REPORT ON MINERAL LEASE S150

1991

PREPARED BY: R D JAMES

SENIOR MINE GEOLOGIST

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1.0 GENERAL OVERVIEW

White Range Gold NL (Receivers and Managers Appointed) owns and operates a producing gold mine and associated mining leases at White Range, 125km by road east-north-east of Alice Springs, Northern Territory. (see Location Map over page)

The current period of mining at White Range under White Range Gold NL commenced in November, 1989. The treatment plant was commissioned in early March 1990 and the first gold was poured on 10 March 1990. Gold production in the period to 30 June 1990 was 6042 ounces and in the year to 30 June 1991 was 26605 ounces.

The probable ore reserves at the commencement of mining in November 1989 were stated as:

850,000 tonnes @ 4.7 g Au/t (M Rogers & Associates – December 1989).

This grade has proved to be an overestimate and the run of mine ore feed grade has been found to be closer to 3.2 g Au/t.

From the commencement of the project, operations were generally unprofitable and by late February, 1991, the position was reached where the company was unable to meet its commitments. On 1 March 1991, at the request of the directors of White Range Gold NL, Alan Raphael Tuttle and Lindsay Richard Dickson of the Brisbane Office of the accounting firm of KPMG Peat Marwick were appointed joint Receivers and Managers of White Range Gold NL. Upon the appointment of Receivers and Managers, mining ceased for a period but milling of stockpiled low grade ore continued.
In late May 1991, mining was recommenced at White Range. After a period of unprofitable operation, a profitable operation before off site costs (eg interest) is being established with all gold produced being sold at the spot price. There have been three key factors behind this improvement. These factors are:

1. Restructuring of the mining arrangements whereby mining is now conducted under an hourly hire contract for the mining of both ore and waste with Roche Bros. Pty Ltd; rather than a BCM contract as was the case pre-receivership with another contractor.

2. The achievement of reliable performance from a barren rejection or scrubbing circuit which upgrades the crushed ore. On an annual basis this plant is capable of upgrading 455,000 tonnes of crushed ore grading 3.2 g Au/t to 245,000 tonnes of ball mill feed grading 5.4 g Au/t. The grade of the material rejected by the scrubber is 0.6 g Au/t.

3. Implementation of a range of measures aimed at reducing operating costs.

Period gold production has achieved 2,950 ounces.

There is good potential to establish additional ore reserves within the mining lease MLS150 and an exploration program has been planned to target some 200,000 tonnes of resource. Under receivership the project has not been able to generate sufficient surplus funds to meet the cost of this exploration program.

The company holds a number of exploration licence areas. One of these, EL6833, a 135 sq. km. exploration licence covering the old Winnecke Gold Field shows good promise and grass roots exploration is in progress on that area.
The decision has now been taken to offer the project, its assets and leases for sale.
2.0 GEOLOGICAL SUMMARY

Gold mineralisation at White Range is confined to conjugate sets of quartz veins within a hard quartzite host rock. Most of the mineralised quartz veins are less than 3.5 m in horizontal width, extend to about 40 m beneath the surface, and outcrop on a hillside over 1 sq. km. in area.

At a 2 g Au/t cutoff over 2 m minimum horizontal width, remaining resources and ore reserves as at 15 October 1991 are:

340,000 tonnes at 3.1 g Au/t containing 33,800 oz Au.

This total comprises 160,000 tonnes at 3.2 g Au/t of Proved Ore Reserves containing 16,500 oz Au, and 180,000 tonnes at 3.0 g Au/t of Measured Resources containing 17,300 oz Au.

Resources and ore reserves are based on drill indicated estimates after imposition of average mine reconciliation factors and gold bullion recoveries achieved over the past twelve months of production.

Good potential exists for the discovery of additional open cut resources adjacent to the present mining areas. There is also potential for additional resources beneath the metatonalite cover immediately east of the existing open cuts.
2.1 LOCATION

The White Range Gold Mine is covered by Mineral Lease S 150 and is located approximately 125km by road east-north-east of Alice Springs, Northern Territory. White Range Gold NL ( Receivers and Managers Appointed) also holds Mineral Lease S 151 covering 13km of water pipeline and a water bore field.

Exploration Licences currently held in good standing are EL 4799; EL 6832 and EL 6833. These Exploration Licences are located 10, 150 and 60km respectively by road from MLS 150 and are prospective for gold and base metals exploration. Locations are shown earlier on the map in Section 1.0 of this brochure.

2.2 GEOLOGY

The White Range Mine Site is located in a nappe complex within an extensive late Paleozoic thrust system. The thrust system forced deep crustal rocks southward over shallower sedimentary rocks.

Mineralisation is hosted by quartz veins in late Proterozoic Heavitree Quartzite rocks which lie immediately below a large thrust contact with older Atnarpa complex schists and metatonalites. Although several smaller thrust faults are recognised within the quartzite, mineralisation at the mine site is confined to quartzite immediately beneath the exposed roof thrust contact between quartzite and metatonalite. A detailed review of the structure of the mineralised quartz veins is provided by D. Kirschner's 1991 report (see Appendix 2). Limited drilling indicates that mineralisation also persists in quartzite beneath the metatonalite at depths exceeding 60m vertically.
Gold mineralisation is contained in sulphidic hydrothermal quartz veins which are discordant to foliation. Vein geometry in cross section consists of individual steeply north dipping planar or sigmoidal veins that are en echelon arrayed in zones dipping south at 40-70°. Individual veins are centimetres to metres in width, and metres to tens of metres in length. The mineable vein zones or vein arrays are metres to tens of metres in width, five to twenty metres in height and strike length. In plan view, vein arrays consist of anastomosing sets commonly intersecting to form parallelograms and less commonly to form pinnate geometries.

Typical oxidised ore is predominantly quartz vein rock in which pyrite has been replaced by limonite, some of which has been totally or partially leached out leaving fragile, open laticework structures and solution cavities. Gold in oxidised ore is frequently visible as wiry and platy particles up to one millimetre in size and loosely attached to the laticework cavities. Below the zone of oxidation, gold ore is typically associated with coarse pyrite and less commonly with minor covellite and chalcopyrite. The average sulphide content is rarely greater than 10%.

Visual observations and detailed sampling have shown conclusively that the distribution of gold is erratic. Considerable gold is contained in patches of high to extremely high grade ore (30-300 g Au/t) with dimensions in the order of centimetres to decimetres in width. These high grade areas invariably correlate with high sulphide content in the primary zone, and with a high proportion of laticeworks and fine grained limonitic material in the oxidised zone.
2.3 ORE RESERVES AND RESOURCES

Proved Ore Reserves and Measured Resources remaining at White Range as at 15 October 1991 are:

- Proved Ore Reserves: 160,000 tonnes at 3.2 g Au/t
- Measured Resources: 180,000 tonnes at 3.0 g Au/t

Total Reserves and Resources: 340,000 tonnes at 3.1 g Au/t

Ore reserves and resources are based on drill intercepts with an average spacing of 7.5m on sections at 10m intervals. Approximately 65% of total drilling is open hole percussion and 35% reverse circulation percussion.

Samples are split at one metre intervals and open hole percussion samples are assayed for gold by acid digest on 40g charges with Atomic Absorption Spectrometry (AAS) determination. Reverse circulation samples are assayed by fire assay on 50g charges and economic grades are checked by acid digest on 35g charges with AAS determination. All assays are repeated by splitting primary drill samples.

Open hole drill collars are surveyed and reverse circulation drill holes are surveyed at the collar and down the hole. Geology and assays are plotted on cross sections and ore lenses are rationalised and interpreted by plotting level plans using customised Surpac mining software. Criteria for the limits of ore lenses are 2 g Au/t cutoff over minimum 2m horizontal width and 10m strike length.

Ore volumes are computed from lens shapes on bench plans at 5m vertical intervals. Tonnage conversion is based on an average specific gravity of 2.5. Grade estimate of ore lenses on bench plans is based on the arithmetic mean of drill intercepts using a top cut of 15 g Au/t. Global pit grades are tonnage weighted on a bench by bench basis.
The above procedures are routinely used to estimate both the remaining and the depleted drill indicated resource. The depleted resource is compared with the actual ore tonnage mined and assayed head grade to obtain average mine reconciliation factors. The mine factors obtained, including the average gold bullion recovery, are imposed on the remaining drill indicated resource to obtain a Proved Reserve or Measured Resource depending upon the resulting average grade and the waste to ore stripping ratio obtained. Proved Reserves are defined as ore at an average bullion grade equal to or in excess of 3.2 g Au/t and mineable at an average waste to ore stripping ratio of about 7:1. Reconciled mineralisation not meeting these criteria is classified as a Measured Resource.

The pre mining ore reserve quoted in the December 1989 M Rogers and Associates report is 850,000 tonnes at 4.7 g Au/t. The ore reserves tonnage and grade were classified as Probable. Mining since the project outset to 15 October 1991 has produced 530,000 tonnes at an assayed head grade of 3.3 g Au/t. Expected remaining tonnage based on the December 1989 figure, therefore, is approximately the same as the current combined resource and ore reserve figure. However, the expected average grade for the remaining ore is drastically reduced to 3.1 g Au/t. With the benefit of hindsight, this is essentially due to an over stated ore reserve grade. The main reasons are:

- The area of influence given to high grade assays using an arithmetic averaging process was unrealistically high based upon the observed erratic geological continuity of ore and sampling results obtained from exposed mining faces and benches.

- The selection of 60 g Au/t as the threshold at which high grade assays were truncated to in the averaging process was excessively high for the same reasons as outlined above.

- The effect of down hole contamination of high grade assays proved to be more severe than anticipated.
2.4 GRADE CONTROL

The complexity of ore body geometries, the erratic gold distribution within quartz veins, and the distance between ore lenses indicate selective techniques are required to mine ore at White Range. Ore body contacts are determined using a combination of visual and drilled assay criteria. Good visual discrimination is possible between ore and barren quartz.

Benches are paddock blasted over 5m vertically and mining is carried out in 2.5m flitches. Excavator movement direction is oriented across the ore body strike in 5m wide strips enabling continuous and regular face mapping. This mapping is marked up on the mining face and the data transferred onto cross sections and level plans. The mining sequence is from hanging wall to foot wall enabling the same geologist (or graduate geotechnician) to co-ordinate both the mapping and supervision of ore excavation. Mining control is greatly assisted by an hourly rate contract which allows for substantial flexibility and care during ore excavation, and by the addition of water to control dust which improves ore visibility.

Drill data is routinely set out by surveyors prior to mining and provides a gross indication of ore lens positions and shapes in plan view. This drilling information broadly conforms to the geologist’s mapping.

2.5 EXPLORATION

The exploration potential of the White Range Mineral Lease has been reviewed on two separate occasions by independent consultants, Gilfillan Associates Pty Limited and Dr Chris Giles. Copies of these reports are available upon request and the main aspects are summarised in the following discussion.
J Gilfillan's February 1991 assessment indicates a high likelihood of success in defining a resource in the order of a further 400,000 tonnes. The potential ore would be of similar grade and at a similar waste to ore stripping ratio to that presently being mined. An additional 100,000-200,000 tonnes of resource potential beneath the barren metatonalite cover is also indicated, albeit at a higher waste to ore stripping ratio.

Most of the potential 400,000 tonnes of resource is located within a one kilometre radius of the existing crusher and is mineable by open cut. The main target areas are mapped but undrilled quartz veins in gullies between existing pits and in an area immediately west of the present open cuts.

With the aim of defining further ore resources at White Range, Dr Chris Giles was commissioned in August 1991 to assess and to plan a drilling program. Giles' report proposes a drilling program with good potential for the discovery of 200,000 tonnes of additional ore mainly from one area and at currently mined grades. Giles' report was prepared following two site visits, inspection of targets in the field, and a review of geological interpretations. Proposed drill hole collar positions are identified giving a total 5000m of drilling (details in Appendix 3).

The main target areas are exposed quartz veins mineable by open cut methods and located within one kilometre of the mill. Drill holes are planned to an average 45m depth and targets are prioritised to maximise the probability of early discoveries of easily mineable ore.
Reconnaissance exploration has commenced on Exploration Licence 6833 which covers 135 sq. km. of prospective gold and base metals exploration incorporating the former Winnecke Gold Field. The Exploration Licence is situated 65km north-west by road from the White Range Mine Site and contains numerous stopes and old workings exploiting gold mineralisation following a line of strike 14km in length. Gold is hosted mainly by gneisses and by quartzite in one area. The geological setting of the old workings is an extensive thrust adjacent to the contact between quartzites and gneisses. This thrust is continuously mappable for over 60km from the White Range mining area to the Winnecke Gold Field (BMR, 1985).

Previous exploration was reviewed and shows that most work concentrated on a single old working covering about 300m of strike length. No exploration drilling is recorded or noted in the field outside this zone apart from shallow, regional drilling for alluvial uranium.

Recent reconnaissance by White Range personnel supports previous results showing that gold is mainly contained in narrow, vugly, limonitic quartz veins with high values obtained in the fine grained limonite, and that some gold values are also obtained from surrounding weathered and sheared gneiss. The area is therefore considered to be prospective for mineralisation which may be amenable to beneficiation by screening/scrubbing similar to that taking place at the White Range Mine, and for high tonnage, low grade disseminated mineralisation in softer, weathered gneisses.
3.0 MINING

The mining at White Range is by open cut method and this is undertaken on the side of a steeply sloping quartzite range, some 200 metres in vertical height.

3.1 PIT DESIGN

Ore is mined from a series of small open pits with depths to 50m. The ground is stable with pit walls standing at better than 70\(^\circ\) without the need for ground support. Access to the pits is by way of a system of 16m wide haulage roads which zig-zag up the side of the range at an average gradient of 1 in 10.

Average haul distances for ore and waste are 550 metres and 350 metres respectively. Much of the waste dumping is now into nearby mined out pits.

Survey requirements are met using a Sokkisha total station. Survey, geology and mine planning utilise Surpac software.

3.2 DRILL AND BLAST

Drilling is carried out under an hourly hire contract by Civil Resources Limited. The two drill rigs used are Ingersoll Rand LM500. All blast hole and grade control drilling is done under a three drill shift per 24 hour day roster which is based on ten days on and four days off.

Bench heights are 5m and 10m. Hole diameters are 89mm and 102mm and the average pattern size is 14sq metres.

Explosives used are Nitroprill and EP Gold slurry mixed using an ICI bowl mantle truck.
3.3 ORE AND WASTE REMOVAL

Ore and waste removal is on an hourly hire contract with Roche Bros. Pty Ltd.

Ore and waste is dug using two 65 tonne Komatsu excavators on day shift only.

Ore and waste are removed from the pits by a fleet of 50 tonne capacity Terex dump trucks. Ancillary mining equipment used comprises:

1 x 440G Caterpillar grader
1 x DBK Caterpillar dozer
1 x 30 ton Euclid water cart with monitor cannon

Mining is based on a ten days on and four days off roster, with machine hours being ten per day.

3.4 MANNING

Excluding the employees of the two contractors, Roche Bros. Pty Ltd and Civil Resources Pty Ltd, the operating workforce comprises:

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<tr>
<td>Mine Superintendent</td>
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</tr>
<tr>
<td>Senior Mine Geologist</td>
<td>1</td>
</tr>
<tr>
<td>Mining Engineer (Planner)</td>
<td>1</td>
</tr>
<tr>
<td>Senior Mine Surveyor</td>
<td>1</td>
</tr>
<tr>
<td>Mine Geologist</td>
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<tr>
<td>Mine Surveyor</td>
<td>1</td>
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<tr>
<td>Geotechnician</td>
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<tr>
<td>Survey Assistant</td>
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<tr>
<td>Shot Firer</td>
<td>1</td>
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<tr>
<td>Shot Firers Assistants</td>
<td>2</td>
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3.5 MINE PERFORMANCE

The total material moved for the 4 week period ended 12 November 1991 was 98,000 BCM's, comprising 85,000 BCM of waste and 12,700 BCM of ore, giving a strip ratio of around 6.7:1. Using an average SG of 2.5, this translates to 32,000 tonnes of ore.
4.0 ORE TREATMENT

Introduction

Most of the ore treatment facility was purchased in late 1988, from Edjudina Gold Mines Pty Ltd where it was used for that company's Porphyry project. This plant was dismantled then transported and erected at the White Range minesite. In addition, Laurie Smith and Associates Pty Ltd, consulting metallurgist, had metallurgically evaluated the White Range ore and determined a flotation – regrind circuit was required for maximum gold extraction. Consequently a flotation – regrind circuit was incorporated into the Porphyry treatment facility.

