioavailability of arsenic around mesothermal gold deposits in a semiarid environment, Otago, New Zealand. *The Scientific World Journal* 2: 308-319.

- Cox S.C. (2001) Lithological controls on mineralisation in East Otago Gold Deposits AUSIMM (NZ Branch) 34th Conference Proceedings, University of Otago, August 2001 p51-67
- Decker H, Ring U, Mortimer N (2002) Cretaceous bivergent extension in the Rakaia accretionary wedge, Otago Schist, New Zealand. *New Zealand Journal of Geology and Geophysics* 45: 537-547.
- de Ronde, C.E.J., Faure, K., Bray C.J., and Whitford D.J., (2000). Round Hill Shear Zone-Hosted Gold Deposit, Macraes Flat, Otago, New Zealand: Evidence for a Magmatic Ore Fluid. *Economic Geology* 95: 1025-1048.
- Ingram, JC (1982) Gold, Quartz and Cyanide – The History of the Barewood Reefs. Otago Heritage Books, Dunedin. 48 pages.
- Jeffery, A (1987) The History of Quartz Mining at Barewood, Central Otago, New Zealand. Report to the Resource Management & Mining Group, Ministry of Energy. 43 pages.
- McKeag S.A. & Craw D. (1989) Contrasting fluids in gold-bearing quartz vein systems formed progressively in a rising metamorphic belt: Otago schist, New Zealand. *Economic Geology* 84, 22-33.
- McKeag, S.A., Craw, D., Norris, R.J.N. (1989) Origin and deposition of a graphitic schist-hosted metamorphic Au-W deposit, Macraes, East Otago, New Zealand. *Mineralium Deposita* 24: 124-131.
- MacKenzie, DJ; Craw, D (1993) Structural control of gold-scheelite mineralisation in a major normal fault system, Barewood, eastern Otago, New Zealand. *New Zealand Journal of Geology and Geophysics* 36: 437-445.
- Mortimer N (2000) Metamorphic discontinuities in orogenic belts: example of the garnet-biotite-albite zone in the Otago Schist, New Zealand. *International Journal of Earth Science* 89: 295-306.
- Mortimer N (2003) A provisional structural thickness map of the Otago Schist, New Zealand. *American Journal of Science* 303: 603-621.
- Petrie B S (2001) Structural and lithological controls in mineralisation in the Hyde-Macraes Shear Zone. Unpublished M.Sc. thesis, University of Otago, New Zealand.
- Roddick-Lanzilotta, A. J.; McQuillan, A. J.; Craw, D. (2002) Infrared spectroscopic characterisation of arsenate(V) ion adsorption from mine waters, Macraes Mine, New Zealand. *Applied Geochemistry* 17: 445-454.
- Teagle, D.A.H., Norris R.J., Craw D. (1990) Structural controls on gold bearing quartz mineralisation in a duplex thrust system, Hyde-Macraes Shear Zone, Otago Schist, New Zealand. *Economic Geology* 85: 1711-1719.

- Turnbull I M, Mortimer N, and Craw D (2001) Textural zones in the Haast Schist - a reappraisal: *New Zealand Journal of Geology and Geophysics* 44: 171-183.
- Williams, G. J. (1974) *Economic geology of New Zealand*. AUSIMM Monograph Series No.4. 490 pages.
- Williamson, J. H. (1939) *The Geology of Naseby Subdivision, Central Otago*. New Zealand Geological Survey Bulletin 39.
- Windle, S.J., Craw, D., Angus, P.V. (1999) Petrographic and mineralogical factors affecting gold recovery at Macraes Flat, Eastern Otago, New Zealand. *Pacrim 1999, Bali Indonesia, October 10-13*. P149-162.