Since the construction of the basic treatment facility, a barren reject circuit has been added immediately prior to the primary ball mill. A detailed description of the barren rejection circuit is given in Section 4.3.

The treatment plant is able to operate on a continuous basis, at a throughput of 330,000 dmt pa through the primary ball mill. Utilising the barren rejection circuit a total of 600,000 dmt pa of fine ore are required to maintain this primary ball mill throughput.
The present strategy is to operate 75% of the total available hours. Accordingly, the treatment facility roster is six days operating, two days closed down. Consequently, the treatment facility operates 21 days out of a possible 28 day period.

A simplified conceptual process flowsheet of the treatment plant is shown on the next page.

4.2 CRUSHING

Freshly mined run of mine ore (ROM), is stockpiled on the crusher pad. Only two categories of ore are stockpiled, high/medium and low grade. High/medium grade ore contains nominally 3.5 - 5.0 g Au/t, whilst low grade ore contains nominally 2.0 - 2.2 g Au/t. These two categories are blended at a ratio of 1 high/medium grade to 2 low grade to obtain a target feed grade of 3.2 g Au/t.

A 966 front end loader is used to reclaim ROM ore and feed it to the two stage closed circuit crushing facility. ROM ore is loaded into a 150 tonne capacity dump hopper immediately prior to the primary crusher.

Primary crushing is achieved utilising a Kobe Steel 914mm x 1219mm jaw crusher, operated at a closed side setting (CSS) of 80mm. The primary crusher is powered by a 160kW motor. Material discharged from the jaw crusher is conveyed to a double deck Malco CADM (6000 x 2400mm) screen. The limiting screen aperture is 14mm x 50mm slotted with the slots at right angles to the direction of mass flow, ie crossflow. The crusher product is nominally 100%, minus 16mm.

Screen undersize, ie minus 16mm material, is conveyed to a 9000 tonne capacity fine ore cone with a 2000 tonne live capacity. Screen oversize is returned to an EL-JAY, 1372mm standard head roller cone crusher powered by a 185kW motor. Secondary crusher discharge is recirculated to the double deck screen.
FIGURE: CONCEPTUAL PROCESS FLOWSHEET.
4.3 BENEFICIATION

Fine ore from the surge cone is delivered to the barren rejection circuit. Fine ore is fed to a 2.2 metre long x 2.2 meter diameter barrel scrubber, powered by a 90kW motor and slurried with process water.

Scrubber discharge is screened on a single deck Hewitt Robins Vibrex screen, 1500mm wide x 4300mm long, at a nominal size of 9.2mm square aperture. Screen oversize is conveyed to a barren reject surge pile and rehandled with a front end loader to the final barren reject pile.

Screen undersize is pumped by a single Warman 4/3 CAH pump to a dewatering screen, where the solids are discharged into the ball mill, whilst the solution is returned to the scrubber discharge hopper. A bleed of the return solution is pumped to the mill discharge pump box.

The barren reject circuit enables 40 - 45% of the feed mass to be rejected, which accounts for only 10% of the total contained gold. Accordingly, a significant increase in mill feed grade results.

4.4 PRIMARY GRINDING

The primary grinding circuit consists of a single ICAL overflow ball mill, 2.9m diameter x 4.8m long, powered by a 600kW motor. The ball mill is rubber lined and operates in closed circuit with a single 380mm diameter Krebs cyclone. The make up ball top size is 65mm.

4.5 GRAVITY CIRCUIT

A bleed from the cyclone underflow continuously flows into the gravity circuit. The circuit consists of a Johnson Drum Concentrator as the primary concentrating unit and Metquip centrifugal concentrators are the secondary unit. The Johnson Drum concentrate is delivered to either of two Metquip concentrators, whilst the Johnson Drum and Metquip tails are returned to the ball mill. Metquip concentrates are collected daily and treated in the gold room.
4.6 FLotation

Classified material, with a particle size distribution of approximately 70% passing 75 micrometres and a solid density of approximately 45% weight/weight is gravity fed to the froth flotation conditioning tank. In the conditioning tank Sodium Ethyl Xanthate is added. Dowfroth 400 is added to the pulp stream as it enters the rougher froth flotation bank.

The rougher concentrate, which consists mainly of pyrite with trace amounts of chalcopyrite and covellite, from the six Agitair cells (2.8m³) is collected and pumped to a 10m diameter concentrate thickener. Approximately five tonnes per hour of flotation concentrate are produced. This concentrate is thickened to 50% solids w/w and discharged from the thickener underflow and pumped to the regrind circuit, whilst the clarified solution from this thickener overflow is returned to the process water tank.

Flotation tailings are pumped directly to the Carbon In Leach (CIL) circuit.

4.7 LEACH AND CIL CIRCUITS

4.7.1 LEACH CIRCUIT

Thickened flotation concentrate is pumped to a 1200mm diameter x 1800mm long ICAL conical regrind mill powered by a 50kW motor. The regrind mill operates in closed circuit with two 100mm diameter Harman cyclones. Classified material, discharged from the regrind circuit, with a particle size distribution of 100% minus 38 micrometers, is gravity fed to the first of eight leach tanks.
The mineral pulp enters the first leaching stage where the pH is adjusted to 9.5–10, by the addition of lime. Dilute cyanide solution (10% weight/volume) is also added to adjust the free cyanide level to 500mg/l. The first two leaching stages have live slurry capacities of 120m³, whilst the remaining six have a live slurry capacity of 40m³.

The mineral pulp flows under the influence of gravity through the leaching circuit and discharges into the CIL circuit. The nominal residence time in the leaching circuit is 70 hours.

4.7.2 CARBON IN LEACH

Flotation tailings and leach circuit discharge combine in the first adsorption stage. The mineral pulp flows under the influence of gravity through the six adsorption stages, in which activated carbon, at a concentration of approximately 15 g/l, is moved counter currently relative to the direction of pulp flow. Each adsorption stage has a live slurry capacity of 120m³.

4.8 CARBON ELUTION

Desorption of gold from loaded carbon, (2800 g Au/t) is conducted daily in a 1.2 tonne column. The Anglo American Research Laboratories desorption protocol is used. Following several elution cycles, cathodes are removed from the electrowinning cell, digested, dried and smelted to produce dore bullion. Dore bullion is dispatched from site fortnightly.
4.9 **TAILINGS DISPOSAL**

Process tailings are deposited into the tailings dam by single point discharge. Satisfactory beaching has been achieved in the tailings dam and it is doubtful that any decommissioning problems will be encountered.

4.10 **MANNING**

A total of eighteen people are employed in the treatment facility. They are as follows:

- Mill General Foreman: 1
- Shift Foreman: 2
- Laboratory Supervisor: 1
- Maintenance Supervisor/Electrician: 1
- Treatment Plant Operators: 6
- Laboratory Assistants: 2
- Fitter/Welders: 4
- Serviceman: 1

The treatment plant operators work a continuous shift roster, whilst all other personnel work day shift only. Treatment operators and laboratory personnel work a six day on, two day off roster, whilst the maintenance personnel work a four weeks on, one week off roster. This roster has been deliberately established to maximise maintenance during mill downtime.
A treatment plant shift consists of the following members:

- Shift Foreman: 1
- Crusher Operator: 1
- Grinding / Flotation Operator: 1
- Leaching / Adsorption Operator: 4

Metallurgical direction is provided on a contract basis by AMET MINING Pty Ltd - consulting metallurgists and mining engineers.

All award treatment plant personnel are paid in accordance with the site enterprise award.
5.0  INFRASTRUCTURE

5.1  POWER HOUSE

Minesite power is generated by a set of four Cummins diesel generators each rated at 0.6MW. Three generators are required to run during treatment plant operations. The fourth unit is to allow continuous online maintenance of the power house.

A 0.48MW Detroit generator is also maintained as an emergency backup unit. The Detroit unit provides sufficient power to maintain the accommodation village and run the critical treatment plant items.

The power house is maintained by Alice Kenworth Pty Ltd, authorised Cummins dealers based in Alice Springs. Generators are serviced after every 300 hours of operations.

Generators are operated on Mereenie Crude Oil.

The total powerdraft required at the minesite is 1.6MW. It is accounted for as follows:

- Hydrometallurgical Treatment Plant 1.2MW
- Crusher 0.2MW
- Accommodation Village 0.2MW
5.2 WATER SUPPLY

The White Range Gold Mine requires approximately 1000 tonnes of water per operating day.

Potable water is recovered from a borefield approximately 13km away from the minesite and pumped via polyethylene pipe to a holding tank adjacent to the accommodation village. Potable water is pumped from the holding tanks to header tanks elevated above the treatment plant. Additional water for ore treatment is recovered from the tailings dam and the concentrate thickener within the processing plant.

5.3 ACCOMMODATION VILLAGE

The accommodation village is situated approximately 3km by road from the minesite and treatment plant.

The village contains 110 accommodation units, mostly single. There are however, seven double units. A total of three male and one female ablution blocks service the village.

Catering within the village is conducted in house.

The village also contains:

- nominal 70 person mess
- wet mess
- swimming pool
- beer garden
5.4 MAINTENANCE – WORKSHOP AND WAREHOUSE

The treatment plant area contains a maintenance workshop and warehouse. The maintenance workshop provides daily and ongoing maintenance for the treatment plant and accommodation village. In addition, the workshop maintains light vehicles.

A store-warehouse is located adjacent to the maintenance workshop and contains a limited number of inventory items and critical spares. These include ore treatment reagents and consumables.

The critical spares held include pump and compressor components and motors for the ball mill and the primary and secondary crushers. As well there is an assortment of larger bearings, eg mill pinion bearings.

5.5 ASSAY LABORATORY

Also contained within the treatment plant area is a small assay laboratory which provides daily assays for grade and process control and occasional exploration samples.

Solid samples are digested with aqua regia and assayed for gold by AAS. Solution samples are extracted into Di-iso-butyl ketone before AAS finish.

The assay laboratory can achieve a nominal throughput of 150 assays per 24 hour period.
APPENDIX 1

REFERENCES

Geology of the Strangways Range Region, Northern Territory.
Australia 1:100000 Geological Special

Geology of the Arltunga-Harts Range Region, Northern Territory. Australia 1:100000 Geological Special.


APPENDIX 2

STRUCTURAL GEOLOGY REPORT

BY D L KIRCHNER, 1991
Geologic Report on Gold-Bearing Quartz Veins of White Range (central Australia)

by
David L. Kirschner

submitted to:
White Range Gold N.L.
(February 1991)
White Range Gold Mine Report

Report Summary

The gold-bearing quartz vein system at White Range has a characteristic geometry (Fig. 1) which is atypical for most vein systems. Individual north dipping veins are en echelon arranged into south dipping zones. These zones are meters to tens of meters in width, five to twenty meters in vertical height, and five to twenty meters in horizontal length. These zones dip variably to the south (40-70°) and most typically strike either 082° or 118°. Gold and sulphide mineralization are contained in individual north dipping veins within the larger en echelon zones.

Suggestions for improving grade control are:

1. Interpret drill data according to the "typical" vein geometry (Fig. 1) when the data does not clearly constrain the ore body geometry and orientation;
2. In ore mark-up and post-excavation pit floor mapping, realize that most veins trend approximately 082° or 118°, and will either be isolated or intersect other vein zones to form X, Y, and rarely U shape geometries;
3. Maintain the practice of spray painting boxwork and pyrite prior to formalizing the ore mark-up;
4. Institute pit floor mapping of quartz veins prior to drilling and blasting of the next bench;
5. Institute quick sketching of excavation cut faces during a dig;
6. Institute spray painting and mapping of ore bodies on pit walls;
7. Continue and improve dust control measures to insure that the grade control personnel can always clearly see the actively excavated face.

Suggestions for exploration:

1. Drill through metiontalite to the underlying quartzite according to the prioritized zones of Fig. 2;
2. After thoroughly exploring east of the present mine area; consider drilling through the basement east of the Great Western pit area (cf. Fig. 34);
3. Do not spend time exploring the metiontalite adjacent to the mine area or the quartzite to the west or south of the present mine area (since no large prospective zones were found in these areas).
Figure 1: Representative quartz vein geometry of the White Range mine area.
Representative Quartz Vein Geometry of White Range Mine Area
Figure 2: Prioritized zones for exploration through the metatonalite into the underlying quartzite. Outside of the elliptical zones, the quartzite at the contact with the metatonalite will most likely be veined.
General Report

General Geology of Mine Area

The White Range mine is located within a large thrust system that developed over 300 million years ago. The thrust system forced deep crustal rocks (e.g. the deformed tonalites underlying the mill and office area) southward over shallower sedimentary rocks (e.g. quartzite of the mine pits) (Fig. 3). One of the major thrusts is located at the exposed contact of quartzite and tonalite. Within the entire White Range area, there are at least seven lesser thrust faults in the quartzite; however, apart from the major thrust separating the quartzite and metatonalite, there are no significant thrusts in the mine area proper. During thrusting, the quartzite was folded and highly deformed. During the very last stages of thrusting, the quartzite was openly folded with NE-SW trending fold hinges. The mine area is located near the hinge zone of one large antiform. The vein system developed and slightly deformed during this time. Based upon recent Ar-Ar dating in Ruby Gap and Harts Range area, there has been no significant deformation of the area following the folding and vein formation (i.e. post 280 million years ago). For a more complete description of the geology of the White Range area refer to paper in appendix #1.

Cross-Sectional Geometry of the Vein System

Veins of all orientations and degrees of deformation are observed in the Range, from entirely recrystallized isoclinally folded or foliation parallel veins to undeformed veins steeply oriented to foliation. This range in orientation and deformation indicate that veins were forming and deforming throughout the development of the thrust system. A special subset of gold-bearing sulfide quartz veins that are undeformed to weakly deformed are localized along the northeastern margin of White Range. This particular vein system, localized in the quartzite immediately adjacent to the basement thrust contact, is associated with the largest NE-trending open upright antiform. The rest of the report will be focused solely upon this particular vein system.

The cross-sectional geometry of this vein system is typically composed of individual north dipping planar or sigmoidal veins that are en echelon arrayed in south dipping zones (Fig. 4a,b). Individual veins are centimeters to meter(s) in width, and meter to tens of meters in length. Though some isolated veins are planar, most veins are sigmoidally shaped with thin vein tips that are steeply to vertically inclined and thick central portions more shallowly dipping to the north and rarely south. The fold axes of the sigmoid veins trend approximately E-W and are subhorizontal to shallowly plunging to the east. More rarely are south dipping individual veins observed in this vein system. These veins are much smaller in size than the north-dipping veins, and are either isolated from other veins or else bifurcations of north dipping veins. The lack of consistent cross-cutting relations and the bifurcation nature of many of the south dipping veins indicate that both the north and south dipping veins developed during the same vein forming event.
The initially planar quartzite mylonite fabric is either truncated by the veins along a sharp angular discontinuity, or more commonly, the fabric is reoriented near the vein contact (Fig. 5). Where the mylonite fabric is reoriented, steeply inclined lineations defined by mica folia are present along the vein-quartzite contact with the displacement of the mylonitic fabric antithetic to the N-over-S thrusting shear couple. Locally, the quartzite fabric between adjacent north dipping veins is rotated and folded about an E-W axis (Fig. 5). This reorientation is consistent with very late, minor N-over-S thrusting associated with the decay of the ductile thrust system.

The steeply inclined sigmoid veins' tips imply that the direction of individual vein propagation was nearly vertical. The more shallowly north dipping segments of the veins imply rotation and concomitant growth during vein formation. Within individual zones, the veins are generally sub-parallel; thus, suggesting the veins formed, deformed, and rotated synchronously. However, the variability observed between pit areas (e.g. more planar, steeply dipping veins of HollyOak versus the sigmoidal, moderately to horizontally dipping veins of Luces and Extended East) suggests either that there has been some large scale variability in the rotational component of the deformation or that the more planar veins formed later in the deformation history.

Adjacent to entirely recrystallized quartzite host, the moderately deformed vein quartz exhibits undulatory extinction, optical subgrains, deformation bands, and a few recrystallized grains. The planar arrangement of solid inclusions in some veins suggest that they developed by numerous cracking and sealing events. Besides ubiquitous secondary fluid inclusions that are preferentially located along the dislocation related microstructures, the corners of the pyrite euhedral grains are surrounded by radiating secondary fluid inclusion trails. These veins also contain minor amounts of primary pyrite (± chalcopyrite, covellite, gold) and secondary goethite and malachite (Mackie 1988). The pyrite grains are moderately fractured, pulled apart, and filled with undeformed quartz fibers that are void of secondary fluid inclusion planes.

Individual north dipping veins are en echelon arranged into moderately (40-70°) south dipping arrays (Fig. 6). These en echelon arrays are typically 5-10 meters in height, and generally less than 20 meters in horizontal length. The central zones of these arrays are composed almost entirely of quartz veins that are separated by thin enclaves of quartzite mylonite. Away from the central zone, vein tips frequently terminate within a couple of meters of the zone, though rarely individual veins extend many meters away. The intersection lineations between individual veins and the envelop of the en echelon array are approximately oriented E-W and shallowly dipping.

The geometry of the south dipping zones are well developed throughout the mine area, while the predicted conjugate north dipping zones are very poorly developed, if at all. The lack of conjugate north dipping zones can be explained by the rotational component of the finite strain field (due to the waning stages of N-over-S thrusting) being superimposed upon the veins' development (Fig. 7). The south dipping
vein zones were favorably oriented for growth in the N-over-S shear environment that White Range occupied during deformation; while, the north dipping zones were unfavorably oriented for growth.

These south dipping en echelon arrays are in turn en echelon arranged into larger south-dipping vein zones (Fig. 6). Given that the vertical dimension of most of the pit walls were of limited extent at the time of this study, no good visual evidence can constrain the vertical dimensions of these arrays. In one case observed, however, a 55° south dipping system, composed of three smaller en echelon arrays, was approximately 20 meters in vertical height.

One of the basic problems has been to identify the attitudes of these zones. According to drill hole interpretations (pre-1991), the following generalizations can be made (Fig. 8):

1. West Block zones dip <40 south;
   Extended West zones dip between 30-50 south;
   Extended East zone dip between 30-50 south;
   Excelsior zones dip between 30-65 south;

2. West Block zones more frequently strike NW-SE (8 vs 6 veins);
   Extended West zones more frequently strike NW-SE (12 vs 6);
   Extended East zones more frequently strike W-E to SW-NE (21 vs 18);
   Excelsior zones more frequently strike SW-NE (33 vs 14);

3. In Extended East & Excelsior, no vein orientations seem to preferentially dip shallowly or steeply; In West Block & Extend West, the SW-NE and SW-SE veins dip than more E-W striking veins;

4. Ore is not restricted to one particularly oriented vein set;

5. In plan view, veins occur in conjugate array with an acute dihedral angle less than 40°.

Of four zones studied in some detail on the pit wall, three of them have apparent dips of 60-70° to the south and the fourth zone dips 40° south, as viewed parallel to a Northing of the mine grid (Fig. 9). However, because the pit walls are not vertical and the vein systems mapped are generally not perpendicular to the Eastings of the mine's grid system, correction must be made to find the zones' dip in cross-sectional view. In one of the three cases studied above, the corrected dip (as would be observed on the mine's cross-sections) would be 56° to the south.

Given the complexity of the deformation history at the White Range, there is no reason to assume that all the en echelon vein arrays should have similar dips to the south. For example, if there were minor fluctuations in the stress field during vein formation, the zones would be variably oriented to the south.
Why are not more shallowly dipping zones observed more often of the pit walls? One explanation could be that most of the pit walls are not elongate north-south, thus the suitable portions for observing pit wall parallel to an Easting is horizontally limited, but vertically more expansive. The lateral extent of shallowly dipping vein zones would be more difficult to observe given such pit wall configurations. However, I am inclined to the idea that most of the vein arrays dip moderately to the south (e.g. 50-70°).

How deep does the vein system extend? I speculate that the vein system decreases in size and degree of development with depth below the basement-quartzite thrust contact (Fig. 10). It is very important to recognize that the gold-bearing vein system is located directly adjacent to the major roof thrust that separates the quartzite from the metatonalite. Quartz vein deposition is solely related to changes in pressure, temperature, and chloride concentrations in the fluid; however, deposition of sulfides and gold is a function of many additional chemically related parameters (e.g. Eh, pH, oxygen fugacity, sulfur activity). It is probable that the chemical environment changed most rapidly at the basement-quartzite contact resulting in mineralization of the quartz veins. The uniqueness of the basement-quartzite contact at the mine area is supported by preliminary oxygen isotope data that suggests the quartzite in the mine area saw fluids from the basement, while the rest of the quartzite in the White Range did not (Fig. 11). Fortunately, for the mining operation, structural contours of the mine area show that the present topographic surface is within meters to a few tens of meters of the now eroded basement-quartzite thrust contact (Fig. 12). Thus, not too much of the gold-bearing vein system has been eroded away.

Plan Geometry of the Vein System in the Mine Area

The vein system in the mine area exhibits similar geometry in plan view for structures on the scale of centimeters to hundreds of meters. Similarity of structures at quite different scales is not uncommon, especially for fracture/vein systems.

In plan view, small individual veins of these two distinct sets commonly intersect to form parallelograms and less commonly to form pinnate geometries (Fig. 13a,b). Such detailed geometries are most easily observed in weakly developed vein arrays. Several important observations can be made from these small veins. First, there is some consistency in spacing between individual veins within one vein set (note: veins that are similarly oriented are called a "set"). Consequently, there is also a constant spacing between non veined zones. Secondly, vein intersections are either "X" or "Y" and very rarely "U" in shape. Thirdly, one vein might intercept many veins of another set to form a pinnate geometry (e.g. the lower right sketch). A similar vein geometry can be seen on the larger scale in HollyOak. Fourthly, both sets of veins can and generally do have a similar dip angle. In larger veins, this detailed geometry is not readily observed and the quartzite appears only as aligned enclaves in the larger quartz vein.

If the there was only one vein set or conjugate pair of two en echelon vein arrays, four linear elements would be collinearly arranged: (1) the "fold" hinge of individual sigmoid veins; (2) the intersection of individual veins with the zone boundary; (3) the intersection of the conjugate zones; and (4)
the intersection between two individual veins (Fig. 7). In the mine area, this symmetry is not observed. For example, instead of all the veins oriented in one direction as would be the case for a simple conjugate pair system, the strike directions of over 200 individual veins are concentrated about two geographic coordinates - 082° and 118° (Fig. 14,15). In addition, traces of 102 individual veins and en echelon vein sets in the Luces area also show two concentrations about similar geographic coordinates (Fig. 16a,b;17). Most of the veins in Luces are between 5-20 meters in horizontal length (Fig. 18).

To the best of my knowledge, the type of vein geometry observed at White Range has not been documented in the geologic literature; however, several geologists have recognized similar geometry for fracture/fault systems (Fig. 19). Since the work of Anderson (1951), most fracture systems (and subsequently, veins systems) have been interpreted in terms of conjugate pairs. Such interpretations have quite adequately described and explained the geometric and kinematic aspects of most fracture systems. However, following the work of Reches (1978), conjugate fracture pairs are now understood to be a special plane strain case of more general fracturing in a triaxial strain deformation. Experimentally produced fracture systems in true triaxial deformations show that three or more sets of fractures develop to accommodate the imposed triaxial strain. The resulting fracture sets were orthorhombically disposed about the principal strain axes. Several field documented fault systems that exhibit similar orthorhombic geometry have been interpreted to have formed synchronously as the result of triaxial deformations. The arguments presented by Reches and others can be extended to include brittle-ductile (e.g. the quartz vein arrays) and ductile zones of displacement.

On the larger (1:250) scale, individual zones of veining also exhibit the anastomosing geometry (Fig. 20a,b). On the Flitch plan of mine pit floors, the envelopes separate zones that have high probability of being veined versus zones that have low probability. It is important to note, that no one particular area in the anastomosing network is barren of ore. However, the intersections between envelopes often time seem to carry large quantities of good ore (Fig. 21). This is not surprising when you consider that fluid flow was probably localized along these intersections. (In first approximation modelling of fluid flow through fractured rocks, the fracture intersections can be considered channels or pipes of fluid flow embedded within an impermeable rock. And the formation of the ore and quartz veins are in part a function of the quantity of fluid that moved through the rock).

On the scale of the entire mine area, there are zones of completely nonveined quartzite that are surrounded by zones of concentrated quartz veining (Fig. 22). The parallelogram arranged concentrated zones of veining anastomose around the nonveined zones. The long axes of the non veined zones trend approximately E-W, long to short axes ratios are three to one, and they seem to be regularly spaced. In addition, envelopes of concentrated veining systematically converge and diverge within the large intersection zones. Apart from a few anomalously large veins at West Block, the development of the overall vein system of the mine area seems to decrease both in terms of vein sizes and frequencies along the northern, western, and southern margins. There are no indications of how far east the vein system extends. Based
upon exploration drilling and present mining operations, the known vein system extends farthest from the roof thrust contact at Extended East, which is located in the center of the exposed vein system. If the vein system is genetically related to the roof thrust (as discussed previously), then the overall 3-dimensional zone of veining must be enveloped by a concave upward surface with the "well" of the surface centered beneath Extended East (or further to the east beneath the basement) (Fig. 10).

**Fold Analysis**

Tight to isocinal folds of bedding with axial planes parallel to mylonitic fabric and hinge lines parallel to N-S mineral lineation developed and rotated during the development of the duplex structure (cf. appendix 1). In addition, small asymmetric folds with E-W trending hinges and north dipping axial planes also developed during N-over-S thrusting. Late open folds spatially associated with the E-W trending vein system (to be discussed) have E-W trending, subhorizontal hinges with axial planes steeply dipping also indicate some N-over-S shearing (e.g. Fig. 5, bottom sketch).

The large scale outcrop pattern of the White Range is controlled by a late forming, NE-trending, open, upright antiform-synform-antiform sequence. Foliation orientation, recorded at over 600 localities within the quartzite, document their fold axes' orientations (Fig. 23). Assuming cylindrical fold shapes, vector analysis of the entire foliation data set constrains the best fit fold axis to be 012, 17°N (trend and plunge, respectively) (Fig. 17). Subsets of the foliation data around individual folds give very similar orientations for fold axes. Small crenulations in the quartzite and dolostones on average are oriented 048, 12°N (trend and plunge, respectively) with variable dipping axial planes.

**Joint Analysis**

The quartzite is extensively jointed in the Range. The joints are predominantly smooth, planar, and continuous for meters to tens of meters. Apart from a few joints exhibiting weakly developed plumose structures and fringe joints, structures and surface morphologies generally associated with joints were not observed. Joint spacings for the different joint sets are on the order of tens of centimeters to a few meters; however, rare E-W striking zones with closely spaced fractures accommodated strike-slip displacement and contained minor quartzite breccia. No consistent cross-cutting relations between joint sets were observed. Neither the joints nor the minor faults localized quartz veins.

Over 800 joint orientations were measured at six localities along the north and east side of the Range (Fig. 24). Within the four mine pits, joints were measured along all available walls in order to representatively capture all joint sets and thus minimize the "cut effect" (Ramsey and Huber 1987, p.648). No significant differences in joints' orientations exist between the seven localities, though some joint sets are not equally represented at all localities. With all the joint data combined and contoured, four moderately distinct steeply dipping joint sets are defined (Fig. 15). Realizing that joint sets often occur in conjugate pairs, the contoured data set strongly suggests that the two NE-SW striking sets can be grouped together as
a conjugate pair. Concerning the other two E-W striking sets, it is not clear if they can be grouped together as a conjugate pair. Since the plane of symmetry that acutely bisects the NE-SW conjugate pair intersects both representative great circles of the other two joint sets at 235°,71°S (trend and plunge, respectively), it suggests that the four joint sets shared a similar stress field, and thus might have formed synchronously.

Relationship between jointing and folding and veining

It has long been recognized that joints are often times systematically arranged about folds. This has led to geometric classifications of joints whose reference frames are related to features of folds. The most common reference frame involves three mutually perpendicular axes (a, b, c) such that the ab plane is the plane that is folded, c is the pole to that plane, and b is parallel to the fold hinge. Six conjugate joint pairs plus four additional sets of fractures can thus be defined about a fold. The NE-SW striking conjugate pair of fractures in the White Range would correspond approximately with h01 fractures whose acute angle would enclose the c-axis of the reference frame (i.e. longitudinal fractures). The ESE-WNW trending fracture set would be one set of a conjugate 0kl fracture pair that has an acute angle about the c-axis of the reference frame. One interpretation of the E-W oriented fracture set would be to say it is parallel to the ac reference plane; an alternative explanation would be to assign them as 0kl fractures. If the second interpretation were correct, then they would form a conjugate pair with the ESE-WNW fracture set. The E-W striking fracture sets are perpendicular to the fold axis; while, the line of intersection between the two NE-SW striking fracture sets is not collinear with the fold axis (Fig. 17).

The symmetry between the joint sets, the antiform fold axis, and the two vein sets strongly suggests that they all formed in similar stress fields, and probably formed synchronously (Fig. 25). Thus, the gold-bearing quartz veins formed very late in the deformation history when the N-over-S thrust system was dying, and an E-W compression event was developing. The vein system was localized near the fold hinge of the large antiform where the fold limb shows the tightest curvature. I am inclined to consider the brittle-ductile quartz vein zones as having developed during the transition between ductile thrusting and brittle jointing.

Grade Control

I think the grade control procedures in effect during the time of my stay, are quite effective in identifying the ore bodies, especially given such complexity of the vein systems. The recommendations and comments I make here are just fine tuning of a fairly effective process.

In grade control mapping, one should not be afraid to superimpose some of the geometry associated with anastomosing networks. For example, one should not be afraid of mapping an ore body as an "X" or "Y", for such an interpretation would be consistent with an intersection zone between two ore zones (Fig.26). One should be very cautious, however, in interpreting an ore body as a "U" shape. Such an interpretation would suggest that two ore bodies merge and terminate at the intersection: based upon
mechanical arguments, such an intersection zone would be highly unlikely. Where the grade control suggests a "U" shape, one should be very carefully not to miss the continuation of at least one of the zones beyond the hook. Though the continuation might not contain ore, it would be worth noting the presence or absence of quartz. Then grade control procedures (e.g. blast hole sampling) for the next bench should check to see if an ore body develops beyond the "U" or "Y" shape.

Another geometry that should not be under used in grade control mapping is the "stair step" geometry. From what I have observed on the pit walls, the south dipping en echelon arrays are usually left stepping, and rarely right stepping. Thus, a new ore body will generally appear southward (i.e. hanging wall side) of a higher, more northerly positioned ore body. This might help to explain partly why the hanging wall of ore bodies often times are more gradational or diffuse.

By keeping in mind what the typical cross-sectional geometry of the vein zones are, with characteristic features such as "risers" and "droppers", the ore zone might be better constrained on the pit floor (Fig. 27). For example, risers in the hanging wall or droppers in the footwall can cause an over-estimation in the size of the ore body. It is hard to conceive how the presence of risers and droppers can cause an under-estimation of the main ore body. However, at the same time, the risers and droppers are themselves infrequently concentrated with sulphides and/or boxworks. Thus the potential dilution which would result from mining the riser and dropper zones would obviously have to be weighed against the potential ore gained. In one case, (with Guy Deryck in Extended East), we were able to identify individual droppers on the footwall of the ore body. In this particular case, the droppers did not contain any sulphides; however, if it had, the ore marker would have extended north another 5-10 meters and then significant dilution of the ore would have possibly occurred.

I think that valuable information is available for grade control on the pit walls just above the pit floor. During ore mark-up, one should take just a minute or two to determine if any ore bodies and/or quartz veins can be observed. If so, then a quick mental note of the dip of the ore body and/or veins should be made and the information incorporated into the ore mark and excavation. For example, on Extended East (670mRL-Fitch), a very wide quartz zone was indicated by drill hole data (Fig. 28a,b). Upon examination of the wall, it became obvious that large sub-horizontal quartz veins veneered the pit floor and were essentially barren of quartz. Without this observation, one might interpret the wide quartz zone as being indicative of very closely packed, south-dipping, en echelon quartz zones. A more comprehensive mapping and spray painting of the ore bodies on the pit wall should also be done after every excavation while the wall is still within easy reach.

Based upon my limited experience, mapping of ore bodies on pit floors that have been blasted (especially on the heave) is difficult especially in distinguishing separate closely spaced individual bodies. Ore mark-ups must thus rely heavily upon the drill hole related data. However, after excavation of the entire 5m of a blasted floor, I think much useful information can be gained by quick subcrop mapping of the scraped, unblasted floor that is exposed. Such mapping should be done totally independent of (without
reference to) other grade control data. This will provide a totally independent interpretation of the ore bodies. Two examples of outcrop mapping on the pit floor shows how useful this information is (Fig. 29a,b; 30a,b). It is important to recognize that the subcrops mapped are not interpreted but factual. The flagging of the veins is somewhat interpretative; however, I chose to flag only those subcrops that I was quite certain of continuity and orientation. The Extended East 675 mRL mapping required six hours to complete; the Extended East 665mRL mapping represents two and a half hours of work. I systematically marked every outcrop with paint - blue if quartzite and red if quartz vein. After doing this, I re-walked the pit floor and noted the general locations of quartz vein rubble and sulphide-bearing rubble on the floor. I finally stretched flagging along the lengths of individual quartz veins. Then the survey team picked-up the end points of the flagging. The widths and geometries of the veins were then marked on 1:250 scale map and the location of ore zones noted. This information would then be superimposed on the pit floor after blasting, along with the drill hole data. The grade control person would then use and reconcile all of the data during ore mark-up.

I think that this type of outcrop mapping is a cheap, easy way of obtaining very factual, useful information.

Face mapping of the ore bodies during excavation might also provide useful information with little effort and expense. During a recent dig of Extended East 677.5 to 675 mRL bench, I was able to mark position, orientation, width, and geometry of the ore bodies during excavation (Fig. 31). This exercise is dependent upon the wall being nearly vertical, mined approximately across the strike of the ore bodies, and air-borne dust levels are kept low. If any of these are not true during excavation, the exercise would be harder and produce questionable results. The mapping will help in the present excavation by requiring the grade control person to consciously make note of the ore width, orientation, and geometry. This could help reduce the dilution or loss of some ore. The mapping will also help during the ore mark-up of the next bench down, since the ore body geometry will be recorded from the bench above. It will also record which grade control data actually predicted the vein/ore geometry most successfully. In future ore mark-ups, more emphasis can then be given to those methods which are proven to be most predictive. It would be a shame not to record the observed geology as the bench is being mined especially since the observations are more accurate than interpreted drill-hole data (given the complexity of the ore bodies' geometries) and human labour is much cheaper than drilling costs.

In reconciling the drill hole interpretation with pit wall observations, I also believe there is a tendency to over-estimate the shallow nature of the ore bodies. Where the drill hole data is closely spaced, the ore body interpretation is generally well constrained and strongly predictive in nature (i.e. new drill hole data confirms expected ore body). In making interpretations, one should not (ad hoc) shy away from interpreting more steeply dipping ore bodies if the drill data warrants it. In addition, given the steeply north dipping veinlets ("risers" and "droppers") which are subparallel to the north dipping and vertical drill holes, some of the drill hole quartz and gold assay data might come from one veinlet and not a whole zone (Fig.32). From the data, one can not easily distinguish between these two possibilities. If a drill hole data
suggests 10-15m of high quartz vein (or ore) concentration, one should be suspicious that one or few individual veinlets have been intercepted (which I have observed on the pit walls). The other viable option is that closely spaced two en echelon zones have been intercepted. Generally, the stepping between two en echelon zones would be left lateral, and thus the second option not quite as frequently the correct one.

In addition to the other aids used in mapping the ore bodies on the pit floor, I think the newly instituted practice of spray painting pieces of boxwork and sulphides observed on the bench is an effective means of giving the grade control person a more comprehensive, unbiased view of the ore body before he/she must formalize the ore outline.

It seems to me that one of the most crucial elements in successful mining of the ore is that the grade control person is able to see the excavated face. The ultimate decision on determining ore from waste is based upon visual observation of the grade control person during excavation. Much effort has wisely gone into enhancing the grade control person's vision. Probably the single most important factor is that the air-borne dust levels are kept to a minimum. By having the to-be-mined bench watered down prior to excavation, four things are accomplished: (1). the rock exposed by each scoop of the bucket can be observed before rubble falls down on the face; (2). the grade control person will remain close to the excavation face instead of backing away from the dust choked air (from personal experience, visibility in these dust clouds is extremely low); (3). the grade control person is not physically irritated during excavation and thus possibly make poorer assessment of the ore bodies; and (4). the moisture might help in keeping the gold enriched fine particles with the coarser rock and thus having a better chance of making it to the mill.

Another visual aid would be to provide the grade control person with a small pocket size (wide-angle?) binocular or monocular (10x) with a lanyard that would effectively bring the grade control person within 1-2 meters of the face when need be (which would physically be impossible during the loading of the trucks). Given that the most effective grade control procedure is the careful, constant visual monitoring of each scoop of the excavator, another small aid would be to provide the person a 10-15 minute break half way through the morning and afternoon digs by having a substitute watch the dig. It would be hard for a person to remain alert and attentive for 5-6 hours straight especially while standing in the sun during a hot summer day. A mental lapse of just 5-10 minutes could easily result in the loss of one or more truck loads of ore to the waste pile.

In order to successfully mine the ore, I think that both the grade control person and the excavator must be knowledgeable about the geometry of the ore body(s) and the capabilities/needs of the excavator. I do not think that even if both parties are proficient at their own jobs will the mining be as effective as if both parties were knowledgeable about both jobs. If the excavator and supervisors were educated in the geometry and complexity of the ore, they would be more understanding of the requests made by the grade control people. At the same time, if the grade control people understand the limitations of the excavation process, they would hopefully make only reasonable requests. Given the contractual agreement between the
earth moving contractor and White Range Gold, compromise is an important part of the mining operation; and, effective compromise usually requires that both parties be knowledgeable. I suggest that one to two hours be spent in presenting the veins' geometries to earth moving excavators and supervisors.

**Exploration**

Based upon the concept of structural similarity, I think that the anastomosing vein geometry exposed on the hillside could be projected eastward underneath the basement rocks and predict reasonably well the zones that will contain veins in the upper part of the quartzite near the roof thrust contact (Fig. 22). I am reasonably confident that ore bodies will persist eastward underneath the basement for at least moderate distances of 50-100 meters if not more. However, given their association with the hinge zone of the large antiform and the presence of a synform to the east (and the fracture zone probably would not cut across both structures) the fracture zone probably would not extend hundreds of meters eastward or so.

Given the tenor of Extended East ore, the well developed large vein system, and the anastomosing vein geometry, I think the most profitable exploration would be to the east of Extended East (zone 1 of Figure 2). Specifically, I would begin exploration on the southern half of the corridor near the presently exposed basement-roof thrust contact. After drilling along this zone, I would continue drilling through the metatonicalite to the underlying quartzite according to the prioritized zones of Figure 2.

Given the scarcity of veins, the basement rocks in the mine area are not favorable exploration targets. East of the mine area, almost no veins are present except in the hanging wall of a basement thrust (Fig. 33). The early 1900's gold miners seemed to have had a close look along this zone but there was only one small working. I had thought that the brittle NE-SW fault zones in the general mine vicinity might also be mineralized (like Mt. Chapman and RoundTop); however, I did not observe anything unusual about these zones, other than their being epidotized and more retrogressed.

Along the north side of the White Range in the basement rocks, there are some large (a few meters wide by 10s of meters long) veins. One particular vein observed along the road just west of the Great Western parking lot seemed to contain a concentration of boxworks. Ron James had samples from this vein assayed with negative results. Similar large veins are found throughout the basement rocks from the White Range northward to the Hale River, and eastward from White Range to Ruby Gap. A few of the veins I have observed might carry gold; however, the vast majority appear to be barren.

The smaller antiform to the SE is strongly fractured by 5-15 meter wide zones trending approximately E-W. Very few veins were observed along this antiform. The quartzite is ubiquitously fractured/jointed across the entire fold; however, apart from some silicification along the fracture surfaces, there are no associated quartz veins. Based upon the similar structural setting of the quartzites (e.g. antiforms, roof thrust contact), it seemed possible that the smaller antiform would also contain veins and be mineralized.
Given the geometric model of the vein system, I do not think there is any likelihood of any significant ore being found to the south of Excelsior. I systematically traversed across the quartzite slopes in this area, and observed only a few small (<5m long and <0.4m wide), widely spaced quartz veins in this area, but no well developed vein system. I have also made several traverses along the western margin of the mine area (e.g. west and southwest of HollyOak) and found only a couple veins of any size. One vein contained boxwork and had been slightly mined by an Old Timer. However, in general, there are few veins of any significance west of the mine area. Given the scarcity, lack of obvious mineralization, and discontinuity of a vein system, the area west of the present mine area is not very prospective.

In addition, I do not think ore will be found just north of West Block and Luces. However, based upon the location and mineralization of the Great Western and several other unnamed stopes, there might be a possibility that ore zones are present to the NE of the mine area (Fig. 34). This would coincide approximately with the hinge zone of the large antiform. Though the overall vein system has an E-W strike, it is possible that on a larger scale another similar vein system lies NE along the hinge zone (i.e. en echelon mega-zones).
Figure 3: Map of the White Range in the Arltunga Nappe Complex. The mine area is located on the northeast side of the range at the quartzite-metatonalite contact.
Figure 4a: Cross-sectional geometries of some of the quartz veins observed in the mine area ('p' represents pyrite/gold occurrence).
Figure 4b: More cross-sectional geometries of the quartz veins.
Observed Vein Geometry in the Mine Area

Floor Block in Extended East

Excision (West Wall)

Excision (East Wall)

Holly Oak

Extended East

Extended East
Figure 5: Orientation of quartzite mylonite fabric adjacent to quartz veins. The fabric is either truncated by the veins along a sharp discontinuity, or more commonly, the foliation is rotated/folded near the veins.
Mylonite foliation reoriented around veins

North

South

Outerop just south of Holly Oak.

North

South

Ravine west of Extended West mine pit
Figure 6: One large, south dipping, en echelon zone composed of three smaller en echelon vein arrays. Individual veins in each array are north dipping. (example from Extended East).
Figure 7: Top figure shows the typical geometry of conjugate vein arrays where four linear elements are collinear. The four elements are not collinear in the White Range vein arrays.

Bottom figure shows the asymmetric development of en echelon vein arrays due to a rotational component of finite strain. At White Range, where only the south dipping vein arrays are developed, the rotational component of finite strain during vein formation is due to late movement of the N-over-S thrusting. (both figures from Ramsey and Huber 1987).
Figure 26.39. Schematic diagram of the relationships of enechelon vein arrays in conjugate shear zones.

A. First increment, initiation of conjugate shear zones

Total deformation

B. Irrotational finite strain

C. Rotational finite strain

Figure 26.37. Relationship of evenly and unevenly developed shear zones to the axes of bulk strain.

from Ramsey & Huber 1987
Figure 8: Orientation of ore bearing zones as interpreted from drill hole data, pre 1991 (equal area stereonet projections).
Orientations of Ore Bearing Zones As Interpreted From Drill Hole Data

(Interpretations made by White Range mine geologists; poles to zones projected onto the lower hemisphere of equal area stereonets)

West Block (N=14)

Extended West (N=18)

Extended East (N=36)

Excelsior (N=48)

Excelsior West
Figure 9a: Pit wall mapping of veins in Extended East shown with the drill hole interpretation for the same pit wall.
True dip where the ore bodies are projected onto 56° same heading (if the ore body reads 065°).
Figure 9b: Pit wall mapping of veins in Central shown with the drill hole interpretation for the same pit wall.
Figure 9c: Pit wall mapping of veins in Extended West shown with the drill hole interpretation for the same pit wall.
Figure 9d: Pit wall mapping of veins in Excelsior shown with the drill hole interpretation for the same pit wall.
Figure 10: Two possible geometries of the gold-bearing quartz vein system at White Range. Field observations, drill data, and probable correlation between mineralization and abrupt change in chemical environment at the quartzite-metatonalite thrust contact suggest that the vein system is spatially related to the thrust contact. Thus, the vein system would diminish with depth. I think the upper geometry is more realistic, and the 'well' of the concave upward envelop lies directly beneath or due east of Extended East mine pit.
Two Possible Geometries of the Gold-Bearing Quartz Vein System

Quartzite-Metatonalite Thrust Contact

Zone of Gold-Bearing Quartz Veins

Quartzite

N
Figure 11: Preliminary oxygen isotope data at White Range suggests that the quartzite in the mine area ($\delta^{18}O = 10.7\%$) saw fluids that migrated through the basement, while the rest of the range did not. This suggests that basement fluids did not pervasively migrate upward through the quartzite thrust system, but rather migrated laterally through the basement until they intersected the quartzite-metatalonalite contact. At this sharp structural and chemical discontinuity, the fluids precipitated the sulphides and gold. (Some gold-sulphide bearing basement fluids did locally migrate upwards along late semi-brittle faults through the quartzite thrust system - e.g. Billy Can, Joker Mine).
Preliminary Oxygen Isotope Data
Figure 12: Structural contours of the quartzite-metatonalite thrust contact. Contours approximately parallel topographic contours, and indicate that only meters to a few tens of meters of quartzite have actually eroded away. (Structural contours are based upon detailed foliation mapping where the quartzite is exposed, and drill data where the quartzite-metatonalite contact is buried).
Structural Contours of Quartzite-Metatonalite Thrust Contact
Figure 13a: Vein geometry as observed in plan view. Two sets of veins are consistently observed - one trending 082° and the other trending 118°. In well-developed vein arrays (e.g., West Block sketch) only enclaves of aligned quartzite blocks are present in the more massive vein array.
Observed Vein Geometry in the Mine Area

This is a portion of a larger vein system which is oriented 080°, 61°S and is approximately 1 m of solid vein with associated mires and holidays.

Luces

Luces

West Block

West Block
Figure 13b: Observed vein geometry in one of the circa 1900 Luce's pits. Though in plan view, two vein sets are observed; in cross-section, both sets have similar north dipping orientations.
Lucy's Old Timers Pit
Figure 14: Quartz veins' orientations measured at six localities in the mine area (equal area, lower hemisphere stereonet projections).
Quartz Vein Data From the White Range Mine Area

West Block & HollyOak
N=76

NW of West Block
N=8

Lucas
N=34

Extended West
N=11

Excelsior
N=34

Extended East & Central
N=51
Figure 15: Combined and contoured data of all joints and individual vein data in the mine area. Four concentration maxima are distinguishable in the joint data: two concentration maxima are distinguishable in the vein data (208,30°S and 172,15°S).
All Joint and Vein Data Combined and Contoured

All Joints

N = 821

C.L. = 1.0%/1% area

All Veins

N = 214

C.L. = 2.0%/1% area
Figure 16: Mapped quartz vein system in the Luces area. Two distinct sets of veins are present in the area. Large completely unveined zones are present in the area (e.g. 5150N 4850E).
Figure 16b: Superposition of 1989 vein map of another geologist for the same area. The 1989 mapping was more interpretative, but corresponds fairly well with my 1990 mapping.
Figure 17: Structural analysis of joint, foliation, and vein data from the mine area.

Four representative great circles (planes) corresponding to the four concentration maxima of Figure 15 are shown. In addition, two acute bisecting great circles are also shown (equal area, lower hemisphere stereonet).

Vector analysis of the foliation data constrains the fold axis orientation of 012, 17°N (equal area, lower hemisphere stereonet).

The two concentration maxima of all individual veins (cf. Fig. 15), the corresponding great circles (planes), and the acute bisecting plane are shown in the lower left stereonet (equal area, lower hemisphere stereonet).

Rose diagram of traces of individual veins and vein arrays from Luces define two sets - an east-west set and a southeast-northwest set.
Structural Analysis of Joints, Foliation, and Vein Data

Joint Analysis

Foliation Analysis

Vein Analysis

Veins' Traces in Luces

N = 620

N = 214

N = 102

Circle = 23%
Figure 18: Histograms of vein lengths in the Luces area. The left histogram contains only those veins where both ends (terminations) were observed in the field; the right histogram contains those veins where one or both terminations were covered or obscure in the field.
Vein and Vein Arrays Lengths in Luces

(a). N=67

(b). N=36

Horizontal length of veins and vein arrays (in meters)

Number of veins & vein arrays of given length

Number of veins & vein arrays known to have greater lengths
Figure 19: Conjugate and orthorhombic faults patterns both in theory (upper two diagrams) and in experimental rock deformation samples (lower two diagrams). Orthorhombic fault patterns develop during triaxial strain deformations, while conjugate faults develop only during plane strain deformations. (Diagrams taken from Krantz 1989, and Reches 1983).

The vein system at White Range displays a similar orthorhombic pattern; however, the two (would be) north dipping en echelon zones have not developed because of the rotational component of the deformation (see text for brief discussion).
Fig. 1. Block diagram and stereonet showing the relationship of two conjugate fault sets to the principal strain axes. The two sets intersect parallel to the intermediate principal strain.

Fig. 2. Block diagram and stereonet showing the relationship of four orthorhombic fault sets to the principal strain axes. Reprinted with permission from the Journal of Structural Geology, volume 10, R.W. Krantz, Multiple fault sets and three-dimensional strain: theory and application, Copyright 1988, Pergamon Press P.L.C.
Figure 20: Anastomosing zones of veins (or zones of high probability for vein occurrence) surround unveined zones; this interpretation is based on drill hole data.
Envelope of Potential Zone of Veining & Ore Formation (Excehior 730-M)

Excelsior 730-M
- 730-R1 ore fill
- 710% quartz
- Blasted increment
- Mapped Ore
Figure 20b: Another example of anastomosing zones of veins (or zones of high probability for vein occurrence) surrounding unveined zones.
Vein System at 11750 ... Similarity in Geometry at 115000 and 1140 Sections

Note: The brown outline does not intend to imply that all the contained areas are ore, or even quartz veins for that matter; but, rather, the contained area to represent the zones with high probability of containing veins and ore. By imposing the anastomosing fracture geometry onto the data, it will be more likely that these zones contain as yet undetected ore pockets. Even the brown zone can be broken up into 5-10m individual ore shells with ore (not shown).

Extended East 685 m RL
- 685 Ore Fill
- 7110 Qtz contour
- mapped interp (DL/BR)
- blast hole data
- Anastomosing fracture geometry
Figure 21: Drill hole interpretation of ore geometry suggests that two mineralized quartz veins intersect to form a "Y" geometry. These intersections might be preferentially mineralized since fluid flow was probably localized along the intersections.
Extended East

The average orientation for intersections in Extended East.

Intersection orientation of this particular example.
Figure 22: Anastomosing vein geometry on the mine scale as observed from another geologist’s 1989 mapping. Elliptical zones of unveined quartzite are surrounded by veined quartzite. This geometry is similar to the vein geometry observed on the mesoscopic scale (i.e. centimeter to meters scale).
Figure 23: All foliation and lineation data collected from the entire White Range plotted and contoured on equal area, lower hemisphere stereonets.
All Foliation & Lineation Data Combined and Contoured

- All Foliation
  - N=620
  - C.I. = 2.0%/1% area

- All Lineations
  - N=351
  - C.I. = 2.0%/1% area
Figure 24: Joints data measured from six areas are all similarly arranged across the entire mine area.
Joint Data From the White Range Mine Area

- West Block & Holly/Oak
  - NW of West Block: N=37
- Luces: N=34
- Extend West: N=165
- Excelsior: N=165
- Extended East & Central: N=229
Figure 25: The joints, folds, and veins of the mine area are symmetrically arranged to one another; thus suggesting they formed concomitantly (or at least in a similar stress field).
Symmetry of Joints, Folds, & Veins

fold axis

- representative veins
- joint bisectors
- vein trace histogram
Figure 26: Some examples of vein array intersections at different scales.
Intersection of Vein Systems in Plan View

1:5000

1:250
Extended East 699.5 RL

1:250
Extended East 737.5 RL

1:120
Extended East 540 RL

1:120
Excelsior 730 RL
Figure 27: Hypothetical example of what two drill hole data would record through an actual vein array mapped in Extended East. In plan view, this array would be composed of a main vein body with associated vein tips.
South

North

Flitch Plan of Ore Body at level A-B

(Sulphides represented by black dots)

Vein mapped on West Wall of Ended East at 1:50 scale.
Figure 28a: Zone of solid quartz vein that is essentially barren of ore (Extended East).
Extended East (670m RL)

- Axis mostly (approximately linear)
- Very little observed sulphide on pit floor.

- Much waste with no sulphide

- Flood
  - >102 g/t gold
  - >1 g/t bleached
Figure 28b: Mapped face just above the solid quartz vein shows that the veins are massive and subhorizontal (Extended East).
Figure 29a: Subcrop mapping of quartz vein, quartzite, and sulphide zones on the scraped floor of Extended East (675 mRL) prior to blast hole drilling. After flagging the quartz vein subcrops, the precise positions of the subcrops were determined by survey. This is an extremely useful and very inexpensive way of collecting good data on the ore bodies.
Figure 29b: Same subcrop map as Figure 29a, but with the Flitch plan interpretation superimposed on the pit floor mapping.
Figure 30a: Another example of a subcrop map of quartz veins, quartzite, and sulphide zones in Extended East.
Spraying and taping of floor and wall = 1 1/2 hours
Survey pick-up of ends of tracks = 3/4 hour
Outcrop mapping of floor = 1 hour
Total time = 2 1/4 hours
Figure 30b: Same subcrop map as Figure 30a, but with the Flitch plan interpretation superimposed on the pit floor mapping.
Spraying and taping of floor and wall = 1 hour
Survey pick-up of ends of ramps = 40 minutes
Outcrop mapping of floor = 1 hour
Total time = 2 hours

>10% quartz vein
Figure 31: Quick sketches made of quartz veins that were being exposed on the cut face of an active excavation. This is another technique for gaining inexpensive but very useful information about quartz veins' orientations and geometries.
Note: By mistake, I have vertically exchanged the depth (25).

Extended East
Figure 32: The ten meters of quartz vein barren of gold in drill hole C-0280 suggests that one or more individual north dipping veinlets were intercepted by the drill hole. A reasonable interpretation of the drill hole data seems to have been made by the mine geologists in this case.
Figure 33: The only quartz veins found within the metatonalite east of the mine area were along a ductile thrust (marked in red). On the north side of the range, where the metatonalite foliation is oriented more east-west, there are quite a few quartz veins. Foliation orientation, rock composition, and localization of strain seemed to have played some role in vein formation. Exploration within the metatonalite in this area is not worth pursuing.
Figure 34: Possibility of other large (hidden) vein systems along the hinge zone of the northeast trending antiform. Following the completion of exploration to the east of the present mine area (cf. Fig. 2), I would suggest drilling a few exploration drill holes through the basement to the east of Great Western. It's a long shot, but.....
Deformation History of the White Range Duplex, Central Australia, with Implications for Fold Reorientation

D. L. Kirschner and C. Teyssier

Department of Geology and Geophysics, University of Minnesota, Minneapolis, MN 55455, U.S.A.

Abstract: The White Range area in the Arltunga Nappe Complex, central Australia, is one of the northernmost exposures of Heavitree Quartzite caught underneath a large, south-directed, crustal nappe (the Paradise Nappe) emplaced during the Late Paleozoic Alice Springs orogeny. Structural, microfabric, and strain analyses of the White Range area show that sub-horizontal foliation, N-S lineation, and N-S isoclinal, recumbent folds were produced during movement of the overlying Paradise Nappe, in a strain history involving components of thrust, wrench, and pure shear. The relative proportion of these components is analyzed using the relationship between finite strain and fold hinge reorientation. A reasonable solution is one in which thrusting dominates over wrenching, and a pure shear is responsible for syn-thrusting extension in the shear direction. This result may indicate the relative weakness of mid-crustal rocks which collapse under the weight of the thrust system and flow in a direction transverse to the belt.

Key words: strain, folds, thrusts, nappes, deformation history, pure shear, wrench, Arltunga Nappe Complex, Arunta block
INTRODUCTION

Structural and strain patterns in thrust sheets can provide useful information on the deformation history associated with nappe emplacement (c.f. Strain Within Thrust Belts, Special Volume, Williams 1982). Strain associated with the motion of thrust sheets can be decomposed into components of simple shears (thrust and wrench) and pure shear (Coward and Kim 1982, Sanderson 1982). The relative importance of these components depends on position in the nappe (Fisher and Coward 1982, Coward and Potts 1983), suggesting that some differential movement of the rock mass takes place within the 3-dimensional sheets.

In this paper, we analyze the strain history in one part of the ductile zones of the Arltunga Nappe Complex, central Australia, where structures, kinematics, and finite strain can be well documented. We propose that the study area (White Range) is located along a lateral ramp, where thrust, wrench and pure shear components are potentially represented. A detailed study of the structures and microstructures at White Range, together with the analysis of strain data from conglomerates place qualitative limitations on the type of strain history recorded in the area. The relative role played by the thrust, wrench and pure shear components is tested using an analysis based on fold reorientation. Results suggest that the relative participation of thrusting is two to three times greater than wrenching. In addition, a pure shear component, possibly related to some type of syn-thrusting gravity collapse, is necessary to explain the data.

REGIONAL SETTING - THE ARLTUNGA NAPPE COMPLEX

The Carboniferous Alice Springs orogenic belt stretches along the entire northern margin of the Amadeus Basin (Wells et al. 1970, Korsch and Lindsay 1989), and is characterized by Arunta basement metamorphics overthrusting basin sedimentary rocks (Forman and Shaw 1971; Rutland 1976) and by decollement tectonics in the basin (Teyssier 1985, Stewart et al. 1990). Three distinct, south-directed thrust and nappe complexes are preserved along this belt and are from west to east: the Ormiston Nappe Complex (Marjoribanks 1976); the
Blatherskite Nappe (Stewart 1967); and the Arltunga Nappe Complex (Forman 1971). The Arltunga Nappe Complex is the largest and best developed, extending E-W for a distance of 100 km.

Only the two basal members of the Amadeus Basin sedimentary sequence (the Heavitree Quartzite and overlying Bitter Springs Formation) are observed in the Arltunga Nappe Complex. The unconformable Heavitree Quartzite, which has an undeformed thickness of <1 km is commonly attached to the Arunta basement (Fig.1), allowing several superposed basement nappes to be recognized (Forman 1971). At the southern front of the complex is the downward facing Giles Creek Synform (tete plongeante of Teyssier 1985). Further north, retrogressed amphibolite basement gneisses are interleaved with the Heavitree Quartzite (at White Range for instance, Stewart 1971), and locally forming a series of antiformal stacks (at Ruby Gap and Amarata/Atnarpa Ranges, Collins and Teyssier 1989). Overlying these structures, basement nappes of amphibolites and granulites were thrust southward along retrogressed, anastomosing ductile shear zones (Forman 1971; Collins and Teyssier 1989). Proterozoic fabrics are preserved in the internal zones of many of these basement nappes (Teyssier et al. 1989).

This paper focuses on the White Range area, one of the northernmost outcrops of Heavitree Quartzite in the internal (ductile) regions of the nappe complex. The White Range is located along the NE dipping, western contact of a major basement nappe (the Paradise Nappe, Fig.1), in a mirror image position to the NW dipping Ruby Gap structure. Transport of the Paradise Nappe probably increases across White Range to the east toward Ruby Gap. This lateral variation in bulk nappe displacement is necessary in order to explain the rapidly decreasing shortening recorded on cross-sections to the west (Teyssier 1985). We will see that this large scale boundary condition may have played a significant role in the deformation history of the White Range area.
GEOLOGY OF WHITE RANGE

Lithologies and metamorphic grade
The White Range (Fig. 1) is composed almost entirely of the resistant Heavitree Quartzite with Bitter Springs Formation to the south and southeast of the range, and is structurally bounded above and below by retrogressed Arunta basement (Stewart 1971). At White Range, the Heavitree Quartzite is composed of a 3 m thick basal conglomerate unit, overlain by 150 to 300 m of blocky quartzite, and 100 m of platy quartzite (Forman 1971). A discontinuous unit of impure quartzite and fine grained conglomerate occupies a continuous horizon within the blocky quartzite, about 50 m above the basal contact (Fig 1). The basal conglomerate unit of the Heavitree Quartzite is exposed mainly along the western and southwestern margin of the range; the middle, more massive units of the Heavitree Quartzite occupy most of the central and eastern portion of the range; the upper platy Heavitree Quartzite and Bitter Springs Formation is exposed only along the southeastern margin of the range.

The Arunta basement to the west of the range is composed of fine grained felsic and mafic schist, with various amounts of fine grained augen gneiss (Mackie 1988). In general, intense deformation precludes a clear recognition of the schist protolith; however, the unconformable relationship with the Heavitree Quartzite basal conglomerate is preserved. The Paradise Nappe overlying the Heavitree Quartzite is mostly composed of granitic augen gneiss, variably crosscut by small leucocratic aplites and pegmatites, and amphibolitic dykes. Locally along the northeast margin of the range, in the vicinity of the White Range gold mine, the augen gneiss is severely retrogressed to a schistose phyllonite.

Results of plagioclase-muscovite geothermometry, Ar-Ar data thermochronology (Dunlap et al. 1990), and petrographic analyses of retrogressed Arunta basement rocks suggest that most of the structures of the Arltunga Nappe Complex developed in greenschist to epidote-amphibolite grade conditions. The granitic gneiss on the eastern side of White Range is increasingly retrogressed and strained with proximity to the basement-quartzite.
contact, such that locally, within several meters of the roof thrust, the granitic gneiss is completely altered to a chloritic schist. Up to several hundred meters away from the thrust, the feldspars are altered to white mica, biotite is partially retrogressed to chlorite, and epidote-clinozoisite-zoisite are less abundant. Plagioclase-muscovite thermometry (cf. Green & Usdansky 1986) on six basement rocks surrounding the White Range yields a temperature range of 280°-409°C with three of the samples clustered at 330°C.

The broad lithological distribution at White Range is therefore relatively simple; the western side of the range is a sheared nonconformity, and the eastern side is a tectonic contact at the base of the Paradise Nappe. Metamorphic assemblages correspond to conditions prevailing at mid-crustal depth. In the following sections, we investigate the geometry and the development of structures observed at White Range itself.

Foliation, Lineation, and Shear Indicators

A well developed S-C foliation observed on outcrop and in thin-section is characteristic of the Heavitree Quartzite. It is generally subparallel to bedding and is defined by muscovite folia wrapping around flattened quartz porphyroclasts. The mineral lineation in the quartzite invariably trends N-S (Fig. 2) and is defined by the elongation of mica grains and aggregates, and by the long axes of ellipsoidal quartz grains. The basal conglomerate contains N-S elongated clasts which define a stretching lineation and average 0.5 m in length (Fig. 3a). Lineation in the basement gneisses is also N-S trending and is defined by the long axes of mica grains, quartz ribbons, and feldspar porphyroclasts.

Mesoscopic sense of shear indicators observed in the White Range area include S-C-C' fabric relations (Fig. 3b) (Berthe et al. 1979, Platt 1984), boudinaged cobbles and veins (Hamner 1986; Goldstein 1988), and σ - porphyroclasts of quartz and feldspars (Passchier & Simpson 1986). Microscopic sense of shear indicators comprise mica fish, recrystallized quartz grain shapes, and quartz crystallographic fabrics (Simpson & Schmid 1983). All of
these criteria indicate a N over S sense of shear, which is consistent with the overall regional
southward vergence of the Alice Springs Orogen.

**Ductile Thrust Faults - The White Range Duplex**

Ductile faults, meters to tens of meters in thickness of concentrated deformation, are present
throughout much of the White Range. Along the western margin of the range, where the
basal conglomerate provides a continuous marker, the location, attitude, and sense of
movement on these faults, define them as thrusts. Quartz-tourmaline rich veins, both
concordant and discordant to the foliation and bedding, are commonly associated with the
ductile thrust zones.

In general, thrusts strike E-W and dip shallowly to the north; however, segments of
the thrust faults have been reoriented by later NE-SW trending folds. Eight ductile thrusts
have been recognized within the Heavitree Quartzite. These thrusts form a hinterland dipping
duplex (Boyer & Elliot 1982) with a well-defined roof thrust of basement rocks overlying the
Heavitree Quartzite to the north and the east. The floor thrust of the duplex is not as well
defined, and consists of a relatively thick zone of mylonitic schists and gneisses below the
quartzite to the west and south. Sense of shear in all of these ductile faults is consistently N
over S.

The amount of displacement on individual thrusts is a few hundred meters maximum
as deduced from the disruption of the basal conglomerate. On the other hand, a lower limit of
N to S displacement across the roof thrust must be at least 5 km since the entire length of the
duplex is overlain by mylonitic basement gneisses to the east. It follows that the ductile
thrusts at White Range only partially accommodate the more substantial total displacement of
the Paradise Nappe. This is consistent with the observation that this same nappe has
recorded several tens of kilometers of southward displacement further east, above the Ruby
Gap duplex (Collins and Teyssier 1989). Nevertheless, considering its overall imbricate
nature and well developed roof thrust, we propose that the White Range structure be called a
ductile duplex.

Folds

The importance of folding vs thrusting in the development of the Arltunga Nappe Complex
has been the source of considerable discussion. Forman (1971) emphasized folding, while
Yar Kahn (1972) and Hobbs et al. (1976, p.411-414) pointed out the significance of the
thrust-imbrication of thin sheets. At White Range, pebble conglomerates were found along
the northern side, overlying the blocky quartzite, and it was proposed that the whole
Heavitree Quartzite could be overturned (Mackie 1988). Our mapping has shown that these
overturned conglomerate beds are part of the system of early, N-trending isoclinal folds
which locally disturb the otherwise upright position of the Heavitree Quartzite.

These N-S trending tight folds of bedding and some quartz veins are more easily
observed on the western side of the range. The axial planes are subparallel to the foliation,
and the fold axes are subparallel to the mineral lineation. These near-recumbent folds (Fig.
3c) are centimeters to hundred(s) of meters in wavelength (the location of large folds is
depicted in Fig. 4a). Small tight folds are observed within the hinge zones and along the
limbs (i.e. parasitic folds) of the larger folds. These folds, especially on the west side of the
range, appear to be cross-cut by the ductile thrusts.

In addition to the N-S folds, three E-W trending tight folds were observed in the
field. In one case, an E-W hinge was traced around into a N-S hinge, defining a sheath fold
geometry. In the other two cases, no such geometry was found. Centimeter scale, E-W
trending, open to tight folds with north dipping axial planes are present locally, their
vergence indicating a N over S sense of shear. Along the southern margin of the White
Range, several large, open, upright folds with E-W trending hinges fold both bedding and
foliation.
NE-SW trending open and kink folds (Fig. 3d) are found throughout the range and affect all earlier structures (foliation, lineation, ductile thrusts, isoclinal folds). Most of the axial planes of these open folds are steeply SE dipping, although they form a conjugate array (Fig. 4b). A broad antiform - synform - antiform upright fold sequence controls the outcrop pattern of the entire White Range with fold axes trending 014° to 027°N, and plunging 19°N (Fig 4c). Smaller scale folds in the Bitter Springs Formation to the S and SE of the range are oriented approximately 045°, 21°N (Fig. 4c). The fold axes of small kinks and crenulations are on average oriented 048°, 12°N (Fig. 4d). Associated with the later folds are NE-SW tracing brittle faults, conjugate joint sets, and an EW striking quartz vein system.

Finite Strain Analysis

Both $R_f/\phi$ and $F_r$ analyses (Lisle 1985; Fry 1979) of the porphyroclasts of 15 quartzite samples record apparent flattening to plane strain (Fig. 5). Strain could be determined from samples even where recrystallized quartz composed 70-80% of the total quartz by volume due to the well-defined quartz grains' outlines by muscovite folia, and to the preservation of the central part of porphyroclasts (Fig. 6a-b). The results of the two types of strain analyses are comparable, though the $R_f/\phi$ in general documents slightly higher, more prolate strains. We interpret the minor differences to be related to measurement error and not to strain partitioning effects between clasts and recrystallized matrix. Beyond a certain "magnitude" of strain, the quartzite is almost entirely recrystallized and muscovite concentrations no longer clearly outline original grain boundaries. This suggests a correlation between strain and recrystallization within these rocks.

The axial ratios of the basal cobble conglomerate (with quartzite clasts up to 1.5 m in length, Fig. 3a) were measured along foliation and joint planes at five localities. Based upon the harmonic mean of the axial ratios, the clasts record high, apparent plane strain to constrictional strain (Fig. 5). In general, strain increases from south to north (localities A to E respectively), although strain is also dependent on the position of the measured localities.
relative to the ductile thrusts. Some clasts show incipient necking and boudinage features; others are folded along through-going shear bands. In the matrix of conglomerate B, quartz porphyroclasts record lower strains (open circle in Fig. 5).

Strain in the conglomerates is so large that the angle between clast long axis and foliation is not measurable. Therefore, pre-tectonic (sedimentary) fabric could not be evaluated by the $R_f$/$\phi$ technique. Despite this difficulty, the consistency in the shape of the strain ellipsoid (plane strain to constriction), together with the general S to N increase in strain (reflecting the regional trend) give some credence to the pebble data. Finite strain derived from deformed quartz grains indicates that the Heavitree Quartzite is not as deformed within the central part of White Range. In fact, strain appears to be higher at the base (in the conglomerate) and at the top (beneath the roof thrust) of the quartzite, and within the ductile thrust zones in the central part of White Range.

Microstructure

The development of microstructures in the quartzite is generally correlate with position in individual thrust sheets. In the internal zones of the sheets, the quartzite is moderately deformed and recrystallized, while within the thrusts zones (especially the roof thrust) the quartzite is increasingly strained and recrystallized (Fig. 6b-c). There is no observed correlation between amount of recrystallization and muscovite content in the quartzite.

Undeformed Heavitree Quartzite protolith contain quartz grains that are rounded and spheroidal, moderately well-sorted within individual beds, and almost entirely monocry stalline. Quartz overgrowths and white mica surround the detrital quartz grains. The weakest deformed quartzites in the White Range have over 50% by volume of the quartz recrystallized relative to total quartz. Quartz overgrowths are no longer observable, and the quartz clasts are generally surrounded by a "matrix" of muscovite and recrystallized quartz. Most clasts are ellipsoidal, though some retain their original, nearly spherical shapes. Undulatory extinction, deformation bands, and optical subgrains are moderately well
developed in the porphyroclasts. While higher concentrations of muscovite still outline and define the original grains, preferential muscovite alignment also defines a foliation.

In more recrystallized quartzite samples (e.g. 70-90% of quartz recrystallized, by volume) only fragments of internally deformed porphyroclasts remain. Long axes of the fragments lie approximately in the plane of foliation. Recrystallized quartz grains are elongate with long axes oriented approximately 10-30° to the muscovite foliation, consistent with a N over S shear. Muscovite folia define a pervasive S-C foliation through the rock. Muscovite is still heterogeneously distributed throughout the rock, mainly occurring in moderately narrow zones that frequently wrap around the remaining clast fragments. In some areas where the quartz is entirely recrystallized, the muscovite is homogeneously distributed.

Within several of the thrust zones, especially along the roof thrust, the quartzite is entirely recrystallized. The recrystallized grains are elongate in shape with long axes inclined approximately 20° to the muscovite foliation (Fig. 6c). This relationship is interpreted as a steady state foliation developed in a south-directed shear (Means 1981; Lister & Snoke 1984; Burg 1986). Grains are elongate, meet at triple junctions, and exhibit undulose extinction. Coplanar recrystallized muscovite grains are homogeneously distributed through the rock and define a mylonitic foliation. Shear bands are present in some of these samples.

Besides the microstructures discussed above, the quartzite contains: (1) microscopic pinch and swell / boudinage structures; (2) quartz veins; (3) open, isoclinal, and kink folds; and (4) ubiquitous secondary fluid inclusion planes.

Quartz Crystallographic Fabrics
Quartz c-axis fabrics were measured for 12 samples from White Range (Fig. 7). For 6 of the samples, separate fabrics for porphyroclasts and recrystallized grains were measured in the same thin-sections. In general, porphyroclasts' c-axes are concentrated away from the foliation plane, and define either single or double maxima, characteristic of flattening fabrics.
(Tullis et al. 1973; Price 1985). A slight asymmetry in several porphyroclast and recrystallized fabrics is consistent with N-over-S shear (Bouchez et al. 1983; Simpson & Schmid 1983), although it is worth noting that most diagrams are quite symmetrical. The entirely recrystallized sample 019 near the roof of the duplex clearly displays a cross-girdle fabric with a slight fabric asymmetry consistent with N-over-S shear. An increase in the amount of recrystallized quartz relative to total quartz weakly correlates with increased fabric intensity.

Kirschner & Teyssier (1990) have discussed the significance of the systematically different c-axis fabrics between porphyroclasts and recrystallized grains from the same thin-section. We concluded that the strain evolved from apparent flattening to plane and constrictional strain during the deformation history. In essence, the early stages of the deformation history would be preserved in the porphyroclast fabric, and the late stages would be more represented by the recrystallized fabric, assuming in part that the preferred orientation of cyclically recrystallized aggregates is more sensitive to changes in the deformation history (Lister & Hobbs 1980, Law et al. 1984). The symmetry of recrystallized and porphyroclast fabrics suggests that there was a component of coaxial deformation during fabric development.

DISCUSSION

Type of strain history

We have demonstrated that the duplex structures at White Range developed in a south-directed thrust system beneath the Paradise Nappe. In addition, the widespread occurrence of S-C foliation and the consistency of sense of shear criteria on a meso- to microscopic scale also indicate that south-directed shear has played a significant role in the development of the planar and linear fabrics at White Range. With respect to these structures, the White Range represents a typical thrust terrain which would have evolved in a predominantly simple shear regime.
However, the attitude of foliation, taken to represent the plane of maximum flattening, does not substantially vary across White Range, irrespective of the magnitude of finite strain. This is in contrast to what is expected from heterogeneous simple shear (Ramsay & Graham 1970) which would predict an angular variation of at least 20° at White Range, given the range in finite strain values (there is no reason to believe that shear planes would vary to keep the foliation constant in orientation). Also, the crystallographic fabric patterns are not markedly asymmetrical, as would be expected with simple shear fabrics (Lister & Hobbs 1980; Bouchez et al. 1983; Law et al. 1986; Schmid & Casey 1986). We therefore propose that some combined pure shear and simple shear participated in the deformation history of White Range.

It is worth noting that White Range is located along the western boundary of the Paradise Nappe which forms a doubly plunging synform between White Range and Ruby Gap (Fig. 8). Bulk N-S displacement probably diminishes westward across the White Range, which in effect creates a dextral wrench component. At White Range, this dextral wrench might be associated with a lateral ramp at the base of the Paradise Nappe.

Following the approaches of Sanderson (1982) and Coward and Potts (1983), we propose to use the strain data in association with the orientation of fold hinges to test several deformation histories involving these thrust, wrench, and pure shear components.

**Fold attitude and finite strain data as guides to strain history**

There are two possible explanations for the N-trending folds being subparallel to the stretching lineation. Either the folds formed and remained in the N-S orientation, or they rotated into that orientation during overthrusting, an interpretation favored by almost all workers in other thrust belts (Bryant & Reed 1969; Bell 1978; Williams 1978). Towards the foreland of the White Range, folds in the Bitter Springs Formation and the Heavitree Quartzite are oriented nearly E-W (Yar Kahn, 1972). Without any evidence from other parts
of the nappe complex to suggest the initiation of folds in the N-S orientation, we propose that
the fold hinges formed at some oblique angle and passively rotated into this orientation.

One of the advantages of the White Range area is the availability of strain markers
within the folded horizons, which provide constraints on the possible rotation of folds during
fabric development. In the remainder of this discussion, we consider the foliation and
lineation at White Range to represent the \( \lambda_1 \lambda_2 \) principal plane and the \( \lambda_1 \) principal axis of the
strain ellipsoid. We also make the critical assumption that folds formed oblique to and
passively rotated towards the shear direction.

Assuming a simple shear model for the deformation of the White Range quartzite, a
maximum shear strain \( \gamma = 7 \) is calculated from the most deformed conglomerate locality (\( \gamma =
3 \) to 5 is more representative of the entire range). Such low to moderate shear strain values
also preclude the N-S folds from having formed as sheath folds, since Cobbold & Quinquis
(1980) predict a shear strain of \( \gamma = 10 \) before sheath folds are well developed (see also
Skjernaa 1980). Below, we study how the addition of a pure shear and a wrench component
allows folds to be reoriented without necessitating extremely high strain.

EFFECT OF PURE SHEAR COMPONENT (FIG. 9a)
The addition of some pure shear to the simple shear deformation history is investigated in
Figure 9a. The deformation history is constrained to be simple shear thrusting (shear plane
horizontal, shear direction south), with an additional elongation in the shear direction
representing the pure shear component. Thus the overall deformation history is plane strain.
Let us consider two finite strain states, corresponding to a stretch of 4 (\( \lambda_1=16 \)) and a stretch
of 7 (\( \lambda_1=49 \)), which are representative of White Range most deformed and moderately
deformed rocks, respectively. In considering the curves in Figure 9a, it is important to keep
in mind that finite strain corresponds to either \( \lambda_1=16 \) or \( \lambda_1=49 \), but that strain is produced by
a variety of combinations of simple shear thrusting and pure shear stretching. The pure shear
component decreases from left to right, proportionally to the increase in the thrust related shear strain.

The reorientation of two sets of particular lines (representing passive fold hinges) is considered. One set (lines #1 to 6 in the stereonet, Figure 9) is in the horizontal plane, and the other set (lines #7 to 12) is contained in a plane dipping 45°W and striking due north. These particular lines have been chosen as end-members of fold hinges that would most likely form and rotate in a thrust dominated environment. Following the approach of Sanderson (1982), a deformation tensor \( \mathbf{D} \) is formed and multiplied with its transpose \( \mathbf{D}^T \), such that tensor \( \mathbf{D} \mathbf{D}^T \) is symmetrical. The lines (#1 to 12) are then multiplied with tensor \( \mathbf{D} \mathbf{D}^T \); and the resulting angles between the rotated lines and \( \lambda_1 \) axis of the strain ellipsoid (i.e. one of the eigenvectors of \( \mathbf{D} \mathbf{D}^T \)) are calculated via the dot product. The angles between the rotated lines and the maximum finite strain axis are shown in ordinate. Unlike Sanderson (1982) and other workers who considered the angles between rotated lines and the theoretical shear direction, the angles presented here are between lines and \( \lambda_1 \) axis. These angles provide a more direct comparison with those observed in the field between fold hinges and stretching lineation.

Two main conclusions can be drawn from the calculations. For lines starting in the horizontal plane, reorientation is significant only for a very large pure shear component, irrespective of finite strain. In contrast, lines starting within the 45° dipping plane are reoriented within 10 to 20° (for \( \lambda_1 = 16 \)) and less than 10° (for \( \lambda_1 = 49 \)) to the lineation direction, irrespective of the relative component of pure and simple shear, except for the pure shear end-member. Application of these results to the White Range area indicates that, in order for pure shear to have played a significant role in the rotation of folds, either the fold hinges must have formed oblique to the thrust plane, or the pure shear component was large. Of course, a combination of these two situations would also efficiently reorient fold hinges. However, there is no evidence at White Range to suggest that pure shear was the dominant component of the strain history or that fold hinges would have ever been steeply plunging.
The introduction of a wrench component which is expected from the large scale geometry of the Arltunga Nappe Complex provides a realistic mechanism to further rotate fold hinges, as discussed below.

EFFECT OF WRENCH COMPONENT (FIG. 9b)

In order to isolate the effect of wrenching, we now consider a thrust-wrench system which can be decomposed into a horizontal shear plane with a southward thrust direction, and a vertical shear plane, with a dextral wrench movement (Fig. 8). The total deformation history is the sum of two orthogonal simple shears with the same shear direction.

In contrast to the results of the thrust-pure shear deformation, these calculations show that a slight increase in the wrench component of deformation dramatically decreases the angle between all rotated lines and λ₁. Apart from the all thrusting no wrenching case, the lines are rotated to within 15° of λ₁ irrespective of finite strain magnitude. Within the thrust-wrench kinematic framework, the λ₂ axes of finite strain is sensitive to the relative proportion of the two components: if wrenching predominates, λ₂ will be steeply plunging; if thrusting predominates, λ₂ will be shallowly plunging (Fig. 9d). Though almost any combination of thrust and wrench can adequately explain the relationship between lineation and fold hinges at White Range, the observed flat lying foliation (Fig. 2) is only compatible with a small component of wrench. Any addition of pure shear superimposed upon the thrust-wrench history will produce an even more shallowly plunging λ₂.

EFFECT OF COMBINED THRUST-WRENCH-PURE SHEAR (TABLE 1)

This deformation history corresponds to the thrust-wrench system as before, upon which is added a quadratic elongation λₓ (stretch= λₓ ) parallel to the shear direction. The introduction of pure shear in this framework results in non-plane strain deformation histories (Sanderson 1982, Coward and Potts 1983), and produces constrictional strain if λₓ >1 (elongation) and flattening strain if λₓ <1. In order to provide some constraints to the infinity
of possible solutions generated by the combination of three strain histories, we have chosen to use the White Range conglomerate strain data (see Fig 5 and Table 1), which display constrictional values. For any given finite strain state and $\lambda_x$ value, there is a unique pair of thrust and wrench components (Sanderson 1982, Coward and Potts 1983). Therefore, using the apparent finite strain at each conglomerate locality and three pure shear stretch values ($\lambda_x = 1.5; 2.0; 2.5$), we calculate the unique pair of thrust and wrench components (Table 1). The wrench component in the thrust/wrench ratio decreases with increasing pure shear. Since the structures at White Range are most obviously related to thrusting than wrenching or pure shear, we need to minimize both wrench and pure shear. Out of the three $\lambda_x$ values studied, this condition is best fulfilled when $\lambda_x = 2.0$. Then the wrench component is approximately one third of the thrust component and the plunge of $\lambda_2$ is approximately $20^\circ$.

The rotation of two unfavorably oriented lines (#1 and #7, Fig. 9) is studied using the finite strains measured at the conglomerate localities. If $\lambda_x = 2$, these lines are reoriented within a few degrees of $\lambda_1$ (Table 1). As predicted, the combined thrust-wrench-pure shear deformation history is very effective at rotating lines. However, we also learn that minimizing the wrench component results in a necessary increase of the pure shear component in order to explain the constrictional strain and the reorientation of fold hinges. This pure shear component may be contributing up to 50% of $\lambda_1$. What is the tectonic significance of this pure shear component?

We propose as a working hypothesis that this component is associated with a transport-parallel gravity collapse of the thrust system. This is similar to the gravity spreading model of Price (1973) in that collapse occurs in a privileged direction perpendicular to the grain of the belt. Price based his conclusions on the large scale behavior of brittlely deformed, upper crustal rocks. We propose that ductilely deforming rocks in the mid-crust are unable to support the load placed upon them by thrusting. These rocks would flow across the gravity potential lines defined by a near-cylindrical mountain chain, in a direction commonly parallel to the thrust direction. This type of gravity-related deformation does not
necessarily produce flattening strain. In fact, if there is differential flow across the belt (i.e. producing a wrench component), finite strain would be constrictional, as in the White Range.

CONCLUSION

In the ductilely deformed internal zones of the Arltunga Nappe Complex, the Heavitree Quartzite at White Range is overthrust by the thick Paradise Nappe. Structural, microfabric, and strain analyses of the White Range area show that sub-horizontal foliation, N-S lineation, and N-S isoclinal, recumbent folds were produced during emplacement of the Paradise Nappe. Given finite strain in the conglomerates and colinearity of fold hinges and stretching lineations in the White Range, our modelling shows that simple shear overthrusting could not be the sole component of the deformation history. The addition of either wrenching or pure shear to the simple shear overthrusting facilitates the rotation of fold hinges towards lineation. However, to best explain all of the structural and strain data of the White Range, it is necessary to add both wrenching and pure shear to the predominantly simple shear thrusting history. The best combination of these three components is when shear strain of thrusting is twice that of wrenching and pure shear stretch is $\sqrt{2}$.

We propose that this pure shear component is the result of ductilely deforming rocks in the mid-crust which are unable to support the load placed upon them by thrusting. These rocks would flow across the gravity potential lines defined by a near-cylindrical mountain chain, in a direction commonly parallel to the thrust direction. This type of gravity-related deformation does not necessarily produce flattening strain. In fact, if there is differential flow across the belt (i.e. producing a wrench component), finite strain would be constrictional, as in the White Range.

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REFERENCES


Table 1 Strain data from five conglomerate localities (A-E) in the White Range are used to constrain the amount of thrusting and wrenching required for three different pure shear stretches (λx). The resulting angles between λ1 and the rotated lines #1 and #7 are given in the last two columns. The structural evolution of the White Range is best explained when λx=2 and thrust to wrench ratio is approximately 2:1 (see text for discussion). Lines #1 and #7 would have rotated between 20° to 150° of lineation (λ1 of finite strain ellipsoid) during this deformation history.

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Figure Captions

Figure 1: Schematic map of the Arltunga Nappe Complex; WR, White Range, AR, Amarata Range, RG, Ruby Gap; note that the White Range is located along the western contact of the Paradise Nappe (PN). Geological map and cross-section of the White Range area; cross-sectional structures are somewhat schematic and should be interpreted with caution, given the fact that N-S trending isoclinal folds are common throughout White Range.

Figure 2: Orientation data of foliation and lineation on map, and on equal area stereonet; note the consistency of lineation orientation on the scale of White Range.

Figure 3: Mesoscopic structures at White Range. (a) Stretched pebble in basal conglomerate (notebook for scale); (b) south directed S-C foliation typically observed in the Heavitree Quartzite (section is normal to foliation and subparallel to lineation, south is to the right of the photograph); (c) North-oriented isoclinal fold of bedding in Heavitree Quartzite at White Range (folded surfaces are outlined); (d) Late crenulation and kink folds fold the main quartzite foliation.

Figure 4: Map scale structures. (a) Thrusts and mappable isoclinal folds (measured fold hinges are shown by filled circles in stereonet; open circles are lineations where indistinguishable from fold hinges); (b) open folds and brittle faults; (c) orientation of foliation (dots) in the two antiforms, NE and SE of the range, showing the computed fold axis; (d) attitudes of kinks and crenulations (dots are poles to axial planes, and open squares are kink axes.

Figure 5: Flinn diagram for finite strain, as derived from the measurement of quartz clasts (filled circles) in thin section, and of pebbles of the basal conglomerate (squares) in the field. The open circle is for quartz clasts from conglomerate matrix of locality B. Note that quartz grains record much less strain and more flattening than pebbles.

Figure 6: Microstructural relations. (a) Stretched clasts in recrystallized matrix; note the asymmetric imbrication of clasts, consistent with a south-directed shear; (b) progressive increase in the amount of recrystallization, resulting in a core-and -mantle microstructure; shear bands indicate south-directed shear; (c) almost entirely recrystallized quartzite,
showing elongation of recrystallized grains at an angle to the main foliation, again indicating south-directed shear.

Figure 7: Quartz c-axis fabric in the White Range quartzite; Schmidt net, lower hemisphere. In six of the twelve samples analyzed, the fabrics of porphyroclasts and recrystallized grains from the same thin section were differentiated. See text for discussion.

Figure 8: The thrust-wrench system characterizes the western lateral ramp of the main thrust which underlies the Paradise Nappe (upper right diagram). In the early stages of deformation, foliation, lineation, and fold hinges are formed and progressively rotate such that both lineation and fold axes become closer to the N-S transport direction. Strain is heterogeneous, as represented by the strain ellipses, and is more severe in the vicinity of the main thrust and in the basal conglomerate of the Heavitree Quartzite. In the middle quartzite, N-S elongation is not as well developed. In the later stages of deformation, the middle quartzite is imbricated, producing the White Range duplex.

Figure 9: (a) Diagram of angle between fold axis and $\lambda_1$ as a function of combined thrusting and pure shear for total strain equivalent to $\lambda_1=16$ and $\lambda_1=49$. The pure shear component corresponds to a stretch in the shear direction. Note that at equivalent finite strain, lines #1-6 are not significantly rotated towards $\lambda_1$. Correspondingly, lines #7-12 are readily rotated towards $\lambda_1$ independently of the relative proportion of pure shear and thrusting. (b) Relative to the thrust then pure shear history, the thrust plus wrench history strongly rotates all lines towards $\lambda_1$. (c) Orientation of lines #1-12 relative to the thrust and wrench planes and the shear direction; these lines represent the possible range in initial orientations of fold hinges at White Range (lower hemisphere Schmidt net). d) Angle between $\lambda_2$ and the thrust plane for $\lambda_1=16$ and 49 for thrusting plus wrenching history. In order to produce relatively flat lying, $\lambda_1\lambda_2$ principal plane, the thrusting must predominate over the wrenching. See text for further discussion.
combined southward thrusting, dextral wrenching, and pure shear

Fig. 8
Quartz c-axis fabric differences between porphyroclasts and recrystallized grains

DAVID KIRSCHNER and CHRISTIAN TEYSSIER

Department of Geology and Geophysics, University of Minnesota, Minneapolis, MN 55455, U.S.A.

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Abstract—Observed differences in c-axis fabrics between quartz porphyroclasts and recrystallized quartz from the same quartzite samples suggest some changes in the fabric-forming parameters during deformation. The fabric patterns are consistent with a change in the incremental strain history from flattening to constriction during duplex development, which is supported by the observed overprinting of structures in the field.

INTRODUCTION

The study of quartz crystallographic fabrics provides useful information on: (1) finite strain states (Marjoribanks 1976. Price 1985); (2) strain path, and in particular coaxial vs non-coaxial deformation (Lister & Williams 1979); and (3) sense-of-shear (Lister & Williams 1979, Bouchez et al. 1983). Crystallographic fabric patterns are the product of intrinsic (e.g. temperature, strain rate, impurity content) and extrinsic (e.g. finite strain, stress history, kinematic history) parameters (see Hobbs 1985 for discussion). Crystallographic fabric analysis can be complicated by any of these parameters changing with time or being heterogeneously distributed during deformation. Lister & Hobbs (1980) and Lister & Williams (1980) addressed in some detail the effects of changing kinematic framework during the closing stages of deformation, and discussed how earlier stages can be obscured or lost. However, apart from kinematic considerations, very little work has been done to document the effects of the other parameters on crystallographic fabrics.

By comparing fabrics from different populations of quartz within the same sample, it might be possible to decipher part of the deformation history. For example, quartzites, initially composed of detrital grains, usually evolve with progressive deformation into a bioturbated rock containing porphyroclasts and recrystallized quartz grains (Marjoribanks 1976. White 1976). In such rocks it could be argued that the fabrics shown by the porphyroclasts would be the products of, and thus representative of, the kinematic framework(s) present during most of the crystal-plastic deformation history. On the other hand, when the cyclic nature of strain and recrystallization (Means 1981), the fabrics of recrystallized aggregates might record only the last stages of plastic deformation.

Similar fabrics for both porphyroclasts and recrystallized aggregates in the same sample might suggest that the kinematic framework did not markedly change during the closing stages of plastic deformation (e.g. Marjoribanks 1976. Law 1986). In contrast, different fabrics might suggest a significant change of the kinematic framework and thus provide a partial picture of the deformation history. Other possible causes for different fabrics between porphyroclasts and recrystallized grains in the same sample will be discussed later.

In this paper, we document quartz c-axis fabrics from the White Range duplex, central Australia, which suggest a change in kinematic framework during the last increments of deformation; this interpretation is consistent with structural relationships observed in the field.

GEOLOGY

The 25 km² White Range duplex is one of several duplexes in the intraplate Arltunga Nappe Complex in central Australia (Fig. 1). Multiply deformed lower Proterozoic basement overlain by Proterozoic quartzite (Heavitree Quartzite) and dolostones (Bitter Springs Formation) were involved in major, crustal-scale, N–S overthrusts during the Paleozoic Alice Springs Orogeny (Collins & Teyssier 1989, Forman 1971, Stewart 1971). The greenschist-grade White Range duplex is composed of seven thrust sheets of Heavitree Quartzite with floor and roof thrusts at the contact with the retrogressed basement (Fig. 1). Recumbent isoclinal folds are ubiquitous in the duplex, with axial planes planar with a gently N-dipping foliation, and hinge lines colinear with a N-trending stretching/mineral lineation. The N-dipping foliation and north trending lineation, defined by the ellipsoidal shapes of quartz grains and mica folia, approximate the XY plane and X-axis of the finite strain ellipsoid, respectively. South-directed thrusts, S–C foliation, shear bands, and sheared quartz veins all indicate north-over-south sense of shear. The duplex-related structures are overprinted by NE-trending folds and crenulations. All of these structures are interpreted as having developed progressively during the formation of the Arltunga Nappe Complex.
MICROSTRUCTURE

Undeformed Heavitree Quartzite, present only south of the White Range in the foreland of the orogen, is composed of detrital quartz grains (average diameter 0.5-0.7 mm) in a quartz cement—muscovite ‘matrix’. Within the White Range, the Heavitree Quartzite exhibits a repetitive sequence of microstructures that are spatially related to individual thrusts.

In the internal zones of the sheets, farthest from the bounding thrusts, there is a bimodal distribution of ellipsoidal quartz porphyroclasts and recrystallized quartz. Quartz overgrowths are no longer present, and the quartz porphyroclasts are surrounded by muscovite and recrystallized quartz. Undulatory extinction, deformation bands, and optical subgrains are moderately well developed in the porphyroclasts. The porphyroclast grain boundaries are similar to typical core–mantle structures described by White (1976), where recrystallized grains entirely surround (mantle) the clasts, and probably formed by progressive subgrain rotation relative to the host grains.

The long axes of the porphyroclasts define a lineation and lie in the plane of muscovite foliation. Porphyroclasts in 14 quartzite samples located throughout the White Range record apparent flattening to plane strain (Fig. 2). The short-axes of the porphyroclasts are approximately 0.20 mm in length, and the recrystallized grains are approximately 0.07 mm in length.

With increasing proximity to the thrusts, the porphyro-
DISCUSSION

Preferred orientations of crystallographic fabrics are the product of many parameters affecting the rock during deformation (Hobbs 1985). For example, the fabrics of recrystallized grains that develop by sub-grain rotation can be influenced by the host grain orientations (Hobbs 1968). Heterogeneous flow of the recrystallized ‘matrix’ around more rigid porphyroclasts might also result in different fabrics developing (Lister & Price 1978, Law et al. 1984, Takeshita 1989). Although both of these parameters were probably important during the quartzite deformation, our data at present can neither preclude nor constrain their effects. Based upon field relationships and preliminary isotopic analysis, the possible roles of strain, temperature, and fluid involvement in fabric development will each be discussed.

Strain

Many studies document a good correlation between crystallographic fabrics and finite strain states for quartz aggregates (see Price 1985 for compilation and discussion of data). The fabrics of porphyroclasts reported here (Fig. 3) are similar to fabrics of samples that have recorded apparent flattening strain (cf. Price 1985, fig. 6g), and are also in agreement with computer simulations of flattening strain (Lister & Hobbs 1980).

The fabrics of recrystallized grains are similar to fabrics of samples that have recorded apparent plane to constriictional strain (cf. Price 1985, figs. 13e and 14g) and are also in agreement with computer simulations involving plane to constriictional strain (Lister & Hobbs 1980). Thus, according to the hypothesis that fabrics of porphyroclasts are the product of much of the crystal-plastic deformation history, and that fabrics of recrystallized grains document the last stages, a simple deformation history of flattening strain progressing to plane or constriictional strain is suggested for these samples.

Is there independent evidence to suggest such a history? Upright folds and crenulations trending NNE overprint the mylonitic fabric in the duplex, thus suggesting a change in the strain field during the final stages of deformation. The deformation history can be divided into three increments which reflect progressive reorientation of strain and kinematic axes. During the formation of the duplex, a south-directed shear (probably resulting in flattening strains, cf. Fig. 2) produced the foliation, lineation, and porphyroclast crystallographic fabrics. During the last stages of plastic deformation, the incremental strain may have gone through a plane to constriictional state with the elongation orientation remaining unchanged, thus producing the crystallographic fabrics of the recrystallized grains. Eventually, the duplex underwent further shortening in a WNW–ESE direction, to produce upright folds, minor faults and crenulations.

Yar Khan (1972) proposed a similar flattening to constriictional strain history for the Atnarpa Range, to the foreland of the White Range (Fig. 1), where the
<table>
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<th>Porphyroclast Quartz</th>
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Fig. 3. Crystallographic fabrics of quartz c-axes for five Heavitree Quartzite samples from the White Range duplex. The porphyroclast fabrics and recrystallized quartz fabrics from the same thin sections differ significantly in their patterns. Number of grains measured is shown at lower right-hand corner of each fabric. Contours are 0.5, 2.0 and 4.0% per 1% area on a Schmidt, lower-hemisphere stereonet.

rocks are less deformed but exhibit similar meso- and microstructures. Thus, the quartzite from the more deformed, hinterland White Range might have experienced a similar history.

Temperature

A change in temperature during the deformation history could also account for the observed differences in fabrics. Experimental results on single crystals indicate that at low temperature basal (a) is the easiest slip system to activate; however, with increasing temperature prism (a) slip becomes relatively easier (Tullis et al. 1973, Blacic 1975). Geometrically, the observed fabrics of the porphyroclasts might suggest basal (a) was the dominant slip system, especially when considering the single maximum fabric of sample 099 (Fig. 3). In contrast, the fabrics of the recrystallized grains might suggest basal, prism and rhomb (a) slip systems were operative. Provided the fabrics of the porphyroclasts are less sensitive to change, the different fabric patterns between recrystallized grains and porphyroclasts might suggest an increase in temperature. Such a scenario is not unrealistic, given that metamorphic grade increases from south to north in the Arlunta Nappe Complex (Yar Khan 1972) and is related to overthrusting of deep crustal rocks onto supra-crustal sedimentary rocks.

Fluid involvement

In grains with low concentrations of aqueous related species, basal slip is the most active slip system; while at higher concentrations prismatic slip is also an important slip system (see Paterson 1989 for discussion). Thus, an increase in fluid involvement during deformation could explain the observed differences between fabrics of porphyroclasts and recrystallized quartz.

Based on recent work (Teyssier & Gregory 1989) in
the nearby Ruby Gap duplex (Fig. 1), homogenization of oxygen isotope values in the Heavitree Quartzite corresponds with increased recrystallization and crystallographic fabric development. Correspondingly, the homogenization of the isotopes might indicate a greater fluid involvement during the development of the recrystallized grains. Preliminary isotopic analyses of nine samples in the White Range suggest a similar correlation between isotopic homogenization and degree of recrystallization and fabric development.

CONCLUSIONS

A number of factors might explain the differences in fabrics of porphyroclasts and recrystallized grains from the same samples: i.e., an increase in temperature or fluid involvement during deformation, the influence of host grain orientations, and/or the heterogeneous flow of matrix around clasts. However, the observed differences in the crystallographic fabrics of the White Range can most readily be explained by a change in the incremental strain history. This is most favorably supported by meso- and macroscopic overprinting of structures, and is consistent with the observations of Yar Khan (1972) to the foreland of the White Range.

Acknowledgements—The authors would like to thank Graham Price and Rob Knipe for many useful comments in their reviews. Support from NSF Grant EAR-8720755 and a McKnight-Land Grant Professorship to C. Teyssier, and from the University of Minnesota Graduate School to D. Kirschner are gratefully acknowledged.

REFERENCES


APPENDIX 3

EXPLORATION REPORT

BY C. GILES, 1991
PROPOSED EXPLORATION DRILLING PROGRAMME

White Range Gold Mine

Chris Giles
CONSULTANT GEOLOGIST

AUGUST 1991
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   C. Extended East 8
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SUMMARY

The current ore reserve position of the White Range Gold Mine necessitates an early, successful exploration programme if operations are to be maintained into the future. A 5000m reverse circulation drilling programme, estimated to cost approximately $200,000 is proposed. This programme is designed to systematically test targets that have the highest probability of adding economically mineable reserves. These include the strike extensions of veins mined in the Excelsior and Extended open pits plus other veins with good indicators such as pyrite boxworks and old prospector’s pits, that to date have never been drilled. There is considered to be good potential for discovery of a further 200,000t of ore at currently mined grades, although additional drilling (and cost) would be necessary to bring any such discoveries to mineable reserve status.

Details of the targets to be tested, plus metreages and proposed drillhole sites are documented in the body of the report and accompanying Table 1 and Plan 1, respectively.
INTRODUCTION

In order, to maintain mining operations beyond the present one year mine life, it is essential that White Range Gold N.L. (WRG) carry out further exploration drilling in the near future. However, in spite of best endeavours, exploration involves considerable risk as success can never be guaranteed. This risk factor is more acute in the case of WRG where the mine operating surplus necessary to fund such exploration, is sparing.

The most prudent course of action in such circumstances is to implement a staged exploration programme in which the areas with the best chance of yielding mineable ore are drilled first. Subsequent stages are contingent upon results of the first phase drilling. In the case of WRG the most promising areas for additional ore lie adjacent to the existing pits as detailed below. The upside in any drilling programme is that previously unsuspected buried or blind mineralisation may be discovered. More than one mine has been given a major rejuvenation as the result of completely new discoveries made during routine exploration in the vicinity of existing operations (e.g. Tanami gold mine, Woodcutters basemetal mine).

The recommendations given in this report are based on two visits to the mine site and extensive discussions with Mr Ron James whose major contribution is acknowledged. It is not proposed herein to duplicate the more general geological aspects of the White Range gold deposits, as these have been adequately covered elsewhere (e.g. Gilfillen, 1991; Kirschener, 1991).
GEOLOGY AND MINERALISATION

The primary gold ore at White Range is pyritic vein quartz that is hosted by massive quartzite of the widespread Heavitree Quartzite Unit. The mineralised veins occur in an east-west trending and south-dipping swarm (Figures 1 and 2). Individual veins typically have a peculiar curved 'herring bone' texture probably as the result of emplacement into a tensional fault/joint set during regional thrusting or folding (Figure 3).

Mining experience has shown that these veins are moderately persistent on the scale of the present open pits, although they often show south-stepping offsets over short distances. Gold mineralisation within the veins is highly erratic and unpredictable, making for difficult grade control (Figures 4 and 5). In some areas, wide envelopes of barren vein quartz surround the mineralised cores (Figures 6 and 7).

Examination of detailed drill sections shows that, in general, the gold lodes have a steep to moderate (75-45°) southerly dip (Figure 8).

The best mineralised vein quartz is invariably marked by abundant massive pyrite accumulations or, the boxwork cavities remaining after weathering of pyrite. Such vein quartz is usually of high grade and, characteristically, free gold grains are found scattered through the pyrite boxworks. It is this factor more than any other that has led to an over-estimation of ore grades in feasibility drilling and to the ability to upgrade mill head grades by ore sorting methods (James, 1991).

Based on structural evidence, Kirschner (1991) has suggested that the White Range vein system was controlled by, and localised along, the north-south trending hinge of a broad regional antiform during the waning stages of the thrusting episode. Notably, the best gold grades in the present open pits similarly seem to follow a roughly north-south trending axis, either side of which gold grades diminish (Figure 1). This axis projects northwards beneath the schist overthrust sheet north of Black Devil perhaps indicating enhanced exploration potential in this area.
DRILLING CONSIDERATIONS

As in past practice, it is proposed to employ reverse circulation (RC) percussion drilling owing to its rapidity and cost-effectiveness. Normally, RC percussion drilling results are accurate, however in WRG's case this method has proven to be an unreliable indicator of the mined gold grades. Both widths and grades of gold intersections have been upgraded due to downhole contamination of free gold dislodged from the fragile pyrite weathering cavities (Figure 9). In this case, the more passive diamond drilling method appeared to give more accurate results (Levings, 1988).

Notwithstanding the above limitations, RC percussion drilling is still considered to be a valid method of testing for gold mineralisation in the White Range area. However, earlier experience dictates that the intersections cannot be used directly to calculate mineable reserves. At best, they can be used to estimate a resource figure which is then modified by an experience-based reconciliation factor to give indicated mineable reserves (R James, pers. comm). During this process, all drillhole intersections need to be carefully screened to minimize the effect of downhole contamination tails, which, if not recognised, would lead to an even greater overestimate of tonnage.

In the past, angles of drilling have ranged from 60°N to vertical, with little noticeable difference in the reliability of results (R James, pers. comm.). Vertical drilling has been preferred in more recent programmes, however, in order to minimize the possibility of intersecting localised barren sections of the generally south-dipping veins. In the present case it is recommended that 60°N angled holes be drilled in order to obtain the maximum across strike intersection intervals.

Where fences of drillholes are planned, a nominal 20m horizontal collar spacing and 45m depth are proposed. In all cases, proposed drillhole collar positions as plotted on Plan 1 are not absolute and should be adjusted to suit the local geography or logistical constraints, provided that the main target is still tested.
PROPOSED EXPLORATION DRILLING PROGRAMME

The proposed exploration drilling programme has three primary objectives:

1. To test the immediate extensions of gold mineralised vein systems along strike from the present open pits (e.g. Excelsior East and West; Extended West: Luces East). This work has the highest priority as it has the highest probability of adding easily mineable ore.

2. To test other as yet unexploited mineralised vein systems near the present open pits (e.g. South Vein, Boulder vein system). These areas also have a high priority of exploration as they represent obviously mineralised targets based on abundant pyrite boxworks in the vein quartz and extensive pitting by early prospectors.

3. To test other areas in the vicinity which have some exploration potential (e.g. under the basement schist cover east of North Block and north of Black Devil; also at depth beneath existing pit floors). Great Western is also included in this lower priority category owing to the uncertainty in gaining mining rights.

As Gillfillan (1991) has observed, there is no reason to expect that any mineralisation discovered in these areas will have markedly different grade or tonnage parameters to that currently being mined.

Outside of the areas cited above, the exploration potential is considered to be low. To the east, the depths of schist overburden rapidly became prohibitively excessive, while to the south and west there is no evidence of well developed mineralised quartz vein systems. Certainly, the comparatively good exposure in the region combined with the early prospecting activity makes it exceedingly unlikely that any outcropping well mineralised veins remain undiscovered. Buried mineralised veins are unlikely to occur without accompanying outcropping veins.
A. **Excelsior East** (Priority 1 exploration target)

Mineralisation remains open at the eastern end of the Excelsior open pit roughly along lines 4590N and 4520N (see Figure 10 - Section 5220E). It is therefore recommended that a fence of seven 60°N inclined holes be drilled along line 5240E, nominal collar spacing of 20m and depth of 45m (Plan 1). Additional holes EE8, 9 and 10 are also recommended to further test the vein systems. Further drill lines to the east of Line 5240 would be recommended if the first phase drilling was successful.

B. **Excelsior West** (Priority 1 exploration target)

Mineralisation remains open at the western end of the Excelsior open pit roughly along line 4510N and 4630N (See Figure 11 - Section 4960E and Figure 12 - Section 4980E, respectively). In addition, the intervening valley area roughly along line 4600N has never been tested. It is therefore proposed that three fences of holes along lines 4960E, 4920E and 4880E, with two intermediate holes be drilled to test this area (Drillholes EW1-16, Plan 1).

Infill drilling along intermediate section lines would be recommended if the first phase drilling was successful.

C. **Extended East** (Priority 2 exploration target)

Extended East mineralisation has largely been closed off by previous drilling along line 5240E. However, it would appear worthwhile infilling the gaps along this line with three drillholes (Ext E1-3) as shown on Plan 1.

D. **Extended West** (Priority 1 exploration target)

Extended West mineralisation remains open along line 4800N (See Figure 13 - Section 4860E - especially drillhole WRC 457). In addition, the valley area between Luces 1 and Extended West, where some quartz veining has been mapped, has not yet been drilled. As a first priority, it is recommended that five drillholes along line 4820E and three drillholes along line 4860 be completed (drillholes Ext W 1-8 respectively), followed by additional drillholes as shown on Plan 1 (drillholes Ext W 9-15, respectively).
E. Extended Depths (Priority 2 exploration target)

There is some scope for discovery of deeper mineralised lenses in the pit wall to the south of the present pit floor (see Figure 13 - Section 4860E and Figure 5 - Section 5040E). Drillhole Ext W 6 (line 4860 E) plus extensions adjacent to earlier drillholes (e.g. WRC 634 - line 5040E, WRC 608, Line 5080E, WRC 254 - Line 5140E) should be considered to test this possibility.

Luces East (Priority 2 exploration target)

Although gold grades deteriorate towards the eastern end of Luces 1 pit, the mineralised veins cannot be regarded as completely closed off. There is justification for 7 drillholes (L1-7) as shown on Plan 1.

G. Boulder Area (Priority 1 and 2 exploration targets)

A quartz vein swarm is mapped in this area; some of these veins have scattered prospecting pits and widespread pyrite boxwork cavities developed along their length. Nine scout drillholes are recommended to test the most obviously prospective portions of these veins in the first-instance (B1-9, Plan 1). An additional twenty six holes to prospect other veins in the vicinity are also recommended if encouragement is received from holes B1-9.

H. Southern Vein (Priority 1 exploration target)

The southern vein is well exposed in cuttings along the haul-roads south of Excelsior open pit. Several small prospecting pits and extensive pyrite boxworks are found along the vein where it outcrops further upslope. Eight drillholes are proposed to explore the vein over its known outcrop length (S1-8, Plan 1).

I. Great Western (Priority 1 exploration target if mining rights granted)

A number of old workings, including some substantial stopes, are scattered along the disjointed Great Western vein system. It represents a good exploration target if current submissions before the NT Government authorities are successful and unfettered mining rights to the area are granted. Drilling will establish whether the well mineralised veins persist beneath existing stoped areas. Nine drillholes are recommended initially, to be followed by more if results are encouraging (GW 1-9, Plan 1).
J. Other Areas (Priority 2 exploration targets)

An obvious area for location of additional reserves is beneath the overthrust schist unit. Earlier drilling has already established continuity of the vein systems beneath schist at Black Devil and North Block. Later rounds of drilling have been less successful, with the exception of WRC 763, where one additional hole 20m west is warranted (SC1, Plan 1). The possibility of eastward extensions of the Extended and Excelsior vein systems beneath the schist appears to be downgraded by limited drilling along the quartzite - schist contact (near line 5300E) which gave negative results. It is not recommended that further drilling beneath the schist be undertaken during the current programme, although the area remains a target for any future extended drilling programmes. If the north-south favourably gold mineralised axis is a valid concept, then a prime area to explore would be under the schist unit north of the proposed Black Devil open pit.

One additional low priority drillhole (SC2-5220E, 5000N) is warranted to completely test the apparently wide quartz vein along strike from WRC 763 and proposed drillhole SC1.
REFERENCES


Levings, J. 1988  Results of diamond drilling programme undertaken at the White Range Gold Prospect, regarding the assay contamination aspect. Internal WRG memorandum.
### TABLE 1

Summary of Proposed Exploration Drilling

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<th>Location</th>
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Proposed Exploration Drilling Programme
1. Development of a typical "herringbone" tensional quartz vein system within brittle quartzite.

2. Continued south block up sense of fault movement produces curvature in the lateral tension veins to produce the characteristic "droppers" and "hangers".

Figure 3 Schematic development of the White Range quartz vein systems.
Figure 4  Extended East 680 RL Level Plan showing patchy distribution of ore lenses
Figure 5: Patchy distribution of gold ore within a portion of the Extended East open pit (section 5040 E)
Figure 6: Distribution of gold ore within wider vein quartz envelope. Extended East open pit (section 4940E)
Figure 7 Distribution of gold ore within wider vein quartz envelope. Extended East open pit (section 4130).
Contamination in reverse circulation drilling chips caused by dislodgement of gold particles from boxwork cavities (after R. James, 1991).
Figure 10: Excelsior East section 5220E showing open end to orebody in the east.
Figure 11  Excelsior-West section 4960E showing open end to orebody in the west.
Figure 12  Excessier West section 4980E
showing open end to orebody in the west
Figure 13  Extended West section.
4860E showing open end
to ore body in the west.